TRANSPORT
ISSN 1648-4142 / eISSN 1648-3480
2022 Volume 37 Issue 6: 411–425
https://doi.org/10.3846/transport.2022.18376

REVIEW PAPER

MCDM APPROACHES FOR EVALUATING URBAN AND PUBLIC TRANSPORTATION SYSTEMS: A SHORT REVIEW OF RECENT STUDIES

Mehdi KESHAVARZ-GHORABAEE[1*], Maghsoud AMIRI[2], Edmundas Kazimieras ZAVADSKAS[3], Zenonas TURSKIS[4], Jurgita ANTUCHEVIČIENĖ[5]

[1]*Dept of Management, Gonbad Kavous University, Gonbad Kavous, Iran*
[2]*Dept of Industrial Management, Allameh Tabataba'i University, Tehran, Iran*
[3, 4]*Institute of Sustainable Construction, Vilnius Gediminas Technical University, Vilnius, Lithuania*
[5]*Dept of Construction Management and Real Estate, Vilnius Gediminas Technical University, Vilnius, Lithuania*

Submitted 5 August 2022; resubmitted 5 September 2022; accepted 26 September 2022

Abstract. Studies related to transportation planning and development have been in the center of activities of many researchers in the past decades. Road congestions issues, economic problems, health problems and environmental problems are some examples of complex problems that can be caused by urban and public transportation in big cities. Evaluating urban and public transportation systems could help to reach effective solutions to overcome these issues. This article presents a short bibliographic review of some recent studies on Multi-Criteria Decision-Making (MCDM) approaches for evaluating urban and public transportation systems. To this aim, *Scopus* was chosen as the database for making a search on journal articles. *Scopus* is trusted by major institutions in the world, and all journals covered in this database are inspected for sufficiently high quality each year. The search was made on the journal articles from 2017 to 2022 (July). The analyses presented in this study show that the Analytic Hierarchy Process (AHP) method is the most used method, which has been applied to different studies in the field of urban and public transportation systems based on MCDM approaches. According to the analysis of the number of articles, Turkey is ranked 1st among different countries, and "Budapest University of Technology and Economics" (Hungary) is 1st in the ranking of institutions. Moreover, most of the articles have been published within the "social sciences" subject area. The recent trend in different studies on urban and public transportation systems shows the importance of using MCDM approaches in this field. Moreover, noticeable employment of fuzzy sets in several studies is a point that can shows the significant role of uncertainty in dealing with this type of problems.

Keywords: public transportation, urban transportation, decision-making, MCDM, MADM, review, fuzzy, AHP, TOPSIS.

Notations

AHP – analytic hierarchy process;
ANP – analytic network process;
APTM – advanced public transport modes;
BRT – bus rapid transit;
BWM – best–worst method;
CBA – cost–benefit analysis;
CMA – consistent matrix analysis;
CoCoSo – combined compromise solution;
CODAS – combinative distance-based assessment;
COPRAS – complex proportional assessment;
CRITIC – criteria importance through inter criteria correlation;
DEA – data envelopment analysis;
DEMATEL – decision-making trial and evaluation laboratory;
EDAS – evaluation-based on distance from average solution;
ELECTRE – elimination and choice translating reality (in French: *ÉLimination Et Choix Traduisant la REalité*);
FUCOM – full consistency method;
GIS – geographic information system;
GLDS – gained and lost dominance score;
GRA – grey relational analysis;
GRAVIG – GRA and VIG;

*Corresponding author. E-mail: *m.keshavarz@gonbad.ac.ir*

LRT – light rail transit;
MABAC – multi-attributive border approximation area comparison;
MADM – multi-attribute decision-making;
MACBETH – measuring attractiveness by a categorical based evaluation technique;
MAGDM – multi-attribute group decision-making;
MAIRCA – multi-attributive ideal real comparative analysis;
MARCOS – measurement of alternatives and ranking according to compromise solution;
MAUT – multi-attribute utility theory;
MCDM – multi-criteria decision-making;
MCGDM – multi-criteria group decision-making;
MODM – multi-objective decision-making;
MOORA – multi-objective optimization by ratio analysis;
MULTIMOORA – multiplicative form of MOORA;
P&R – park-and-ride;
PROMETHEE – preference ranking organization method for enrichment of evaluations;
QOL – quality of life;
SA – simulated annealing;
SAW – simple additive weighting;
SD – system dynamics;
SIMUS – sequential interactive modelling for urban systems;
SVNS – single-valued neutrosophic set;
SWARA – stepwise weight assessment ratio analysis;
TOPSIS – technique for order of preference by similarity to ideal solution;
VIG – variable iterated greedy;
VIKOR – multi-criteria optimization and compromise solution (in Serbian: *Višekriterijumska optimizacija I KOmpromisno Rešenje*)
WASPAS – weighted aggregated sum product assessment;
WPM – weighted product model;
WSM – weighted sum model.

Introduction

Improvement of urban and public transportation is a complicated and important process. Several dimensions can affect this process such as the type of improvement, people involved in the decision process and the factors that should be improved (Chau, Ng 1998). Usually, the decisions related to this process are somewhat top-down and generally made by representatives or managers of local transport companies. However, the process of decision-making can be improved by involving communities in the strategic planning to have more sustainable plans (Vulevic 2016). Urban and public transportation is an essential element of QOL in any city. By helping people to get their destinations in an appropriate way, it has many significant effects on different aspects of communities and environment (Tirachini *et al.* 2013). All developing and developed cities around the world are confronted with fast suburbanization and growing population. While the demand for public transport is increasing, the supply is usually inadequate. Implementing optimized systems for urban and public transportations can reduce some serious issues like environmental, public health, financial and traffic congestion problems (De Cea, Fernández 1993; González-Gil *et al.* 2013). Using efficient methodologies is required for planning and management of urban and public transportation systems, studying the needs of stakeholders and making decisions based on consensus.

In many real-world problems, it is usually improbable to define the problem with only one criterion. It is common for decision-makers to make reasonable and efficient decisions in relation to multiple conflicting criteria. Because of the conflicting nature of multiple criteria, real-world decision-making process is relatively complex (Keshavarz-Ghorabaee 2021; Pamučar *et al.* 2022). According to the literature, there have been several approaches to deal with this type of problems, which are known as MCDM problems. The MCDM approaches are usually divided into 2 categories: (1) MADM and (2) MODM (Dutta *et al.* 2022; Keshavarz-Ghorabaee *et al.* 2019). However, the term MCDM, which is the focus of this study, has been referred to MADM approaches in several studies over the past years. This includes a broad range of methodologies and problems that involve the evaluation process of a number of alternatives in terms of a number of criteria (Keshavarz-Ghorabaee *et al.* 2018; Liao *et al.* 2022). Since urban and public transportation managerial decisions usually involve multiple criteria, employment of MCDM approaches seems to be a good way to deal with the complexity of making effective decisions (Farkas 2009; Fierek, Zak 2012).

During the past years several MCDM methods and techniques has been introduced and applied to different fields of studies. Several researchers have used the advantages of these methods. Some of them used only one MCDM method for the evaluation process, and some other present innovative integrations of various methods and techniques to deal with problems. The aim of this study is to present a short bibliographic review of recent studies on using the MCDM methodologies in problems related to urban and public transportation systems. For this purpose, the *Scopus* database was chosen as a reputable database to make the search. The search was made for the journal articles for the period from 2017 to 2022 (July). The methodologies are classified as 2 categories including: (1) single approaches, which only used one MCDM method, and (2) hybrid approaches, which utilized an integration of different methods. The consideration of uncertainty in the evaluation process of these studies was also examined in the review. Moreover, the review presents analyses of content, most used methods, authors, countries and institutions, and contributions to different subjects. Table 1 shows abbreviations of different MCDM methods considered in this review and their brief description.

Table 1. List of methods and their abbreviations and description

Method (abbreviation)	Full Title	Description
AHP	Analytic Hierarchy Process	a structured technique for analysing MCDM problems according to pairwise comparisons
ANP	Analytic Network Process	a generalization of AHP, which incorporates the interdependences among criteria
BWM	Best Worst Method	a pairwise comparison-based method based on identifying the best and the worst criteria
CBA	Cost–Benefit Analysis	a systematic approach to estimating the strengths and weaknesses of alternatives based on cost–effectiveness analysis
CODAS	COmbinative Distance-based ASsessment	a distance-based MCDM method that uses a combination of Euclidean and Hamming distances
COPRAS	COmplex PRoportional ASsessment	a stepwise method is aimed at ranking a set of alternatives according to their significance and utility degree
CoCoSo	COmbined COmpromise SOlution	a method based on a distance measure, which originates from grey relational coefficient and targets
CRITIC	CRiteria Importance Through Intercriteria Correlation	a method of determining objective weights based on the contrast intensity and the conflicting character of the evaluation criteria
DEA	Data Envelopment Analysis	a non-parametric method for measuring the efficiency of a set of decision-making units
DEMATEL	DEcision-MAking Trial and Evaluation Laboratory	an effective method for the identification of cause-effect chain components of a complex system
EDAS	Evaluation-based on Distance from Average Solution	a method based on positive and negative distances from the average solution
ELECTRE	elimination and choice translating reality (in French: *ÉLimination Et Choix Traduisant la REalité*)	a method to outrank a set of alternatives by determining their concordance and discordance indexes
FUCOM	FUll COnsistency Method	a method based on 2 groups of constraints including: (1) the relations of the weight coefficients of criteria and (2) the conditions of mathematical transitivity
GLDS	Gained and Lost Dominance Score	a method based on loss aversion of the decision-makers with more sensitivity to the bad facets of alternatives
GRA	Grey Relational Analysis	a method based on the performance of all alternatives in a comparability sequence and an ideal target sequence
MABAC	Multi-Attributive Border Approximation area Comparison	a method based on the distance measure between each alternatives and the bored approximation area
MACBETH	Measuring Attractiveness by a Categorical Based Evaluation TecHnique	an interactive approach that uses semantic judgments about the differences in attractiveness
MAIRCA	Multi-Attributive Ideal Real Comparative Analysis	a simple method with a high degree of stability related to changes in both the nature and character of the criteria
MARCOS	Measurement of Alternatives and Ranking according to COmpromise Solution	a method based on the measurement of choices and their ranking as a compromise solution
MAUT	Multi-Attribute Utility Theory	a systematic method to identify and analyse multiple variables for providing a common basis for making a decision
MOORA	Multi-Objective Optimization by Ratio Analysis	an efficient outranking method, which uses a ratio system to analyse an MCDM problem
MULTIMOORA	Multiplicative form of MOORA	a method that consists of MOORA method and the full multiplicative form
PROMETHEE	Preference Ranking Organization METHod for Enrichment of Evaluations	an MCDM method based on using a preference function for each criterion forming a MCDM problem
SWARA	Stepwise Weight Assessment Ratio Analysis	a method to determine the criteria weights according to rank of criteria in order of importance
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution	a method based on the distance from negative and positive ideal solutions
VIKOR	multi-criteria optimization and compromise solution (in Serbian: *Višekriterijumska optimizacija I KOmpromisno Rešenje*)	a method for determining the compromise ranking-list of a set of alternatives according to the measure of closeness to the ideal solution
WASPAS	Weighted Aggregated Sum Product ASsessment	a method based on a combination of 2 models: (1) WSM and (2) WPM
WSM	Weighted Sum Model	it is the best known and simplest MCDM method and also called SAW

The rest of this review article is organized as follows. In Section 1, the procedure of conducting the review is presented. In Section 2, the reviewed studies are briefly discussed in different subsections, and a summary of them is provided in a table. Section 3 resents the findings and analyses of the review from different aspects. Conclusions are presented in the final section.

1. Review method

In this section, the method used in the current review article is briefly presented. The steps of the procedure of making the review are described and some details of these steps are delineated. The method includes 7 main steps as follows.

Step 1. Choosing a database to search documents. One of the challenges in the current study was choosing a suitable database for searching documents. There were several options including *Clarivate Analytics* (*Web of Science*), *Scopus*, *Google Scholar*, etc. Each of these databases had their own advantages and disadvantages. For example, although the *Clarivate Analytics* (*Web of Science*) database includes the most prestigious journals, it does not include many journals that are at a moderate level of reputability. On the other hand, the use of *Google Scholar* database could include documents from journals with a low degree of reputability (or even non-reputable journals) into the current study. Therefore, the *Scopus* database, which has an appropriate level of accessibility for the world's scientific institutions, was chosen and the indexed journals have an acceptable level of reputability. *Scopus* is *Elsevier*'s abstract and citation database launched in 2004. *Scopus* uniquely combines a comprehensive abstract and citation database with enriched data and scholarly literature across a wide variety of disciplines. It can provide access to reliable data, metrics and analytical tools and find authoritative and relevant research. *Scopus* claims that it is the largest abstract and citation database of peer-reviewed literature and high quality web sources with smart tools to track, analyse and visualize research. The *Scopus* database provides 2 options for searching: (1) basic and (2) advanced. In advanced search of *Scopus*, several codes can be used to reach appropriate and efficient results.

Step 2. Determining the time period for the review. The time period of the research was determined based on the topic of the study. It was important to start the search from a year in which a considerable number of documents were published while choosing a period of time close to the present. As previously mentioned, this study aims at presenting a review of recent journal articles that used MCDM approaches to deal with problems related to urban and public transportation systems from 2017 to 2022 (July).

Step 3. Deciding on the type of documents to be reviewed. The focus of this article was on original researches and journal articles. The *Scopus* database is reliable and popular to search journal articles, and it indexed several reputable journals. Conference articles and book chapters were excluded from the results of this study.

Step 4. Choosing some keywords for making the search. The keywords used in this study were included in the following code, which was used to search for related journal articles in *Scopus* database: *TITLE-ABS* (*"public transport" OR "public transportation" OR "urban transport" OR "urban transportation"*) *AND TITLE-ABS* (*"decision-making" OR "decision model" OR "MCDM" OR "MADM" OR "MCGDM" OR "MAGDM" OR "group decision"*) *AND TITLE-ABS* (*"multiple criteria" OR "multi-criteria" OR "multiple attribute" OR "multi-attribute"*) *AND* (*LIMIT-TO* (*PUBYEAR, 2022*) *OR LIMIT-TO* (*PUBYEAR, 2021*) *OR LIMIT-TO* (*PUBYEAR, 2020*) *OR LIMIT-TO* (*PUBYEAR, 2019*) *OR LIMIT-TO* (*PUBYEAR, 2018*) *OR LIMIT-TO* (*PUBYEAR, 2017*)) *AND* (*EXCLUDE* (*DOCTYPE, "cp"*) *OR EXCLUDE* (*DOCTYPE, "ch"*) *OR EXCLUDE* (*DOCTYPE, "cr"*) *OR EXCLUDE* (*DOCTYPE, "er"*)).

Step 5. Performing the search and initial check. At the time of conducting this study, 84 journal articles were found as the result of the search.

Step 6. Screening the documents result from the search. After assessment of these articles, a screening process was made and unrelated articles were removed. Based on this screening process 72 journal articles were selected to make the final review.

Step 7. Classifying and analysing the documents. The articles were classified according to authors, year of publication, type of the MCDM approach, and consideration of uncertainty. In this review article, the methodology of the selected articles that only used one MCDM method is classified as "single approaches", and the methodology of the articles used more than one MCDM method is classified as "hybrid approaches". It should be noted that consideration of different types of uncertainty (fuzzy, neutrosophic, and so on) in the selected articles was also assessed. The details of this step are presented in the following sections.

2. Overview of the studies

In this section, firstly, the studies related to the single MCDM approaches are discussed, then a review of the studies that used hybrid MCDM approaches are presented, and finally a summary of the reviewed studies is shown in a table containing their authors, year of publication, type of methodology, the MCDM methods used, consideration of uncertainty, and the considered problem of the studies.

2.1. Single approaches

As in many other fields of study that use MCDM approaches, the AHP method is the most common and widely used method here. This method was applied to several problems of urban and public transportation planning and management as a single approach methodology. Lee (2018) presented an approach for prioritization of APTM in Korea. Urban types of new towns were considered in the study, and the AHP method was applied to evaluate competitiveness of each APTM and illustrate the role of the development of transportation policy. Stanković *et al.*

(2018) defined the criteria with a great effect on traffic accessibility in suburban areas. The aim of their study was development of an operational model for traffic accessibility in these areas. They used a fuzzy AHP method and showed that networks of public transport lines, networks of accessible roads, travel time, and timetables were significant to develop the model. In a similar study, the fuzzy AHP and rough AHP methods were used to evaluate traffic accessibility systems (Stanković *et al.* 2019). A study on identification and prioritization of a set of important criteria for choosing a mode for urban and public transportation was carried out by Kumar and Ganguly (2018). Using the AHP method they showed that in a developed country (US) safety and reliability was more preferable, while in a developing country (India) price/fare was an important criteria. Public transportation mode choice using AHP was also the subject of a study made by Duleba *et al.* (2022b). In a case study made by Jasti and Ram (2019a) an AHP-based framework of mode-specific benchmarking was developed for metro systems of Mumbai based on 9 performance indicators and 34 evaluators. They showed that the service, quality and societal sectors are in acceptable condition, and the sector of multimodal integration needed to be improved. A benchmarking framework based on AHP for urban bus systems was presented in a comparable study (Jasti, Ram 2019b). Evaluation of users' satisfaction and needs is one of the other important problems in urban and transportation management, which was addressed using the AHP method in studies made by Dinulescu, Bugheanu (2020) and Bivina, Parida (2020). Ortega *et al.* (2020) proposed a fuzzy approach based on AHP to analyse a real-world P&R facility location problem in Cuenca city (Ecuador). They found that "accessibility of public transport" was the most significant issue in the P&R facility location problem. To deal with P&R problem, Barauskas *et al.* (2018) also proposed a methodology based on the EDAS method. Alkharabsheh *et al.* (2022) analysed travel demand based on a real-world problem in Amman (Jordan). According to their study, the transport quality issues needed to be improved with a focus on the safety of traveling by public vehicles. Another study on the transportation demand management problem was conducted based on the FUCOM by Pamucar *et al.* (2020). The AHP method was also used as a single approach in evaluation of urban and public transportation systems concerning different aspects like quality, energy, economic and so on (Alkharabsheh *et al.* 2021; Rivero Gutiérrez *et al.* 2021; Munjal *et al.* 2022, Santos, Lima 2021).

The ANP is an efficient generalization of AHP that helps us to consider the interrelation between different criteria and alternatives. Qing and Abdullah (2017) studied on different attributes related to the definition of the QOL using the ANP method. The results of their study showed that public transport was one of the essential attributes of the QOL. Bastida-Molina *et al.* (2022) examined different factors that prevented the electrification of urban mobility in Mediterranean cities. Based on the results of the ANP method obtained from a case in Spain, the insufficient subsidies for development of electric vehicles and the battery autonomy power were influential barriers. Wołek *et al.* (2021) also made a study on electrification of public transportation vehicles based on the CBA method. TOPSIS is another MCDM method that has been used as a single approach. Dehghani *et al.* (2017) proposed a methodology based on interval type-2 fuzzy sets and TOPSIS for evaluation of service quality in urban and public transportation systems in Shahrekord (Iran). Mei and Xie (2019) also used the TOPSIS method with interval type-2 fuzzy sets and applied it to evaluate evacuation strategies for metro stations in emergency situations. A study on planning traffic pollution control was made by Wei *et al.* (2019) using the TOPSIS method. They presented an integration of 11 hybrid-type indicators concerning the implementation of a pollution control plan, emissions and traffic flow.

Evaluation of the sustainability of urban and public transportation systems is another problem, which has been addressed by researchers using single MCDM approaches. Smith (2019) used SVNSs to select a public transportation system under uncertainty and considering sustainability criteria. A case study in Canada was presented in the study. Chen and Zhang (2020) proposed a method based on WSM to determine the interaction among multiple criteria for evaluation of the sustainability performance of some cities in China. Their study showed that lagging public transportation is one of the most important criteria, which had negative effect on sustainability of the cities. Ogrodnik (2020) made a study on development of smart and sustainable solutions for urban and public transportation systems and infrastructure. The PROMETHEE method was used as a single approach to evaluate smart cities with respect to 6 main criteria including: (1) smart people, (2) smart economy, (3) smart governance, (4) smart environment, (5) smart mobility and (6) smart living. Garcia-Ayllon *et al.* (2022) investigated the plans of 47 cities in Spain for implementing sustainable urban mobility over 15 years. They analysed different factors and proposed some solutions based on the WSM method and SIMUS. Marleau Donais *et al.* (2019) presented a framework based on the MACBETH method for assessment of the potential streets for redesigning to increase the sustainability of urban and public transportation systems. Romero-Ania *et al.* (2021) proposed an MCDM methodology based on ELECTRE to evaluate urban and public transportation systems according to the sustainability dimensions including economic and environmental criteria.

Site selection of car sharing stations using MULTIMOORA (Lin *et al.* 2020), locating bicycle-sharing stations with MOORA (Lee *et al.* 2020) and utilization of GLDS for performance evaluation of bus companies (Wang *et al.* 2022) are other studies, which used single MCDM approaches in the evaluation problems of urban and transportation systems.

2.2. Hybrid approaches

To take the advantage of different MCDM methods, 2 or more method can be used in an integrated manner. In this study, these approaches are referred to as hybrid approaches. Like the single approaches, the hybrid approaches have been utilized by many researchers to handle different problems related to urban and public transportation systems. The AHP method has also been a popular method in several hybrid approaches.

Nadafianshahamabadi *et al.* (2017) used AHP and MAUT for evaluation process of a highway project in Tehran (Iran). They explored different criteria concerning urban transportation project with respect to technical experts and community members. It was shown that value judgments and critical technical assessments could affect the results of evaluation. Vincent *et al.* (2018) addressed the optimization of the design of driver seat to reduce the effect of blind spots in heavy transport vehicles. For this purpose, they presented an approach based on AHP and COPRAS under fuzzy environment. Vincent *et al.* (2017) studied on a similar problem based on Entropy and COPRAS. Kiciński and Solecka (2018) presented an integrated methodology for scenario evaluation in urban and public transportation systems. With respect to 11 criteria and 6 alternatives they generated several scenarios by a simulation software. The AHP and ELECTRE methods were applied to make the evaluation. Güner (2018) applied the AHP and TOPSIS method to measurement of the quality of urban and public transportation systems. The most important service quality criteria were identified in the study, and quality of bus transit services was evaluated according to them. Erdogan and Kaya (2019) introduced a methodology based on an interval type-2 fuzzy AHP method and a stochastic TOPSIS method. Using the methodology and experts' evaluations obtained by Delphi, important factors of the failures for BRT systems were evaluated. Seker and Aydin (2020) addressed a public transportation problem to evaluate the alternatives designed for a university. To make this evaluation, they used an integration of interval-valued intuitionistic fuzzy AHP and CODAS.

In another study, a hybrid approach based on AHP and MOORA was applied to evaluate public bus transport systems in Budapest (Hungary) (Moslem, Çelikbilek 2020). Canbulut *et al.* (2022) presented an integration of AHP and GRA for assessment of 8 vehicles with various features and selection of the best one for a company working at the public transport sector in Turkey. Ghosh *et al.* (2021) studied on detailed criteria of e-rickshaw evaluation, and the AHP method used to calculate the weights of them. Then the TOPSIS method was employed to evaluate different e-rickshaw alternatives. Duleba *et al.* (2022a) addressed a public transport development problem and used AHP and Entropy methods to deal with the evaluation process. They utilized intuitionistic fuzzy sets and distance-based aggregation operators in their methodology. Ortega *et al.* (2021) applied a methodology based on AHP and BWM for evaluation and selection of locations of P&R facilities. They considered a 2-level hierarchical P&R facility location problem in Cuenca city (Ecuador). Regarding a similar problem, Yaliniz *et al.* (2022) presented an approach based on AHP and ANP to deal with a P&R evaluation problem. There are some other studies used AHP in hybrid approaches including AHP–GIS (Saplıoğlu, Aydın 2018), AHP–TOPSIS (Öztürk 2021), AHP–WASPAS (Aydin *et al.* 2022; Tumsekcali *et al.* 2021), AHP–BWM (Moslem *et al.* 2022), BWM–AHP–MOORA (Çelikbilek *et al.* 2022) and AHP–PROMETHEE (Oubahman, Duleba 2022).

As can be seen in the abovementioned studies, the TOPSIS method has also been a common method in various studies for evaluation processes in urban and public transportation systems. In addition to the abovementioned studies, there have been some other studies, which has used TOPSIS in integration with the other MCDM methods. Büyüközkan *et al.* (2018) applied the Choquet integral and the TOPSIS method to the evaluation of sustainable urban and public transportation alternatives. The results of their research showed that interdependencies of criteria plays an important role in the evaluation and rankings of the sustainable urban and public transportation systems. Hamurcu and Eren (2019) addressed a monorail route selection problem in Ankara (Turkey). They used the TOPSIS and ANP methods to evaluate 8 alternatives for monorail routes. Shekhovtsov *et al.* (2020) proposed a methodology to determine the effectiveness of different criteria in development of sustainable public transportation systems. They examined a case of electric bikes evaluation with respect to 8 criteria, and used the Entropy, TOPSIS and VIKOR methods to make the evaluation. Hajduk (2022) studied on an MCDM problem related to urban and public transportation system consisted of 7 criteria and 44 alternatives. Then Entropy and TOPSIS were used to deal with the problem. Shabani *et al.* (2022) proposed a methodology to evaluate users' satisfaction of urban and public transportation systems over the COVID-19 pandemic in Tehran. The results of their research showed higher degrees of satisfaction in using taxicabs in comparison with the other modes.

Evaluation of bike sharing service quality in public transportation systems was studied by Ma *et al.* (2019). They used the DEMATEL and VIKOR methods to assess the service quality gap according to different stakeholders including platform operators, government regulators, users and bike association. Peng and Shen (2018) proposed a methodology based on GRA and VIG, called GRAVIG, for crew scheduling in public transportation systems. They applied the methodology on eleven real-world crew scheduling problems. Using an integrated approach based on DEMATEL, ANP an VIKOR, Lu *et al.* (2018) made a study on evaluation of international airports performance. The results of their study showed the public transportation systems as an important factor in improvement of international airports performance. Luan *et al.* (2019) presented a hybrid approach based on CMA and Entropy for evaluation of different planning designs for LRT network as an essential element for development of urban and public transportation systems. Hashemkhani Zolfani *et al.* (2020) employed the BWM and MAIRCA methods to deal with evaluation of neighbourhoods for a newcomer in Chile. They considered 2 different scenarios in the evaluation process: (1) using public transportation and (2) having a private car. Baç (2020) proposed an integrated approach for evaluation of smart card systems for urban and public transportation systems. The SWARA and WASPAS methods were used for evaluating alternatives with respect to performance, user satisfaction and reliability criteria. A hybrid approach based on CRITIC and EDAS was used by Görçün (2021) to evaluate and select a suitable metro and tram vehicle. 22 criteria were defined and different rail tram types operated in Turkey were considered as the alternatives. Türk *et al.* (2021) presented a methodology based on interval type-2 fuzzy sets, SA and WSM to determine the location of electric charging stations in Istanbul, Turkey. In another location selection problem, Lin *et al.* (2021) applied the ANP, DEMATEL and VIKOR methods to evaluate bubble tea shops locations. They showed that proximity to public transportation systems is a very important criteria to select a location.

Prioritizing the alternatives of the hydrogen bus using BWM and MARCOS (Pamucar *et al.* 2021), sustainable public transportation systems evaluation based on a BWM–MABAC (Keshavarz-Ghorabaee *et al.* 2021), ANP–ELECTRE (Kalifa *et al.* 2022), FUCOM–CoCoSo (Demir *et al.* 2022) approaches, application of SD and DEA for forecasting travel demand (Norouzian-Maleki *et al.* 2022) and using a CRITIC–MABAC approach for transportation pricing system evaluation (Simic *et al.* 2022) are some of the other studies in the field of urban and public transportation systems related to the hybrid approaches.

3. Findings and analysis

In this section, the findings are presented and the reviewed journal articles are analysed. Table 2 represents a summary of the reviewed articles including author(s), year of publication, type of methodology (single or hybrid), methods used (methodology), consideration of uncertainty, and the problem of the study.

According to Table 2, the type of methodology in 40 articles is hybrid. In fact, most of the reviewed articles used hybrid approaches as the methodology.

The ATLAS.ti 9 (*https://atlasti.com*) software was applied to analyse the whole text of 72 journal articles chosen to review. ATLAS.ti is an efficient tool that can be used to perform qualitative text analysis. It can also be useful to identify and visualize the content. ATLAS.ti can help researcher from different disciplines uncover and analyse hidden structures in data (Friese 2019). The word cloud obtained from analysing the reviewed articles using ATLAS.ti is shown in Figure 1. According the analysis of ATLAS.ti, the word "fuzzy" was repeated 2295 times and the word "AHP" was repeated 1322 times. Therefore, consideration of uncertainty is a very important factor for the evaluation processes of urban and transportation systems. Moreover, the AHP method can be regarded as the most prominent method in this field of study according the analysis of the content.

According to Table 2, AHP was used in 34 articles. This is another fact, which shows that the AHP method is the most popular method. TOPSIS, which was used in 11 articles, is the 2nd-ranked popular method, and ANP and BWM, which were utilized in 7 articles, are ranked as the 3rd common methods. VIKOR, WSM, DEMATEL, ELECTRE and MOORA, which was utilized in more than 3 articles, can also be considered as useful methods to deal with MCDM problem related to urban and public transportation systems.

The importance of the consideration of uncertainty can also be seen in Table 2. According to this table, 35 articles studied on the MCDM problems under uncertainty. Uncertainty is not exclusive to urban and public transportation systems. Many other scientific and managerial fields are confronted with a wide range of uncertainties in their work. Uncertainty is a complex concept that can be described in multiple ways, and its consideration in decision-making has evolved over time. Uncertainty usually comes from a state of incomplete knowledge that can result from a lack of information or the degree of confidence that a decision-maker has about possible outcomes. The reviewed articles were analysed according to this feature since it is an integral part of supportive information and inherent in all evidence and in all decisions.

Figure 2 shows the number of articles in different years and a linear trend line. The examination of the trend in the number of journal articles published over the time period of the analysis indicates a growth in studies related to the applications of MCDM methods in urban and public transportation systems. The number of journal articles has risen from 4 articles in 2017 to 16 articles in 2021. This increasing trend imply that MCDM problems related to urban and public transportation systems are significant problems in the transportation sector. Since 17 articles were found around the middle of 2022, it is expected that the number of articles in 2023 could be more than 25.

Figure 3 represents the authors with more published articles during the period of analysis. As can be seen, having 8 articles, "Duleba, S." and "Moslem, S." are the authors with highest number of published articles (eight articles). After them, "Deveci, M." with 4 articles, and "Alkharabsheh, A." and "Çelikbilek, Y." with 3 articles have been the authors published significant number of articles on applications of MCDM methods in urban and public transportation systems. The focus of different authors on this field can be another fact that shows the high importance of the decision-making problems related to urban and public transportation systems.

Table 2. The summary of the reviewed articles

No	Reference	Type	Method	Uncertainty	Problem
1	Nadafianshahamabadi *et al.* (2017)	hybrid	AHP–MAUT	×	highway projects
2	Vincent *et al.* (2017)	hybrid	Entropy–COPRAS	×	blind spot reduction in heavy vehicles
3	Qing, Abdullah (2017)	single	ANP	✓	QOL
4	Dehghani *et al.* (2017)	single	TOPSIS	✓	quality of public transportation
5	Vincent *et al.* (2018)	hybrid	AHP–COPRAS	✓	blind spot reduction in heavy vehicles
6	Kiciński, Solecka (2018)	hybrid	AHP–ELECTRE	×	urban public transportation scenario planning
7	Barauskas *et al.* (2018)	single	EDAS	×	P&R location
8	Peng, Shen (2018)	hybrid	GRAVIG	×	public transport crew scheduling
9	Lee (2018)	single	AHP	×	prioritizing APTM
10	Güner (2018)	hybrid	AHP–TOPSIS	×	ranking the bus transit routes
11	Stanković *et al.* (2018)	single	AHP	✓	assessment of the impact of traffic accessibility
12	Lu *et al.* (2018)	hybrid	DEMATEL–ANP–VIKOR	×	evaluation for international airports
13	Kumar, Ganguly (2018)	single	AHP	×	public transit user mode
14	Saplıoğlu, Aydın (2018)	hybrid	AHP–GIS	✓	choosing bicycle routes
15	Büyüközkan *et al.* (2018)	hybrid	Choquet integral–TOPSIS	✓	sustainable urban transportation
16	Ma *et al.* (2019)	hybrid	DEMATEL–VIKOR	×	assessment of bike sharing service
17	Hamurcu, Eren (2019)	hybrid	ANP–TOPSIS	×	evaluation of monorail routes
18	Luan *et al.* (2019)	hybrid	CMA–Entropy	×	LRT planning
19	Erdogan, Kaya (2019)	hybrid	AHP–TOPSIS	✓	prioritizing failures for corrective actions in BRT
20	Mei, Xie (2019)	single	TOPSIS	✓	metro station evacuation strategy
21	Stanković *et al.* (2019)	single	AHP	✓	assessment of traffic accessibility
22	Smith (2019)	single	SVNS	✓	public transport sustainability
23	Wei *et al.* (2019)	single	TOPSIS	✓	traffic pollution control planning
24	Marleau Donais *et al.* (2019)	single	MACBETH	×	redesigning streets
25	Jasti, Ram (2019a)	single	AHP	✓	benchmarking of metro rail system
26	Jasti, Ram (2019b)	single	AHP	✓	benchmarking of a public transport system
27	Ogrodnik (2020)	single	PROMETHEE	×	analysis of smart cities
28	Dinulescu, Bugheanu (2020)	single	AHP	×	improving users' satisfaction
29	Hashemkhani Zolfani *et al.* (2020)	hybrid	BWM–MAIRCA	×	neighbourhood selection
30	Lin *et al.* (2020)	single	MULTIMOORA	✓	site selection of car sharing station
31	Pamucar *et al.* (2020)	single	FUCOM	✓	transportation demand management
32	Seker, Aydin (2020)	hybrid	AHP–CODAS	✓	sustainable public transportation
33	Bivina, Parida (2020)	single	AHP	×	prioritizing pedestrian needs
34	Chen, Zhang (2020)	single	WSM	✓	evaluation of city sustainability
35	Ortega *et al.* (2020)	single	AHP	✓	P&R location
36	Shekhovtsov *et al.* (2020)	hybrid	Entropy–TOPSIS–VIKOR	✓	sustainable transport problems
37	Baç (2020)	hybrid	SWARA–WASPAS	×	smart card systems evaluation
38	Moslem, Çelikbilek (2020)	hybrid	AHP–MOORA	✓	public transport service quality
39	Lee *et al.* (2020)	single	MOORA	×	locating bicycle-sharing stations
40	Görçün (2021)	hybrid	CRITIC–EDAS	×	evaluation of metro and tram vehicles

End of Table 2

No	Reference	Type	Method	Uncertainty	Problem
41	Keshavarz-Ghorabaee *et al.* (2021)	hybrid	BWM–MABAC	✓	sustainable public transportation evaluation
42	Canbulut *et al.* (2022)	hybrid	AHP–GRA	×	public transportation vehicle selection
43	Ghosh *et al.* (2021)	hybrid	AHP–TOPSIS	×	selection of e-rickshaw
44	Duleba *et al.* (2022a)	hybrid	AHP–Entropy	✓	public transport development
45	Türk *et al.* (2021)	hybrid	WSM–SA	✓	locating the electric charging stations
46	Alkharabsheh *et al.* (2021)	single	AHP	✓	evaluating urban public transportation
47	Rivero Gutiérrez *et al.* (2021)	single	AHP	×	urban public transport systems
48	Lin *et al.* (2021)	hybrid	ANP–DEMATEL–VIKOR	×	location determinants of tea shops
49	Ortega *et al.* (2021)	hybrid	AHP–BWM	×	P&R location
50	Romero-Ania *et al.* (2021)	single	ELECTRE	×	analysis of public transport systems
51	Pamucar *et al.* (2021)	hybrid	BWM–MARCOS	✓	prioritizing the alternatives of the hydrogen bus
52	Öztürk (2021)	hybrid	AHP–TOPSIS	✓	evaluation of public transport services
53	Santos, Lima (2021)	single	AHP	×	quality of public transportation
54	Wołek *et al.* (2021)	single	CBA	×	electrification of public transport
55	Tumsekcali *et al.* (2021)	hybrid	AHP–WASPAS	✓	transportation service quality
56	Norouzian-Maleki *et al.* (2022)	hybrid	SD–DEA	×	forecasting travel demand
57	Kalifa *et al.* (2022)	hybrid	ANP–ELECTRE	×	prioritization of public transport system
58	Yaliniz *et al.* (2022)	hybrid	AHP–ANP	×	P&R application
59	Garcia-Ayllon *et al.* (2022)	single	WSM	×	sustainable urban mobility plans
60	Hajduk (2022)	hybrid	TOPSIS–Entropy	×	linear ordering of urban transport
61	Çelikbilek *et al.* (2022)	hybrid	BWM–AHP–MOORA	✓	evaluate public transportation systems
62	Moslem *et al.* (2022)	hybrid	AHP–BWM	×	evaluation of commuting transport alternatives
63	Shabani *et al.* (2022)	hybrid	BWM–TOPSIS	✓	satisfaction of public transportation
64	Munjal *et al.* (2022)	single	AHP	×	energy-efficient public transport evaluation
65	Wang *et al.* (2022)	single	GLDS	✓	performance evaluation of bus companies
66	Simic *et al.* (2022)	hybrid	CRITIC–MABAC	✓	transportation pricing system evaluation
67	Duleba *et al.* (2022b)	single	AHP	✓	public transportation mode choice
68	Demir *et al.* (2022)	hybrid	FUCOM–CoCoSo	✓	sustainable urban mobility
69	Oubahman, Duleba (2022)	hybrid	AHP–PROMETHEE	×	perceptions of different transport modes
70	Alkharabsheh *et al.* (2022)	single	AHP	✓	analysing public travel demand
71	Aydin *et al.* (2022)	hybrid	AHP–WASPAS	✓	location of mobility hub
72	Bastida-Molina *et al.* (2022)	single	ANP	×	electrification of urban mobility

Figures 4 and 5 show the number of articles with respect to the countries and institutions (of the corresponding authors), respectively. According to these figures, Turkey has the highest number of articles in this field of study, and Hungary and China are also countries with relatively high number of publications. In fact, the corresponding author of about 60% of the reviewed articles are from these 3 developing countries. This analysis indicates that evaluation of urban and public transportation systems has been of great interest in Turkey, Hungary and China. Moreover, "Budapest University of Technology and Economics" (Hungary) is the institution that has the highest rank, and "Milli Savunma Üniversitesi", "Yildiz Technical University" and "Deniz Harp Okulu" are ranked lower than it in terms of the number of published articles related to the application of MCDM approaches in urban and public transportation problems. As it can be seen, Turkish institutions have a high contribution to this field of study.

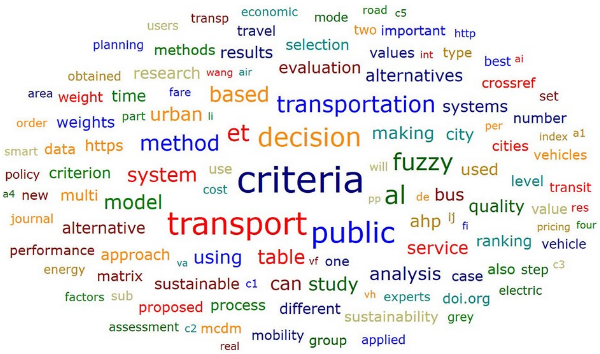

Figure 1. The word cloud resulted from the analysis made by ATLAS.ti

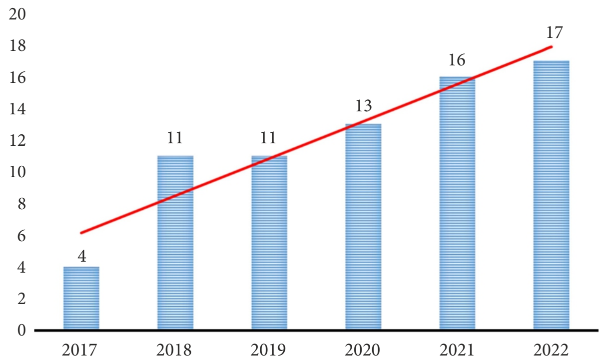

Figure 2. The number of articles in different years

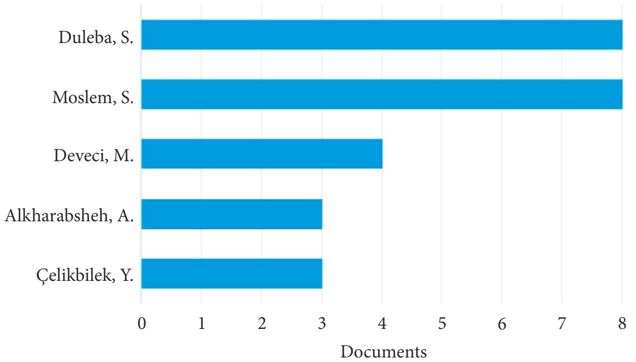

Figure 3. The number of articles in terms of authors

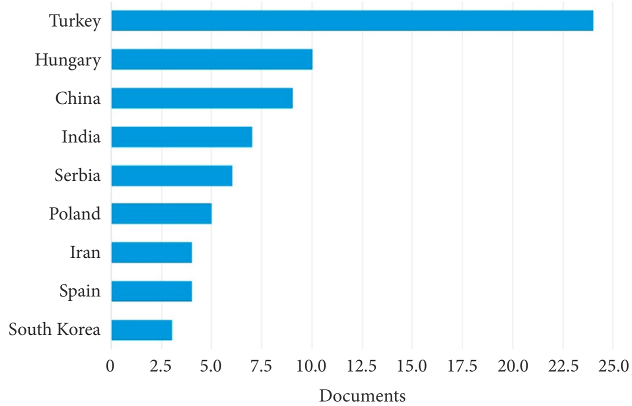

Figure 4. The number of articles in terms of different countries

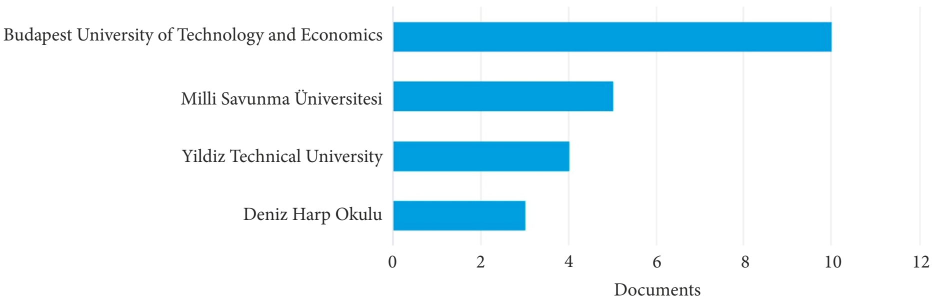

Figure 5. The number of articles in terms of different institutions

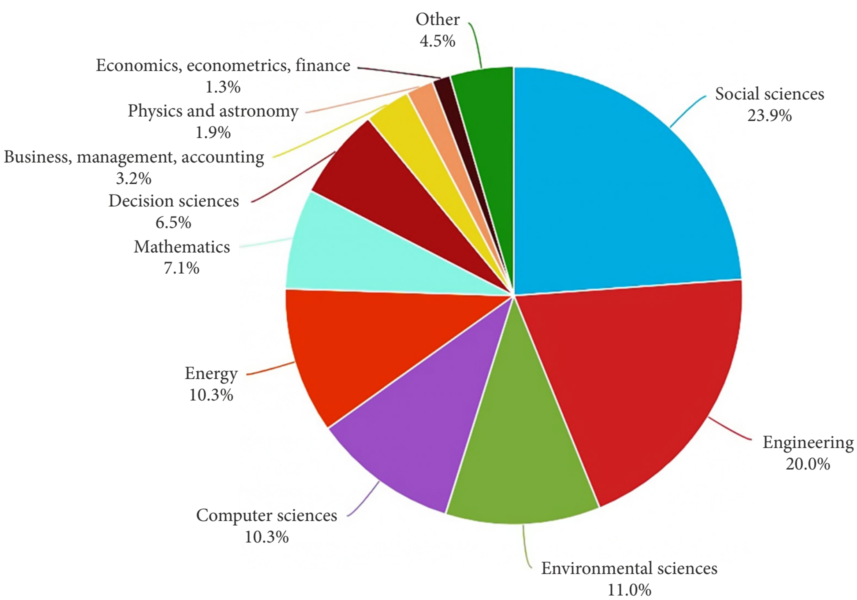

Figure 6. The percentage of articles in terms of different subject areas

In Figure 6, the percentage of the journal articles related to the applications of MCDM methods in urban and public transportation systems are scattered in different scientific subject areas defined by *Scopus*. According to this figure, about 23.9% of the articles belong in the area of "social sciences"; another 20% involve articles in "engineering; environmental science" accounts for 11% of the articles; each of "computer science and energy" areas covers about 10.3% of articles; and "mathematics and decision sciences" areas account for 7.1% and 6.5% of articles, respectively. The other subject areas in total cover less than 11% of the reviewed articles. More than 75% of the articles falls within "social sciences", "engineering, environmental science", "computer science and energy" subject areas. Accordingly, "social sciences" and "engineering, environmental science" can be considered as the most important subject areas with greater percentage of the journal articles.

4. Discussion

The rapid growth of population and urbanization in recent decades has caused many problems in the daily life of human beings. One of the most important issues in this field is the development of urban and public transportation systems based on possible priorities, which has received much attention (Elmansouri *et al.* 2020; Maitra, Sadhukhan 2013). Consequently, the evaluation processes for the development of urban and public transportation systems have seriously been considered by urban managers and researchers in this field in recent years. Due to the significant impact of urban and public transportation systems on the lives of citizens and the massive amount of necessary investment, evaluation and decision-making processes requires deliberation and precision (Bruun 2013; Gershon 2005). Any error at this stage can cause a non-optimal decision and thus impose huge costs on the city. This is emphasized by many researchers that the topic of urban and public transportation systems has very extensive and complex functions and has several important effects on many groups of society (Murray *et al.* 1998; Porru *et al.* 2020).

Today, the development models of urban and public transportation systems are used in many cities around the world. In addition to providing different transportation options, the development of urban and public transportation systems could also lead to "improvement of the QOL" in communities and neighbourhoods. When this development is combined with economic plans, it could create values for social life. In addition, this type of development is a key plan in the reconstruction of neighbourhoods and urban centers. It improves the creation of new business units and job opportunities, makes communities safer, and thus provides attractiveness and comfort for people. This issue is effective in certain matters such as traffic control and pollution reduction (Gao, Wang 2021; Hahn *et al.* 2021). A logical and scientific means is needed to support the decisions made by public transport policy makers for the development of urban and public transportation systems.

Decision-making regarding these multifaceted systems is very complicated due to the wide range of impacts and criteria on the one hand and the diversity of stakeholders on the other hand. There is not one specific factor involved in issues related to urban and public transportation systems. Several factors such as economic, social and environmental factors are effective in their evaluation processes. Therefore, it is not possible to pay attention to only one factor for development of such systems and consider it in the process of evaluation. An approach is needed that can consider and analyse the effect of several factors at the same time and provide a reasonable result. MCDM methods are one of the most efficient approaches used in the world for the simultaneous analysis of quantitative and qualitative indicators in evaluation processes (Cavone *et al.* 2018; Yannis *et al.* 2020; Yatskiv *et al.* 2013).

In this article, with the aim of improving development approaches in urban and public transportation systems, the focus was on recent studies that used MCDM methods to solve problems. If researchers know which MCDM methods have received more attention recently, they could have a better view of future decisions to develop urban and public transportation systems. Although MCDM methods usually provide a general structure for dealing with various problems, in many cases, knowing the literature in a specific field helps us choose methods that provide us with better conditions in terms of complexity and efficiency. However, the hierarchical structure of several MCDM problems usually leads us to traditional methods like AHP, which have a stronger background in solving various decision-making problems. Therefore, a review of recent studies of the literature can be useful for creating insight into the applicability of new MCDM methods. The combination of different MCDM methods is another topic that this article can contribute to. By examining various hybrid approaches that have been used in the past years, it is possible to determine the general direction of using weighting and evaluation methods in MCDM problems related to urban and public transportation systems. In addition to the topic of methodologies, the type of data and information is also very important for decision-making. Considering uncertainty in decision-making is one of the other issues that have been investigated in this study. According to the analyses carried out, it is possible to observe the growing trend of using decision-making approaches under uncertainty in public transportation issues and understand the necessity of focusing on the development and extension of these approaches in the future.

Conclusions

Urban and public transportation systems are one of the most important elements affecting the QOL in most cities, especially big cities. The increase in the population of cities in developing and developed countries makes urban and public transportation systems even more consequential. The service and supply are not enough for the daily and continuous increase in demand for public transportation. The use of effective methods for managing and planning urban and public transportation systems, as well as their optimal implementation, not only ends with meeting the needs of users, but also reduces many other problems such as environmental problems, public health, and traffic. Since the problems related to urban and public transportation planning and management usually include a set of goals and criteria, the use of MCDM methods seems to be a suitable solution for making important decisions for the implementation of such systems.

In this article, a short bibliographic review of recent studies on using MCDM approaches for evaluation of urban and public transportation systems has been presented. The MCDM approaches has been categorized into single and hybrid approaches, and journal articles published in the period from 2017 to 2022 (July) were reviewed. *Scopus* database was chosen to search for articles in this period. After an initial screening, 72 articles were selected to be reviewed. These articles were analysed from different aspects. The ATLAS.ti software was applied to analyse the content of the selected articles. The word cloud obtained from ATLAS.ti showed that the word "fuzzy" was repeated 2295 times and the word "AHP" was repeated 1322 times. According to the methodologies used in the selected articles, it was found that the AHP method was the most popular MCDM method, and the TOPSIS method was the 2nd-ranked prevalent method. Presenting the methods that have been more popular in the literature helps to identify and choose practical methods in urban and public transportation systems. In addition, according to the structure of previous methods like AHP and TOPSIS, newer and more efficient methods with similar structures can be considered for use in future research, e.g. BWM and EDAS.

The results of the current review showed that a considerable portion of the methodologies in dealing with urban and public transportation problems were the hybrid approaches. The importance of hybrid approaches increases when there is a need of individual methods for weighting and ranking in MCDM problems. Such problems could be encountered in evaluation processes in urban and public transportation systems. Another aspect of the reviewed articles was consideration of uncertainty. The results demonstrated that nearly half of the articles considered uncertainty in the evaluation procedure. This highlights the importance of using developed MCDM methods under uncertainty in future research.

The analysis showed that Turkey, Hungary and China had the highest number of articles in the considered time period. This can imply that studies on the application of MCDM methods in urban and public transportation systems has been the focus of developing countries. Therefore, other developing countries can emulate the success of leading countries in this field of study like Turkey and use their results. Although "Budapest University of Technology and Economics" (Hungary) conducted more research than other institutions, Turkish institutions have also been among the leading institutions based on the results of the current study. Furthermore, according to the subject areas defined by *Scopus*, "social sciences", "engineering, environmental science", "computer science and energy" subject areas covered most of the reviewed articles.

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