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TOPICAL REVIEW

A Systematic Review of Analytic Hierarchy Process Applications to Solve Transportation Problems: From 2003 to 2022

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ABSTRACT Transportation improvements affect technological and socio-economic development, and several scholars have researched various transportation problems. The current study aims to illustrate a thorough review of those transport problems, where the Analytic Hierarchic Process (AHP) is used for enumerating the related criteria and alternatives. A systematic review methodology, the PRISMA protocol, is applied in the review process. The contribution of this work is highlighted along with the extensions of the AHP improving decision-making support. To this end, current research demonstrates the relevant results of 58 papers published from 2003 to 2019. The results indicated that most researchers applied the conventional AHP method to deal with transportation issues, while the most critical issue was public transport, followed by logistics problems. On top of that, TOPSIS was integrated with AHP more than other MCDM methods when dealing with multi-criteria transportation problems. Moreover, the ''Transportation Research Part A: Policy and Practice'' journal achieved first place by publishing ten papers on the topic, and the highest number of articles was published in 2018. The results are discussed adequately, and in the conclusion, policy implications are presented.

INDEX TERMS MCDM, AHP, transportation systems, PRISMA protocol, urban transport.

I. INTRODUCTION

Transportation science comprises the fundamental theories of transportation processes and observational and experimental research [1]. Furthermore, transportation science emphasizes novel methodologies, mathematical models, and applications for various purposes, including design, operation, planning, and construction. At the same time, there is a focus on maintaining different transportation modes [2], [3]. For instance, selecting a decent transportation enterprise may be biased due to potential interconnected challenges like delivering on time but cost-effectiveness, making decision-making more challenging [4]. Also, sustainability in transportation has made decision-makers evaluate and redesign their processes considering sustainable development indicators. In other words, developers need to assess their progress in adopting sustainability, motivating the decision-makers to imply advanced frameworks to increase the accuracy and reliability of the evaluation [5]. On top of that, transportation efficiency is critical for companies, urging them to develop assessment frameworks for evaluating the efficiency considering various criteria, barriers, or challenges, while evaluation

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usually happens under uncertainties, complexities, indeterminacy, and vagueness [6]. Performance measurement is also a requirement in designing, producing, and applying new facilities in the transportation sector, such as evaluating the performance of battery electric vehicles (BEVs). To this end, decision-makers need to take a wide variety of indicators into account in the decision-making process, motivating them to propose a personalized evaluation framework to deal with specific issues, like BEV selection [7] or, in general, selecting the best way of transportation among all available options [8].

Due to the aforementioned challenges, policymakers should deal with such concerns as the cost of transportation, efficiency, the quality of the transportation service, and the transportation system's performance [9], motivating them to apply flexible, applicable, and robust Multiple Criteria Decision-Making (MCDM) approaches to cope with a variety of problems in the transportation sector [1], [10], [11]. Generally speaking, decision-making is a process of choosing one or more options from a set of alternatives; however, the best alternative may not be among the available options [1]. In this process, the experts' opinions are vital due to the limited resources and many constraints [12]. Besides, not only the best option may not be chosen by the decision-makers, but trustable information might not be accessible while making a decision [13]. The performance of the alternatives concerning the identified criteria is primarily evaluated through the MCDM approach using arithmetic and mathematical tools [14]. The MCDM approach has been applied over the past two decades in various fields, including operation research and management science [15], [16], [17], [18], [19], [20], medicine and healthcare [21], [22], [23], energy [24], [25], [26], [27], [28], as well as sustainable development [29], [30], [31], [32], computer sciences [30], [33], [34], project evaluations [29], [33], [34], and transportation [10], [11], [35], [36], [37].

The MCDM approaches comprise an enormous variety of methods including the Combined Compromise Solution (CoCoSo) [38], [39], the Tomada de Decisao Interativa Multicriterio (TODIM) [40], [41], [42], [43], the Evaluation Based On Distance From Average Solution (EDAS) [44], [45], [46], the Step-wise Weight Assessment Ratio Analysis (SWARA) [47], [48], [49], the Complex Proportional Assessment (COPRAS) [50], [51], [52], [53], the Best-Worst Method (BWM) [22], [54], [55], [56], the Improved Gained And Lost Dominance Score (GLDS) [57], [58], [59], [60], as well as the Multi-objective Optimization on the Basis of Ratio Analysis (MOORA) [61], the Multi-Attributive Border Approximation Area Comparison (MABAC) [62], [63], [64], [65], and the Double Normalization-Based Multiple Aggregation (DNMA) [66]. Other methods are the Additive Ratio Assessment (ARAS) [67], [68], [69], [70], the Multi-Attribute Ideal-Real Comparative Analysis (MAIRCA) [18], [71], the Weighted Aggregated Sum Product Assessment (WASPAS) [72] [73], [74], [75], as well as the Multi-Objective Optimization by a Ratio Analysis plus the Full Multiplicative Form (MULTIMOORA) [20], [33], [76], [77], [78], the Combinative Distance-based Assessment (CODAS) [79], [80], [81], and the Analytic Hierarchy Process (AHP) [82], [83], [84].

The AHP method, one of the MCDM approaches frequently applied in transportation, was proposed by Saaty [85] to cope with complex multi-criteria situations. Since its introduction, several studies have applied this method to solve such transportation problems as sustainable urban transport development [86], public transport service development [12], as well as problems connected to the general public transport services [87], the sustainable transport strategies [88], the transport systems [89], urban transport [90], urban transport projects [91], sustainable mobility [92], logistics. Tseng and Pilcher [170]; Madushika and Wijayanayake [157]; Dushenko et al. [169], transportation planning Ignaccolo et al. [92], green transportation planning Ma et al. [176], transportation service quality Güner [175], freight transport [93], road safety [94], and rail transportation [95].

As mentioned above, the MCDM technique can be applied in various fields, including transportation. For this reason, some scholars conduct systematic reviews to determine the contribution of the MCDM approach to solving transportation issues. Pérez et al. [96] examine the connection between the MCDM approach and the urban passenger transport system. However, transportation issues have various aspects, Pérez et al. [96] studied only one of the issues. There is a shortage of studies investigating the MCDM approach's application in the case of different transportation issues. Rezaei also conducted review research to assess the MCDM approach to logistics. Although the study is not a comprehensive review, the results indicate that AHP is the most popular method for dealing with logistics-related cases. Moreover, Mardani et al. [97] systematically review the literature to investigate the MCDM approach's implementation in transportation. The results indicate that the AHP and the fuzzy AHP methods are primarily applied in transportation. Furthermore, Yannis et al. [1] examine the literature systematically to find the contribution of the MCDM approach to various transportation problems. The results show that AHP is the most common method applied in the field.

According to the previous reviews, AHP is the most practical MCDM approach in transportation; however, a complete overview of recently published papers in this field is currently missing. To be more specific, the present study aims to fill the following research gaps: (1) many AHP extensions were developed over the years, while some were applied in transportation, but some were not. Therefore, the present study aims to analyze the status quo of AHP applications in transportation so that not only the efficiency of the obtained results of the AHP applications can be investigated but also it could be figured out which extensions of AHP have not been applied so far, motivating future studies to take advantage of them. (2) As mentioned, AHP has been frequently used in transportation; however, there might be further transportation problems that could be solved using AHP. While highlighting the applications of AHP in dealing with various transportation

problems could boost the knowledge of scholars regarding the applicability of AHP and motivate them to apply AHP when a decision support system is needed. Therefore, the present study addresses the following research questions to fill the mentioned gaps:

RQ1. What is the contribution of AHP to transportation problems?

RQ2. How is AHP used to deal with transportation problems?

RQ3. What kind of transportation problems has been solved by AHP so far?

RQ4. How is the distribution of the papers by the year of publication, journals, and authors' nationalities?

The present study is organized as follows. Section 1 covers the introduction. Section 2 presents the recent extensions of AHP. In Section 3, the methodology is described. The results of the research are demonstrated in Section 4. A discussion of the research findings is to be found in Section 5. Finally, Section 6 presents the main conclusion of the study.

II. A REVIEW OF AHP EXTENSIONS

A. THE PARETO OPTIMAL SOLUTIONS

The most recent extension of AHP concentrates on gaining more reliable results on the decision maker's knowledge or preference while optimizing the weight distribution of the pairwise comparisons. The eigenvector method is applied to derive the weights from the pairwise comparisons in the AHP approach [85]. However, recently, it has been proven that the eigenvectors and the final scores of the criteria and the alternatives are not necessarily Pareto optimal [98]; thus, the eigenvectors can be improved to get a better solution.

1) THE PARSIMONIOUS AHP (PAHP)

AHP contains several pairwise comparisons, which require strenuous cognitive effort from the decision-makers. Recently, it has become an aim to reduce this effort or to allow them to provide preliminary evaluations in the survey. The a priori reduction of the number of comparisons is called parsimonious AHP, while the ex-post analysis is called incomplete AHP.

2) THE FUZZY AHP (FAHP)

Recently, several authors have extended the AHP approach based on fuzzy logic to address the consistency and demonstrate the application with illustrative examples. A type of many-valued logic called fuzzy logic allows for the truth value of variables to be any real number between 0 and 1 [99], [100], [101].

3) THE FUZZY AHP WITH INTERVAL TYPE-2 FUZZY SETS (IT2FS)

In many real situations, the evaluators' judgments might be imprecise, or the evaluators cannot select the exact number for the evaluation process. Kahraman et al. [102] create a new model to solve these significant problems by combining the fuzzy AHP and the IT2FSs. In their paper, the authors extend the fuzzy AHP method utilizing the interval type-2 fuzzy sets. Additionally, linguistic scales are developed to be employed in the fuzzy AHP.

4) THE HESITANT FUZZY LINGUISTIC AHP (HFL-AHP)

The information connected to the decisions might be vague and uncertain; thus, considering a fuzzy set is an appropriate solution to address the problem Zheng et al. [51] develop a super decision matrix including objective and subjective criteria to derive the total scores. Their model is based on the hesitant fuzzy linguistic Analytic Network Process (ANP). Furthermore, the authors illustrate the new model with a real-life problem [103].

5) THE GROUP INTUITIONISTIC FUZZY AHP (GIF-AHP)

Liao, et al. [99] provide theoretical support for the GIF-AHP to express the evaluators' uncertain judgments. The authors propose a novel aggregation technique to integrate personal preference relations. Additionally, if the particular intuitionistic fuzzy preference relations have perfect multiplicative consistency, the aggregated intuitionistic fuzzy preference relation always provides perfect multiplicative consistency.

6) THE INTERVAL-VALUED INTUITIONISTIC FUZZY AHP (IVIF-AHP)

The evaluators' linguistic judgments overcome various AHP problems, such as uncertainty and vagueness. Therefore, Abdullah and Najib [104] developed a novel approach for the preference scale based on the IVIF-AHP. Their research shows that IVIFs with a hesitant degree represent the pairwise comparison matrix.

B. THE PYTHAGOREAN FUZZY AHP (PF-AHP)

The conventional fuzzy AHP approach is unsuitable for assessing some issues properly since the linguistic judgment involves uncertainty, and the summation of the membership and non-membership functions should be less than one [105], [106]. To this end, Mohd and Abdullah [107] extend the AHP method by integrating the Pythagorean Fuzzy Sets. In the PF, the summation of the membership's square and non-membership's square must be less than one.

1) THE AHP-HESITANT GROUP DECISION-MAKING (AHP-HGDM)

Zhu and Xu [108] develop a new group decision-making AHP method to overcome the evaluators' hesitant judgments. The evaluators might apply several possible values to refer to the original judgments, which can be considered an extension of AHP-group decision-making.

2) THE HESITANT FUZZY AHP

The hesitant fuzzy AHP approach is proposed by Öztaysi et al. [109] to aggregate the experts' evaluations. Furthermore, Oztaysi et al. [110] use the proposed method

to select a warehouse location in Turkey under an uncertain fuzzy environment.

3) THE NEUTROSOPHIC AHP

Due to the evaluators' limited knowledge, they might not be able to express their points of view precisely by evaluating the pairwise comparison judgments in group decision-making. Abdel-Basset et al. [111] employ the neuromorphic set theory to handle the problems represented by a triangular neuromorphic number.

4) THE INTERVAL-VALUED NEUTROSOPHIC AHP (IVN-AHP)

Bolturk and Kahraman [112] propose the IVN-AHP model to select the modes of alternative energy, which illustrates the integrated model.

5) THE TYPE-2 FUZZY SET OF LINGUISTIC AHP

Abdullah and Najib [113] developed a novel model for fuzzy AHP characterized by interval type-2 fuzzy sets, which can solve the uncertainty and vagueness problems more optimally to enhance judgment in the decision process.

6) THE Z-NUMBER EXTENSION OF AN INTEGRATED AHP

Azadeh et al. [114] extend the Z-number of the AHP approach to avoid the uncertainty and vagueness problems in the classical AHP method. Moreover, the new model differentiates the criteria priority ranking problem.

III. MATERIALS AND METHODS

Related articles are selected and reviewed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol. The protocol is primarily used to report a review of randomized trials and can be used to evaluate interventions [115]. PRISMA has some benefits over other reviewing methods motivating the present research to apply the PRISMA: firstly, it includes a thorough, accurate, well-described checklist that enables researchers to achieve more robust systematic review reports and meta-analyses. Secondly, the protocol has been updated many times over the years to overcome its weaknesses, making PRISMA a novel method for reviewing articles [116]. Moreover, Abelha et al. [117] reviewed 69 published articles over the period 2009-2019 using PRISMA on competence development, graduate employability, and intending to develop an international framework. They reviewed. Also, Regona et al. [118] conducted review research in which 72 articles were reviewed to identify the challenges to adopting Artificial intelligence (AI) in the construction industry. Also, How et al. [119] employed the PRSMA protocol to review published articles between 2000 and 2020 on music practice, and a total of 296 out of 3102 articles were reviewed. Therefore, the literature shows that the PRISMA method could be applied in various fields successfully, while the elementary step of PRISMA is scrutinizing the research literature. To this end, Scopus, Google Scholar, and Web of Science (WOS) are selected to find published articles related to the research topic. Subsequently, the key journals are scanned, and the lists of references are scanned based on the experts' ideas. Secondly, the eligibility of the publications is analyzed, which is emphasized in various publications. These aspects are the publication status and language, the study's design, the population of interest, the time duration, and the year of publication. Afterward, the information sources are investigated based on the PRISMA guidelines.

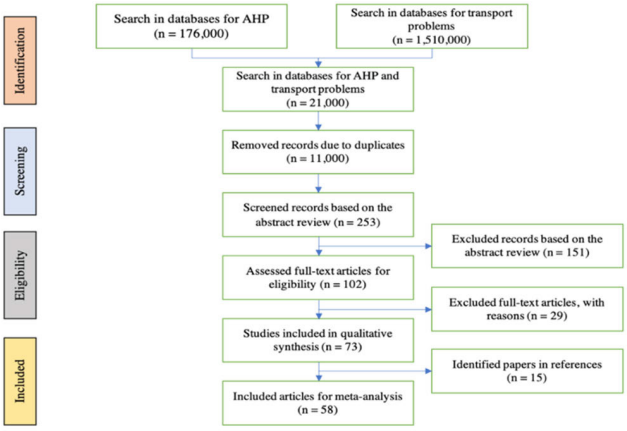

FIGURE 1. The selection process.

A. SCRUTINIZING THE LITERATURE

For the current research, public databases are available to find related papers. These databases are ''Science Citation Index Expanded'' (SCI-E), ''Emerging Sources Citation Index'' (ESCI), ''Arts and Humanities Citation Index'' (AHCI), ''Social Sciences Citation Index'' (SSCI), and ''Science Citation Index'' (SCI). Different keywords include 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 container 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 are applied to find the most related publications within selected databases storing papers published between 2003 and 2019.

B. THE ELIGIBILITY OF THE PAPERS

Two hundred fifty-three publications are identified at the first attempt. The full texts of the selected papers are reviewed to check their eligibility of the papers. Ph.D. and master dissertations, book chapters, editorial notes, press papers, and non-English papers are excluded. Finally, 58 papers related to applying AHP in transportation were selected after a multi-step refining process from 23 international journals. The selection process is illustrated in Figure 1. The results of reviewing the selected papers are presented in the Annex.

TABLE 1. The distribution of the papers based on the field of applications.

Field of application	Number of papers	Percentage
Public transport	11	18.97%
Logistics	10	17.24%
Other transportation	9	15.52%
Marine transportation	5	8.62%
Airline industry	4	6.90%
Railways industry	4	6.90%
Airport industry	4	6.90%
Transportation planning	4	6.90%
Road transportation	3	5.17%
Transport operations	2	3.45%
Shipping industry	1	1.72%
Pedestrian	1	1.72%
Total	58	100%

IV. RESULTS

A. THE CLASSIFICATION OF THE APPLICATION AREAS

One of the primary purposes of this paper is to find the various fields of transportation where AHP is used to deal with specific issues. The papers are classified concerning the experts' opinions. As a result, the selected papers are classified into the following 12 application areas: Public transport, Logistic, Marine transportation, Airline industry, Railways industry, Airport industry, Transportation planning, Road transportation, Transport operations, Shipping industry, Pedestrian, and Other transportation. Table 1 illustrates that AHP is significantly used for public transport problems (18.97%), followed by logistics problems with 17.24%, and other transportation issues (15.52%) with nine papers.

The results indicate that public transport is the most popular section of transportation in which AHP is applied to deal with its problems. Traffic congestion is one of the severe problems in urban management, provoking policymakers to improve public transport performance. Public transport performance measurement is the first step in resolving the complex problems outlined since it is important for evaluating performance over time and continuously enhancing the transportation system. Service quality, productivity, effectiveness, and efficiency are crucial to evaluating the performance of transportation systems which could be done using MCDM methods, especially AHP, such as those presented by Duleba et al. [120], Duleba et al. [121], and Lupo [87]. On top of that, AHP could successfully deal with logistics problems, as indicated by the results. Logistics is the planning, applying, and monitoring activities to efficiently flow materials, products, and information, requiring decision-makers to select sites and providers and evaluate their performance frequently. Therefore, AHP could be a valuable method for selecting and evaluating effectively, such as presented by Yazdani-Chamzini and Yakhchali [122], [123], and [124]. The third most relevant field of application is other transportation covering a wide set of options, while other papers deal with more specific fields, such as maritime, airline, railways, and airport industry.

TABLE 2. The distribution of the papers by the journals.

Name of the journal	Number of publications	Percentage
Case Studies on Transport Policy	1	1.72%
Environmental Modelling & Software	1	1.72%
European Transport	2	3.45%
Expert Systems with Applications	2	3.45%
International Journal of Logistics Research and Applications	1	1.72%
International Journal of Production Research	1	1.72%
International Research Conference on Smart Computing and Systems Engineering 2018	1	1.72%
Journal of Air Transport Management	5	8.62%
Ocean Engineering	2	3.45%
Procedia Computer Science	1	1.72%
Research in Transportation Business & Management	1	1.72%
Sustainability	7	12.07%
The International Journal of Logistics Management	1	1.72%
Total Quality Management & Business Excellence	1	1.72%
Transport	2	3.45%
Transport Policy	5	8.62%
Transportation	1	1.72%
Transportation Research Part A: Policy and Practice	10	17.24%
Transportation Research Part D: Transport and Environment	4	6.90%
Transportation Research Part F: Traffic Psychology and Behaviour	1	1.72%
Transportation Research Procedia	7	12.07%
Tunneling and Underground Space Technology	1	1.72%
Total	58	100%

B. THE DISTRIBUTION OF THE PAPERS BY JOURNAL

Table 2 provides information about the 23 journals where the selected papers are published. Accordingly, ''Transportation Research Part A: Policy and Practice'' ranks first with ten publications, followed by ''Transportation Research Procedia,'' with seven records. Transport Policy, Transportation Research Procedia, Sustainability, Journal of Air Transport Management, Transportation Research Part D: Transport and Environment have several papers, while the topic occasionally appears in other journals.

C. THE DISTRIBUTION OF THE ARTICLES BY THE YEAR OF PUBLICATION

Figure 2 illustrates the distribution of the papers based on the year of publication. The number of published papers related

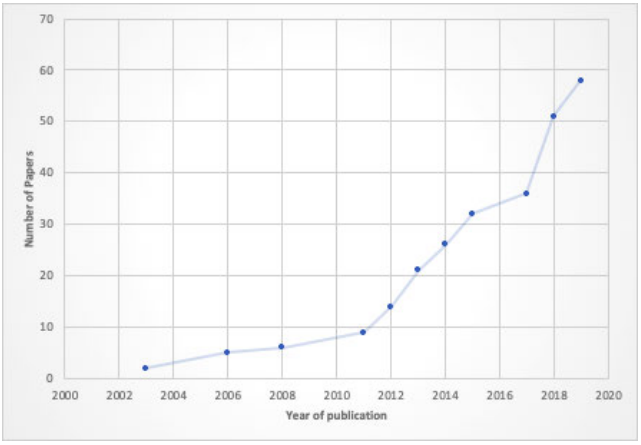

FIGURE 2. The distribution of the articles by the year of publication (cumulative).

TABLE 3. The distribution of the papers based on the applied methods.

Applied method	Number of papers	Percentage
AHP	23	39.66%
Fuzzy-AHP	13	22.41%
AHP and TOPSIS	3	5.17%
AHP-ISM	2	3.45%
Fuzzy TOPSIS and fuzzy AHP	2	3.45%
AHP and ELECTRE III/IV	2	3.45%
IPA model with fuzzy AHP	1	1.72%
AHP and VIKOR	1	1.72%
AHP, PROMETHEE, and VIKOR	1	1.72%
AHP and MILP	1	1.72%
Interval type-2 fuzzy AHP and TOPSIS	1	1.72%
AHP and VIKOR with interval fuzzy	1	1.72%
AHP integrated PROMETHEE and VIKOR	1	1.72%
Interval AHP	1	1.72%
FAHP and ELECTRE III	1	1.72%
AHP and DEMATEL	1	1.72%
AHP and IPA	1	1.72%
AHP and Unascertained Measure	1	1.72%
AHP and Dempster	1	1.72%
Total	58	100%

to AHP and its application in transportation is noticeable, especially in 2018, with 15 publications. Researchers applied AHP dealing with public transport, airport location, logistics, maritime transportation, railways, road safety, freight transport, service quality issues, and evaluating walkability in pedestrian areas, while logistics issues were the most popular.

D. THE DISTRIBUTION OF THE PAPERS BASED ON THE APPLIED METHODS

Table 3 provides information about the different extensions of AHP used by scholars. The results indicate that the conventional AHP method has the most contributions in transportation, with almost 40%, while FAHP is the second approach scholars use in transportation, with 22%. Furthermore, AHP-TOPSIS is used in three papers, Fuzzy Topsis-Fuzzy AHP and AHP-ISM are applied in two papers, and other techniques are found only once. The reason that many researchers applied conventional AHP or F-AHP more than other integration methods could be rooted in the comprehensiveness of AHP since it can not only calculate the weight of the criteria but also evaluate alternatives based on the weighted criteria. Therefore, it is clear that AHP can solve multi-criteria issues without integrating with other methods.

V. DISCUSSION

This section demonstrates some findings which are not trivial and could be concluded based on the current extensive review. First, it can be stated that a distinction must be made between those transport decision-related cases, where the uncertainty of the evaluations can be excluded, and those cases where there is a high risk of uncertainty in the decisions (e.g., layman evaluators participate, or the problem is too complex to evaluate even in a hierarchical decision structure). The high uncertainty is recommended to be handled by a properly selected methodology, most likely by fuzzy AHP or interval AHP techniques.

Another interesting issue is the redundancy of the results due to the applied methods. In many papers, for more reliable final results, the authors applied combined methods, e.g., AHP-TOPSIS, AHP-DEMATEL, AHP-PROMETHEE, and AHP-ELECTRE. In these cases, the AHP method is dominantly applied for determining the weights of the criteria, while the other method gains the ultimate ranking of the decision alternatives. Redundancy is twofold in every application of the AHP method or its integrations. On the one hand, redundancy might occur when the evaluators express their subjective judgments, and the applied technique quantifies these judgments. During the quantification, some evaluators' scoring intentions might be resilient. That is why linguistic or hesitant methods are applied. The problem is the same for the group AHP applications, where the scoring intention of some individual evaluators might disappear during the aggregation in the quantification phase. On the other hand, redundancy might occur when the evaluators' scoring intentions are well approximated, but their real intentions are not adequately presented in their scoring. The hybrid models try to capture the real intention by applying another technique for creating the ultimate decision on the alternatives through the criteria.

As a limitation, the PRISMA statement contains an evidence-based checklist of items many journals have endorsed. However, including articles might be biased toward highlighting significant findings. Also, selecting, screening, and reviewing articles based on the PRISMA checklist is time-consuming. On top of that, selecting the primary keywords for searching articles on data based might affect the comprehensiveness of the review paper.

The current study states that many extensions of the AHP method are available and applied in various transportation areas, and the results demonstrate that the AHP extensions are appropriate for evaluating and developing transportation systems. However, there are some fields where it would be necessary to provide more contributions. For instance, there is a lack of studies in which scholars apply integrated approaches, such as AHP-MABAC [125], [126], AHP-WASPAS [127], [128], and AHP-COPRAS [129], [130] to deal with transportation problems. Furthermore, there are various types of fuzzy extensions, such as Intuitionistic fuzzy sets [131], [132], Pythagorean fuzzy sets [133], [134], Hesitant fuzzy sets [135], and Neutrosophic sets [136], [137], which scholars may wish to apply to deal with uncertainty in transportation problems. Many AHP extensions were presented in section 2, which could be applied to cope with transportation problems.

One of the critical concerns for the local operators and the government is improving the quality of the urban transportation system. A system upgrade can reduce traffic congestion and pollution while increasing user satisfaction and drawing in new users. Efficient approaches are needed to address complicated traffic challenges and ensure sustainable growth. Based on the outcomes, it can be stated that AHP can deal with complexities in public transport management, where various criteria and challenges affect the transportation system's performance, making developing policies and decision-making difficult. Similarly, in the field of logistics, numerous factors, approaches, and methods must be used to select adequate and complementary third-party providers. The decision-making process complexity and the number of involved factors make the MCDM approaches appealing. Therefore, selecting a third-party logistics provider can be seen as a complex MCDM problem because several quantitative, qualitative, and other characteristics must be considered.

The future of the AHP models in transportation is the integration of two different processes. The researchers unburden the participants as much as possible by offering simple evaluation schemes. Simultaneously, the applied techniques become more complicated to mitigate the two types of redundancies. Nevertheless, MCDM is proven to be an excellent support for many transportation-related problems.

VI. CONCLUSION

This systematic review focuses on the problems of the transportation systems regarding the MCDM theory and practice. An extensive literature review is carried out for specific research areas where AHP can be applied to develop practical approaches for providing suitable solutions to complex problems. AHP can be used for various application areas, such as public transport, logistic, marine transportation, airline industry, railways industry, airport industry, transportation planning, road transportation, transport operations, shipping industry, and in case of pedestrians. Over the decades, the popularity of this MCDM approach in transportation has increased, where the AHP extensions provide different results

TABLE 4. The application of MCDM in transportation research.

No	Author(s) & Year	Technique & Approach	Application area & Scope	Study purpose	Gap & research problem	Result & Outcome
1	[138]	Fuzzy-AHP	Selection of a port for transshipment	Evaluating the criteria for selecting a port for transshipment	Previous studies lack adequate research on the selection of a port for transshipment.	The adequate criterion for selecting a port for transshipment is geographical positioning.
2	[89]	AHP	Transport system	Investigating the criteria for arriving at the most suitable Delhi transportation system in terms of environmental sustainability	Further studies are required due to problems with the urban transportation of Delhi.	The critical quantitative factors are the environment and energy cost, whereas qualitative factors are the technology, the result barriers, and the adaptability.
3	[90]	AHP	Urban transportation	Comparing the two results of the cost-benefit analysis and AHP in an urban transport system	Further studies are required on the economic aspects of the urban transportation system.	The general public connects sensitivity to the available information on the projects.
4	[139]	AHP	Terminal and container ports	Evaluating and identifying the competitiveness of terminal and container ports	An investigation is needed on the strategic policies of the container port competition.	The whole port is significant in the efficient operation of the terminal and container ports.
5	[140]	AHP	Overpasses, transport operations	Examining the elimination of the overpasses in Korea	Further studies are needed on the importance of eliminating those overpasses in Korea that are no longer useful.	In eliminating useless overpasses, the most important criteria are traffic efficiency, the traffic safety and functionality, the environmental amenity, and

TABLE 4. *(Continued.)* **The application of MCDM in transportation research.**

						the structural stability.
6	[141]	Fuzzy-AHP	Airline market	Evaluating the corporate image in the airline market	More attention is necessary on the corporate image for increasing the customer loyalty.	Service delivery and safety records are the most critical factors in the airline market.
7	[142]	Fuzzy-AHP	Airline industry	Evaluating the quality of the service offered by the international air transport industry	Past studies lack adequate information on the quality of the service in the airline industry based on SERVQUAL measurement.	Reliability and assurance are significant criteria for assessing the quality of the service in this industry.
8	[143]	AHP	Electrified vehicles	Evaluating and identifying the existing potential markets in Europe for electrified vehicles	There is a need for ranking the performance and the suitability of the different electrified vehicles.	The criteria for categorizing the electrified vehicles are among others car density, the availability of infrastructure, GDP per capita, gas emissions, state incentives, and cost savings.
9	[144]	AHP	Multi-airport system	Examining the employment of the MCDM approach toward the analysis of multi-airport system	The role and position of multi-airport systems have a problem.	The location, facilities, and classes have similar weights.
10	[145]	Fuzzy-AHP	Transshipment	Investigating the logistics costs and customer service	A framework is required to decrease logistics costs and increase the customer service..	The problems in this sector can be solved by emphasizing the customer service. The best factor is the reliability of the fulfillment of orders.

TABLE 4. *(Continued.)* **The application of MCDM in transportation research.**

11	[122]	Fuzzy-AHP	Logistics	Finding a new criterion for selecting a tunnel boring machine	There is a need to carry out further analysis of the selection of tunnel boring machine for increased speed and reduced time.	Assessing cost factors is critical in an appropriate selection of a tunnel boring machine.
12	[120]	AHP	Public transportation	Evaluating the public bus transportation from different evaluators' point of view.	There is a demand for sharing the strategic decision process related to public transportation with the general public.	There are differences in the priority of the various evaluator groups.
13	[121]	AHP-ISM	Public transportation	Evaluating public transportation supply quality criteria	There is a need to spotlight the missed linkages in the original hierarchical structure.	The elaborated model provides reliable results by considering all the interrelations and feedback between the criteria.
14	[146]	Fuzzy TOPSIS and fuzzy AHP	Public transportation	Examining SERVQUAL measurement of customer satisfaction	Public transport needs to be critically analyzed to solve many existing problems.	Tangible factors and fees are the core factors in weighing customer satisfaction.
15	[87]	Fuzzy-AHP	Public transport service	Assessing the performance in the public transport service	The service performance in public transport presents uncertainties, which need to be handled appropriately.	According to the achieved results, the existing perception of the management in this service has an impact on the overall performance.
16	[88]	AHP	Strategies for sustainable transport	Assessing the strategies for sustainable transport	The transport system in Taiwan requires laid-out strategies for sustainability.	Local circumstances determine the measures of the tailor.
17	[147]	AHP	Road transportation	Evaluating the interaction of transport system factors and the rate of	Traffic systems are critical for increasing the efficiency in the transport system.	The most significant element is the interaction between transport participants

TABLE 4. *(Continued.)* **The application of MCDM in transportation research.**

				traffic accidents		and vehicles.
18	[91]	AHP	Urban transport projects	Screening the projects by using a framework that identifies the sustainability of the projects in urban transportation	There is a need for further studies on the screening criteria for urban transport projects.	The suggested framework is appropriate for local, sustainable transport needs.
19	[139, 148]	Fuzzy-AHP	Aerotropolis, transport operations	Evaluating the benefits of the metropolises in East Asia with FMCDM	Previous studies lack empirical evidence.	The most critical factors are convenience operation and infrastructure.
20	[149]	AHP	Railways	Investigating the improved Serbian Railways, which consist of two-phased models	Following the Serbian War, there is a need to prioritize development projects.	The priority is placed on restructuring the old model of the Serbian Railways despite the poor technical conditions.
21	[150]	Fuzzy-AHP	Airline industry	Investigating the criteria used in selecting an appropriate retailer for the airline industry	There are conflicting quantitative and qualitative criteria regarding the criteria for the selection of a retailer.	The significant criteria in selecting a retailer is financial stability.
22	[151]	AHP	Airport	Evaluating and analyzing the development of a multi-airport systems Creating a framework	There is a need to find the factors concerning the territorial competitiveness in airport development.	Cape Town City requires a single-airport system up until the volume of the passengers increases beyond the current annual 27 million. Safety and accessibility

TABLE 4. *(Continued.)* **The application of MCDM in transportation research.**

23	[152]	Fuzzy-AHP	Rail transit	to assess the customer satisfaction in public transportation	There are problems in the rail transit system regarding the customer satisfaction.	are pivotal factors in evaluating the customer satisfaction in Turkey's rail transit.
24	[153]	Fuzzy-AHP	Airline industry	Evaluating and selecting cargo alliances in the airline industry	Further studies are required regarding the cargo alliances in the airline industry.	The three most crucial criteria are enhancing the flight route and frequency, increasing the revenue, and improving the load factor.
25	[123]	Fuzzy TOPSIS and fuzzy AHP	Logistics	Assessing 3PL logistics and transportation	Due to the uncertainty and complexity involved, the selection of a 3PL provider is often difficult.	Depending on the proposed model, the selection of 3PL service providers can reflect the expectations.
26	[154]	AHP and ELECTRE III/IV	Public transport project	Enumerating urban transportation projects	There are axiomatic differences between the methods.	The outcomes are substantially different. The values of the computed utilities of particular transport projects are quite diversified.
27	[124]	IPA model with fuzzy AHP	Logistics	Evaluating the service requirements of the dedicated container terminals	The managerial implications of the findings in improving service quality need to be discussed.	The results provide practical information to improve the service quality of the container terminals.
28	[155]	AHP and VIKOR	Maritime transportation industry	Finding a practical solution for the design selection problem	There is a need for a study proposing a hybrid theoretical methodology in multiple-attribute decision-making problems.	The outcomes help those shipowners who have difficulty finding appropriate hatch cover types during the construction of the ship.

TABLE 4. *(Continued.)* **The application of MCDM in transportation research.**

29	[86]	AHP	Public bus transportation	Enumerating the public transport supply quality systems	Further studies are needed to investigate the differences between the public and the decision-makers' opinions.	There is a significant gap between the evaluator groups.
30	[71]	AHP, PROMETHEE, VIKOR	Airport	Selecting a military airport location	Different approach results are to be compared for selecting the best location.	The employed methods provide the same alternative as the best location.
31	[156]	AHP and mixed-integer linear programming	Logistics	Reducing the transport price	Achieving the highest satisfaction for customers and gaining their loyalty are necessary.	Optimal customer satisfaction is found by minimizing the transportation cost.
32	[157]	Interval type-2 fuzzy AHP and TOPSIS	Maritime transportation	Selecting the most efficient ship loader type	The uncertainty problem of the experts' judgments needs to be solved.	Practical benefits are provided to those people who want to select the ship holder type in a dry bulk cargo shipment.
33	[155]	AHP and VIKOR with interval type 2 fuzzy	Maritime transportation	Selecting the appropriate hatch cover design	The model needs to deal with uncertainty problem during the evaluators' linguistic assessment.	The shipmakers are supported to make their decisions.
34	[71]	AHP integrated PROMETHEE and VIKOR	Airport	Selecting a military airport location	There is a need to investigate a complex real-world problem regarding selecting the most appropriate airport location.	The results are compared with other applications, and they are the same.
35	[158]	AHP-TOPSIS	Marine transportation	Reducing marine air pollution	The most critical barriers hampering effective compliance to ships operating are to be highlighted.	The results indicate that lack of infrastructure, and comprehensive marine air pollution laws and high capital and operational costs of sulphur reduction solutions emerged as the top three ranked barriers. The findings are useful not solely for policymakers but for shipowners, too.
36	[159]	F-AHP	Pedestrian	Evaluating the walkability issue to assess different neighborhoods	Developing the walkability environment is necessary.	The public security and traffic safety are the most important criteria for improving the walkability environment.
37	[160]	AHP and TOPSIS	Public transport	Evaluating the unconventional modes of transport	There is a need for works enumerating the real complex problem for the public transport in the capital of Bangladesh.	Shortcomings are addressed providing efficient plans for public transport services.
38	[95]	Interval AHP	Rail	Examining passengers' demands toward the high-speed rail service quality	Passengers' demands should be ranked based on the dynamic analysis.	The light is spot on the passengers' demand to the infrastructure and facilities of rails.
39	[161]	AHP	Marine transportation	Enumerating the competitiveness of ports by considering 18 related factors	A study is required to take the real operation status of ports in consideration as well as their position in the changing global maritime transport network.	An efficient evaluation is provided by enumerating 99 ports in 51 countries.
40	[162]	FAHP and ELECTRE III	Logistics	Evaluating the competitiveness of a Chinese Port based on related criteria	There is a need for studies implementing a comprehensive evaluation method to improve the future strategic plans of the ports.	Quanzhou port is ranked as the least important.

TABLE 4. *(Continued.)* **The application of MCDM in transportation research.**

41	[163]	FAHP	Logistics	Understanding the role of sale and purchase	There is a low number of research works related to sale and purchase and its priority for shipping companies.	The most significant ship option is indicated.
42	[164]	AHP and DEMATEL	Logistics	Applying the MCDM tools to support the decision process of choosing the measures for distributing goods	The complexity of implementating the decisions on the development measures of goods movement in the city needs to be examined.	The coefficients from different operation measures are highly interconnected.
43	[165]	AHP and Importance Performance Analysis	Logistics	Evaluating the adopted innovations for the urban bus companies, which develops the sustainability of the cities	The radical transformation of and the increase in car utilization need to be discussed.	There are efficient solutions to develop the logistics; the solutions support the decision-makers.
44	[166]	AHP and unascertained measure	Rail	Enumerating the construction plans for sustainable railways	There is a need for research ranking related factors and implementing the index system to measure the sustainability of the line.	Light is spotted on the most critical project highlighting its efficient economic benefits.
45	[167]	AHP	Logistics	Analyzing a real-life problem to evaluate the urban logistics	Theinvolvement of various stakeholders in the evaluation process is needed to provide more efficient urban logistics.	A high level of transferability is provided to various local contexts.
46	[168]	AHP	Logistics	Evaluating the best relocation for a container terminal	Further studies are required to support the decisions through dynamical analysis, not just through theoretical analysis.	There isdisparity between the significance of what sustainability models describe and its significance in practice.
47	[94]	AHP	Road safety	Developing the drivers' education to reduce accidents	Six different groups to be involved in the problem and AHP considering the appropriate application to solve it.	Motorcycle riders are the lowest educated group while pedestrians have the highest education score.
48	[169]	FAHP	Logistics	Evaluating the most significant factor related to the green port policies	Not solely quantitative but qualitative interviews have to be done, as well.	The environmental policy is the most critical factor, while the qualitative analysis improves the outcome by involving different stakeholders.
49	[93]	AHP	Freight transport	Enumerating the city ports to boost the interrelation between the essential factors	Identifying the optimal design between the related factors is necessary.	The most significant factors related to improving the city ports are identified from the stakeholders' point of view.
50	[170]	AHP-ISM	Public transport	Evaluating the public transport supply quality	There are missing interrelations among the factors at various levels of the hierarchy.	There are sustainable solutions for public transport complex problems, which is helped by involving the passengers in the decision process and considering the optimal connections and feedbacks among the criteria.
				Evaluating the impact of environmentally-friendly	It is necessary to find a common framework to	The approach comprises selecting evaluation criteria, data collection, and

TABLE 4. *(Continued.)* **The application of MCDM in transportation research.**

51	[171]	AHP and Dempster	Transportation planning	transport measures, such as intelligent transport solutions, mode sharing, multi-modal transport solutions	aggregate the data coming from multiple information sources for evaluating the sustainability of transportation measures.	information fusion, evaluating the city sustainability by using a Transport Sustainability Index and the impact assessment of the proposed transportation measure.
52	[172]	AHP	Transportation planning	Supporting the involvement process of the public in the whole transportation planning process	The public is rarely involved; thus, it is necessary to involve them more and more significantly in the strategic planning phase.	A new framework and model is conducted to involve the public in strategic planning.
53	[173]	AHP and Electre III/IV	Public tram system	Evaluating the criteria of redesigning a public tram system in Poland	Further studies are required to improve the public transportation network in Gorzow city, Poland, due to the unbalance in the modal split; the dominating component is the bus transportation sub-system.	The multiple criteria evaluation of the redesigning variants of the public tram system shows different results than the intuitive decision process, which has been carried out in the local Town Hall.
54	[174]	AHP-TOPSIS	Service quality	Improving the quality of bus transit services	Providing a useful and practical methodology for bus transit operators to monitor and improve the quality of bus transit services is needed.	University students are primarily concerned about the convenience of the public transportation service and less concerned about the comfort.
				Evaluating	It is necessary to achieve a	The combined method not solely obtains

TABLE 4. *(Continued.)* **The application of MCDM in transportation research.**

55	[175]	AHP	Green transportation planning;	the urban green transportation planning	comprehensive evaluation of urban green transportation planning.	satisfactory evaluation results but finds the weaknesses and shortcomings in the planning and provides guidance for the next decision-making and improvement measures of the governments.
56	[92]	AHP	Transportation planning	Investigating a transport decision-making problem and evaluating the solutions	Involving more stakeholders in the transport planning decisions is essential.	The best transit system solution is presented out of four possible alternatives.
57	[176]	AHP	Road safety	Judging the effectiveness of the preparedness activities in case of accidents in road tunnels	A decision support system (named Civil Protection Assets Evaluator or shortly evaluator) is needed to judge the emergency response system.	The evaluator can be the element that creates an everyday basis for risk assessment among multi-actor civil protection organizations.
58	[177]	AHP	Public transportation	Discovering weak points of the public expenditure increase and the decline of the revenue shortfalls	There are difficulties in the social and economic situation in Tunisia, a decline in the revenue shortfalls, and an increase in public expenditure; these critical phenomena have to be examined.	Land transport regulations require a more considerable contribution of the state, such as compensating the operator for loss of earnings due to the reduced rates.

to assess and redesign problems in the transportation system. Consequently, scholars want to develop efficient and robust

decision-making frameworks to deal with complexity, uncertainty, and indeterminacy.

Based on a thorough overview of AHP and transport-related scientific literature, it can be stated that the AHP method is proven well-applicable in many fields of transportation. Regardless of the type of the decision problem (i.e., public or private transport), the selected transport mode (i.e., road, rail, maritime, air), and the level of the problem (i.e., micro or macro), the methodology is successfully applied several times. The results indicate that public transport issues are the most exciting topics that researchers have studied. Moreover, the highest number of articles on logistics was published in 2018, with 15 publications. In these studies, AHP, either in conventional form or integrated with other MCDM methods, was applied to solve multi-criteria problems.

APPENDIX

See Table 4.

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