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Analysis of industry 4.0 implementation in mobility sector: An integrated approach based on QFD, BWM, and stratified combined compromise solution under fuzzy environment

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ABSTRACT

The role of new technologies in industrial and service sector is inevitable. Various sectors like transport / mobility have decided to remodel and redesign their infrastructures by implementing innovative devices and strategies. Transport / mobility sector is one of the most fast-growing industries which demands innovative solutions, however, it will be complex to derive optimal decision while one confront uncertain conditions and variables. In this paper, we develop a decision support system for technology adoption in transport / mobility division within the context of Industry 4.0 considering a case study in Spain. To find the adopted technology in this sector, several alternatives (options) and variables (criteria) should be assumed. We propose an integrated decision-making system including quality function deployment (QFD) and best-worst method (BWM) to find the importance weight of each criterion. After we apply the stratified Combined compromise solution (S-CoCoSo) to rate the alternatives and rank them under a multi-scenario perspective. The results will be analyzed through some sensitivity analysis actions. The novelty of our proposed decision support model contributes to the mobility sector and releases guidelines to managers and policy makers.

Nomenclature

QFD Quality function deployment
BWM Best-worst method
S-CoCoSo Stratified Combined compromise solution
IT Information technology
SERVQUAL SERVice QUALity
MULTIMOORA Multi-Objective Optimization by Ratio Analysis
TFNs triangular fuzzy numbers
FBWM Fuzzy best-worst method
HoQ house of quality
T/M Transport/mobility
MADM Multi attribute decision system
AHP Analytical hierarchy problem
PROMETHEE Preference ranking organization method for enrichment of evaluations
DEMATEL Decision-making trial and evaluation laboratory
SF-CoCoSo Fuzzy Combined compromise solution
GMIR Graded mean integration representation
SCM Supply chain management

1. Introduction & background

1.1. Sustainable and smart urban mobility

The concept of smart city comes from the cooperation of the information and communication technology, utilization of Internet, and other devices to direct the city operations and services. At the same time, in response to the complex and pressing challenges the concept of city associated with "circular" should be considered, as it allows for sustainable urban development [32]. While this concept is becoming more utilized and applied, the term technology advancement always is unified to smart city. Technology transformation has evolved during years in many sectors. Technologies such as robotics, Artificial Intelligence, machine learning and big data are closely linked within the innovation processes in the economy as a whole, and particularly in the industrial

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sector [8].

In addition, global changes and developments mean that the population is facing mobility and sustainability challenges, where transportation plays a key role [40]. Business owners, governments, sectors like production and manufacturing, education and other sectors became more concerned about technology acquisition, adaptation and advantage. Innovative initiatives are becoming major element of advancing society and economy growth. Bearing in mind the technologies, the concept of the smart future proposed by Streitz [80] should be taken into account, where innovation acquires special relevance helping to solve problems in an intelligent way to secure a humane environment. Governments and policy makers are planning for effective adoption of the national or global programmes to technology and its implementation to the required parts of society. Technology transfer is derived from the application of information technology (IT) facilities in directing data and offering operations in the industry and service sector to decrease the cost and waste in urban life and enhance the citizens life quality [61].

Current information technology is causing technology adoption patterns to change rapidly [76]. One of the most pertinent service sectors is transport and mobility which received extra attention during globalization and commercialization. Current technological innovations in transportation appear to be clean and sustainable, however many of them may pose a problem in relation to the global ecological balance [37]. Therefore, as cities grow and economies expand, the role of transport/mobility (T/M) is highlighted for several reasons. Policy makers and governors promote the investment in logistic infrastructure, transport equipment and technologies. For instance, in a sharing economy, the modern and sustainable transport system has impacted remarkably urban mobility in recent years [19]. Like an essential need of a society is the establishment of a dynamic and well-structured T/M system, this matter must be discussed as a top priority. A well-designed T/M system improves the mobility quality, accuracy & delivery, operation costs, the resource & energy consumption [22]. T/M facilitates easier movement of citizens, merchants, passengers and services and cause employment in wider range. Therefore, rethinking on investment in transport/mobility sector achieves a more sustainable economy and grows GDP.

When considering the role of new technologies, it is necessary to explore the different existing innovation processes, as Lee and Trimi, [51] highlighted the different types of existing evolution. From 1.0 which is considered closed innovation, 2.0 which refers to collaboration, 3.0 which considers open innovation or 4.0 which represents co-innovation. The latter is the most representative since it is in line with industry 4.0 as it allows development through the exchange of data analysis with the aid of IT [45]. Technology and intelligent systems are means that assist governments and politicians in different aspects to draw a brighter vision for the next generation based on their requirements. It is perceived that technology initiative and renovation can increase the quality of life and deliver satisfaction to the users and system owners [91].

From a transportation perspective, the following should be highlighted. Giannopoulos [30] considers how technologies affect transportation; thus, it proposes three main areas. The first is related to network management, which includes information collection systems, traffic control and management, vehicle systems and facilities, and driver assistance and fee collection systems; on the other hand, it refers to information and guidance to users, which requires applications that allow the "collection", "creation" and "provision" of data and information, and finally, the operation and management of freight transport systems, which would include information and communication systems for terminals and ports or freight tracking, among others.T/M is recognized as the most decisive strategy for a city's functionality, development and fluency and directly impresses daily life activities [38]. Traditionally transport systems focused on design, infrastructure and developing economic efficiency. However, and nowadays technology and modern devices are trying to predict community requirements not just people movement, even the value of environmental protection and social responsibility. Rather than that, an updated and adequate T/M system should build platforms to resolve complex conditions, reducing carbon emission (traffics) and enhance safety and commodity.

A sustainable transport system should support mobility needs and promote humane and ecosystem health, economic progress, and social changes [14]. Concluding the above interpretation, some studies observe at the transport as a service which should be regulated and upgraded timely to keep performance and effectiveness. For example, group of researchers have measured the transport service quality in southeast of Spain using SERVice QUALity (SERVQUAL) model with data collection of 400 respondents. Factors like personal interaction, design, physical environment were assumed [11]. The results of such studies will be applied in making decision in rural, urban, and territorial planning.

1.2. Passenger service in mobility

Customer service in transport/mobility (T/M) system is a strategic issue in urban design and planning. It is proved that service assurance continuity and control is an initial right of each advanced community and should be monitored rigorously [62]. The role of the customers is essential as, through their knowledge, they have the ability to influence decisions by responding to the specific needs and desires [83] that will condition business developments and implementations. In this way, customers will have a perception of the quality provided based on the evaluation of their performance at multiple levels, which will be combined in the final assessment. In this way, as Caro and Garcia [11] pointed out, customers may have a positive opinion of each individual dimension and subsequently obtain a negative opinion based on unfavorable overall service quality. Thus, it will be necessary to consider the real needs of individuals and society and provide differential value associated with the specific needs identified. A transportation system that is developed under customer requirements will improve society well-being and deliver safety, security and socioeconomic advantages. In T/M system, it is vital to comprehend customer (public clients) expectation and adapt the system characteristics based on that. For most frequent passengers, a timely service is a very important factor while for many others an affordable price that is offered by the legislation would be a satisfaction. Accordingly, the stakeholders and leaders should provide a platform that measure passenger requirements, quantify, and convert them to standard records [17]. Therefore, researchers and experts have dedicated during years to configure how to translate customer attitudes and connect them to the technical variables in a system like T/M. Among enormous research, QFD was released to transform customers' requirements to engineering or technical variables [96]. The role of the QFD is to realize the customer expectations quantitatively and enable decision makers to direct them to the target specifications of a product or service. QFD was addressed in various studies like logistics and supply chain, design and engineering, and marketing [4,81,97]. Utilizing QFD can permit system decision makers to detect solutions for customers attribute and increase the level of satisfaction. Rarely application of QFD was investigated in transport sector and this motivates the current study to employ that and fill the gap where customer needs must be covered by T/M system [20].

Passenger attitude toward public service has been changed. They look for best and cheapest cost for the travel that fits to their economy, however indicators like security, safety, flexibility, and punctuality complement the customer's needs. In modern communities, a public transport system should be automatized and digitalized to serve passenger's daily routines. Using new technologies, applications and devices enable customers and passengers to move faster, comfortable, and convenient. Scientists divide innovations in transportation technology into three elements as efficiency, ease, and safety [90]. Transportation industry experts agree that new technologies motivate more passengers to use public transport with less cost while the technology in other side facilitates their movement and quicker access to information. Updated innovation technologies not even benefit passengers, they accommodate transport industry in maintaining its global competitiveness [23]. New technologies and initiatives like Internet of things (IoT), automated vehicles, hyperloops and Industry 4.0. are being employed to improve existing transportation methods and offer a high-quality service [92]. In fact, industry 4.0 undertakes the information technology resources, digitalization and IoT in the industrial context. Industry 4.0 is interpreted as a framework for connecting various devices to produce value added using optimized and network databases [25,50]. The aim of such technology is to integrate data/information to harmonize operations and to enable system users to monitor process trend. T/M sector has been faced with drastic challenges caused by software and impact of new technologies, and rapid changes in shifting process to operations [53]. Industry 4.0 contributes to T/M when there are huge data volumes which should be processed along with computational power and connectivity. The complexity in this sector causes merging robotics and artificial intelligence, specific sensors, big data analytics; cloud business models; mobile applications and devices; and algorithms. This will enable us to navigate car sharing and integrate companies, logistics and passengers [29].

In terms of customer satisfaction measurement, based on a report, customers (or users of a transport systems) satisfaction attributes are categorized into three levels: core attributes which includes on-time performance, travel speed, price and service frequency; interactional attributes that contain personal and driver characteristics, and physical attributes that compose information technology, safety, ease of utilization, noise and other indicators [60]. Similar studies suggested less or same factors [27]. The novelty of our proposal is to form a global six side umbrella for customer satisfaction management, as urban mobility plan, multimodal integration, use of ICT, accessibility and agility, safety and security and environmental policy. In fact, there is no concrete study in area of transport and customer service that analyze all these variables together. In total, the variables we involved can cover other studies plus concerning environmental attention as well.

1.3. Decision-making in mobility systems

Evaluation of transport system has been studied for long time since T/M sector has always attracted academic and industrial parties. Gołda et al. [31] proposed a sustainable transport system assessment using scenario analysis and multi attribute decision system (MADM) in Poland. They utilized factors like noise, pollution production and social responsibility. In another evaluation study, Nassereddine and Eskandari, [63] unified analytical hierarchy problem (AHP) and preference ranking organization method for enrichment of evaluations (PROMETHEE) methods to prioritize Tehran city transport methods (metro, taxi, BRT, bus, and van). Márquez and Cantillo [55] in Colombia introduced a model for transport evaluation system of railways, highways and waterways under internal (operational) costs and external costs. In a different research, Cruz et al. [15] analyzed the performance of urban transportation in Portugal using Data Envelopment Analysis and indicated that efficiency can be an interesting factor to compare transport performance of distinct vehicles. To release the best integrated urban transportation system, a macro simulation software with aid of multi criteria decision analysis (ELECTRE method) was supposed under various scenarios and authors believed that the model could enhance the quality of urban planning [26]. Integrated approach of AHP, cost–benefit analysis and Dempster-Shafer theory methods were conducted to decide about transport infrastructure decisions in Taiwanese Highway Project [75]. While decision analysis tools are among the leading methods in multi variable evaluation, Martí et al. [56] indicated that DEA approach can determine an index of logistics and transport performance in the EU countries and release that higher income and modern infrastructure influence the performance. Except than above models, Research on applications of MCDM methods in evaluating T/M sector can be divided into categories, like measuring service quality, customers' and passengers' satisfaction, financial assessment, social responsibility, safety and technology management [41,98]. For instance, Yang et al. [95] developed a decision-making structure including decision-making trial and evaluation laboratory – analytical network process (DEMATEL-ANP) and goal programming techniques to indicate the best performance of transport system. The authors showed that their model help managers to assess the sustainable development of a transport infrastructure and develop the transport infrastructures selection process. In Brazil, Barbosa et al. [10] invented a model to evaluate urban public mobility. The model focuses on the user perceptions, while at the same time can capture the quantitative and qualitative assessment variables. AHP and total interpretive structural modeling under fuzzy conditions were aggregated to produce the most critical factors affecting the performance of sustainable transportation sector Pathak et al. [69]. In the literature, we rarely found the demonstration of QFD method in T/M sector. Among them Dinulescu et al. [20] explored a survey with a sample of 175 respondents to measure the quality service and customer satisfaction level. In China, to evaluate the performance of a smart bike-sharing system, a model combining QFD and Multi-Objective Optimization by Ratio Analysis (MULTIMOORA) methods was proposed. The authors used bike quality, internet service, green practices, and payment method to ask bike clients to conduct their opinion [82]. In terms of logistics, Yazdani et al. [96] integrated QFD with DEMATEL and tried to measure the performance of suppliers in green logistic and suppl chain context.

1.4. Research gaps, contributions & novelties

In any transportation service, the customer attitude must be protected and analyzed. This is an action for effective service design, development, and improvement. Customer data as we stated beforehand can be translated by QFD method and house of quality matrix into technical factors. Such data are often obtained through quantitative values for proximate computation, however, frequently uncertainty of the customer requirements should be gathered in qualitative or linguistic values because analyzers (system directors) are unable to state their judgment and opinion by numerical measures. In such situations, researchers are suggested to use fuzzy sets and fuzzy linguistics to overcome the uncertainty and lack of accurate data [93,17]. Fuzzy approach is an instrument in hand of decision analyzers to make sure the reliability of the results [13]. In this study we request experts to determine their preference by fuzzy variables considering T/M system comparison. Through above references and discussions, we carry out a decision support model that enables us to evaluate T/M methods in different scenarios. In the proposed model, an analytical and evaluation-based approach is supposed with integration of stratified and fuzzy variables. Therefore, we aim to highlight the following points:

- Choosing a method (here method is called alternative; Metro lines, bus systems, taxi services and sharing electric vehicles) involves a manner for a passenger to move from one point to his/her destination in an uncertain and risky condition. While there are various manners, why, how and where to choose them underline a complex debate for customers in transport sector.
- Integration of best-worst method (BWM) and QFD under fuzzy values and taking advantage of stratified combined compromise solution (S-CoCoSo) method. Integration of BWM-QFD generates the weights of evaluation criteria, while CoCoSo produces the ranking of alternatives.
- A case study of transport/mobility decision making problem in Spain is developed. In this context and according to deep background review there is a lack of such research that conduct and solve the complex decision problem. Through stratified approach we set several conditions, and this presumes the more specific and distinct study.

- We have explored our evaluation platform based on customer / society needs and intelligent devices (technology) which are inevitable. According to our knowledge, there is not similar research in the history of transport system yet.

In summary the proposed decision-making model insists on the following fundamental contributions:

To address such complicated decision-making problems considering customers' requirements and technical indicators as well as various scenarios, multi-criteria decision-making methods are very useful tools. MCDM methods can empower real-life managers and policymakers to address such problems with higher accuracy and reliability through soft computing approaches. In this regard, this paper develops a novel decision-making approach to analyze the implementation of industry 4.0 in mobility sector. To determine weight coefficients of customer requirements, BWM under fuzzy environment is applied where decision-makers can express their judgments and opinions in a flexible environment under uncertain conditions. Then, QFD under fuzzy environment is used to determine score of indicators using the weight coefficients of requirements. Finally, to consider impacts of various scenarios within the decision-making environment, CoCoSo method is extended under concept of the stratification, called as stratified CoCoSo (S-CoCoSo). To enhance the accuracy of the decision-making environment under uncertain conditions, the stratified CoCoSo is implemented under fuzzy environment (SF-CoCoSo). Two significant methodological contributions of this study are S-CoCoSo, and SF-CoCoSo methods which are developed for the first time in the literature. For the best of our knowledge, this study is first in its type to develop a novel decision-making approach by integrating fuzzy BWM, fuzzy QFD, and SF-CoCoSo methods. Finally, last contribution of this study is to apply the developed approach to address an industry 4.0 problem in T/M sector. Moreover, application of the above model in transport/mobility sector in Spain is a motivation and not surprisingly, this leads an initiative and novel study that brings brighter view and information to the relevant beneficial parties (governments, executives, politicians).

2. Methodology

This section presents complete information on the preliminaries of the developed approach through explaining fuzzy sets, fuzzy QFD, fuzzy BWM, and stratified CoCoSo.

2.1. Fuzzy sets

Zadeh [101] introduced concept of the fuzzy logic as an uncertain soft computing sets to handle uncertainty in problems. In this regard, triangular fuzzy numbers (TFNs) are considered as one of the initial versions of the fuzzy logic which are generally used to address different problems. Some important preliminaries of TFNs are as follows.

Definition 1- A fuzzy number is a special fuzzy set $K = (x, \mu_K(x), x \in \Re)$, where $\mu_K(x)$ is accepted as a membership function and $0 \le \mu_K(x) \le 1$.

Definition 2- A TFN can be shown as $Z = (\alpha, \beta, \gamma)$ where $\alpha \le \beta \le \gamma$. The α, β, γ represent the lower bound value, the center, and the upper bound value, respectively. The triangular membership function of Z is expressed as below.

$$\mu_K(x) = \begin{cases} 0, & x < \alpha \\ \dfrac{x-\alpha}{\beta-\alpha}, & \alpha \le x \le \beta \\ \dfrac{\gamma-x}{\gamma-\beta}, & \beta \le x \le \gamma \\ 0, & x > \gamma \end{cases} \tag{1}$$

Suppose $Z_1 = (\alpha_1, \beta_1, \gamma_1)$ and $Z_2 = (\alpha_2, \beta_2, \gamma_2)$ are two TFNs. Some important arithmetic operations are as below.

$$(\alpha_1, \beta_1, \gamma_1) + (\alpha_2, \beta_2, \gamma_2) = (\alpha_1 + \alpha_2, \beta_1 + \beta_2, \gamma_1 + \gamma_2) \tag{2}$$

$$(\alpha_1, \beta_1, \gamma_1) + (\alpha_2, \beta_2, \gamma_2) = (\alpha_1\alpha_2, \beta_1\beta_2, \gamma_1\gamma_2) \tag{3}$$

$$(\alpha_1, \beta_1, \gamma_1)/(\alpha_2, \beta_2, \gamma_2) = (\alpha_1 / u_2, \beta_1 / \beta_2, \gamma_1 / \gamma_2) \text{for } \alpha_i > 0, \beta_i > 0,\ \gamma_i > 0 \tag{4}$$

$$(\alpha_i, \beta_i, \gamma_i)^{-1} \approx \left(\frac{1}{\gamma_i}, \frac{1}{\beta_i}, \frac{1}{\alpha_i}\right) \text{ for } \alpha_i > 0, \beta_i > 0,\ \gamma_i > 0 \tag{5}$$

Definition 3- The graded mean integration representation (GMIR). Suppose $Z_j = (\alpha_j, \beta_j, \gamma_j)$ is a TFN and GMIR $R(Z_j)$ of Z_j is computed via Eq. (6).

$$R(Z_j) = \frac{\alpha_j + 4\beta_j + \gamma_j}{6} \tag{6}$$

2.2. Fuzzy best worst method (F-BWM)

For the first time, Rezaei [71] introduced the BWM to determine weight coefficients of criteria for an MCDM problem through an optimization model. Due to high applicability and reliability of BWM results, various extensions of the traditional BWM are developed in recent years. Fuzzy BWM [34], intuitionistic fuzzy BWM [59], stratified BWM [87], BWM based on Z-numbers [2], and interval-type 2 fuzzy BWM [94] are some of the well-known extensions of the BWM. Moreover, BWM attracted high attention of researchers dealing with complicated MCDM problems in different fields and industries such as waste management [86,88], air quality assessment [89], supply chain management [48], transportation management [72], industry 4.0 [58], manufacturing [24], healthcare management [3], and tourism [46].

According to its high reliability and easiness to use in real-life decision-making problems by experts, fuzzy BWM (FBWM) [34] is used to determine the optimal weight coefficients of decision criteria. Fuzzy BWM is implemented based on the following steps.

Step 1- For an MCDM problem, decision criteria are identified through literature review and team of experts. For an MCDM problem with n criteria, we have $C_1, C_2, \ldots, C_n$.

Step 2- Best criterion (most important), C_B, and worst criterion (least important), C_W, are determined based on decision-makers' opinion.

Step 3- Fuzzy pairwise comparison is performed for the best criterion. A fuzzy pairwise comparison is conducted for all included criteria. Decision-maker(s) chooses the preference of the best criterion over others using the fuzzy linguistic scale (Table 1). The comparison outcome constructs a vector, labelled as the Best-to-others vector: $\widetilde{A}_B = (\widetilde{a}_{B1}, \widetilde{a}_{B2}, \ldots, \widetilde{a}_{Bn})$ where $\widetilde{a}_{Bj}$ represents the preference of the best criterion over the criterion j. It is obvious that $\widetilde{a}_{BB} = (1,1,1)$.

Step 4- Fuzzy pairwise comparison is performed for the worst criterion. Decision-makers complete a pairwise comparison between other criteria against the worst criterion. Results construct as a vector, labelled as the other-to-worst vector: $\widetilde{A}_W = (\widetilde{a}_{1W}, \widetilde{a}_{2W}, \ldots, \widetilde{a}_{nW})$ where $\widetilde{a}_{jW}$ represents the preference of the criterion j over the criterion worst criterion W and $\widetilde{a}_{ww} = (1,1,1)$.

Step 5- The optimal weightings of criteria are determined as $(\widetilde{W}_1^*, \widetilde{W}_2^*, \ldots, \widetilde{W}_n^*)$. For each pair of $\frac{\widetilde{W}_B}{\widetilde{W}_j}$ and $\frac{\widetilde{W}_j}{\widetilde{W}_w}$ the optimal weight has to hold the

Table 1
Fuzzy linguistic scale for FBWM.

TFN	Linguistic terms
(1,1,1)	Equally important (EI)
(2/3, 1, 3/2)	Weakly important (WI)
(3/2, 2, 5/2)	Fairly important (FI)
(5/2, 3, 7/2)	Very important (VI)
(7/2, 4, 9/2)	Very important (AI)

requirement of $\frac{\widetilde{W}_B}{\widetilde{W}_j} = \widetilde{a}_{Bj}$ and $\frac{\widetilde{W}_j}{\widetilde{W}_W} = \widetilde{a}_{jW}$. To satisfy these equations, the researchers minimize the maximum absolute differences of $|\frac{\widetilde{W}_B}{\widetilde{W}_j} - \widetilde{a}_{Bj}|$ and $|\frac{\widetilde{W}_j}{\widetilde{W}_W} - \widetilde{a}_{jW}|$ for all criteria. We represent the fuzzy weight value as $\widetilde{W}_j = (\alpha_j^w, \beta_j^w, \gamma_j^w)$ to calculate weight of risk factors. However, a converted crisp value is required after obtaining fuzzy weight of criterion based on linguistic terms of decision-makers. Considering above conditions, the BWM model can be modeled based on the non-negativity characteristic and sum condition of the weights.

$$\min \max_j \left\{ \left| \frac{\widetilde{W}_B}{\widetilde{W}_j} - \widetilde{a}_{Bj} \right|, \left| \frac{\widetilde{W}_j}{\widetilde{W}_W} - \widetilde{a}_{jW} \right| \right\} \tag{7}$$

s.t:

$$\sum_j R(\widetilde{W})_j = 1$$

$$\alpha_j^w < \beta_j^w < \gamma_j^w$$

$$l_j^w \geq 0$$

for all j where $\widetilde{W}_B = (\alpha_B^w, \beta_B^w, \gamma_B^w)$, $\widetilde{W}_j = (\alpha_j^w, \beta_j^w, \gamma_j^w)$, $\widetilde{W}_W = (\alpha_W^w, \beta_W^w, \gamma_W^w)$, $\widetilde{a}_{Bj} = (\alpha_{Bj}^w, \beta_{Bj}^w, \gamma_{Bj}^w)$, and $\widetilde{a}_{JW} = (\alpha_{jW}^w, \beta_{jW}^w, \gamma_{jW}^w)$. Initial model can be reformulated as:

$$\min \widetilde{\xi} \tag{8}$$

s.t:

$$\left| \frac{\widetilde{W}_B}{\widetilde{W}_j} - \widetilde{a}_{Bj} \right| \leq \widetilde{\xi}, \textit{for all } j$$

$$\left| \frac{\widetilde{W}_j}{\widetilde{W}_W} - \widetilde{a}_{jW} \right| \leq \widetilde{\xi}$$

for all *j*

$$\sum_j R(\widetilde{W}_j) = 1$$

$$a_j^w < \beta_j^w < \gamma_j^w$$

$$\alpha_j^w \geq 0$$

for all *j* Considering $\alpha^\xi \leq \beta^\xi \leq \gamma^\xi$, we suppose that $\widetilde{\xi}^* = (k^*, k^*, k^*)$ and $k^* \leq \alpha^\xi$. Then, problem (8) can be written as problem (9).

$$\min \widetilde{\xi} \tag{9}$$

s.t:

$$\left| \frac{(\alpha_B^w, \beta_B^w, \gamma_B^w)}{(\alpha_j^w, \beta_j^w, \gamma_j^w)} - (\alpha_{Bj}^w, \beta_{Bj}^w, \gamma_{Bj}^w) \right| \leq (k^*, k^*, k^*)$$

$$\left| \frac{(\alpha_j^w, \beta_j^w, \gamma_j^w)}{(\alpha_W^w, \beta_W^w, \gamma_W^w)} - (\alpha_{jW}^w, \beta_{jW}^w, \gamma_{jW}^w) \right| \leq (k^*, k^*, k^*)$$

$$\sum_j R(\widetilde{W}_j) = 1$$

$$a_j^w < \beta_j^w < \gamma_j^w$$

$$a_j^w \geq 0$$

for all *j* To obtain consistency ratio (CR), Guo and Zhao [34] stated that ε should be divided on the value of related to the Consistency Index (CI) of $\widetilde{a}_{BW}$ (Table 2). According to Rezaei [71], CR is an important index to evaluate the preference information in pairwise comparison.

2.3. Fuzzy quality deployment function (F-QFD)

Quality function deployment (QFD) is one of the important techniques to include expectations and requirements of customers in engineering problems. The first QFD concept was formalized in Japanese companies in 1960s and then was spread to the rest of the world eventually [12,66]. In recent years, QFD has been integrated with MCDM weighting methods to empower decision-makers and managers to include importance of customer requirements within more systematic way. In this regard, QFD is combined with several methods such as analytical network process (ANP) for environmental sustainability [49, 81], analytical hierarchy process (AHP) for supply chain management (SCM) [1], BWM [33] for SCM, and DEMATEL [96] for SCM.

In this study, we adopt fuzzy QFD (F-QFD) to determine score of decision criteria considering requirements of customers under a fuzzy environment. In this manner, F-BWM is used to determine weight coefficients of the requirements and later F-QFD is used to determine the final scores based on obtained weight coefficient values. F-QFD is implemented based on the following steps.

Step 1 – QFD matrix, called as house of quality (HoQ), includes WHATs matrix, HOWs matrix, relationships between WHATs and HOWs, weight of WHATs, interrelation between HOWs, and weights of HOWs. In the first step, WHATs should be identified. WHATs indicate requirements for the decision-making problem.

Step 2 – HOWSs are identified. HOWs indicate the decision criteria for the decision-making problem.

Step 3 – HOWs matrix is constructed based on inner dependance among the HOWs.

Step 4 – Weight coefficients of the WHATs (requirements) are determined by fuzzy BWM method.

Step 5 – For each expert, relationship matrix or HoQ is completed by experts using the fuzzy linguistic scale in Table 1. This matrix aims to assign values by judging the degree of impact between WHATs and HOWs.

Step 6 – Using the fuzzy HoQ matrix and weight coefficients of the WHATs, scores of HOWs are determined by multiplication of HoQ values and corresponding weight coefficients. At the end, final fuzzy score is calculated by normalizing the score through dividing them to the total value of weights.

2.4. Stratified fuzzy combined compromise solution (SF-CoCoSo)

Combined Compromise Solution (CoCoSo) was initially developed by Yazdani et al. [100]. Since its development, CoCoSo has been used in different applications and fields such as waste management [52,84], supply chain management [21], technology [70], transportation [18, 67], industry 4.0 [35], and manufacturing [16]. Due to popularity of the CoCoSo in addressing MCDM problems, various extensions of CoCoSo have been developed recently. Fuzzy CoCoSo [70], Interval-valued neutrosophic CoCoSo [99], Pythagorean CoCoSo [16], and Single-valued neutrosophic CoCoSo [57].

In this paper, we develop a novel extension of CoCoSo under the concept of stratification [5,6,87,84] to improve its structure and to

Table 2
Estimated CI for FBWM.

Fuzzy variables	EI	WI	FI	VI	AI
$\widetilde{a}_{BW}$	(1,1,1)	(0.667,1,1.5)	(1.5,2,2.5)	(2.5,3,3.5)	(3.5,4,4.5)
CI	3.00	3.80	5.29	6.69	8.04

provide a decision-making environment based on different scenarios. This is the first study to develop an extension of CoCoSo under stratification environment. Moreover, Stratified CoCoSo method is extended based on TFNs to empower decision-makers to express their scenario-based judgments and opinions considering the uncertainty. The second contribution in this regard is to develop stratified fuzzy CoCoSo (SF-CoCoSo) method. And finally, we develop group SF-CoCoSo method for decision-making problems with group of decision-makers.

SF-CoCoSo method is applied based on the following steps.

Step 1- To provide a scenario-based decision-making environment; required scenarios are identified accordingly. Based on the *t* defined scenarios, the size of decision-making environment will be 2^t.

Step 2- Based on the defined scenarios, experts will indicate likelihood of occurrence of each scenario. Based on these scenarios, corresponding states, represented by *s*, will be generated. Probabilities for transitioning between the states are calculated. Probabilities for transitioning is shown as P^s for each state *s*.

Step 3- For each state *s*, experts are asked to construct a decision matrix based on the characteristics of each state using fuzzy linguistic scale (Table 3) according to Eq. (10).

$$X_{ij}^S = \begin{bmatrix} x_{11}^s & \cdots & x_{1n}^s \\ \vdots & \ddots & \vdots \\ x_{m1}^s & \cdots & x_{mn}^s \end{bmatrix} \text{ for } i = 1, \ldots, m \text{ and } j = 1, \ldots, n \text{ and } s = 1, \ldots, T \tag{10}$$

Step 4- For each state, decision matrix is normalized based on the nature of the criteria as equations (11–12).

$$r_{ij}{}^s = \frac{x_{ij}^s - \underset{i}{min} x_{ij}^s}{\underset{i}{max} x_{ij}^s - \underset{i}{min} x_{ij}^s} \tag{11}$$

$$r_{ij}{}^s = \frac{\underset{i}{max} x_{ij}^s - x_{ij}^s}{\underset{i}{max} x_{ij}^s - \underset{i}{min} x_{ij}^s} \tag{12}$$

where Eq. (11) is used of benefit criteria, and Eq. (12) is used for cost criteria.

Step 5- For each state, the sum of weighted comparability sequence (SW_i) and the power-weighted comparability sequences (PW_i) for each alternative are calculated based on the equations (13–14).

$$SW_i{}^s = \sum_{j=1}^{n} \left(w_j r_{ij}{}^s \right) \tag{13}$$

$$PW_i{}^s = \sum_{j=1}^{n} \left(w_j \right)^{r_{ij}{}^s} \tag{14}$$

Step 6- For each state, aggregated appraisal scores, equations (15–17), are used to calculate the relative weights of alternatives.

$$Q_1{}^s = \frac{PW_i{}^s + SW_i{}^s}{\sum_{i=1}^{m} (PW_i{}^s + SW_i{}^s)} \tag{15}$$

$$Q_2{}^s = \frac{SW_i{}^s}{\underset{i}{min} SW_i{}^s} + \frac{PW_i{}^s}{\underset{i}{min} PW_i{}^s} \tag{16}$$

$$Q_3{}^s = \frac{\lambda (SW_i{}^s) + (1-\lambda)(PW_i{}^s)}{\lambda \underset{i}{max} SW_i{}^s + (1-\lambda) \underset{i}{max} PW_i{}^s} \tag{17}$$

where $0 \leq \lambda \leq 1$ and is usually considered as 0.5 ($\lambda = 0.5$ is taken in this study).

Step 7 – For each state, appraisal value for each alternative is determined based on Eq. (18).

$$Q^s{}_i = (Q_1{}^s Q_2{}^s Q_3{}^s)^{\frac{1}{3}} + \frac{1}{3}(Q_1{}^s + Q_2{}^s + Q_3{}^s) \tag{18}$$

Step 8 – In order to obtain the final appraisal value for each alternatives considering all states, probabilities of transitioning between states are multiplied to the appraisal value in each state according to Eq. (19).

$$Q_i = \sum_{s}^{T} Q^s{}_i P^s \tag{19}$$

Step 9 – For group decision-making problems with more than one decision-maker, combined results of SF-CoCoSo is determined based on Q_i value for each decision-maker and importance coefficient, φ_d, of the decision-makers. Total of importance coefficient of decision-makers must be equal to 1 (Eq. (20)).

$$A_i = Q_{id}\varphi_d + (1 - \varphi_d) Q_{id} \tag{20}$$

where φ_d, as a positive value smaller than 1, represents importance of expert *d* and Q_{id} denotes final appraisal score of alternative *i* based on expert *d*.

3. Model implementation

3.1. The proposed model

The proposed methodology is illustrated in Fig. 1. We have conducted a three-phase decision making platform to reach the optimal solution. *Phase 1* explores the review of the history of transport mobility system evaluation and encounter research gap. How are we able to improve existing studies and add value to the body of the decision analysis in the relevant context. Setting objectives, contribution, research on the relevant studies in Spain are carried out in this phase. At the end, the main indicators, variables, and customer related technologies are explored. *Phase 2* formulates the mathematical operations, algorithms, and methods to build the decision-making model. As in Section 3 was shown, we examined the ability of QFD, BWM and stratified CoCoSo under fuzzy variables to incur a comprehensive and concrete model. Case study developed by research team; while expert's opinions and interviews, data collection and model running were the additional tasks in Phase 2. The story will end by results release, sensitivity analysis and statement of implication for T/M managers and policy makers, research limitation and future approach for practitioners (*Phase 3*).

3.2. Case study

Spain is the third biggest economy in Europe and its strategic geography surrounded by Mediterranean Sea and Pacific Ocean attracts considerable attentions in aspects like tourism, ocean and sea transport and logistic, cultural, and historical activities and commercial goals. It has become an important corridor that connects northern Africa and Latin America to other parts of the Europe and Asia [98]. In Spain, the T/M sector in urban areas is equipped by high-speed trains, inter-urban bus systems. Mobility for a city like Madrid with more than four million

Table 3
Linguistic scale for ranking evaluation.

TFN	Linguistic term
(1,1,1)	Absolutely low (AL)
(1,2,3)	Very low (VL)
(2,3,4)	Low (L)
(3,4,5)	Medium low (ML)
(4,5,6)	Equal (E)
(5,6,7)	Medium high (MH)
(6,7,8)	High (H)
(7,8,9)	Very high (VH)
(8,9,9)	Absolutely high (AH)

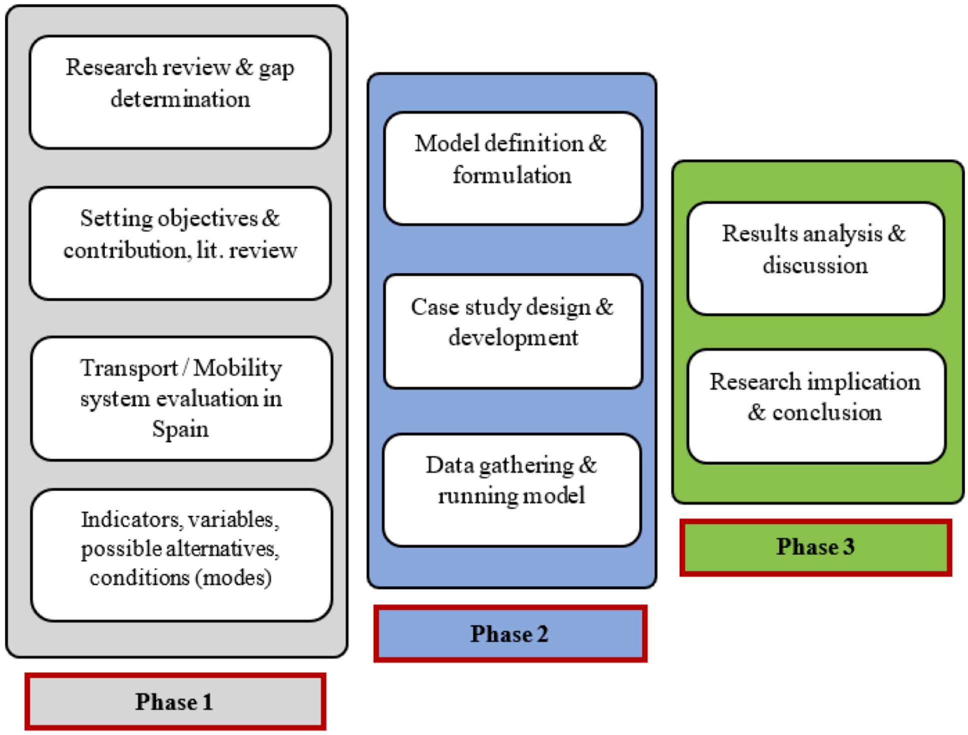

Fig. 1. The three phases decision support flow for T/M evaluation system.

of population is a quite tight and complex project. Within the city also, metro lines, taxi services and sharing cars are serving passengers. Nowadays Barcelona and Madrid are among the most important economic capitals in south and west of Europe. In addition, Spain, every year, hosts more than 80 million of tourists in target destinations like Madrid, Barcelona, Andalucía, Valencia and Asturias. Therefore, it is paramount to observe and measure its performance in terms of how it adopted high tech, service quality and advance economy of the society [68].

The case study is designed to implement a decision support model for analyzing transport mobility methods in Spain. For this decision-making system, we use several methods. The external variables (QFD what's, customer need) to meet customer needs in a smart city are the requirements from society, politicians or policy makers. In the proposed evaluation model, we have assumed six fundamental customer needs and twelve decision criteria [9,17,53,103]. It is suggested to analyze and evaluate these four alternatives as options in city transport as shown in Table 4. In our survey, we have contacted to two experts in the relevant sectors to assist in this project. *Expert 1* (male) experienced more than 18 years as senior director in transport, logistics and supply chain systems and infrastructures in public and private organizations. He incorporated in several European union projects related to sustainable transport and logistic development and some projects in national level in Andalucian and Cataluña governments. The *expert 2* (female) is the transport mobility consortium sub-director in Madrid and has experiences as project manager and coordinator in transport and mobility projects including railway systems, high speed trains and traffic control. She has a master in transport and civil engineering. More information can be found in Table 4.

3.3. Results of F-BWM

In this section, we present results of the F-BWM method on weight coefficients of customer requirements which are defined in previous section. In this regard, two experts expressed their fuzzy judgments and opinions using Table 1. As discussed in Section 3.2, most initial part of F-BWM method is to determine best and worst criteria. According to Table 5, both experts chose D_1 as the best criterion, while expert 1 (DM_1) selected D_3 and expert 2 (DM_2) chose D_4 as worst criterion, respectively (Table 6). In the next step, experts constructed best-to-others and others-to-worst vectors using the fuzzy linguistic terms in Table 1. Input data of experts for these vectors are reported in Table 5 and 6.

Using model (9) of F-BWM, input data of experts in Tables 5 and 6 are used in order to obtain optimal fuzzy weight coefficients. Results of F-BWM for both of the experts are reported in Table 7. For the ease of comparison, crisp values of fuzzy weight coefficients are also represented in Table 7. According to the results, D_1, best criterion, has the highest weight coefficient in both cases. Based on crisp values, customer requirements are ranked as $D_1 > D_2=D_5 > D_6 > D_4 > D_3$, and as $D_1 > D_3 > D_2=D_6 > D_5 > D_4$ by DM_1 and DM_2, respectively. Results show that smart urban mobility plan is the most important requirement need based on both decision-makers, while multimodal integration and public safety and security are both ranked as the second significant customer requirement by DM_1. On the other hand, information and communication technology is selected as the second important customer requirement by DM_2. However, results of DM_1 indicates that information and communication technology is the least important customer requirement.

3.4. Results of F-QFD

In the second phase of the proposed methodology, experts are asked to express their opinions on matrix of HoQ (Fig. 2) based on the characteristics of the requirements and indicators. In this figure as seen, the customer requirements (d) should be evaluated in front of each M/T indicators (c). Our expert team have delivered their comparative judgment toward HoQ. In this regard, linguistic terms in Table 1 are used to express values for HoQ by both of experts. Table 8 represent experts' judgments and opinions on HoQ matrix using fuzzy linguistic terms.

Using the fuzzy weight coefficients of requirements obtained by F-BWM method, and information in Table 8, score of indicators is calculated accordingly. For DM_1, score of indicators is calculated based on sum of multiplication of fuzzy weight coefficient of requirements with

Table 4
Alternatives, dimensions, decision criteria and experts' information.

Alternatives	criteria	Dimensions	Experts
A_1: Metro lines	Cleanness & tidy (C_1)	Smart urban mobility plan (D_1)	**Expert 1**: 46 years old, master's degree in logistics engineering, senior director in transport, logistics and supply chain systems.
A_2: Integrated Bus line systems	Affordable price (C_2)	Multimodal Integration (D_2)	**Expert 2**: 51 years old, 25 years' experience as coordinator in transport and mobility projects.
A_3: Taxi services (eco, hybrid, e-taxi)	Flexible system (C_3)	Information and communication technology (ICT) (D_3)	
A_4: sharing services (E-car, e-bike, e-scooter)	On-time service (C_4)	Accessibility & agility (D_4)	
	Updated info (C_5)	Public safety and security (D_5)	
	Smart mobile app (C_6)	Environmental policy (D_6)	
	Road quality (C_7)		
	Smart parking (C_8)		
	Smart traffic lights (C_9)		
	System capacity (C_{10})		
	Automated vehicles (C_{11})		
	CSR & Environmental protection standards (C_{12})		

Table 5
Best-to-others vectors.

DMs	Best criterion	D_1	D_2	D_3	D_4	D_5	D_6
DM_1	D_1	EI	WI	AI	FI	WI	VI
DM_2	D_1	EI	FI	WI	AI	VI	FI

EI: Equally important, WI: Weakly important, FI: Fairly important, VI: Very important, AI: Very important.

Table 6
Others-to-worst vectors.

DMs	DM_1	DM_2
Worst criterion	D_3	D_4
D_1	AI	AI
D_2	VI	FI
D_3	EI	VI
D_4	WI	EI
D_5	FI	WI
D_6	VI	FI

EI: Equally important, WI: Weakly important, FI: Fairly important, VI: Very important, AI: Very important.

fuzzy score between each pair of requirement and indicator. Complete results of F-QFD for both experts are presented in Table 9. Based on results of DM_1, C_6 and C_2 are the most important and least important indicators, respectively. On the other hand, results of DM_2 indicates that C_4 and C_8 are the most important and least important indicators, respectively.

Table 7
F-BWM results for two DMs.

Requirements	DM_1	Crisp value	DM_2	Crisp value
D_1	(0.281,0.327,0.327)	0.32	(0.277,0.277,0.277)	0.28
D_2	(0.142,0.181,0.191)	0.18	(0.092,0.173,0.173)	0.16
D_3	(0.062,0.068,0.068)	0.07	(0.138,0.242,0.277)	0.23
D_4	(0.099,0.117,0.122)	0.11	(0.069,0.069,0.069)	0.07
D_5	(0.142,0.181,0.191)	0.18	(0.069,0.104,0.138)	0.10
D_6	(0.115,0.149,0.166)	0.15	(0.092,0.173,0.173)	0.16
$\tilde{\xi}^*$	0.807		0.500	

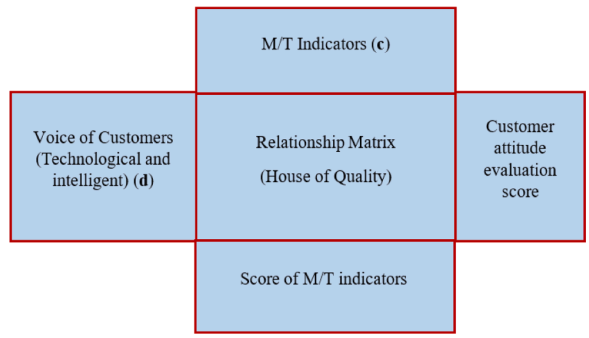

Fig. 2. Interrelationship of customer needs and M/T indicators.

Table 8
Fuzzy HoQ matrices by two DMs.

DM_1									
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
D_1	FI		VI	AI	VI	FI	WI		
D_2			WI	FI	FI	FI		FI	
D_3			WI	WI	FI	VI		WI	WI
D_4			WI	VI	FI	WI	FI		
D_5	FI	FI			EI	VI		FI	FI
D_6	WI					FI			VI
DM_2									
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
D_1	WI	FI	WI	FI	AI	FI	EI		WI
D_2				VI	WI		WI		
D_3				VI	WI	FI		EI	
D_4			WI	FI	VI	FI	FI		WI
D_5	FI	EI		VI		AI		WI	WI
D_6	FI				FI	FI	WI		AI

EI: Equally important, WI: Weakly important, FI: Fairly important, VI: Very important, AI: Very important.

Table 9
Fuzzy weight coefficients of indicators.

Indicators \DMs	DM_1	Crisp value	DM_2	Crispvalue
C_1	(0.05,0.103,0.21)	0.112	(0.03,0.074,0.163)	0.081
C_2	(0.015,0.032,0.065)	0.035	(0.034,0.058,0.113)	0.063
C_3	(0.063,0.12,0.234)	0.129	(0.016,0.031,0.071)	0.035
C_4	(0.091,0.168,0.312)	0.197	(0.089,0.2,0.399)	0.214
C_5	(0.097,0.193,0.381)	0.179	(0.1,0.184,0.354)	0.198
C_6	(0.097,0.193,0.381)	0.209	(0.077,0.172,0.356)	0.187
C_7	(0.023,0.05,0.108)	0.055	(0.035,0.068,0.132)	0.073
C_8	(0.033,0.07,0.144)	0.076	(0.013,0.031,0.066)	0.034
C_9	(0.038,0.078,0.158)	0.085	(0.042,0.101,0.205)	0.109

Table 10
Decision matrices in SF-CoCoSo by two DMs.

DM$_1$									
Alt.	C$_1$	C$_2$	C$_3$	C$_4$	C$_5$	C$_6$	C$_7$	C$_8$	C$_9$
A$_1$	ML, VH, VH, H	VL, L,L, L	ML, ML, L,E	ML, H, MH, ML	L, ML, L,E	ML, VL, VL, H	E, VH, VH, E	AL, L,L, L	ML, ML, L,E
A$_2$	MH, VH, H,H	E,L, L,H	L, ML, E,L	MH, MH, ML,L	L,E, E,ML	AL, H,H, H	ML, H,E, H	AL, L,L, E	E,E, E, MH
A$_3$	MH, H,H, MH	H, MH, H,H	L,L, L,L	L,L, L,L	MH, ML, ML, MH	AL, MH, H, AL	L,H, H,L	VL, L,E, AL	ML, MH, MH, ML
A$_4$	VL, ML, L,VH	E, ML, L,L	ML, L,H, ML	L,L, L, MH	L, MH, ML,E	ML, ML, L,H	E, MH, MH, H	AL, VL, VL, L	MH, H,E, E
DM$_2$									
Alt.	C$_1$	C$_2$	C$_3$	C$_4$	C$_5$	C$_6$	C$_7$	C$_8$	C$_9$
A$_1$	MH, ML, ML, H	H,H, MH, H	E,H, E,E	L,E, H, MH	MH, MH, H, ML	L,E, E, ML	L,H, VL, MH	E,L, L, AL	ML, H,H, E
A$_2$	L, MH, L,H	E, AL, L, MH	H,L, ML, L	L, AL, MH, E	E, ML, H,H	ML, H,L, E	E, MH, L,H	L, ML, VL, L	H,E, ML, VH
A$_3$	H,E, H,E	H,H, ML, L	MH, H, MH, H	ML, L,E, ML	ML, E,L, H	H,H, MH, E	H,L, ML, L	E,L, L,L	H,L, E,H
A$_4$	MH, VH, MH, MH	H,H, H, ML	L,L, MH, ML	L,H, E,E	MH, ML, ML, ML	AL, ML, L,H	L,E, MH, H	AL, L, AL, VL	ML, E,E, MH

3.5. Results of SF-CoCoSo

Most important and initial step in SF-CoCoSo method is to define scenarios for the decision-making environment. In this regard, both experts agreed on the two major scenarios for implementation of industry 4.0 in mobility sector of Spain. In this regard, experts define one scenario for the situation that implementation of industry 4.0 is only focused on mobility sector of the Madrid. In the same way, experts define one scenario for the situation that implementation of industry 4.0 is only focused on mobility sector of the Barcelona. According to the concept of stratification, four states are generated based on the defined two scenarios. First state (S_1) is that decision-making problem is considered for whole Spain rather than only Madrid and Barcelona. State 2 (S_2) denotes that the scenario for Madrid is considered, while state 3 (S_3) indicates that the scenario for Barcelona happens. Finally, state 4 (S_4) indicate a scenario where decision-making is exclusively considered for only Madrid and Barcelona at the same time. DM$_1$ estimated likelihood of scenario for Madrid, and scenario for Barcelona as 65% and 55%, respectively. Likelihood of scenario that decision-making is focused on the whole Spain rather than exclusively for Madrid and Barcelona is 30%. We consider the probability of the state occurring based on the lowest provided likelihood. For example, the probability of state 1 is represented by P_1. The probability of other states is $6.5P_1$, $5.5P_1$, and $35.75{P_1}^2$. In the same way, DM$_2$ estimated likelihood of scenario for Madrid, and scenario for Barcelona as 50% and 45%, respectively. Likelihood of scenario that decision-making is focused on the whole Spain rather than exclusively for Madrid and Barcelona is 20%. The probability of other states based on DM$_2$' s opinion is $5P_1$, $4.5P_1$, and $22.5{P_1}^2$.

According to likelihood of occurrence of DM$_1$, probability of P_1 is calculated as follows.

$$35.75{P_1}^2 + 14P_1 = 1$$

$P_1 = 0.0617$; therefore, as likelihood of occurrence of state 1 was 30%, the probability of state 1 is 0.185. The probability of state 2, 3, and 4 is 0.401, 0.339, and 0.136, respectively. Similarly, according to likelihood of occurrence of DM$_2$, probability of P_1 is calculated as follows.

$$22.5{P_1}^2 + 11.5P_1 = 1$$

$P_1 = 0.0757$; thus, as likelihood of occurrence of state 1 was 20%, the probability of state 1 is 0.151. The probability of state 2, 3, and 4 is 0.379, 0.341, and 0.129, respectively.

In this regard, SF-CoCoSo method is constructed based on four different states. Each expert provides decision matrices based on goals and characteristics of each state. In order to construct the decision matrices, linguistic terms in Table 3 are used. Table 10 presents the whole decision matrices of both DM$_1$ and DM$_2$. For the ease of understanding, Table 10 is explained considering the example of A$_1$ against C$_1$. Four linguistic terms are included for evaluation of alternative A$_1$ against indicator C$_1$ which show evaluation scores for state 1, 2, 3, and 4, respectively.

Based on the steps of the SF-CoCoSo method in Section 3.4, results of each state are reported in Table A1-A4 in Appendix A. Each Table in Appendix A include fuzzy results of SF-CoCoSo for important components of the SF-CoCoSo in terms of SW_i^s, PW_i^s, $Q_1{}^s$, $Q_2{}^s$, $Q_3{}^s$, and $Q_i{}^s$. Defuzzified results of the SF-CoCoSo four all states are reported in Table 11 (columns 2–7 for DM$_1$, and columns 9–14 for DM$_2$). Corresponding Q_i values are calculated based on the probabilities of states multiplied by ${Q_i}^1$, ${Q_i}^2$, ${Q_i}^3$, ${Q_i}^4$ for both experts. According to the results presented in Table 12, SF-CoCoSo provides A$_2$ > A$_1$ > A$_4$ > A$_3$ ranking order based on DM$_1$, and A$_1$ > A$_3$ > A$_2$ > A$_4$ ranking order based on DM$_2$. In order generate a combined solution based on results of both experts, Eq. (20) is used to determine the final score A_i based on equal importance of the experts ($\varphi_1 = \varphi_2 = 0.5$). Table 12 shows the final results where A$_2$ (integrated bus line system) is selected as the best alternative, followed by A$_1$ (metro lines) as second, A$_3$ (taxi services) as third, and A$_4$ (sharing e-vehicles) as fourth alternative.

3.6. Sensitivity analysis: impact of experts

Results in Table 12 are based on equal importance of DMs. To analyze how the importance of DM$_s$ could affect the results, a sensitivity test is conducted on φ_1 value (impact of DM$_1$).

For this purpose, 11 cases are defined for φ_1 values which starts with 0 and increase with 0.1 interval to the 1. As the φ_1 value increases, the value of φ_2 decreases. Major changes in ranking order of the alternatives are where $\varphi_1 < 0.5$, we observe that A$_1$ is selected as the top alternative in all cases. In addition, A$_2$ and A$_3$ are experiencing quite slight changes as well. As $\varphi_1 > 0.4$, we observe that A$_2$ is selected as the best alternative and A$_1$ is selected as the second top alternative in the rest of cases. This shows that as importance of DM$_1$ increases, ranking in first place changes. This change denotes the fact that DM$_2$ has higher impact in making A$_1$ as first alternative. So, as importance of DM$_2$ decreases, A$_2$ replaces A$_1$ in the first place. Another noticeable change is related to A$_4$ which turns to be the third alternative and A$_3$ drops to fourth place as $\varphi_1 \geq 0.7$. All changes are elaborately shown in Fig. 3.

3.7. Comparative analysis

This study developed a novel extension of CoCoSo using concept of stratification under fuzzy environment. As concept of stratification works as a tool to consider uncertainty in decision-making problems under different circumstances and scenarios, there exists two different ways to handle the ranking process. Asadabadi [5] proposed stratified MCDM (SMCDM) where the initial decision matrix was constructed based on integration of criteria values in all states. Then, the new decision matrix was taken forward to get the weighted decision matrix and

Table 11
Decision matrices in SF-CoCoSo by two DMs.

DM_1 Alt.	Q_i^1	Q_i^2	Q_i^3	Q_i^4	Q_i	Rank	DM_2 Alt.	Q_i^1	Q_i^2	Q_i^3	Q_i^4	Q_i	Rank
A_1	3.035	3.052	2.374	4.114	3.151	2	A_1	2.697	3.611	4.618	2.317	3.647	1
A_2	2.300	4.388	3.787	2.590	3.823	1	A_2	3.595	3.200	2.685	4.455	3.245	3
A_3	1.770	2.334	2.971	0.645	2.359	4	A_3	4.354	2.695	3.667	3.283	3.352	2
A_4	2.680	1.914	2.469	4.455	2.708	3	A_4	1.322	2.409	2.314	4.026	2.419	4

Table 12
Final results of SF-CoCoSo.

Alternative	Q_i (DM_1)	Q_i (DM_2)	A_i	Rank
A_1	3.151	3.647	3.399	2
A_2	3.823	3.245	3.534	1
A_3	2.359	3.352	2.856	3
A_4	2.708	2.419	2.564	4

to prioritize the alternatives accordingly. In context of a MCDM ranking method, this would mean to integrate all decision matrices based on transitioning probabilities at the first stage. There is also another way of addressing a MCDM ranking problem where decision matrices in all states can be considered separately; then, final results of MCDM ranking method can be merged considering transitioning probabilities. However, as this study is addressing a multi-scenario decision-making problem, decision matrices for each state were used separately in CoCoSo method to decrease the possible biasedness of results due to initial integration. Using this technique, final results of CoCoSo method in all states were combined to generate a final single solution.

To analyze possible effects on both of integration techniques, a comparative analysis is conducted to compare the results of currently developed SF-CoCoSo method with another form of SF-CoCoSo where decision matrices were combined using transitioning probabilities. In this regard, the initial decision matrix values will be calculated as equation (21).

$$x_{ij} = \sum_{s=1}^{T} x_{ij}^{s} P^{s} \text{ for } i = 1, \ldots, m \text{ and } j = 1, \ldots, n \tag{21}$$

Similar to Eq. (20),a weighting operator is used later to combine the initial decision matrices of both decision-makers into a single decision matrix. Later, fuzzy CoCoSo will be applied to determine the ranking order of alternatives.

Fig. 4 presents the ranking order of alternatives using the proposed SF-CoCoSo and SF-CoCoSo based on the equation (21).

Results of comparative analysis between two versions of SF-CoCoSo methods indicates that there are not any differences in ranking order of alternatives. Thus, there is a full consistency between results of both versions. Although the second version, using the equation (21), reduces the computational size, there is always possibility of obtaining different results for decision-making problems such as scenario analysis where input data may have critical effects on the computational process. On the other hand, the proposed version of SF-CoCoSo empowers decision-makers in understanding what happens in each state separately as it may be of high importance for stakeholders for decision-making and managerial purposes. However, SF-CoCoSo using equation (21) makes it

Table A1
Results of SF-CoCoSo for state 1 based on two experts.

DMs		A1	A2	A3	A4
DM1	SW_i^1	(0.209,0.508,1.388)	(0.19,0.366,0.707)	(0.151,0.342,0.954)	(0.179,0.453,1.289)
	PW_i^1	(5.322,5.747,5.928)	(4.766,4.885,4.944)	(2.854,3,3.036)	(4.71,4.971,5.056)
	Q_1^1	(0.237,0.309,0.398)	(0.213,0.259,0.307)	(0.129,0.165,0.217)	(0.21,0.268,0.345)
	Q_2^1	(2.049,3.402,11.251)	(1.838,2.697,6.409)	(1.154,2,7.369)	(1.804,2.983,10.293)
	Q_3^1	(0.756,1,1.323)	(0.677,0.839,1.022)	(0.411,0.534,0.721)	(0.668,0.867,1.147)
	Q_i^1	(1.73,2.587,6.133)	(1.552,2.102,3.842)	(0.958,1.46,3.818)	(1.526,2.257,5.526)
DM2	SW_i^1	(0.149,0.343,0.835)	(0.184,0.418,0.983)	(0.271,0.668,1.56)	(0.123,0.24,0.476)
	PW_i^1	(4.373,4.786,4.948)	(6.234,6.701,6.892)	(6.834,6.991,7.028)	(1.954,1.979,1.991)
	Q_1^1	(0.183,0.232,0.287)	(0.26,0.322,0.391)	(0.287,0.346,0.427)	(0.084,0.1,0.123)
	Q_2^1	(2.51,3.85,9.342)	(3.518,5.13,11.544)	(4.001,6.321,16.323)	(1.239,2,4.9)
	Q_3^1	(0.527,0.67,0.814)	(0.747,0.929,1.108)	(0.827,1,1.209)	(0.242,0.29,0.347)
	Q_i^1	(1.696,2.426,4.779)	(2.389,3.28,6.059)	(2.689,3.854,8.021)	(0.815,1.184,2.383)

Table A2
Results of SF-CoCoSo for state 2 based on two experts.

DMs		A1	A2	A3	A4
DM1	SW_i^2	(0.288,0.561,1.099)	(0.404,0.793,1.551)	(0.184,0.379,0.766)	(0.177,0.345,0.666)
	PW_i^2	(6,6,6)	(8.481,8.722,8.853)	(4.725,4.863,4.933)	(3.679,3.825,3.909)
	Q_1^2	(0.27,0.324,0.386)	(0.381,0.469,0.566)	(0.211,0.259,0.31)	(0.165,0.206,0.249)
	Q_2^2	(2.383,3.64,9.369)	(3.365,5.226,13.352)	(1.816,2.731,6.795)	(1.462,2.283,5.771)
	Q_3^2	(0.859,1.049,1.283)	(1.215,1.521,1.881)	(0.671,0.838,1.03)	(0.527,0.667,0.827)
	Q_i^2	(1.991,2.744,5.348)	(2.813,3.957,7.689)	(1.535,2.116,4.007)	(1.222,1.731,3.341)
DM2	SW_i^2	(0.257,0.574,1.279)	(0.177,0.399,0.864)	(0.164,0.38,0.884)	(0.132,0.358,0.889)
	PW_i^2	(5.39,5.75,5.918)	(5.686,5.863,5.952)	(4.041,4.586,4.848)	(3.654,3.886,3.978)
	Q_1^2	(0.228,0.286,0.358)	(0.237,0.283,0.339)	(0.17,0.224,0.285)	(0.153,0.192,0.242)
	Q_2^2	(3.247,5.303,13.461)	(3.227,4.629,10.09)	(2.373,3.903,9.688)	(2.112,3.457,9.29)
	Q_3^2	(0.657,0.826,1.013)	(0.683,0.818,0.959)	(0.49,0.648,0.807)	(0.441,0.554,0.685)
	Q_i^2	(2.165,3.216,6.64)	(2.188,2.933,5.282)	(1.594,2.42,4.899)	(1.424,2.117,4.56)

Table A3
Results of SF-CoCoSo for state 3 based on two experts.

DMs		A1	A2	A3	A4
DM1	SW_i^3	(0.203,0.394,0.769)	(0.344,0.673,1.309)	(0.268,0.542,1.08)	(0.176,0.343,0.673)
	PW_i^3	(4.854,4.926,4.965)	(7.286,7.608,7.788)	(5.717,5.847,5.919)	(5.173,5.538,5.754)
	${Q_1}^3$	(0.217,0.262,0.312)	(0.327,0.409,0.495)	(0.257,0.315,0.381)	(0.23,0.29,0.35)
	${Q_2}^3$	(1.885,2.795,6.826)	(2.886,4.506,11.384)	(2.261,3.533,9.212)	(1.952,2.849,6.462)
	${Q_3}^3$	(0.691,0.851,1.037)	(1.043,1.324,1.645)	(0.818,1.021,1.265)	(0.731,0.94,1.162)
	${Q_i}^3$	(1.587,2.157,4.027)	(2.414,3.425,6.608)	(1.892,2.667,5.263)	(1.66,2.279,4.038)
DM2	SW_i^3	(0.311,0.679,1.497)	(0.187,0.375,0.831)	(0.185,0.418,1.007)	(0.113,0.233,0.482)
	PW_i^3	(7.401,7.737,7.886)	(3.591,4.76,4.902)	(6.609,6.832,6.935)	(4.365,4.648,4.817)
	${Q_1}^3$	(0.312,0.38,0.466)	(0.153,0.232,0.285)	(0.275,0.328,0.395)	(0.181,0.221,0.263)
	${Q_2}^3$	(4.369,6.744,16.249)	(2.197,3.969,9.289)	(3.707,5.199,11.763)	(2.429,3.323,6.394)
	${Q_3}^3$	(0.898,1.099,1.321)	(0.44,0.67,0.807)	(0.791,0.947,1.118)	(0.521,0.637,0.746)
	${Q_i}^3$	(2.929,4.154,8.167)	(1.459,2.476,4.748)	(2.521,3.331,6.157)	(1.656,2.17,3.546)

Table A4
Results of SF-CoCoSo for state 4 based on two experts.

DMs		A1	A2	A3	A4
DM1	SW_i^4	(0.289,0.642,1.484)	(0.175,0.443,1.145)	(0.091,0.168,0.312)	(0.363,0.782,1.751)
	PW_i^4	(7.857,8.503,8.788)	(4.673,4.931,5.016)	(1,1,1)	(8.225,8.71,8.903)
	${Q_1}^4$	(0.35,0.451,0.559)	(0.208,0.265,0.335)	(0.047,0.058,0.071)	(0.369,0.468,0.58)
	${Q_2}^4$	(2.996,4.711,12.887)	(1.786,2.94,9.329)	(0.458,0.825,2.411)	(3.222,5.191,14.696)
	${Q_3}^4$	(1.114,1.462,1.857)	(0.663,0.859,1.114)	(0.149,0.187,0.237)	(1.174,1.518,1.926)
	${Q_i}^4$	(2.539,3.667,7.474)	(1.512,2.229,5.109)	(0.365,0.564,1.251)	(2.705,3.937,8.275)
DM2	SW_i^4	(0.153,0.339,0.696)	(0.29,0.629,1.398)	(0.208,0.429,0.991)	(0.215,0.477,1.072)
	PW_i^4	(3.915,3.96,3.979)	(7.22,7.621,7.827)	(5.526,5.788,5.916)	(6.325,7.636,7.852)
	${Q_1}^4$	(0.165,0.194,0.232)	(0.304,0.373,0.458)	(0.232,0.281,0.343)	(0.265,0.367,0.443)
	${Q_2}^4$	(2.287,3.418,7.711)	(4.235,6.478,15.41)	(3.213,4.715,11.113)	(3.628,5.849,12.761)
	${Q_3}^4$	(0.474,0.561,0.658)	(0.874,1.077,1.299)	(0.668,0.812,0.972)	(0.761,1.059,1.256)
	${Q_i}^4$	(1.538,2.111,3.923)	(2.845,4.018,7.816)	(2.163,2.96,5.691)	(2.452,3.74,6.743)

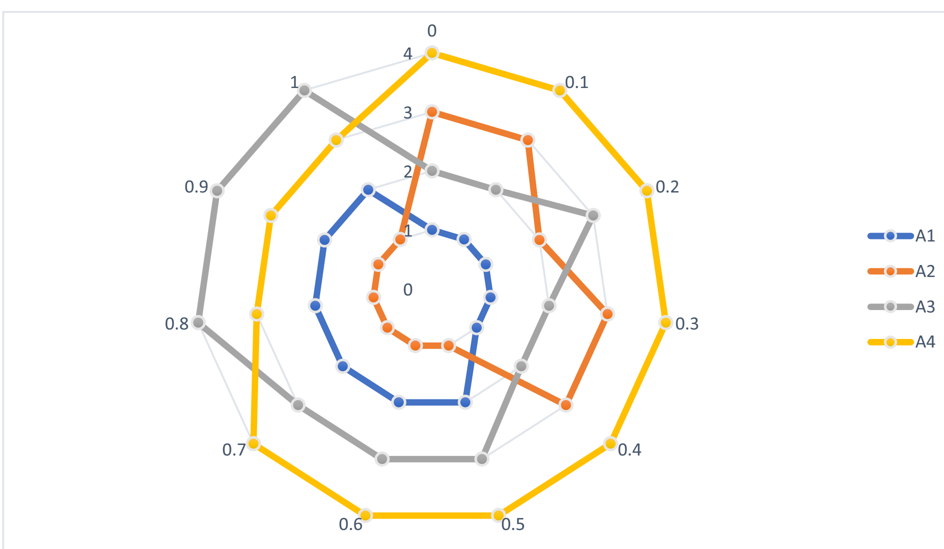

Fig. 3. Sensitivity analysis on impacts of DMs on final results.

impossible to analyze the results of each state differently as it integrates all initial decision matrices and then solve only one ranking problem. Both versions have some advantages and disadvantages; thus, in future studies, preferred version of the SF-CoCoSo can be adopted based on the problem definition and goals as well as complexity of data collection process.

4. Discussion

Analyzing the variables considered in the research; it is necessary to note that in the F-BWM smart urban mobility plan model (D_1) is the best criterion. This infers that for majority of the community and in high level authority, development and maintaining a long term and up-to-date mobility program should be top priority. In addition, the influence that smart cities have is linked to the implementation of several beneficial changes in the functioning of the dynamics of the city [65]. In turn,

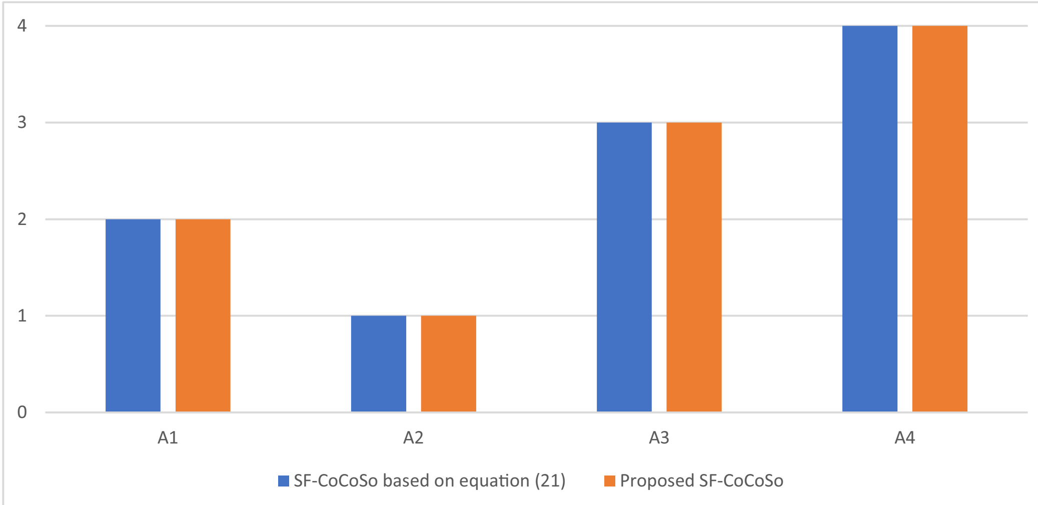

Fig. 4. Comparative analysis.

the results of F-QFD have shown in a matrix that integrates the requirements of consumers when considering mobility aspects. In this way, their opinion and technology are relevant in the selection of T/M indicators. Urban planners have tools at their disposal to analyze the smartness of cities which enables them to move towards smart urbanism [28]. The innovative concept of a smart city is the result of the complexity of the changing environment and its impact on the urban environment, as well as the challenges arising in terms of mobility, population, the natural environment, and other social aspects [64]. Thus, it becomes relevant to address the influence of the environment.

Buses in Spain specifically in Madrid and Barcelona (the most crowded) cities are examples of an intelligent and under control systems. All buses are connected to the main commander and a smart platform that directs them by GPS and satellites. Buses are equipped with free Internet service, plugs for charging mobile phones, and specific spaces for pregnant and old people. There are two monitors that inform passengers with the next station, distance and time needed to reach. Such service enables passengers to find the better route and handle the destination by other connected lines available. Most buses are working with hybrid system and recently many lines are serviced by electric and zero emission busses and till 2025 this quantity will be enhanced exponentially. The second preferred alternative in our list is metro system. Madrid's metro is the second-longest in Europe and the sixth-longest in the world. Madrid currently has 12 metro lines and three light rail lines (LIGERO). The metro service is offered at cheapest price (for more than 15 years) by 1.5€ (this price for passengers less than 26 years is 23€ /monthly and for older than 65 years old less than 5€/month). It must be mentioned that all the buses are equipped by air-condition system. Metro lines are connected easily to the high-speed train stations and airport terminals. Its interior always is designed by short stories, poems, and historical biographies for passengers. There are advantages that makes customers choose this service, the service is available 19 h every day and nonstop. Weekends and special days, there are plenty possibilities to taking bikes and carrying animals in the metro as well. All in all, it is implied that the selected alternative in both gran cities of Barcelona and Madrid proves our decision results.

5. Conclusions

Various decision-making techniques are unified to resolve the real-world problems. Combined and extended decision support system looks for various methods to overcome complex conditions and difficulties exist in real world context. Current research dedicates to build a platform for evaluation of T/M system in specific and determined conditions (modes). The study was implemented in Spain and for T/M evaluation system distinct solutions (alternatives) were reflected. These alternatives should be compared under different objectives (criteria) and experts participated to deliver us their comparative judgement and preferences under uncertainty. Uncertainty means when decision making problem does not access to enough data or accurate quantitative values. In this case, fuzzy measures aid decision experts to handle it. In this study, an integrated decision analysis model is presented. This model utilizes best worst method and quality function deployment to conquer the customer requirements and determine the essential criteria for T/M evaluation. Ultimately, stratified and fuzzy CoCoSo method validates the ranking of each alternative.

Nowadays, urban mobility has an important role in the ecosystems of each complex smart city [54]. The research presented in this paper provides an empirical evidence of different dimensions that support the adaptation of technology to the mobility sector. The results contribute to the mobility sector and give guidelines to managers and policy makers. More on that, it is necessary to consider the relative importance of consumer or individual satisfaction aspects in the evaluation processes. However, this work has some limitations. We could not contact face to face to the experts due to COVID regulations although online meetings were held. The presented decision model is recommended to be tested in other case studies, so that the solutions and inputs obtained can be replicated and scaled. In addition, this model could incorporate other variables and parameters such as energy or other innovative technologies. In turn, relationships and considerations could be generated through government policies. Therefore, we can consider the limitations of this research as the starting point for further scientific work.

This study can be extended in various future studies in different directions. As pointed out by Lee and Trimi, [51], innovation should contribute to the creation of an intelligent future in which people obtain a better quality of life. Thus, it becomes relevant to consider their opinions in terms of requirements and needs in mobility. Most possible direction is to adopt the proposed decision-making approach and apply it for other industry 4.0 problems in different fields and industries. In the same way, the proposed approach can be used to address scenario-based MCDM problems in other fields such as supply chain management, waste management, environmental & energy planning, sustainability, circular economy, COVID-19, and many other engineering and decision-making problems. In terms of methodology, one may use different weighting MCDM method such as analytical hierarchy process (AHP) [73], analytical network process (ANP) [74], stepwise weight assessment ratio analysis (SWARA) [42], base-criterion method (BCM) [36], and others. One major direction for future studies would be integration of concept of stratification with other MCDM ranking methods such as measurement of alternatives and ranking according to compromise solution (MARCOS) [79], evaluation based on distance from average solution (EDAS) [43], mulTi-noRmalization mUlti-distance aSsessmenT (TRUST) [85], technique for order of preference by similarity to ideal solution (TOPSIS) [39], combinative distance-based assessment (CODAS) [44], and others. Another important direction for future study is to extend the proposed approach under other advanced fuzzy sets such as intuitionistic fuzzy sets [7], neutrosophic sets [77,78], Z-numbers [102], and spherical fuzzy sets [47].

CRediT authorship contribution statement

Ali Ebadi Torkayesh: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Morteza Yazdani:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Domingo Ribeiro-Soriano:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

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

Data availability

The data that has been used is confidential.

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