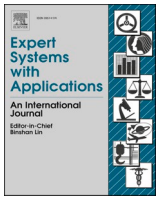
Expert Systems With Applications 261 (2025) 125491

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa



Review

Analytic hierarchy process in transportation decision-making: A two-staged review on the themes and trends of two decades

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ARTICLE INFO

Keywords:
AHP
Analytic hierarchy process
Bibliometric analysis
Systematic review
Hybrid models

ABSTRACT

The utilization of various multi-criteria decision-making methods has spread in the field of transportation, which presents challenge when identifying the most relevant research topics and applied methods. This paper uses the combination of two advanced review methodologies, the bibliometric review approach and the systematic review approach, to investigate how the well-known analytic hierarchy process (AHP) has been used to support transportation-related decisions in the last two decades. A total of 2659 scientific documents are screened, and the keywords are identified by the bibliometric analysis, while the systematic review analyzes 108 relevant publications based on the keywords identified by the bibliometric analysis. According to the results, the subthemes of transportation infrastructure, location selection, and accident prevention are the most important topics along with the environmental impacts of transportation. Considering the methodologies, the fuzzy-AHP, the TOPSIS, and the Delphi techniques are usually applied with AHP as hybrid models. The systematic review sheds light on the capability of the AHP method to identify the safety factors of different transport modes, the possibility of handling quantitative and qualitative criteria in location selection, and the potential to gain a trustworthy choice among transportation infrastructure development alternatives.

1. Introduction

Over the past few decades, there has been a noticeable rise in the adoption of multi-criteria decision-making (MCDM) methods in the field of transportation research. This trend is likely attributed to the effectiveness of these methods in simplifying complex problems (Kumar et al., 2022) while maintaining coherence. Among the various MCDM techniques, the analytic hierarchy process (AHP), introduced by Thomas L. Saaty (Saaty, 1977), stands out as the most widely adopted (Kaushik et al., 2024), especially in transportation studies. Its widespread adoption can be attributed to the following three key factors outlined by Nassereddine and Eskandari (2017): the flexibility of the AHP in handling the structure of the criteria and alternatives in decision problems, its provision of consistency checks on responses, and its attractiveness from the evaluators' perspective. The prominence of the AHP is strikingly evident, as presented in a systematic review by Broniewicz and Ogrodnik (2020), which utilizes data from the Web of Science (WoS) and Scopus databases. When analyzing the keywords "MCDM/MCDA in transport" between 2000 and 2019, the AHP emerges with nearly as many results as the combined total of the next four leading techniques. Therefore, the focus of this systematic review should be on the AHP method and its variants when discussing transportation problems.

Although a notable trend of using AHP exists, the classic AHP method exhibits evident limitations, which restrict the circle of possible applications in the transportation domain. First, there are some

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https://doi.org/10.1016/j.eswa.2024.125491
Received 30 May 2024; Received in revised form 23 September 2024; Accepted 2 October 2024
Available online 5 October 2024

transportation problems for which this method is not suggested based on the existing literature. The primary reason is that the original method requires a detailed questionnaire with several pairwise comparisons, which makes its application impractical for public surveys due to the high demand from the evaluators (Duleba, 2022). Consequently, without adjustments, the AHP is not necessarily suitable for those transportation problems in which the evaluator sample is large and the respondents are non-experts, e.g., large-scale questionnaires of revealed preferences for public transport development (Guzman et al., 2023). Likewise, the AHP is not the most appropriate method for mode choice analysis due to the reduced number of alternatives. In such scenarios, the prioritization objective could lead to overly trivial outcomes (Moslem et al., 2022). Moreover, in route planning, the knowledge acquisition feature of the AHP cannot be utilized. Instead, other operation research tools and algorithms, such as the alternating direction method of multipliers models, prove to be more effective in this context (Feng et al., 2024). Still, in the broader realm of transportation, there are sub-themes that could be adequately examined by the AHP method and its hybrid versions where its efficacy might surpass alternative techniques, such as discrete choice modeling (Guarda & Qian, 2024).

Furthermore, it is noteworthy that since its inception, the AHP method has been increasingly integrated with other methods to overcome its limitations and improve its effectiveness in decision-making. To mitigate the potential ambiguities in responses, the evaluation scores can be fuzzified to bolster the reliability of the calculation outcomes (Verma & Rastogi, 2024). Consequently, fuzzy logic is incorporated into the conventional decision-making method (Rawat et al., 2022). Another typical application of the hybrid AHP models involves their combination with the technique for order of preference by similarity to the ideal solution (TOPSIS) method (Chaube et al., 2024; Menon & Ravi, 2022). In such cases, the AHP is applied to determine the weights of the decision criteria, while a more straightforward technique for prioritization, TOPSIS is utilized to create the final ranking of the decision alternatives. Lastly, as implied by its name, the AHP can be used exclusively for a strictly hierarchical structure of decision criteria, which assumption is not valid in case of several transportation problems where overlaps and interconnections among the criteria are often observed. To overcome this strict precondition, network-type techniques, such as the Choquet integral (Tan & Chen, 2010) or the interpretive structural modeling (Duleba et al., 2013), are frequently combined with the AHP. Thus, applying the AHP with other methods provides a suitable solution to a range of transportation problems.

Based on the aforementioned arguments, the objective of this review is twofold. On the one hand, this study aims to identify the most popular sub-themes in transportation benefited from the characteristics of the AHP by effectively implementing the AHP method. On the other hand, to overcome the limitations of the classic AHP in the transportation domain, the research aims to identify the combinations of the techniques that have garnered popularity over the last two decades. Both objectives are unique and represent novel contributions to the existing knowledge of transportation research. Additionally, these aims can significantly support the successful implementation of future applications of AHP. To achieve the objectives of this research, a two-stage review methodology comprising a bibliometric analysis and a systematic literature review is implemented. Moreover, various transportation-related sub-topics are analyzed together with advanced combinations of the method.

Despite having studies demonstrating the application of AHP in the field of transportation, there remains a notable lack of comprehensive literature reviews that consolidate these contributions, leaving a research gap in understanding the status of AHP research in specific areas. Although several reviews on MCDM in the transportation sector exist (Camargo Pérez et al., 2015; Mardani et al., 2016; Yannis et al., 2020) – where AHP is discussed alongside other MCDM methods – their focus is too broad, offering an overview of MCDM methods rather than concentrating on AHP specifically. A limited number of reviews have focused solely on AHP, but these explore application areas (Sipahi & Timor, 2010), examine development patterns over time (Emrouznejad & Marra, 2017), or analyze AHP integration with other tools (Ho, 2008) across various sectors, such as logistics, business, and manufacturing. Only three studies specifically review AHP in the transportation domain. The first provides a state-of-the-art review of AHP primarily focusing on urban mobility during the 2020–2021 period (Ruiz Bargueño et al., 2021). The second offers an empirical review centered on the evaluation of road transport vehicle projects between 2014–2021 (Baric & Zeljko, 2021). The third presents a thorough review of transportation problems where AHP is applied to enumerate related criteria and alternatives from 2003 to 2019 (Moslem et al., 2023). Our research differs from these studies by incorporating two distinct review approaches (bibliometric analysis and systematic literature review), covering a broader time span (2000–2022), and pursuing a two-fold objective: examining the sub-themes of AHP within transportation and investigating the integration of AHP with other techniques. A detailed comparison between our review and previous studies is provided in Table 1.

This paper is structured as follows. After the introduction in Section 1, Section 2 presents the two-stage methodology applied to conduct this review. Section 3 is dedicated to the results of the systematic review. More precisely, an overview of the sub-themes in transportation using the AHP and its integrations with other methods is provided. A comprehensive discussion is established in Section 4. Finally, Section 5 demonstrates a conclusion and further perspectives for this work.

2. Methodology

This research introduces a coupled process of bibliometric analysis and systematic literature review. Integrating these methods is crucial for adopting a meticulous approach to present quantitative and qualitative knowledge in the research field (Goyal & Kumar, 2021). On the one hand, bibliometric analysis can efficiently collect and process a mass amount of research information (Huang et al., 2020). Furthermore, it serves as a valuable tool for researchers to mine scientific documents thus unveiling trends and specific patterns of change (Huang et al., 2020). On the other hand, the systematic literature review aids in narrowing the scientific focus by using precise search terms. This research method proves instrumental in preventing the reinvention of already addressed issues and existing solutions (Gil et al., 2020). Specifically, current bibliometric analysis is based on the framework established by Donthu et al. (2021) and Toaza and Esztergár-Kiss (2023), while the systematic literature review adheres to the procedure outlined by the preferred reporting items for systematic reviews and *meta*-analyses (PRISMA) guidelines (Swan et al., 2022). Consequently, the entire process is structured in two stages where the first stage corresponds to the bibliometric analysis involving four steps and the second stage is the systematic literature review comprising three steps, as shown in Fig. 1.

2.1. Bibliometric analysis

In the initial phase of the bibliometric analysis, the aims and the scope of the review are defined. As stated previously, the aim is to identify prevalent sub-themes in the field of transportation that have successfully utilized the characteristics of the AHP and effectively implemented this method. Additionally, another aim is to uncover the combination of techniques that have gained popularity over the past two decades to overcome the limitations of the classic AHP in the transportation domain. To achieve these research goals, this study sets out to answer the following research questions (RQs):

- **RQ1.** What is the role of the AHP method in transportation, and what kinds of problems have been solved by using the AHP method in the last two decades?
- **RQ2.** Why has the AHP become so popular for solving transportation-related problems, especially in recent years?

Table 1
Comparison of earlier reviews and current paper on AHP implementation in transportation.

Author	Aim	Coverage; Method	Range; Database	Search string	Doc.
Ruiz Bargueño et al. (2021)	Discovering how AHP has been applied to solve decision problems regarding urban mobility	Application areas; State of the art review	2020–2021; Scopus	- analytic and hierarchy and process governance public and management urban and mobility	103
Baric and Zeljko (2021)	Determining the extent to which the AHP is applied for evaluating road vehicles.	Application areas, N/A	2014–2021; WoS and Scopus	- AHP and Analytical Hierarchy Process and road and transport and traffic	180
Moslem et al. (2023)	Analyze the contribution of the AHP to solve transportation problems	Application areas, PRISMA	2003–2019; Scopus, WoS, and Google Scholar	- AHP and transportation AHP and airline industry AHP and road industry AHP and airport industry AHP and transport AHP and railways industry AHP and urban transport AHP and terminal and ports AHP and logistics transportation AHP and public transport AHP and transport operations AHP and public bus transport AHP and transportation planning AHP and marine transportation AHP and freight transport	58
Current paper	Investigating how the AHP has been used to support transportation-related decisions	Application areas, combination of methods; Bibliometric analysis and PRISMA	2000–2022; WoS and Scopus	(analytical hierarchy process OR analytic hierarchy process OR ahp) AND transport* OR mobility	112

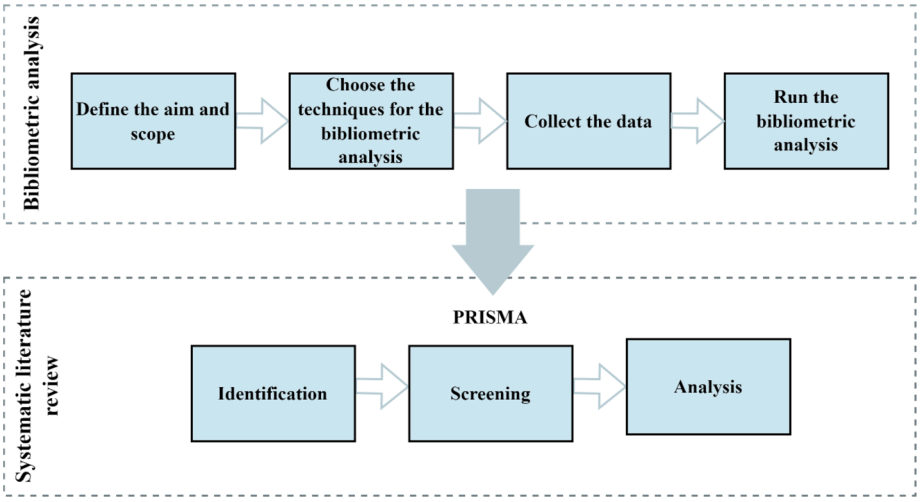

Fig. 1. Steps of the bibliometric analysis and systematic literature review methods.

- **RQ3.** How have the researchers modified the original AHP method to adapt to specific transportation problems in the last two decades?
- **RQ4.** What are the most promising hybrid techniques that could be applied more adequately to support transportation-related decisions?

The second step involves selecting the techniques for the bibliometric analysis, specifically focusing on performance analysis (i.e., the total publications and the number of active years of publications) and science mapping (i.e., citation, co-citation, and co-word analysis). The outcomes of these analyses can be effectively visualized through maps, graphs, or networks, which offer a meaningful representation of large datasets. Recently, this form of research mapping has acquired popularity in gaining insights into scientific fields by depicting bibliometric parameters. By combining these methods, various aspects of scientific production can be comprehensively assessed while utilizing the conceptual, intellectual, and social structures of the paper sample.

Thirdly, the data collection involves customizing the search terms and retrieving information from the Scopus and WoS databases. Two strategies are adopted to define the suitable search terms for addressing the RQs. The first strategy includes consulting the existing literature to identify a meaningful combination of search terms, while the second strategy consists of brainstorming and refining the appropriate search terms. Consequently, the terms “analytic hierarchy process,” “mobility,” and “transport” are applied to search for document titles, abstracts, and keywords published between 2000 and 2022. The search is limited to journal articles in the English language excluding grey literature, such as conference papers, books, book chapters, and technical reports. The detailed queries used in Scopus and WoS are outlined in Table 2. The search criteria result in 2186 relevant articles fetched from Scopus and 1604 articles from WoS. Nevertheless, the raw results of the search may contain duplicate documents. To address this problem, the duplicates are systematically removed, which results in a refined dataset comprising a total of 2659 documents suitable for subsequent analysis.

Finally, the bibliometric analysis is performed by using the visualization and mapping tool VOSviewer. This tool facilitates the

Table 2
The queries to retrieve publications from Scopus and WoS.

Database	Query	Result
Scopus	TITLE-ABS-KEY ((“analytical hierarchy process” OR “analytic hierarchy process” OR ahp) AND (transport* OR mobility)) AND PUBYEAR > 1999 AND PUBYEAR < 2023 AND DOCTYPE (ar)	2186
WoS	TS= (“analytic hierarchy process” OR “analytic hierarchy process” OR ahp) AND TS= (transport* OR mobility) AND PY= (2000–2022) AND DT= (Article OR Early Access)	1604

construction, visualization, and exploration of node-link maps with a specific focus on distance-based bibliometric networks. VOSviewer is freely accessible to the bibliometric research community (van Eck & Waltman, 2014) and offers the essential features required to address the RQs posed in this study.

2.1.1. Total and annual publications

Fig. 2 illustrates the evolving trend in the utilization of the AHP method in the realm of transportation and mobility. The visual representation highlights a substantial increase in scholarly publications surging from 12 articles in 2000 to 377 in 2022. The period from 2000 to 2008 is set as the build-up stage, which is characterized by an annual publication count of less than 50. The period from 2008 to 2022, which is identified as the growth stage, witness an exponential increase in research pertaining to AHP applications in transportation and mobility. Although the growth is gradual until 2017, the subsequent year exhibits a significant leap surpassing the 2017 count by almost 100 publications. This increase persists until the final year of the analysis (i.e., 2022).

2.1.2. Citation analysis

Citation analysis is a method used to examine the impact of articles despite their susceptibility to certain biases, such as citation bias and self-citation. Nevertheless, it stands as a standard tool for assessing the overall influence of scholarly works. Citations serve as indicators of the significance and vigor of a paper’s contributions to the literature on a specific topic (Donthu et al., 2021). Table 3 outlines the list of the most impactful papers that have more than 100 citations. The works by Tzeng et al. (2005), Kulak and Kahraman (2005), and Önüt and Soner (Önüt & Soner, 2008) garner the highest number of citations, i.e., 506, 384, and 343 citations, respectively. All three influential articles were published during the build-up period. In the growth stage, the paper by Senthil et al. (2014) stands out as the most cited with 155 citations and holds the fifth position regarding the overall citations for the entire analysis period. Tzeng et al. (2005) explore the development of buses powered by alternative fuels, such as electricity, fuel cells, and methanol. The assessment focuses on the applicability of these fuels to public transport.

Table 3
The most impactful articles with more than 100 citations.

Author	Title	Topic	Cit.
Tzeng et al. (2005)	Multi-criteria analysis of alternative-fuel buses for public transport	Use of TOPSIS and VIKOR to select alternative-fuel buses for public transport and AHP to determine the relative weights of evaluation criteria	506
Kulak and Kahraman (2005)	Fuzzy multi-attribute selection among transportation companies by using axiomatic design and AHP	Selection of the best transportation company by making comparisons with fuzzy-AHP	384
Önüt and Soner (2008)	Transshipment site selection by using the AHP and TOPSIS approaches under fuzzy environment	Use of fuzzy-TOPSIS for solid waste transshipment site selection applying the AHP to calculate the criteria weights	343
Yedla and Shrestha (2003)	Multi-criteria approach for the selection of alternative options for environmentally sustainable transportation system in Delhi	Selection of alternatives for sustainable transport systems by applying AHP with weighted arithmetic mean method for group aggregation	182
Senthil et al. (2014)	A robust hybrid MCDM methodology for contractor evaluation and selection in third-party reverse logistics	Hybridization of the AHP and fuzzy-TOPSIS for selecting the most efficient reverse logistics contractor	155
Winebrake and Creswick (2003)	The future of hydrogen fueling systems for transportation: An application of perspective-based scenario analysis by using the AHP	Application of perspective-based scenario analysis by using the AHP to evaluate hydrogen fuel processor technologies for transportation	108

The research applies multiple attribute evaluation and the AHP method to ascertain the relative weights of the evaluation criteria. Furthermore, the study compares the TOPSIS and VIKOR methods to pinpoint the optimal compromise among the alternative fuel modes. Kulak and Kahraman (2005) delve into the utilization of the AHP for selecting the most suitable transportation company based on multiple criteria in the context of supply chain management. The researchers draw comparisons with the fuzzy-AHP method from the existing literature by introducing a fuzzy multi-attribute axiomatic design approach. Önüt and Soner (2008) combine the AHP and fuzzy TOPSIS to model a transshipment site selection problem regarding solid waste. Fuzzy TOPSIS is used to select a solid waste transshipment site, and the AHP is applied to calculate criteria weights. Senthil et al. (2014) propose a hybrid method that combines the AHP and fuzzy-TOPSIS for the evaluation and selection of

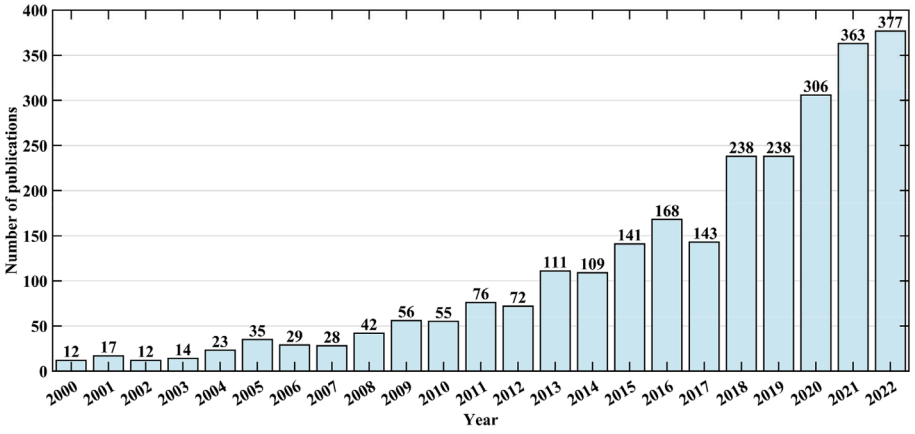

Fig. 2. Number of annual publications using the AHP method in transportation and mobility.

the most efficient reverse logistics contractor in third-party reverse logistics. The article with the lowest number of citations in the list, i.e., by Winebrake and Creswick (2003), applies the AHP to analyze scenarios of future hydrogen fuel processor technologies, which could be market-ready in 15–20 years. The sensitivity analysis of the AHP outcome is conducted by applying the perspective-based scenario analysis.

2.1.3. Co-citation analysis

A co-citation network is composed of nodes representing journal articles and edges that indicate the co-occurrence of these nodes in other papers. This means that two publications are considered co-cited when they appear together in the reference lists of another publication (Xu et al., 2018). The frequency of co-citations indicates a likelihood of shared subject areas or thematic relevance. Furthermore, the nodes in the network are organized into clusters where the connection density among the nodes within the same cluster surpasses the density between the nodes in different clusters. In a co-citation network, a cluster represents a collection of well-connected publications in a specific research area demonstrating limited connections to the publications in other clusters or research areas.

Fig. 3 illustrates the co-citation network of the documents with a minimum of 20 citations. Each node in the graph represents a publication with its size reflecting the overall link strength to other publications. The connections between the nodes signify instances where two documents co-occur in the reference list of another publication, and the thickness of these links indicates the intensity of the co-occurrence. Furthermore, the analysis reveals five distinct clusters. **Cluster one** (red) comprising 72 items stands out as the largest. It predominantly explores policies and strategies pertaining to the utilization of renewable energies or alternative fuels in diverse transportation systems. **Cluster two** (green) consisting of 42 documents emphasizes the assessment of suitability to ensure safety and mitigate risks in supply chain management, the transportation of goods, and other transportation projects. **Cluster three** (blue) serves as a transitional link between Clusters two and four. The research works in this cluster predominantly evaluate logistic strategies in intermodal transportation and the identification of selection criteria. **Cluster four** (yellow) concentrates on evaluating urban transportation networks and stakeholder engagement. Research in this cluster explores stakeholders' perspectives to evaluate and select sustainable transportation strategies. **Cluster five** (purple) revolves around site selection and resource allocation in transportation. The topics covered in this cluster include the allocation of stations for autonomous vehicles or the selection of ships for watch-keeping officers.

2.1.4. Co-word analysis

Co-word analysis is a method that examines the content of publications by extracting words from the keywords, titles, abstracts, or full texts of documents. This technique operates on the principle that the words frequently appearing together share a thematic relationship (Donthu et al., 2021). The frequency of their co-occurrence establishes the degree of relatedness among the items in documents. Fig. 4 shows the co-occurrence map of the author keywords of the documents related to the AHP in transportation and mobility formed by using the software VOSviewer. Each node signifies a keyword in this representation with its size indicating its occurrence in a document and its connections to other documents. Two keywords are linked when they occur together, and the thickness of the link shows the strength of the co-occurrence. Moreover, the overlay visualization provides insights into the average year when a keyword is most frequently mentioned. As anticipated, the keyword "ahp" stands out with the highest number of occurrences thus positioned at the center of the network. Excluding this keyword, "fuzzy ahp" with 323 instances emerges as the most frequently occurring keyword, which is followed by the "topsis method" with 131 occurrences. Additionally, Fig. 4 shows the emerging keywords that hold promise for future research. Within the realm of the methods, notable mentions include the "best-worst method," "fuzzy dematel," and "fuzzy vikor." Similarly, in the domain of applications, such keywords as "autonomous vehicles," "vehicle-to-vehicle communication," and "electric vehicles charging" are discernible, which might suggest avenues for further exploration, as well.

Table 4 presents a more detailed list of the keywords with their respective frequencies organized into two research domains. The first group comprises the alternative trending methods utilized alongside the AHP, while the second group encompasses the topics of interest related to the application of the AHP.

The keywords identified through the bibliometric analysis serve as input search terms for the systematic literature review, which applies the PRISMA method in the second stage of the review.

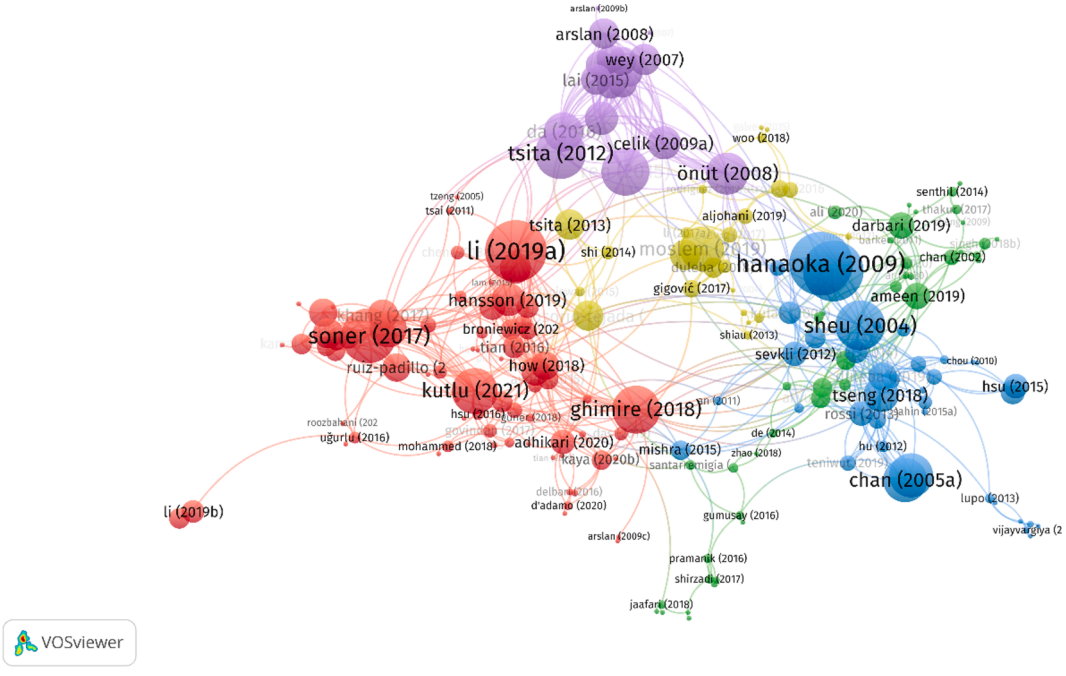

Fig. 3. Co-citation network of the publications with a minimum of 20 citations.

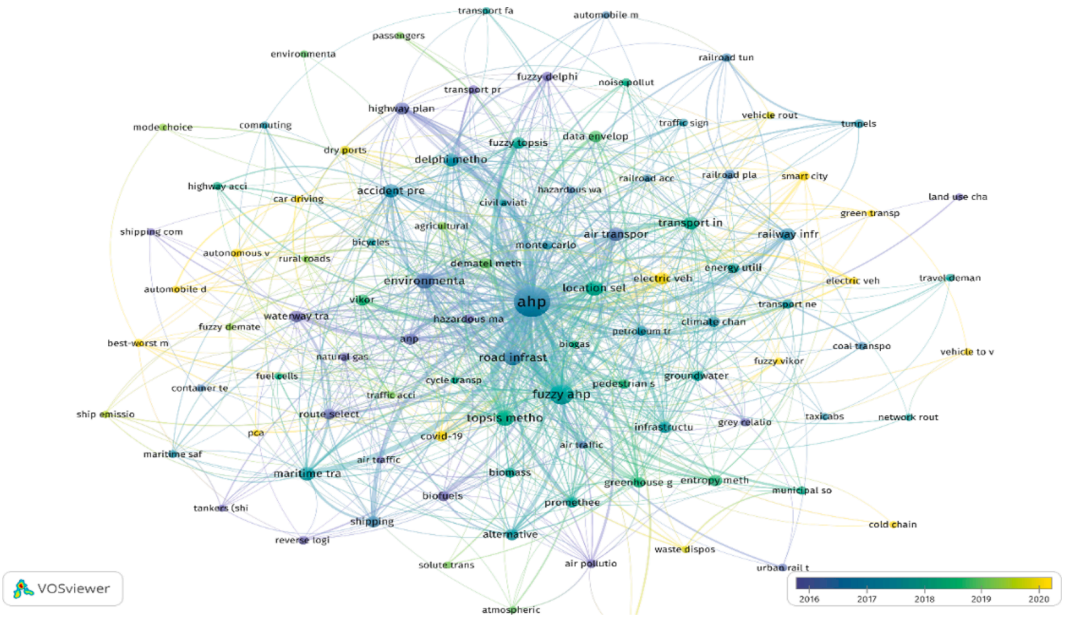

Fig. 4. The co-word (keyword co-occurrence) network of author keywords presented in publications.

Table 4
Keywords on alternative methods to the AHP and its application topics.

Method			Application topic		
Keyword	**Occurrence**	**Year**	**Keyword**	**Occurrence**	**Year**
Fuzzy-AHP	323	2018	Infrastructure	121	2017
TOPSIS method	131	2018	Environmental impact	119	2017
DELPHI method	56	2017	Location selection	105	2018
			Accident prevention	73	2017

2.2. Systematic review

This paper applies a systematic literature review methodology based on the PRISMA guideline. A systematic literature review aims to unify the existing concepts and find the areas requiring further investigation by researchers (Miskolczi et al., 2021). The PRISMA provides guidance on how to conduct systematic reviews consisting of checklists and a flow diagram developed to enhance the transparency and accuracy of the literature review (Liberati et al., 2009; Pahlevan-Sharif et al., 2019). Fig. 5 illustrates the steps of the literature review, which outlines the PRISMA guideline.

Identification

(1) Date of publication: Papers published between 2000 and 2022.
(2) Language and reliability: Papers published in peer-reviewed journals in English.
(3) Database selection: Two scientific databases (Scopus and WoS). Although these databases have limited coverage, they primarily provide high-quality documents and are positioned among the best sources of bibliographic data (Baas et al., 2020; Birkle et al., 2020).
(4) Multiple keywords: The keywords are derived from the findings in the previously conducted bibliometric analysis. The focus is on prevalent topics in the utilization of the AHP method in transportation studies encompassing infrastructure, environmental impact, location selection, and accident prevention. Subsequently, the selected keywords are merged with AHP-related and transportation-related terms to ensure comprehensive coverage.
(5) Duplicate records: A total of 632 results are obtained initially. Afterward, the duplicate records are removed, which leads to 436 papers for the first screening.

Screening based on the abstracts: The abstracts are studied, and those deemed irrelevant to the scope of the RQs are removed. A total of 245 papers are excluded during the second screening.

Screening based on the full contents: After conducting a thorough review of the full papers, 83 studies are excluded from the analysis.

Qualitative analysis: The relevant information is extracted from the remaining 108 papers encompassing details regarding the applied methodologies and obtained pertinent results.

3. Results

3.1. Classic AHP and the hybrid models

Based on the systematic review, 86 papers use the classic AHP method, while 20 research works conduct fuzzy-AHP. Meanwhile, some authors lengthen the analysis by incorporating methods to complement the AHP and fuzzy-AHP, such as PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation), VIKOR, Entropy, and TOPSIS. Some qualitative assessments, such as SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis and Delphi, are often performed along with the AHP. Appendix A provides a summary of the methods used in the papers along with the key results.

3.2. Accident prevention

One of the most popular topics regarding the use of the AHP in transportation studies is associated with accident prevention. 11 papers are evaluated for the qualitative analysis on the topic of accident prevention. The AHP is used to determine the weights of some factors argued to have impacts on preventive measures of accidents. Luo et al. (2021) examine the key factors in determining lane-changing safety and find that when changing lanes, driver characteristics are the most important followed by the vehicle types and road conditions. Similarly, Sun et al. (2020) argue that fatigued drivers with acceleration and deceleration behavior have higher driving risks. Since human factors are considered the most crucial in explaining the cause of traffic accidents (Farooq & Moslem, 2020), Obregón-Biosca et al. (2018) try to define the

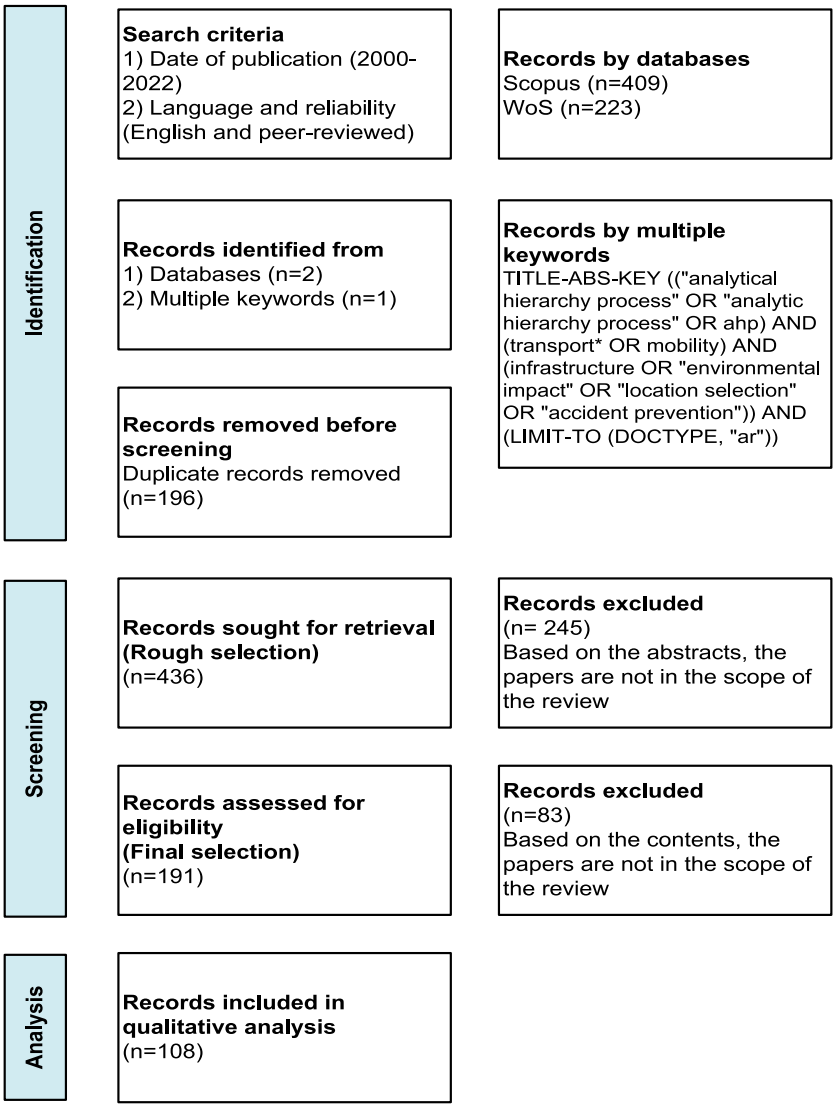

Fig. 5. Steps of the PRISMA guideline for the systematic literature review.

most important area of knowledge in road traffic accidents. The researchers find that drivers should learn the applied situations (i.e., passing maneuver, movement in a roundabout, and response to a yellow traffic light) and the present situation of transit safety (i.e., the effect of alcohol, speeding, emergency number, and post-accident recommendation). Furthermore, Hirasawa et al. (2007) investigate the most recognizable colors of uniforms worn by traffic control personnel to reduce traffic accidents. The scholars argue that orange tends to have the most recognizable visibility in autumn and winter, while red and dark blue are evaluated as having very low visibility. Furthermore, some studies use the AHP to make an index related to transportation safety. A study in India performs the AHP method to develop a pedestrian safety index, which results in pedestrian parameters (e.g., crossing type, crossing time, and signal break) getting the highest ranking (Mukesh & Katpatal, 2020). Meanwhile, by developing a model associated with black spot identification, a study in Thailand indicates that traffic accidents causing death are weighted as the highest influential factor (Treeranurat & Suanmali, 2021). The interaction levels of the transportation system are argued to have impacts on the accident rate where the most significant interaction causing a high accident rate is between traffic participants and vehicles (Podvezko & Sivilevičius, 2013).

Besides the topics related to road traffic accidents, the AHP method is applied to examine the safety issues in marine transportation, as well. Arslan and Turan (2009) argue that human-related and meteorological factors are the leading factors affecting marine casualties. Thus, Kececi and Arslan (2017) study the efforts reducing ship accidents and confirm that refreshing team culture training has the top priority to prevent marine accidents caused by human factors. Meanwhile, for ship navigation safety, the operator's professional literacy is the main determinant (Hsu, 2012).

3.3. Location selection

In terms of location selection, 27 papers are assessed, where the AHP method is widely used in urban mobility studies related to electric vehicles (EVs), bike-sharing stations, and mobility hub selection. Karolemeas et al. (2021) argue that EV car-sharing supports multimodal travel behavior. Some infrastructural, technical, and economic barriers, such as the lack of charging stations and the higher purchase price of EVs compared to internal combustion vehicles, are present behind the slow adoption of EVs (Adhikari et al., 2020). Kaya et al. (2021) develop a methodology which allows a more suitable diffusion of EV charging areas and find that the environment and urbanity are the most essential criteria for selecting the charging stations. Similarly, a study in Turkey focusing on taxis states that suitable areas for electric taxis are the regions with high traffic mobility (Kaya, Alemdar, et al., 2020). Other

studies imply that parking lot availability (Kaya, Tortum, et al., 2020), the residential dimension (Khalife et al., 2022), and the security of the power system (Karaşan et al., 2020) are the most important criteria in determining EV charging stations. Moreover, a study mentions that public EV charging should be located in private spaces to ensure their protection against vandalism (Anthopoulos & Kolovou, 2021). Other findings reveal that when deciding on the location of super-fast charging stations for EVs, public transport connections, land use, and population density should be considered (Costa et al., 2018). Furthermore, Bahadori et al. (2022) identify the criteria for bike-sharing locations and reveal that the areas with high population density and low slopes are preferred. Another study presents that bike-sharing parking points should be located near bus and subway stations (Cheng & Wei, 2020). Meanwhile, accessibility is considered important in determining the location of mobility hubs (Aydin et al., 2022) and bus garages (Bilisik et al., 2014). In addition, the distance to public places is essential in finding the best place for parking lots (Kazazi Darani et al., 2018) and priority roads to implement bus lanes (Borchers & Ribeiro, 2022).

Determining locations for transportation infrastructure is particularly tricky where several criteria should be considered. Thus, the AHP method could be performed to help decision-makers understand which factors should be prioritized. Palevičius et al. (2013) identify the territories requiring car parking solutions and find that car ownership and public transport development levels are the most crucial factors. Pekkaya and Keleş (2022) examine the important factors in determining freight village location selection. The researchers argue that economic factors and transportation networks have the highest priorities. A study in China finds that besides transportation-related factors, land prices and salaries should be considered when determining the site location of dry ports (Ka, 2011). Similarly, other research works demonstrate that cost is the leading factor in a logistic center and container transshipment terminal location selection (Kadaifci et al., 2019; Kim et al., 2020; Yildiz et al., 2022), which is followed by environmental factors (Kim et al., 2020) and the frequency of vessel calls (Kadaifci et al., 2019). Additionally, related to economic factors, a study identifying the location of a logistic center suggests that the GDP per capita should be first considered (Komchornrit, 2021). The closeness to import/export areas is considered important to find the best location for container transshipment (Zabihi et al., 2016). Besides technical suitability, political sustainability is an essential factor in identifying a suitable multimodal freight terminal location (Kumar & Anbanandam, 2019). Natural factors are considered in a study defining areas for marinas and where tsunami wave height is weighted the highest followed by landslide risk (Gumusay et al., 2016). Similarly, geological factors should be considered when evaluating the site selection of subsea tunnel projects (Xue et al., 2021). Additionally, environmental factors are essential in determining airport site selection, as well (Erkan & Elsharida, 2020). Sennaroglu and Varlik Celebi (2018) investigate the appropriate location for a military airport and identify that the level of military necessity in the region is the most important factor.

3.4. Environmental impacts

A total of 25 studies are discussed on the topic of environmental impacts, where the AHP method is used to determine suitable alternatives to tackle environmental issues in the transportation sector. One area that often uses the environmental impact is the determination of the best strategies to reduce energy consumption. A study compares two different energy sources to find suitable options for achieving zero-carbon shipping (Inal et al., 2022) and presents that Ammonia has higher sustainability than Hydrogen. Another study on selecting alternative fuel for buses identifies the compressed natural gas as the best option for buses in Istanbul (Erdoğan & Kaya, 2016). In the marine sector, Mandić et al. (2021) include the climate change impact as a factor in supporting the decision on alternative fuel selection. In the aviation industry, Singh, Sharma, et al. (2019) argue that the technology innovation factor is the main contributor to the reduction of aviation fuel consumption. Additionally, Haddad and Fawaz (2013) emphasize that environmental criteria are more important than economic priority when checking the alternative airplane fuels. However, a study confirms that airlines mostly choose aircraft based on the price rather than their environmental aspects, such as pollution and noise (Kiracı & Akan, 2020). Meanwhile, in analyzing the current status of green port development, the environmental management system is weighted the highest as a sub-criterion, which is followed by the capacity to deal with wastewater (Wan et al., 2018). The AHP is used to investigate the methods related to minimizing the transportation costs of end-of-life tire collection (Nowakowski & Król, 2021). It is found that the routing of heavy trucks and the pickup of waste tires from a local network after preprocessing is the most profitable method. In the case of end-of-life vehicles, financial benefit, followed by pollution and resource utilization, is the most important criterion in the decision to select the sustainable end-of-life vehicle management alternative.

Another transportation-environmental research stream using the AHP is on the topic of road transportation. Tuzkaya (2009) measures the environmental effects of various transport modes and finds that the emission reduction potential and energy resource utilization have the highest effects on the selection of transport modes. In developing a sustainable transportation system, clean environment and change in travel behavior are considered essential (Al-Atawi et al., 2016). In contrast, a study evaluating the effectiveness of traffic calming strategies argues that operational efficiency has the largest weight instead of environmental impacts (Joo et al., 2019). Similarly, economic criteria are the most important in evaluating public road transportation (Gutiérrez et al., 2021). Moreover, the tax schemes promoting environmentally friendly transport modes are identified as the best transportation policies to reduce the adverse climate change impacts (Berrittella et al., 2008). Sustainable transportation is ranked as the most important in mitigating both the threats to public health and urban heat, too (Dano et al., 2023). A study in Iran argues that air and noise pollution should be prioritized when choosing transport modes in dense populations (Mousavimasouleh et al., 2022). Similarly, an Indian study finds that the impacts of air pollution and traffic congestion are major threats to the sustainable development of a city (Nag et al., 2018). To reduce the effect of traffic noise, a rubberized surface reinforcement mixture combined with noise barrier could be used (Ruiz-Padillo et al., 2016). Reductions in speed and heavy vehicle traffic are important factors in lowering the noise generated by road traffic (D'Alessandro et al., 2022). Additionally, in the case of rural areas, mobility by train is a preferred alternative to public investment for sustainable mobility (López-Iglesias et al., 2018).

Regarding logistic transportation, recyclability, the ease of disassembly, and energy consumption are argued to be essential factors in the production planning model (Entezaminia et al., 2016). Meanwhile, David et al. (2021) analyze the impact of the sustainability and environmental protection factors on the final choice of a shipping route that mostly suits the customers' needs. The researchers observe that the ecological aspect of cargo transportation is the most important factor. Moreover, when choosing depot logistics, the total environmental impact should be minimized (Palacio et al., 2018). It is argued that the use of renewable energy is the most essential indicator in the smart port design (Yen et al., 2023). In selecting vehicle types to distribute forest products, transportation, environmental, and road surface damage risks are among the crucial factors (Akay & Demir, 2022).

3.5. Transportation infrastructure

The AHP method is extensively used in transportation infrastructure studies, in which the method is performed to rank the criteria associated with infrastructure improvement strategies. A total of 45 papers are discussed qualitatively on the topic of transportation infrastructure. Economic benefits and efficiency are essential in terms of evaluating the

investment in transportation construction projects (Chang et al., 2018; Feng et al., 2020; Pires & de Carvalho, 2013). Some studies argue that multi-criteria analysis captures the decision-makers and experts' preferences and goal settings more adequately than the traditional cost-benefit analysis (Leviäkangas & Lähesmaa, 2002; Tudela et al., 2006). The reliability during the design and the improvement of the transportation network should be maintained in the development of the infrastructure (Paraskevadakis et al., 2021). Similarly, a connected network supporting the old public transport systems should be considered when implementing new bus lanes (Borchers & Ribeiro, 2022). A study in Thailand argues that the success of rail infrastructure development projects is primarily related to the adequate rail development master plan (Peetawan & Suthiwartnarueput, 2018). In road transportation studies, the AHP is often applied to examine the cause factors of the declining road quality and find the best strategies for improving the driving experience. A study exploring the factors that affect the road infrastructure performance in Western Australia finds that heavy vehicles contribute the most to road defects (Wu et al., 2022). In the case of road handling priority, the level of damage and economic factors are considered the most essential to determine which roads should be repaired (Warnars et al., 2021). Other findings state that in supporting pavement management decision-making, high priority should be given to important pavement sections with high traffic volume (Abu Dabous et al., 2020). In terms of maintenance strategy, road condition, maintenance type, mobility, and accessibility are the primary criteria (Kamil et al., 2017). The improvements in lighting, cleanliness, and crossing facilities are the highest-ranked factors in the development of pedestrian facilities (Aromal & Naseer, 2022). Some natural hazard factors (e.g., ground slope, soil texture, and landslide susceptibility) should be considered when planning forest road networks (Hayati et al., 2013). Another natural factor called inadequate depth of rivers is considered crucial in explaining the slow development of inland waterways in India (Totakura et al., 2022). Meanwhile, Barić (2016) evaluates the road section design in an urban environment and finds that functional efficiency is weighted the highest, while the lowest coefficient is associated with the ecological criterion.

Moreover, some studies use the AHP method to examine the alternatives related to transportation sustainability. A study in Pakistan states that overpasses mean the best alternative to reduce the congestion in cities (Raza et al., 2022). However, it is worth mentioning that transportation development should consider environmental quality improvement, as well (Pujiati et al., 2022). A study proposes high-quality public transport and slow traffic networks as the most important indicators of low-carbon transportation planning (Bai et al., 2021). Furthermore, animal habitats should be considered when designing railways (Song et al., 2021).

In the planning of developing transportation infrastructures, some evaluations are needed to examine which factors should be prioritized and to find the potential risks that might happen. Public transport frequency is ranked as the most essential factor in evaluating transportation demand management alternatives, and the social impact factor is the second in the ranking (Tanadtang et al., 2005). A Spanish study finds that traffic flow and traffic composition should be considered when determining which road and rail infrastructure areas are subject to hazards (e.g., landslides, fires, and infrastructure safety) (Rúa et al., 2022). Several risks, such as political and legal risks in urban rail transit projects (Feng et al., 2021), air logistic hubs (Tsai & Su, 2002), government policies in public–private partnership projects of EVs (Gupta et al., 2023), are to be considered in transportation projects. Some technical risks in forest road projects (Akay et al., 2018), elevated metro rail corridor projects (Singh, Sarkar, et al., 2019), and rail-based multimodal freight transportation networks should be acknowledged, as well. The risks in elevated metro rail corridors are mostly related to the girder erection (Singh, Sarkar, et al., 2019). Cost is among the most important factors in determining which projects, such as railway reconstruction projects (Galdiani et al., 2022), bridges (Rashidi et al., 2017; Salem et al., 2013), or transportation infrastructures in general (Rabello Quadros & Nassi, 2015), should be prioritized. Even when selecting the contractor for transportation infrastructure development, experience and quality come after the cost factor (Inti & Tandon, 2017). Additionally, a study argues the possibility of getting support from European funds as the leading factor in buying new asphalt mixing plants (Sivilevičius et al., 2021). In an African study, it is found that the chronic lack of financial resources should be tackled when developing strategies for the railway transportation system (Bouraima et al., 2020). When selecting capital-intensive transportation projects, the capacity enhancement (e.g., the impact of developing a new dedicated freight corridor on capacity enhancement) is the most important criterion (Bhatia et al., 2023). Furthermore, the factor related to safety is common in deciding on transportation infrastructure projects, such as the development of a multimodal freight transportation network (He et al., 2021), the rail infrastructure (Nyström & Söderholm, 2010; Peetawan & Suthiwartnarueput, 2018), steel bridges (Rashidi et al., 2017), and choosing which overpasses should be eliminated (Sohn, 2008).

In developing existing ports, their infrastructure and facilities should be taken into account, which factors are followed by the port-city development (Tseng & Yip, 2021). Meanwhile, when selecting materials for new airport runways, fire resistance is among the crucial factors to be considered (AlKheder et al., 2022). In the case of autonomous vehicles, physical infrastructure readiness is more important than the cyber infrastructure (Jiang et al., 2022).

The quality of transportation infrastructures could be assessed by using the AHP method. The geometric factor called slope (de Aquino Traldi et al., 2022) and traffic safety are considered as the most important factors in determining the quality of cycling (de Aquino Traldi et al., 2022) and walking infrastructure (Bivina & Parida, 2020). Moreover, the structural index is the most essential factor in monitoring the structural health of concrete bridges (Darban et al., 2021). In evaluating port competitiveness, the port efficiency index has high ranking (Peng et al., 2018). Another study argues that transportation and distribution costs are crucial in assessing the competitiveness of ports (Yang & Chen, 2016). In identifying the sustainability metrics of transportation projects, the connectivity of the network and the commute cost have the highest weights (Oswald Beiler & Treat, 2015). In case of evaluating the functional criteria of subway stations, the structural and security functions are the most important criteria (Semaan & Zayed, 2009). Fig. 6 summarizes the sub-topics of the application of AHP in transportation decision-making research and their most important factors.

4. Discussion

4.1. Review results

Following the completion of the two-stage comprehensive review process, several essential characteristics of the AHP models utilized in transportation are found. While some of these findings may have been anticipated, others prove to be surprising yet explainable. Consequently, a thorough discussion of the review results is deemed essential.

It is foreseeable that the AHP model best suits the sub-themes in the transportation domain characterized by a finite number of criteria and alternatives where the attributes of the problem can be hierarchically structured. This is the reason why location selection (i.e., once possible spots have already been found for the decision) is one of the most popular sub-themes, as accurately identified by the bibliometric analysis. Furthermore, the development of the transportation infrastructure, particularly when dealing with specific scenarios aimed at prioritizing various options, presents a highly suitable application for the AHP method. However, upon a closer examination during the systematic review phase, it turns out that the AHP models are the most effective when dealing with a moderate number of criteria (i.e., 10 to 40) and a low number of alternatives (i.e., three to nine). Otherwise, the application of the method is very rare. The rarity of application beyond these

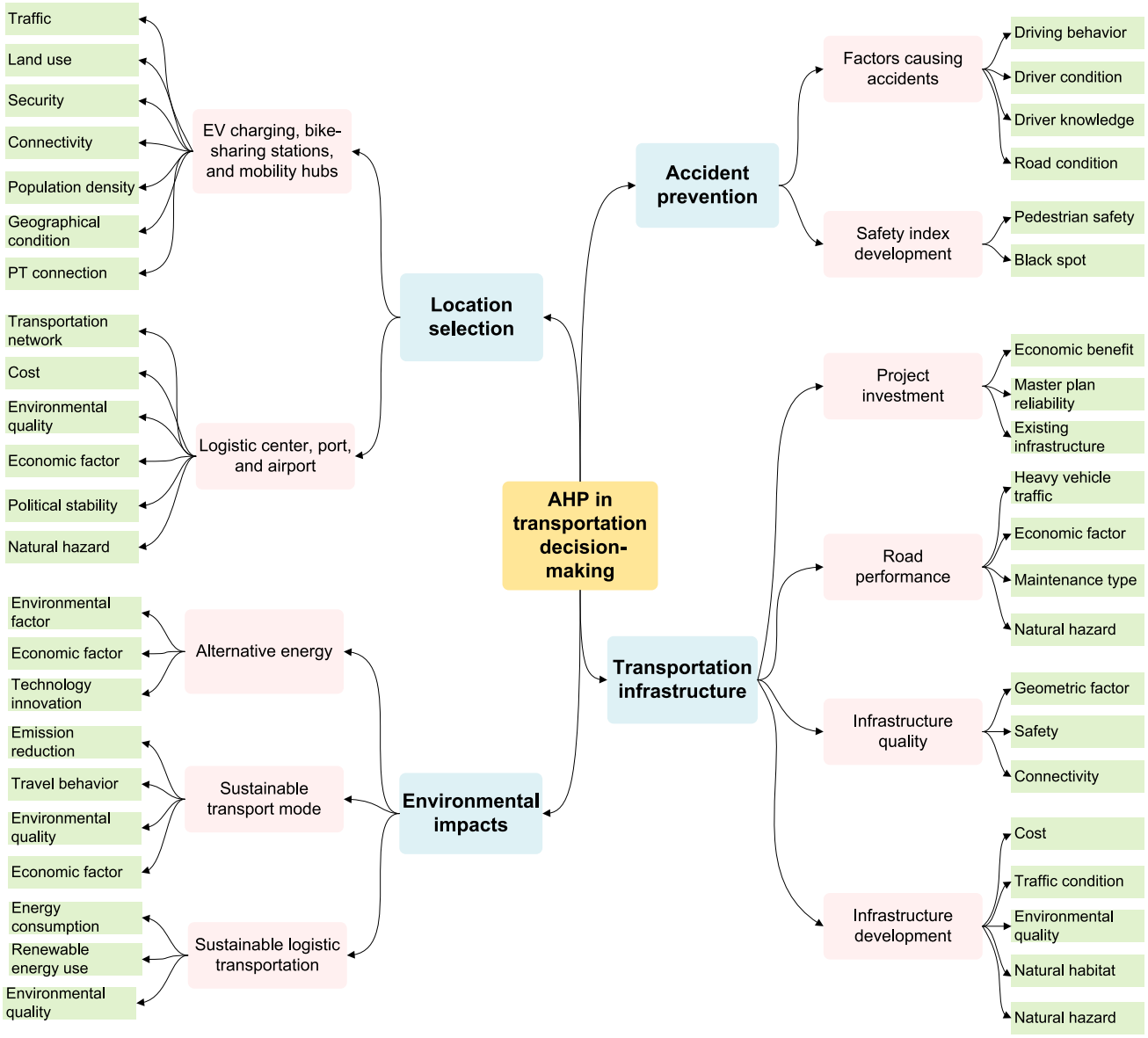

Fig. 6. Summary of the most important factors of AHP decision-making in the field of transportation.

thresholds can be attributed to the restricted comparing capacity of the human brain, as noted by Saaty (1977). This precondition ensures a clear structure avoiding possible overlaps among the criteria in the decision structure.

Another attractive feature of the AHP is its capacity to handle quantitative and qualitative attributes simultaneously. This may explain why the accident analysis and environmental impact sub-themes have become appealing domains for the application of the method. Moreover, both the bibliometric analysis and systematic literature review stages reveal that the characteristics of the AHP are essential for creating transportation-related indices. Thus, accident or environmental measure figures including several components can be determined as well as provide information for experts in the field.

Surprisingly, based on the conducted two-stage review, the AHP method could be suitable for mode choice analysis but with strict preconditions. The overviewed papers could set up a clear hierarchical structure of the attributes affecting the mode choice of the public, and the number of possible modes ranges from four to six to avoid trivial (i.e., two or three) or complicated (i.e., over six) prioritization among the transport modes.

As for the second objective of this paper, the review process validates the preconceptions but unveils an unexpected outcome regarding the possible combination of the AHP with other techniques, as well. The hybrid AHP models apply fuzzy sets and the TOPSIS method for a more sophisticated prioritization (Li et al., 2023) of the existing alternatives. As supported by both the bibliometric and systematic reviews, the fuzzification of the scores aims to enhance the reliability of the results by considering the possible vague responses. The TOPSIS measures the distance of the alternatives from the ideal solution thus providing a more comprehensive prioritization of the options for the decision problem. However, the review of several relevant papers unveils that the creation of hybrid AHP-Delphi models is a prevalent trend in the scientific literature. The Delphi method (Barrios et al., 2021) relies on expert opinion synthesis (i.e., some exceptions for surveying the public by this technique exist) and aims to achieve consensus while targeting the means of the group responses in a certain domain by using repetitive rounds of questioning. The combination of these techniques stresses the necessity of consensus-creation in the AHP models because it deals with the group opinions by a simple mean-based aggregation. Still, identifying the best consensus-creation technique remains a subject of further

research with the Delphi procedure likely serving as a temporary solution.

Finally, the RQs are considered based on the conducted two-staged review process.

RQ1. On the one hand, the role of the AHP method in transportation could be predictable supporting complex transportation-related decisions that have both tangible and intangible criteria and a finite number of alternatives. On the other hand, the conducted review process sheds light on the possibility of creating indices to characterize and compare transportation systems or complex transportation problems and use the method on a macro level, as well. The systematic review shows successful attempts of researchers in this domain, which can be applied as precedents in further research.

RQ2. According to the results, the popularity of the method can be explained by the fast and systematic knowledge acquisition of experts or even layman participants in a transportation-related problem. This could be the reason for the recently growing popularity since more emphasis has been put on the involvement of the public and various stakeholders in transportation decisions. Additionally, the increased number of applications can be due to the more sophisticated models created to solve the disadvantages of the original or previous versions of the AHP method.

RQ3. Owing to the modifications of the method in the last two decades, those solutions must be highlighted that aim to unburden the evaluators in the survey process, i.e., by parsimonious AHP (Duleba, 2022). Moreover, it is notable that instead of involving a few decision-makers as the original technique advises, recently, the large-scale pattern application has been made possible; thus, a broader circle of participants can be reached and examined. This phenomenon predicts the approximation of statistics and MCDM methods in the near future.

RQ4. This research points out that the TOPSIS and DELPHI techniques are the most preferred to combine with AHP for criteria weight determination where the AHP model is applied, and for determining the final ranking, the other two methods seem to be the best solution. The systematic review finds that other operation research models, especially optimization-oriented procedures, might effectively amend the analysis of decision-making. The extension of the original model by fuzzy sets decreases the risk of getting to a false conclusion due to the evaluators' untrustworthy responses. Table 5 summarizes the RQs and their relevant future research directions.

4.2. Limitations

Despite the contributions of this study, some limitations must be identified. First, both the bibliometric and systematic reviews use Scopus and WoS as database sources. While it is generally argued that these databases can provide high-quality articles (Birkle et al., 2020), some research works might be overlooked since the journals are indexed by neither Scopus nor WoS. This limitation might lead to biased findings. Should future research conduct bibliometric and systematic reviews, more databases could be used. In the case of the systematic review, an independent decision to determine the relevance of each study might not be enough to eliminate biases. However, as the PRISMA guideline is followed in this research to provide more transparency in conducting the review, future studies could replicate the process and identify the possible gaps in the approaches of current study. Furthermore, the exclusion of the grey literature and conference papers could limit the potential findings related to current review. While it can be true that recent findings might be available in conference papers and grey literature (e.g., project reports), more comprehensive results are primarily presented in journal articles. Therefore, it can be assured that current research provides essential insights into the trends of using the AHP method to support decision-making in transportation research.

Table 5
The summary of RQs and future scopes.

RQ	Summary	Future research direction
RQ1	The AHP method applied in transportation supports decisions that have complex criteria	Integrating the AHP with other MCDM methods to improve the robustness of the outcomes
RQ2	The growing popularity of the AHP method in transportation is driven by its ability to systematically gather expert or public input	Improving the precision and reliability of the prioritization processes by applying hybrid AHP models
RQ3	Recent modifications to the AHP method have eased the survey process and enabled large-scale applications	Searching for the balance between the loss of information and the reduction of the pairwise comparisons to unburden the evaluators
RQ4	TOPSIS and DELPHI are the preferred methods to combine with AHP, while fuzzy sets improve decision-making accuracy	Separating the criteria and the alternatives in the evaluation process, still maintaining the integration of decision support

4.3. Future scope

For future research of the AHP method in the mobility domain, an important aspect regarding the location selection sub-theme is that a deeper integration of the AHP with the geographic information system (GIS) might enhance the decision-making by incorporating the spatial data more effectively in the decision process. In transportation infrastructure development, future studies should focus on enriching scenario-based AHP models to prioritize the options more adequately in complex, multi-criteria environments. The use of the AHP in accident analysis and environmental impact assessments should be expanded particularly by integrating it with other MCDM methods to improve the robustness of the outcomes. Furthermore, while the mode choice analysis presents challenges, research should investigate the development of stricter preconditions and refined criteria for the AHP application in this domain potentially unlocking new insights into traveler behavior and mode preferences.

On the other hand, future research on hybrid AHP models should explore the potential of these combinations to address complex decision-making scenarios. Integrating fuzzy sets with the AHP and TOPSIS methods shows significant potential for improving the precision and reliability of the prioritization processes, especially in situations characterized by uncertainty and imprecise data. Future studies could explore the refinement of these hybrid models in various transportation subfields, such as infrastructure planning and environmental assessment, to evaluate their effectiveness in different contexts. Additionally, the development of hybrid AHP-Delphi models represents a significant trend. Future studies should focus on optimizing these models for consensus-building among experts, potentially incorporating digital and automated tools to streamline the iterative Delphi process thus increasing the robustness of the AHP outcomes in transportation studies.

5. Conclusion

In this paper, the widespread utilization of the AHP method in transportation research is investigated with two primary objectives. Firstly, the aim is to identify those sub-themes for which the AHP is especially appropriate. The second objective is to reveal the combination of those techniques that enhance the traditional AHP to reach more efficient results. A two-stage thorough review procedure is conducted, which makes it possible to list and overview all relevant papers published from 2000 to 2022 by using both bibliometric and systematic review analyses. The results show that the most widespread sub-themes are location selection, transportation infrastructure development, accident analysis, and analysis of the environmental impacts of transportation. As hybrid methodologies, fuzzy-AHP, AHP-TOPSIS, and AHP-Delphi are the most significant combinations to highlight.

Future research in transportation science should focus on applying the AHP method to scenario-building in emerging fields, such as

autonomous vehicles, while advancing hybrid models that enhance consensus-building and streamline pairwise comparisons. For further research, the scenario-building of new emerging fields of transportation (e.g., autonomous vehicles and micromobility) seems the most promising trend in terms of applying the AHP methodology. As for hybrid modeling, the consensus-creation techniques as well as methods considering the interconnections of the decision problem criteria along with the reduction of pairwise comparisons in the survey procedure might gain the most space in the future usage of the AHP method in transportation science.

CRediT authorship contribution statement

Willy Kriswardhana: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – original draft, Visualization, Writing – review & editing. **Bladimir Toaza:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Writing – original draft, Visualization, Writing – review & editing. **Domokos Esztergár-Kiss:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – review & editing, Supervision, Funding acquisition. **Szabolcs Duleba:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgement

The research reported in this paper is part of project no. BME-NVA-02, implemented with the support provided by the Ministry of Innovation and Technology of Hungary from the National Research, Development and Innovation Fund, financed under the TKP2021 funding scheme. The research was supported by OTKA FK23 145899 project funded by the National Research, Development and Innovation Office. The linguistic revision of this paper is prepared by Eszter Tóth.

Appendix

Appendix A. . The compilation of literature pertaining to AHP method applied in the field of transport related decision-making

Author (year of publication)	Location	Method	The main aim	Key result
Accident prevention				
(Treeranurat & Suanmali, 2021)	Thailand	AHP	Developing a model related to the black spot identification	The EAN values are 57, 28, 10, and 5 for death, severe injury, minor injury, and damaged property only, respectively
(Luo et al., 2021)	China	AHP	Defining key factors in lane-changing safety	Key factors influencing lane changes include driver characteristics, vehicle types, and road conditions
(Sun et al., 2020)	China	AHP, entropy method	Defining models for the safe driving behavior	Drivers exhibiting fatigue, acceleration, and deceleration behavior face increased driving risk
(Mukesh & Katpatal, 2020)	India	AHP	Developing a pedestrian safety index	The normalized weights show 35.32 % for the age parameter, 55.59 % for pedestrian parameters, and 9.04 % for built-up density
(Obregón-Biosca et al., 2018)	Mexico	AHP	Defining the most important area of knowledge in road traffic education	For pedestrians, drivers, passengers, and PT users, situational factors carry the most weight, followed by current transit safety conditions
(Kececi & Arslan, 2017)	Turkey	Fuzzy AHP	Investigating the efforts to reduce ship accidents	Promoting a strong team culture and prioritizing training are key strategies to prevent similar accidents
(Podvezko & Sivilevičius, 2013)	Lithuania	AHP	Examining the impacts of interaction levels of the transport system on the accident rate	The interaction between traffic participants, particularly freight and vehicles, is the most critical, with vehicle-to-vehicle interactions being the second most important
(Hsu, 2012)	China	Fuzzy AHP	Discussing the service attributes of ports for ship navigation safety	Operators' professional competence is the primary factor in ensuring ship navigation safety
(Arslan & Turan, 2009)	Turkey	SWOT, AHP	Factors that are affect marine casualties are examined	Human-related and meteorological factors continue to contribute to accidents and incidents
(Hirasawa et al., 2007)	Japan	AHP	Identifying the most recognizable colors of uniforms worn by traffic control personnel	In the evaluation of autumn and winter visibility, orange stands out as the most recognizable color, while red and dark blue have the lowest visibility ratings
Location selection				
(Borchers & Ribeiro, 2022)	Brazil	AHP	Providing a framework for selecting priority roads for bus lane implementation in medium-sized cities	Access to public facilities holds the greatest weight, followed by population density, bus flow, road hierarchy, the current bus network, and lastly, mixed land use
(Khalife et al., 2022)		AHP	Assisting municipalities in planning the strategic deployment of public charging infrastructure, focusing on both size and location	The municipality's strategy prioritizes the residential dimension, with the commercial dimension coming in second
(Pekkaya & Keleş, 2022)	Turkey	DEMATEL, AHP	Establishing criteria priorities for selecting Freight Villages locations	Trade potential, transportation networks, and economic factors rank the highest and have the strongest interactions, making them central to the decision-making process

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Author (year of publication)	Location	Method	The main aim	Key result
(Bahadori et al., 2022)	Portugal	AHP, TOPSIS	Identifying and ranking relevant system criteria for bike-sharing station locations	In terms of city infrastructure, proximity to areas with higher population density and lower slope areas were more critical than other criteria
(Aydin et al., 2022)	Turkey	Type-2 fuzzy AHP	Developing an integrated AHP-based Weighted Aggregated Sum Product Assessment (WASPAS) method under a type-2 fuzzy environment for selecting mobility hub locations	The most influential factors are accessibility to the city center and public interest, respectively
(Yildiz et al., 2022)	Turkey	AHP, VIKOR	Determining the weights of criteria for optimal logistics center location selection	cost is the most important criterion for selecting logistics locations
(Anthopoulos & Kolovou, 2021)	Greece	AHP	Presenting an MCDM framework for the deployment and operation of EV charging infrastructure	The preferred approach for deploying public EV charging stations is to install and operate them in private spaces within urban areas to protect against vandalism.
(Kaya et al., 2021)	Turkey	AHP, TOPSIS	Promoting a methodology for better diffusion of EV charging areas	When choosing EV charging stations, environmental and urban factors are the most significant
(Komchornrit, 2021)	Thailand	AHP, TOPSIS	Investigating the most suitable provincial location for a logistics center	The key weightings include GDP per capita, highways, and labor
(Karolemeas et al., 2021)	Greece	AHP	Introducing a new evaluation index to assess the suitability of road links for electric vehicle charging station (EVCS) placement	There is strong consensus that transport hubs (train, metro, airport, and ports) align with the concept of EVs as a multimodal travel support system
(Xue et al., 2021)	China	AHP	Identifying an objective and accurate method for evaluating site selection of a subsea tunnel project	Ventilation conditions and geological structure are the key factors influencing the site selection of subsea tunnels in the Bohai Strait
(Kaya, Alemdar, et al., 2020)	Turkey	Fuzzy-AHP, TOPSIS	Identifying new potential locations for electric taxi charging stations (ETCS)	Regions with high traffic mobility are best suited for ETCS
(Erkan & Elsharida, 2020)	Libya	AHP, Rank Order Centroid (ROC)	Determining the appropriate site for an airport	The environmental criterion has the highest weight value
(Karaşan et al., 2020)	Turkey	Intuitionistic fuzzy DEMATEL, AHP, TOPSIS	Selecting locations for EV charging stations	Power system security and traffic convenience are the most influential sub-criteria in the selection process
(Kaya, Tortum, et al., 2020)	Turkey	AHP, VIKOR, PROMETHEE	Selecting locations for EV charging stations	The primary criterion for transportation is parking lot availability as a sub-criterion
(Kim et al., 2020)	South Korea, China	EFA, AHP	Analyzing the location competitiveness of regional logistics distribution centers	A logistics factor holds the highest importance, followed by market, costs, services, and environmental factors
(Adhikari et al., 2020)	Nepal	AHP	Introducing a framework for identifying and analyzing the obstacles to the adoption of EVs	Infrastructure, policy, economic, and technical barriers are more significant than social barriers.
(Cheng & Wei, 2020)	China	AHP	Studying the location selection for bike-sharing parking spots	For bike-sharing locations, proximity to bus and subway stations and population density are key concerns for the advisory board
(Kumar & Anbanandam, 2019)	India	Intuitionistic fuzzy analytic hierarchy process (IF-AHP), TOPSIS	Identifying social, technical, economic, environmental, and political (STEEP) sub-criteria for multimodal freight terminal location assessment	Technical sustainability is the most crucial criterion for location assessment, with political sustainability also playing a significant role
(Kadaifci et al., 2019)	Turkey	AHP, Fuzzy rule-based systems (FRBS)	Selecting container transshipment terminal locations	Terminals outside Istanbul were considered more suitable for transshipment, mainly due to lower costs and fewer vessel calls
(Kazazi Darani et al., 2018)	Iran	Fuzzy-AHP, TOPSIS	Identifying the optimal location for a parking lot	Distance from public places is regarded as the most important factor in determining the best location for a parking area.
(Sennaroglu & Varlik Celebi, 2018)	Turkey	AHP, PROMETHEE, VIKOR	Choosing the best site among alternatives for a military airport	Military necessity is the key criterion for military airport selection, with military importance in the region as the top sub-criterion
(Costa et al., 2018)	Brazil	AHP, Weighted Linear Combination, GIS	Determining the best locations for EV supply equipments to accommodate the needs of light-duty electric vehicles (LDEV), aiming for a 1 % market penetration by 2025	For super-fast charging stations, the highest-rated attributes were proximity to roads, public transportation links, shopping centers, and areas with high population density
(Gumusay et al., 2016)	Turkey	AHP	Defining areas suitable for marina construction	tsunami wave height and landslide risk are the most weighted criteria
(Zabihi et al., 2016)	Iran	AHP, TOPSIS	Identifying the best location for a container transshipment hub	Closeness to import/export areas is the most important sub-criterion.
(Bilisik et al., 2014)	Turkey	Fuzzy-AHP	Determining optimal locations for bus garages to support maintenance and repair operations	The accessibility and infrastructure are among the most important criteria to determine the bus garage location
(Ka, 2011)	China	Fuzzy-AHP, ELECTRE	Listing all factors influencing dry port site selection	Transportation is considered as the most important factor, followed by trade level, land prices, and salaries.
Environmental effects				
(Yen et al., 2023)	11 countries	AHP, Tobit regression	Investigating how smart port design can influence the efficiency of maritime transport	For the environmental aspect, the most crucial indicator is producing and using renewable energy
(D'Alessandro et al., 2022)	Italy	AHP	Defining a method for evaluating infrastructural interventions for the mitigation of noise generated by roads	Speed reduction is regarded as the most critical factor, with a secondary emphasis on decreasing traffic flow, particularly for heavy vehicles

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Author (year of publication)	Location	Method	The main aim	Key result
(Inal et al., 2022)	Turkey	AHP	Comparing two different energy sources to find suitable fuel options for zero-carbon shipping	Safety and environmental impact are the key criteria when using alternative fuels. Ammonia stands out as a safer, more cost-effective fuel with fewer storage issues and greater sustainability
(Akay & Demir, 2022)	Turkey	Fuzzy-AHP	Revealing the weight values of the criteria that are effective in selecting the most suitable vehicle types in forest products transportation	Environmental concerns, such as CO2 emissions and road surface damage risk, are important factors in selecting vehicles for forest product transportation
(Dano et al., 2023)	Saudi Arabia	AHP	Assessing the impacts of climate change	Sustainable transportation is recognized as the best approach to mitigating public health risks and urban heat island effects
(Mousavimasouleh et al., 2022)	Iran	AHP	Defining relevant criteria for evaluating and prioritizing urban transportation strategies with a focus on environmental sustainability	Air pollution and noise pollution are the top criteria for choosing a travel mode in densely populated areas
(Nowakowski & Król, 2021)	Poland	AHP- PROMETHEE	Investigating the costs of collecting and transporting end-of-life tires	The most profitable method for collecting end-of-life tires involves routing heavy trucks to pick up waste tires from a local network after preprocessing
(Mandić et al., 2021)	Croatia	AHP and Simple Additive Weighting (SAW)	Demonstrating the use of multicriteria analysis as a decision-support tool for choosing alternative marine fuels in coastal traffic	Different stakeholders (shipowners, government, academia) have varying perspectives, but on average, fuel price ranks highest
(David et al., 2021)	–	AHP	Analyzing the impact of sustainability and environmental protection factors on selecting a shipping route that best fits customer needs	From a customer's perspective, the ecological aspect of cargo transport is the most important factor
(Gutiérrez et al., 2021)	Spain	AHP	Assessing public road transportation vehicles based on their alternative engine technologies and combustion characteristics	The economic criterion is deemed the most important. Within the environmental criterion, NOx emissions are the most significant sub-criterion
(Kiracı & Akan, 2020)	Turkey	Interval type-2 fuzzy sets AHP (IT2FAHP)	Proposing a novel model for aircraft evaluation and selection that considers both airline and passenger interests	Environmental factors like pollution and noise hold the lowest weight, while aircraft price holds the highest
(Singh, Sarkar, et al., 2019)	India	AHP-Entropy	Categorizing influential factors and assessing their relative importance for fuel-efficient aviation	Technological innovations are the main contributors to reducing aviation fuel consumption
(Joo et al., 2019)	South Korea	AHP	Evaluating the effectiveness of traffic calming measures	Operational efficiency is the most important objective
(Nag et al., 2018)	India	AHP	Offering a framework to assess the sustainability of existing transport environment using sustainability indicators	Experts concern about traffic congestion, air pollution, and road encroachment in the city's sustainable development.
(López-Iglesias et al., 2018)	Spain	AHP	Analyzing different public investment alternatives for promoting sustainable mobility in rural areas	When weighing criteria equally, train mobility performs best in a tendential scenario, while intermodal mobility leads in the optimistic scenario, both slightly outperforming a "do-nothing" strategy
(Palacio et al., 2018)	Spain	Fuzzy-AHP	Identifying the best container depot logistics network in a hinterland, aiming to minimize both the total cost and environmental impact of the network	If environmental impact is prioritized over other objectives, more existing depots are selected over new ones
(Wan et al., 2018)	–	AHP	Analyzing the current status of green port development worldwide	The environmental management system is given the highest weight among the subcriteria, with the capacity to handle wastewater following closely
(Ruiz-Padillo et al., 2016)	Spain	Fuzzy extended analytical hierarchy process (FEAHP)	Selecting appropriate alternatives to mitigate traffic noise on various road segments	All methods agree that surface reinforcement with a rubberized mixture, combined with either a shorter noise barrier or additional 5 dB insulation for house windows, is an effective solution
(Entezaminia et al., 2016)	Iran	AHP, Linear programming	Developing a comprehensive multi-objective aggregate production planning model for a green supply chain	Recyclability, ease of disassembly, and energy consumption are given more weight in decision-making
(Al-Atawi et al., 2016)	Saudi Arabia	AHP	Creating a sustainable transport system that considers user attitudes and preferences	Important strategies include fostering a clean environment, changing travel behavior, choosing public transportation when available, and implementing road pricing
(Ahmed et al., 2015)	Malaysia	DEMATEL, AHP, FEAHP	Proposing an integrated model to select dimensions and criteria for evaluating sustainable options for end-of-life vehicle (ELV) management	Financial benefit is the top criterion for selecting a sustainable ELV management alternative
(Erdoğan & Kaya, 2016)	Turkey	Delphi, Fuzzy-AHP, TOPSIS	Managing both qualitative and quantitative criteria with uncertainties to select the best alternative fuel bus for public transportation	Compressed natural gas is identified as the best alternative for public transport buses in Istanbul.
(Haddad & Fawaz, 2013)	Canada	AHP	Examining whether microalgal jet fuels are technologically feasible, environmentally sustainable, and economically viable	In scenarios where environmental priorities are emphasized, environmental criteria carry more weight compared to economic ones
(Tuzkaya, 2009)	Turkey	Fuzzy-AHP	Measuring the environmental effects of different transportation modes	Emission reduction potential and energy resource utilization are key factors influencing the choice of transport modes

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Author (year of publication)	Location	Method	The main aim	Key result
(Berrittella et al., 2008)	–	AHP	Evaluating transport policies that support the mitigation of climate change impacts	Tax schemes promoting environmentally-friendly transport modes are identified as the most effective policy to combat climate change impacts
Transportation infrastructure				
(Rúa et al., 2022)	Spain	AHP, Best-Worst Method	Identifying areas of road and rail infrastructure vulnerable to hazards such as landslides, fires, and safety risks	Traffic flow and composition are the most critical factors
(Wu et al., 2022)	Australia	Spatial-AHP	Investigating factors influencing road infrastructure performance	Heavy vehicles contribute the most to road defects, followed by soil moisture
(Jiang et al., 2022)	UK	AHP	Assessing different stakeholders' criteria for evaluating city readiness for connected and autonomous vehicles	Infrastructure readiness is key, with physical infrastructure prioritized over cyber infrastructure
(de Aquino Traldi et al., 2022)	Brazil	AHP	Evaluating the quality of cycling infrastructure	Slope and traffic safety are the most crucial factors in determining cycling infrastructure quality
(Raza et al., 2022)	Pakistan	Fuzzy-AHP, TOPSIS, VIKOR	Ranking selected alternatives to alleviate congestion and promote sustainability	Among alternatives, parking areas are the least preferred, while flyovers are the best.
(AlKheder et al., 2022)	Kuwait	Fuzzy-AHP	Developing sustainable assessment criteria to aid design teams in choosing between material options for a new runway	Fire resistance is the most important technical criterion, while health and safety, along with minimizing pollution, are essential socio-economic and environmental factors
(Pujiati et al., 2022)	Indonesia	AHP	Formulating a sustainable transportation strategy	The top priority for transportation policies is developing system facilities and infrastructure
(Galdiani et al., 2022)	Iran	AHP	Prioritizing railway reconstruction projects in two regions of Iran's railway network	In reconstruction projects, cost is the most important factor
(Gupta et al., 2023)	India	Fuzzy-AHP	Analyzing risk factors in Public-Private Partnership (PPP) projects for EVs	Government policies were found to be the most dominant risk factor in a project
(Bhatia et al., 2023)	India	AHP	Offering insights into decision-making processes for capital-intensive transport projects	Capacity enhancement is the most important criterion, followed by transit time
(Sivilevičius et al., 2021)	–	AHP	Exploring why and when road construction companies purchase new asphalt mixing plants	The most important factor for road construction companies is improving the quality of asphalt mixtures, with the second being support from European funds
(Bai et al., 2021)	China	AHP	Building a micro-technical evaluation indicator system for low-carbon communities	High-quality public transport and slow traffic networks are the main indicators of low-carbon transportation planning, helping reduce or replace private car travel
(Darban et al., 2021)	Iran	AHP	Proposing a method for monitoring the structural health of concrete bridges	The structural index holds the highest weight, with girders being the most important component
(Song et al., 2021)	China	AHP	Designing railways with environmental concerns in mind	The ecology factor is significant, with animal habitat as the top sub-criterion
(Tseng & Yip, 2021)	Taiwan	Fuzzy-AHP	Developing an analytical model to assess the key criteria influencing the development of four cruise ports	Port infrastructure and facilities are the most important criteria
(Y. Feng et al., 2021)	China	AHP	Evaluating risks during the construction and operation of urban rail transit projects	Political, legal, and project promotion risks are the three most important risk indicators
(He et al., 2021)	China	AHP	Assessing the development of a multimodal freight network integrating rail, water, and road transportation	Transport operational performance, including technical improvements and safety control, is crucial
(Spits Warnars et al., 2021)	Indonesia	AHP	Determining the prediction and priority order for road maintenance	Damage and economic factors are key drivers
(Paraskevadakis et al., 2021)	UK	AHP, Important performance anaylsis (IPA)	Identifying service performance gaps in different modes of transport and generating future scenarios to evaluate their impact on sustainable development	Reliability should be prioritized in transport network design, with maintenance kept at good service levels
(Bouraima et al., 2020)	West Africa	AHP, SWOT	Formulating a strategy for railway transportation	Infrastructure obsolescence and lack of financial resources should be addressed
(Bivina & Parida, 2020)	India	AHP	Determining priority factors influencing pedestrians' choices for walking	Pedestrians rate safety as the most important factor, more than traditional considerations like mobility and infrastructure
(Abu Dabous et al., 2020)	–	AHP, Multi-attribute utility theory (MAUT)	Supporting pavement management decisions by quantifying sustainability-related factors like safety, noise, and pollution	High-traffic pavement sections should be prioritized
(H. Feng et al., 2020)	China	AHP, Grey theory	Constructing an index system for investment decision-making in high-grade highway projects	Economic rationality is weighted highest, with economic impact being the most important sub-criterion
(Singh, Sharma, et al., 2019)	India	Fuzzy-AHP	Developing and comparing risk indices for an elevated metro rail project	Risks like girder erection and traffic and utility diversion are significant
(Peng et al., 2018)	Maritime silk road	AHP-Entropy	Designing a comprehensive Critical Collaborative Professional Enquiry model to measure port competitiveness	The network status index plays a decisive role, while port efficiency is strongly correlated with rankings
(Akay et al., 2018)	Turkey	Fuzzy-AHP	Assessing risk factors in forest road design and construction	Technical and environmental risks are the most critical risk factors
(Peetawan & Suthiwartnarueput, 2018)	Thailand	Fuzzy-AHP, AHP	Identifying factors influencing the success of rail infrastructure projects	Key factors in rail development include cost structures, quality of life, and safety dimension.

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Author (year of publication)	Location	Method	The main aim	Key result
(Chang et al., 2018)	China	AHP	Conducting a comprehensive evaluation of sustainability in high-speed railway (HSR) construction projects	Economic benefits are the highest priority for evaluation
(Inti & Tandon, 2017)	US	AHP	Selecting contractors for transport infrastructure projects	Costs, experience, and quality are critical in decision-making
(Kamil et al., 2017)	Indonesia	AHP	Developing a model to choose maintenance strategies based on prioritized criteria	Road condition, maintenance type, mobility, and accessibility are the top criteria for road maintenance
(Rashidi et al., 2017)	Australia	Simplified AHP	Presenting a decision support system for managing steel bridge assets within safety, functionality, and sustainability limits	Safety and cost are crucial factors
(Barić et al., 2016)	Croatia	AHP	Evaluating road section design in urban areas by applying differential weighting to various criteria	The highest weight is assigned to functional efficiency, while the lowest is for ecological factors
(Yang & Chen, 2016)	China, South Korea, Japan	AHP, Grey relational analysis	Exploring global logistics hub port assessment criteria and comparing the competitiveness of the ports	Cost environments are essential, with transport and distribution costs being the most important sub-criteria
(Oswald Beiler & Treat, 2015)	Philadelphia	AHP, GIS	Identifying sustainability metrics that address environmental, economic, and social aspects of transportation projects	Network connectivity (link-to-node ratio) is the key factor
(Rabello Quadros & Nassi, 2015)	Brazil	AHP	Studying the priority of criteria in transportation infrastructure investment decisions	Reduction of the transportation costs is a crucial factor
(Salem et al., 2013)	US	AHP	Extracting quantitative weights that reflect the importance of project objectives and selecting a bridge construction plan accordingly	Cost is the most important factor
(Pires & de Carvalho, 2013)	Brazil	AHP	Proposing a multicriteria methodology for analyzing inland waterway infrastructure investments	Allocative economic efficiency and environmental impact are important
(Hayati et al., 2013)	Iran	Delphi, AHP, GIS	Efficiently planning a forest road network	Ground slope, soil texture, and landslide susceptibility are the top three criteria
(Palevičius et al., 2013)	Lithuania	AHP	Identifying and justifying territories that require the development of car parking solutions	Car ownership levels and public transport development are important
(Semaan & Zayed, 2009)	Canada	AHP	Evaluating functional criteria for subway stations	The structural and security/ communication functions criteria are the most important ones.
(Sohn, 2008)	South Korea	AHP	Developing criteria for identifying overpasses that should be eliminated	Traffic safety is a critical concern
(Tudela et al., 2006)	–	AHP	Comparing the results between cost-benefit analysis and multi-criteria analysis applied to urban transport investments	Multi-criteria methods often differ from cost-benefit analysis but align with final authority decisions
(Tanadtang et al., 2005)	Thailand	AHP, Multiple attribute utility theory (MAUT)	Proposing a methodology to evaluate transportation demand management alternatives	Increasing transit frequency was ranked as the best alternative, while increasing fuel taxes ranked worst, with social impacts playing a significant role
(Leviäkangas & Lähesmaa, 2002)	Finland	AHP	Reviewing evaluation methods for intelligent transport system investments	Multicriteria analysis provides different investment selection criteria compared to benefit-cost analysis
(Tsai & Su, 2002)	Taiwan	AHP	Conducting a political risk assessment of an air logistics hub development	Among the micro-risk factors, the freight parking issue is the most significant for air hub developments

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