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Measuring the customer satisfaction of public transportation in Tehran during the COVID-19 pandemic using MCDM techniques

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ABSTRACT

The expeditiously spreading of coronavirus disease 2019 (COVID-19) has affected every facet of human lives, including transportation. Due to some characteristics of COVID-19, like high infectivity, people prefer to use their private cars more than before. On the one hand, this circumstance caused public transportation to face an unprecedented decrease in demand and, consequently, revenue. On the other hand, it could intensify traffic congestion during rush hours. This study provides a computational framework to assess public transportation's customer satisfaction in Tehran during the COVID-19 pandemic. To this end, a combined multi-criteria decision-making (MCDM) approach based on the best-worst method (BWM) and fuzzy technique for order performance by similarity to ideal solution (fuzzy TOPSIS) is introduced, which benefits from all the advantages of BWM and fuzzy TOPSIS procedure and consequently provides consistent and reliable outcomes. Outcomes of the implemented model provide precious insight for improving service quality during and after the pandemic; for example, it reveals the performance of each transport mode about each criterion which can help policymakers and transit agencies to allocate resources more intelligently. Final results indicate that during the pandemic, taxis had a better performance compared to other transportation modes.

1. Introduction

The emergence of coronavirus disease 2019 (COVID-19) and its different variants have deeply affected human life. Some of these impacts resulted from governmental countermeasures against pandemic and others from the people themselves to reduce the risk of contamination. Public transportation is one of the sectors that has experienced the harshest changes during this period (Aparicio et al. (2021); Jenelius and Cebecauer, 2020; Tirachini and Cats, 2020). High infectivity of COVID-19 and some of the characteristics of public transportation like limited space and high passenger density, especially in rush hours, have increased the risk of contamination in public transportation and declined demand for it.

Iran is one of the highly-affected countries by COVID-19, and its capital Tehran has been a COVID-19 hot spot since December 2019 (Arab-Mazar et al., 2020). Tehran with more than 9.4 million in the city (The municipality of Tehran, 2019) and 15 million in its metropolitan area is the most populous city of Iran (Statistical Center of Iran (2019)). Over the past five decades, Tehran’s population has grown, partly due to the surging birthrate and increasing migration rate, but also because of being the largest economic center in the country. Despite population growth, Tehran’s infrastructure and especially transportation system has not developed adequately, making Tehran one of the most congested and polluted cities in the region. Tehran’s principal public transport modes are taxis, vans, metro, which is an underground electric railway system, buses, and bus rapid transits (BRT). It should be stated that taxis are usually shared between four passengers, and they are a part of public transportation in Iran. According to statistics, 19.3 million trips are made daily in Tehran, and approximately half of them are made by public transportation systems (The municipality of Tehran, 2019).

The traffic congestion in Tehran has been turned into a formidable challenge for policymakers and the municipality. This situation has deteriorated after COVID-19 outbreaks as people prefer to use their private cars more to minimize the risk of contamination in public transportation. On one hand, this contemporary phenomenon caused an unexpected decrease in demand and consequently revenue of the public...
transportation sector, and on the other hand, it could exacerbate the traffic congestion in rush hours. Moreover, there is a risk that this behavior becomes a habit, and this irreplaceable sector is perceived as unhealthy, even after the pandemic.

The first step to overcome the mentioned complex situation is performance measurement of public transportation because it is essential for monitoring, comparing performance over time, and continuously improving the transportation system. Efficiency, effectiveness, productivity, and service quality are fundamental parts to measure the performance of transportation systems. However, efficiency, effectiveness, and productivity are the performance measures from the transit agency viewpoint (Eboli and Mazzulla, 2011), while many academicians consider the customer’s viewpoint as the most significant element for assessing transportation systems performance; for instance, Berry et al. (1990) mentioned that “customers are the sole judge of service quality.” Service quality is a comparison between customer expectations of service and his/her perceptions (Eboli and Mazzulla, 2011). Measuring customer satisfaction could help policymakers optimally allocate resources and improve service quality in public transportation. Therefore, this study provides a framework to evaluate the customer satisfaction of public transportation systems in Tehran throughout the COVID-19 pandemic. For this aim, a hybrid multi-criteria decision-making method integrating BWM and fuzzy TOPSIS is introduced. This study’s first intention is to identify and prioritize the most prominent criteria of the evaluation process. Literature review, Delphi method, and panel discussion were used to identify the criteria. Further, the BWM method was applied to determine the priority of each criterion. The second intention of the present research is to evaluate and prioritize public transportation systems in Tehran during the COVID-19 pandemic. For this purpose, 392 online questionnaires were filled by current passengers and potential users of the public transportation system. A combination of fuzzy concept and the TOPSIS method was utilized to deal with the uncertainty of respondents’ thoughts.

Main advantages of this study can be summarized as follows: (i) this is the first research work that addresses the problem of measuring customer satisfaction of public transportation during the COVID-19 pandemic. (ii) customer satisfaction assessment of public transportation systems during the pandemic may provide precious insight for improving the service quality during and after the pandemic and helps policymakers and transit agencies restore public transportation systems’ ability to fulfill their social role. (iii) former studies in the field of measuring the customer satisfaction level in Tehran like Ebrahimii and Bridgelall (2020) and Nassereddine and Eskandari (2017) considered narrow criteria for the assessment, while in our study, the decision team has taken a closer look at the topic for selecting and finalizing criteria based on a comprehensive literature review, Delphi method, and hours of panel discussion with the decision team (iv) some of the criteria can affect contagion, so after evaluation, it can be seen which transport mode meets which criteria better. (v) there is some research that used BWM and fuzzy TOPSIS concurrently, but to the extent of our knowledge, there is no research to assess public transportation systems using a model integrating BWM and fuzzy TOPSIS.

The remainder of this paper is organized as follows: Section 2 provides a review of the related literature. A new methodology based on the BWM and fuzzy TOPSIS methods is explained in Section 3. Section 4 presents an application of the introduced methodology. Ultimately, conclusions are presented in the Section 5.

2. Literature review

This section is dedicated to a literature review of the application of Multi-Criteria Decision-Making (MCDM) procedures in transportation, and the use of the mentioned methods in the assessment of customer satisfaction in public transportation.

MCDM is a methodological approach for structuring, analyzing, and finding the solution to complicated decision problems (Kahraman, 2008). MCDM procedures are powerful tools that can be used in various fields. Behzad et al. (2020) utilized MCDM to evaluate waste management performance in the Nordic countries, Mousavi-Nasab and Sotoudeh-Anvari (2017) for solving the material selection problem, and Ahmadinejad et al. (2021) to prioritize the factors that inhibit COVID-19 transmission.

In the transportation area, every decision should be based on numerous criteria associated with environmental, economic, and socio-political features (Camargo Pérez et al., 2014). Thus, MCDM has turned into one of the vital procedures employed by academicians and practitioners for evaluating and decision making in the transportation section (Awasthi et al., 2011b; Camargo Pérez et al., 2014; Tsamboulas et al., 1999). Awasthi et al. (2018) applied three different MCDM techniques to evaluate the sustainability of urban mobility projects. In the first step of their proposed methodology, the criteria for evaluation were selected by experts. In the next step, the criteria were evaluated using linguistic scales, and in the final step, three sustainable mobility projects in the city of Luxembourg were assessed. The results of this study yielded that the implementation of a new tramway has priority over other projects. Kabak et al. (2018) used a hybrid MCDM approach, including analytical hierarchy process (AHP) and multi-objective optimization by ratio analysis (MOORA), to assess the status of bike-share stations. They determined the criteria using a literature review and expert opinion. Further, the authors applied AHP to obtain criteria weights and MOORA to assess the alternatives of bike-sharing stations. Recently Sobhani et al. (2020) evaluated the competitiveness and sustainability of the unconventional modes of transport (UMT) in Dhaka, Bangladesh. They used a novel framework which integrated AHP, and TOPSIS method.

There is a considerable amount of research studies that have worked on the problem of assessing customer satisfaction of public transportation systems. In the following, a short review will be presented of papers that deal with the problem of evaluating customer satisfaction in the public transportation system and the application of MCDM methods in the mentioned problem.

Eboli and Mazzulla (2011) offered a methodological framework to assess service quality for transportation systems. The proposed framework is considered both customer’s and transit agencies’ point of view. Celik et al. (2013) presented a mathematical framework for evaluating customer satisfaction in the public transportation section in Istanbul. They used a combination of statistical analysis, survey study, and MCDM techniques in their research. Their suggested MCDM method integrated the gray relational analysis (GRA), TOPSIS, and type-2 fuzzy sets. Aydin et al. (2015) provided a framework to assess the rail transit systems of Istanbul. The used framework combined statistical analysis, fuzzy AHP method, and Choquet integral to evaluate rail transit lines’ performance. Mardanip et al. (2016) reviewed a number of papers about the application of MCDM methods in transportation systems. They concluded that AHP, as a singular technique, and hybrid MCDM, as an integrated approach, are the most prevalent techniques. Efthymiou and Antoniou (2017) explored the impact of the financial crisis in Greece on bus customer’s satisfaction and demand. They compared the importance of factors and users’ satisfaction level between 2008 and 2013 and 2013–2017. The comparison of results showed some changes in the preferences of the respondents. The importance of some factors like on-time performance and waiting time were decreased, while the importance of the information provision criterion was increased. Also, the usage of public transportation during these years has increased. Coppola and Silvestri (2018) introduced a methodology to evaluate railway passengers’ perceived security and safety. The findings of this study showed that security issue is more threatening than safety from train travelers’ viewpoint. Also, criminal acts like thefting and frauding have the most significant impact on travelers’ perception of safety and security. Kiani Mavi et al. (2018) offered a computational framework to improve BRT performance. For this aim, they defined and then simulated four different scenarios as possible alternatives. Then, they utilized a hybrid MCDM method integrating the step-wise weight assessment ratio
analysis (SWARA) and complex proportional assessment of alternatives (COPRAS) to evaluate and rank scenarios.

Nassereddine and Eskandari (2017) presented a hybrid approach integrating the Delphi method, group-AHP, and preference ranking organization method for enrichment of evaluations (PROMETHEE) to evaluate five major public transport modes in Tehran. They evaluated public transportation systems with respect to six criteria (cost of travel, waiting time, duration of travel, accessibility, suitability, and safety). The outcomes of this research indicated that metro is ranked first, followed by taxi and BRT. However, their proposed method neglected the vagueness and uncertainty involved in the responses of decision-makers. Ebrahimli and Bridgellall (2020) applied a hybrid MCDM method to assess public transportation modes in Tehran. The authors considered reliability, frequency, cost of travel, safety, accessibility, comfort, and information provision as the essential criteria. The final results demonstrated that the metro ranked first, followed by ride-hailing, BRT, bus, and taxi. They used the fuzzy AHP method to evaluate criteria and transport modes that need more pairwise comparisons and provide less consistent and reliable results in comparisons with the Best-Worst method (Mi et al., 2019). Also, they ignored passengers’ points of view which increases the error margin of their findings.

However, all the aforementioned studies were performed in a normal situation without considering a global pandemic in evaluation process. To this end, this paper provides a computational framework to evaluate the customer satisfaction of public transportation in Tehran during the COVID-19 pandemic to understand passengers’ behaviors by the scientists of the RAND Corporation in the 1950 s. Delphi method seeks to achieve consensus and stable results on a topic by a structured group of experts. In this method, practitioners separately respond to a questionnaire based on their opinion and knowledge. After each round, an anonymous summary of answers is shared with the participants, and they can revise their responses considering others’ opinions. This process will continue until the convergence of responses and achievement of consensus (Dalkey and Helmer, 1963).

3. Methodology

The proposed integrated method has three steps. Firstly, using a comprehensive literature review, Delphi method, and panel discussion, the criteria will be selected and finalized. Then, each criterion’s weight will be computed by applying BWM method, and finally, fuzzy TOPSIS will be employed for computing the rank of public transportation systems. The basic definition of BWM, fuzzy set theory, and fuzzy TOPSIS procedures are presented in the following sections.

3.1. Delphi

Delphi method was originally introduced through a series of experiments by the scientists of the RAND Corporation in the 1950s. Delphi method seeks to achieve consensus and stable results on a topic by a structured group of experts. In this method, practitioners separately respond to a questionnaire based on their opinion and knowledge. After each round, an anonymous summary of answers is shared with the participants, and they can revise their responses considering others’ opinions. This process will continue until the convergence of responses and achievement of consensus (Dalkey and Helmer, 1963).

3.2. Best worst method

Best Worst Method (BWM) is one of the strongest and latest MCDM techniques that is extensively used by many academics and practitioners to solve their decision-making problems. The aforementioned method is based on pairwise comparisons between the most desirable criterion to and achievement of consensus (Dalkey and Helmer, 1963). BWM has some salient advantages such as (Mi et al., 2019; Rezaei et al., 2016):

1) The BWM needs fewer times of pairwise comparisons. For instance, in AHP, the decision-maker has to compare each criterion with all the other criteria, and it means n(n−1)/2 pairwise comparisons, while in the best worst method, the decision-maker only needs to do 2n−3 times of pairwise comparisons.
2) It provides more consistent and reliable outcomes due to its structure and elimination of redundant pairwise comparisons.
3) In this method, the decision-maker only uses integer values for pairwise comparisons, which is more understandable than fractions.

Procedural steps of the BWM method are summarized as below (Rezaei, 2016, 2015):

Step 1: Specify a set of decision criteria. The set of criteria can be evaluated as \( K_1, K_2, ..., K_n \).
Step 2: Identify the best (most significant) and the worst (least significant) criterion from the set of decision criteria.
Step 3: Compare the best criterion \( K_b \) to all the other criteria by applying numbers in the range of 1 to 9 and then establish the Best to Other (BO) vector.

\[ BO = (a_{b1}, a_{b2}, ..., a_{bn}) \]

Where \( a_{bj} \) denotes the preference degree of the best criterion \( K_b \) over criterion \( j \).
Step 4: Compare all the other criteria to the worst criterion by applying numbers in the range of 1 to 9 and then establish the Others to Worst (OW) vector.

\[ OW = (a_{w1}, a_{w2}, ..., a_{wn})^T \]

Where \( a_{wj} \) denotes the preference degree of the criterion \( j \) over the worst criterion \( K_w \).
Step 5: Determine the optimal weights of criteria \( (w_1, w_2, ..., w_n) \) by minimizing the maximum absolute differences \( |w_j - a_{bj}w_b| \) and \( |w_j - a_{wj}w_w| \) for all j. This can be formulated as follows:

\[
\min \left\{ \left| w_j - a_{bj}w_b \right|, \left| w_j - a_{wj}w_w \right| \right\}
\]

subject to

\[
\sum_{j=1}^{n} w_j = 1, \quad w_j \geq 0, \quad \text{for all } j.
\]

Model (1) can be transferred to a linear model which gives better results, the model is illustrated below:

\[
\min \varepsilon^{w}\n s.t.
\begin{align*}
|w_j - a_{bj}w_b| &\leq \varepsilon^{w}, \quad \text{for all } j \\
|w_j - a_{wj}w_w| &\leq \varepsilon^{w}, \quad \text{for all } j \\
\sum_{j=1}^{n} w_j &= 1 \\
w_j &\geq 0, \quad \text{for all } j
\end{align*}
\]

By solving model (2) optimal weights \( (w_1, w_2, ..., w_n) \) and the optimal value of \( \varepsilon^{w} \) are obtained. \( \varepsilon^{w} \) is defined as the consistency ratio of the comparison system. The closeness of value \( \varepsilon^{w} \) to zero means a minimal inconsistency of the comparison system.

3.3. Fuzzy set theory

For the first time, Zadeh (1996) proposed fuzzy set theory to represent vagueness, uncertainty, and imprecision (Awasthi et al., 2011a; Li et al., 2020). Due to the mentioned characteristics, the fuzzy set theory used extensively in decision-making problems. The use of fuzzy set theory allows decision-makers to verbalize their preferences in linguistic terms (Chen and Chen, 2007). In fuzzy sets theory, all the numbers have a varying degree of membership between zero and unity rather than the traditional binary association. To be clear, fuzzy set numbers choose a value in the range of 0 to 1; the nearer the value to unity, the higher the
grade of membership (Zadeh et al., 1996). There are various types of fuzzy numbers, including trapezoidal, Gaussian, and triangular. Triangular fuzzy numbers are extensively utilized to represent fuzzy numbers due to its simplicity of membership function and easier algebraic operation (Pedrycz, 1994).

A triangular fuzzy number $\tilde{G}$ can be expressed by a triplet $(r, s, t)$. Where $r, s, t$ are real numbers and $r \leq s \leq t$, which $r$ and $t$ stand for lower and upper value of $\tilde{G}$ and $s$ gives the most probable value of it. The membership function $\mu_G(x)$ of $\tilde{G}$ is described as (Awasthi et al., 2011a; Chang, 1996):

$$\mu_G(x) = \begin{cases} 
0, & x \leq r, \\
\frac{x - r}{s - r}, & r < x \leq s, \\
1, & s \leq x \leq t, \\
\frac{t - x}{t - s}, & s < x \leq t, \\
0, & x > t,
\end{cases}$$

(3)

For two triangular fuzzy numbers $\tilde{G} = (r_1, s_1, t_1)$ and $\tilde{H} = (r_2, s_2, t_2)$ basic arithmetic operations are described as follows (Chang, 1996; Sirisawat and Kiatcharoenpol, 2018):

$\tilde{G} \oplus \tilde{H} = (r_1 + r_2, s_1 + s_2, t_1 + t_2)$

(4)

$\tilde{G} \odot \tilde{H} = (r_1 - t_2, s_1 - s_2, t_1 - r_2)$

(5)

$\tilde{G} \otimes \tilde{H} = (r_1 \times r_2, s_1 \times s_2, t_1 \times t_2)$

(6)

$\tilde{G} \oslash \tilde{H} = (r_1/t_2, s_1/s_2, t_1/t_2)$

(7)

And the distance between $\tilde{G}$ and $\tilde{H}$ using the vertex method is calculated as:

$$d(\tilde{G}, \tilde{H}) = \frac{1}{3} \sqrt{[(r_1 - r_2)^2 + (s_1 - s_2)^2 + (t_1 - t_2)^2]}$$

(8)

3.4. Fuzzy TOPSIS method

TOPSIS is an acronym that stands for Technique for Order Performance by Similarity to Ideal Solution. It is a multi-criteria decision making technique that was proposed by Hwang and Yoon in 1981. As the name implies, TOPSIS evaluates alternatives to rank them based on their distance from the positive ideal solution (PIS) and negative ideal solution (NIS) (Hwang and Yoon, 1981). The mentioned procedure has been successfully applied in diverse areas like supply chain management, manufacturing systems, business and marketing, tourism industry, healthcare management, environment management, urban management, etc. (Behzadian et al., 2012).

The TOPSIS is characterized by some noticeable specifications such as: ease of use and low mathematical complexity, comprehensibility, rationality, good computational efficiency, and the ability to perform with any number of positive or negative criteria (Roszkowska, 2011; Samaie et al., 2020). Although this method is interesting, it fails to take the uncertainty of human thoughts into account. In the old version of the TOPSIS method decision-makers express their opinion by crisp values, and it cannot consider decision-makers’ ambiguity and uncertainty. The fuzzy type of TOPSIS was introduced to rectify the mentioned problem. In this procedure, the decision matrix elements individually or with the weight of criteria are expressed with fuzzy numbers. The fuzzy TOPSIS method based on triangular fuzzy numbers and for $T$ decision makers $D_t = \{t = 1, 2, ..., T\}$ and a decision making problem with $m$ criteria $C_j (j = 1, 2, ..., m)$ and $n$ alternatives $A_i = \{i = 1, 2, ..., n\}$ consist of the following steps (Awasthi et al., 2011a; Chen, 2000):

Step 1: The weights of criteria and ratings of alternatives with respect to each criterion can be calculated as:

$$\tilde{w}_j = \frac{1}{T} \left[ \tilde{w}^1_j + \tilde{w}^2_j + ... + \tilde{w}^T_j \right]$$

(9)

$$\tilde{x}_{ij} = \frac{1}{T} \left[ \tilde{x}^1_{ij} + \tilde{x}^2_{ij} + ... + \tilde{x}^T_{ij} \right]$$

(10)

Where the rating and the importance weight of the $j$th decision-maker are expressed by $\tilde{x}_{ij}$ and $\tilde{w}_j$.

Step 2: Construct the fuzzy decision matrix as follows:

$$\tilde{V} = \left[ \begin{array}{cccc}
\tilde{v}_1 & \tilde{v}_2 & ... & \tilde{v}_n \\
\tilde{w}_1 & \tilde{w}_2 & ... & \tilde{w}_m
\end{array} \right]$$

(11)

$$C_1 \cdot C_2 \cdot ... \cdot C_m$$

$$\tilde{A}_i = \left[ \begin{array}{cccc}
\tilde{x}_{i1} & \tilde{x}_{i2} & ... & \tilde{x}_{im} \\
\tilde{y}_{i1} & \tilde{y}_{i2} & ... & \tilde{y}_{im}
\end{array} \right]$$

(12)

Where $\tilde{x}_{ij}$ are linguistic variables and can be described by triangular fuzzy numbers.

Step 3: Calculate the normalized fuzzy decision matrix $\tilde{R}$ through the following equations:

$$\tilde{R} = \left[ \begin{array}{ccc}
\tilde{r}_{1j} & \tilde{r}_{2j} & ... & \tilde{r}_{nj}
\end{array} \right]$$

(13)

$$\tilde{r}_{ij} = \left( \frac{\tilde{v}_{ij} - \tilde{v}_{\min}}{\tilde{v}_{\max} - \tilde{v}_{\min}} \right) \quad \text{and} \quad \tilde{r}_{ij}^+ = \max_{i} \tilde{r}_{ij} \text{ (benefit criteria)}$$

(14)

$$\tilde{r}_{ij}^- = \left( \frac{\tilde{v}_{ij} - \tilde{v}_{\min}}{\tilde{v}_{\max} - \tilde{v}_{\min}} \right) \quad \text{and} \quad \tilde{r}_{ij}^- = \min_{i} \tilde{r}_{ij} \text{ (cost criteria)}$$

(15)

Step 4: In this step, we should compute the weighted normalized decision matrix $\tilde{V}$ by multiplying the weights ($\tilde{w}_j$) of evaluation criteria with the normalized fuzzy decision matrix $\tilde{R}_j$:

$$\tilde{V} = \left[ \begin{array}{c}
\tilde{v}_1 \\
\tilde{v}_2 \\
... \\
\tilde{v}_n
\end{array} \right] \quad \text{and} \quad \tilde{v}_j = \tilde{r}_j(\cdot) \tilde{w}_j$$

(16)

Step 5: Compute the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) as follows:

$$\tilde{V}^+ = (\tilde{v}_1^+, \tilde{v}_2^+, ..., \tilde{v}_n^+), \quad \text{where} \quad \tilde{v}_i^+ = \max \{v_{ij}\}$$

(17)

$$\tilde{V}^- = (\tilde{v}_1^-, \tilde{v}_2^-, ..., \tilde{v}_n^-), \quad \text{where} \quad \tilde{v}_i^- = \min \{v_{ij}\}$$

(18)

Step 6: Distances of alternatives from (FPIS) and (FNIS) are obtained using the following equations:

$$d_i^+ = \sum_{j=1}^{T} d(\tilde{v}_i, \tilde{v}_j^+)$$

(19)

$$d_i^- = \sum_{j=1}^{T} d(\tilde{v}_i, \tilde{v}_j^-)$$

(20)

Step 7: Calculate the closeness coefficient $CC_i$ of each alternative through the following equation:

$$CC_i = \frac{d_i^+}{d_i^+ + d_i^-}$$

(21)

Step 8: Compute the ranks of alternatives according to the closeness coefficient in decreasing sequence. The preferred alternative is closest to the (FPIS) and farthest from the (FNIS).
4. Case analysis and application using the proposed methodology

In this section, we apply our proposed model for the evaluation of public transportation systems of Tehran in the age of COVID-19. Our model consists of three steps.

1. Selection and finalization of evaluation criteria
2. Criteria and sub-criteria's weights computation using BWM
3. Ranking of transportation systems using fuzzy TOPSIS

The steps of the proposed methodology are presented in detail in Fig. 1.

4.1. Selection and finalization of criteria

For the purpose of selection and finalization of evaluation criteria, we formed a decision team consists of 10 experts with academic and engineering background in the field of transportation and at least 15 years of experience. Thereafter, based on a comprehensive review of literature, discussion with experts using the Delphi method, and panel discussion with the decision team, the criteria and sub-criteria to evaluating transportation systems during the COVID-19 pandemic were identified. Initially, after a comprehensive review of related literature, primitive criteria were extracted and presented to the decision team for finalization. After a series of discussions using the Delphi method and then a panel discussion with our decision team total of 21 criteria were selected. Afterward, the selected criteria were clustered into six main criteria for the purpose of evaluation. Table 1 indicates the finalized main criteria and sub-criteria.

4.2. Criteria and sub-criteria's weights computation using BWM

After identifying and finalizing the criteria, the weights of them were calculated using the BWM. The decision team was asked to determine the most significant and the least significant criteria among the main criteria and then sub-criteria. The selected best and worst main criteria for each member of the decision team are illustrated in Table 2.

After identifying the worst and the best criteria, all the experts who are the members of the decision team were asked to compare their chosen best criterion to all the other criteria and the other criteria to their chosen worst criterion on a scale of 1 to 9 for the main criteria as well as sub-criteria. A score of 1 means equal importance, and 9 means extremely more preferred. Accordingly, best to others (BO) and others to worst (OW) vectors were established. The results of the comparison matrix for the main criteria by all members of the decision team are presented in Table 3 and Table 4. Next, using model (2) and the linear programming, the weight of main criteria, and subsequently sub-criteria were calculated for all members of the decision team, and then the final weight of each criterion was computed by the arithmetic mean. The final weight of each criterion is given in Table 5. The consistency ratio of all comparison matrix were computed; all of them were fairly close to zero that shows an acceptable level of consistency in pairwise comparisons.

4.3. Survey

Most scientific researches are carried out based on a sample because studying the whole population is a time-consuming process and not economically efficient (Verma and Verma, 2020). Determining the sample size is one of the most critical steps of research because an inadequate sample size could significantly affect the quality of research. In this study, the sample size is determined using Cochran’s formula.
Table 1: Criteria for evaluation of public transportation systems.

| Criteria                      | Sub-criteria | Description                                                                 |
|-------------------------------|--------------|-----------------------------------------------------------------------------|
| Comfort (C)                   | Seats (C1)   | The sufficiency and comfort of sitting areas                                |
| Ventilation (C2)              |              | Existence and effectiveness of air conditioning system                       |
| Passenger density (C3)        |              | Passenger density in the vehicle                                             |
| Hygiene (C4)                  |              | It refers to conditions and practices that help to maintain passenger's health and prevent the spread of diseases between them |
| Driving ability of drivers (C5) |          | Drivers ability to drive smoothly and safely                                |
| Accessibility (A)             | Access (A1)  | Being in the optimum location for the access of passengers                  |
|                                | Accessibility to disabled and mobility-impaired people (A2) | Being suitable for the usage of those who have a physical disability |
| Network coverage (A3)         |              | The geographical area of the city that covered by the transportation system  |
| Easiness of transition (A4)   |              | Easiness of transition from a transportation system to another               |
| Time (T)                      | Travel time (T1) | Average time to reach a destination                                        |
|                                | Waiting time (T2) | The time that passengers have to wait at stations or vehicles in order to continue their trip |
| Punctuality (T3)              |              | Is a feature consisting in that a vehicle arrives or depart at a predefined point at a predefined time |
| Payment (P)                   | Travel cost (P1) | The cost that passengers should pay for using a vehicle                     |
|                                | Types of tickets (P2) | Providing various types of ticket and discounts to encourage passenger to use that kind of transportation system |
| Mode of payment (P3)          |              | The ways that passengers can pay the travel cost (providing some ways to remove cash transactions) |
| Safety and security (SS)      | Safety (SS1) | Safety of transportation system occupants against traffic collisions         |
|                                | Security (SS2) | Sense of protection against external threats and criminal activities         |
| Environmental impact (E)      | Lost property finding (S3) | Easiness of finding lost properties in the transportation system |
|                                | Air pollutions (E1) | Air pollutants produced by the transportation system                       |
|                                | Noise (E2)    | Loud and unpleasant sounds from the transportation system                   |
|                                | General look of transportation system (E3) | General look of transportation system and its stations/terminals from the perspective of urban aesthetics |

Table 2: Best and worst main criteria identified by decision team.

| Criterion                  | Selected as best by expert | Selected as worst by expert |
|----------------------------|----------------------------|----------------------------|
| Comfort (C)                | 3, 4, 0, 10                | 7                          |
| Accessibility (A)          | 1, 9                       | 4                          |
| Time (T)                   | 6, 7                       | 8                          |
| Payment (P)                | 8                          | 2                          |
| Safety and security (SS)   | 2, 5                       | 1, 2, 3, 5, 6, 8, 9, 10    |

Table 3: BO vectors for each member of decision team.

| Expert NO | C | A | T | P | SS | E |
|-----------|---|---|---|---|----|---|
| 1         | A | 2 | 1 | 2 | 4  | 3 | 8 |
| 2         | SS | 2 | 2 | 4 | 3  | 1 | 7 |
| 3         | C | 1 | 2 | 3 | 3  | 5 | 5 |
| 4         | C | 1 | 3 | 6 | 5  | 2 | 4 |
| 5         | SS | 4 | 2 | 3 | 2  | 1 | 6 |
| 6         | T | 3 | 2 | 1 | 3  | 2 | 4 |
| 7         | T | 2 | 6 | 1 | 3  | 4 | 4 |
| 8         | P | 4 | 5 | 6 | 1  | 5 | 9 |
| 9         | A | 3 | 1 | 5 | 3  | 4 | 6 |
| 10        | C | 1 | 2 | 5 | 4  | 3 | 7 |

C = Comfort, A = Accessibility, T = Time, P = Payment, SS = Safety and security, E = Environmental impact.

Table 4: OW vectors for each member of decision team.

| Expert NO | C | A | T | P | SS | E |
|-----------|---|---|---|---|----|---|
| 1         | C | 4 | 5 | 6 | 2  | 3 | 2 | 7 |
| 2         | A | 8 | 3 | 4 | 2  | 3 | 6 | 4 |
| 3         | T | 3 | 2 | 3 | 1  | 2 | 4 | 6 |
| 4         | P | 2 | 3 | 3 | 2  | 3 | 2 | 9 |
| 5         | SS | 3 | 7 | 2 | 4  | 6 | 3 | 2 |
| 6         | E | 1 | 1 | 1 | 1  | 2 | 1 | 1 |

C = Comfort, A = Accessibility, T = Time, P = Payment, SS = Safety and security, E = Environmental impact.

Table 5: Final weights.

| Main criteria | Main criterion weights | Sub criteria | Sub criterion weights | Final weights | Ranking |
|---------------|------------------------|--------------|-----------------------|---------------|---------|
| Comfort       | 0.223                  | C1           | 0.084                 | 0.019         | 19      |
|               |                        | C2           | 0.161                 | 0.036         | 12      |
|               |                        | C3           | 0.365                 | 0.081         | 3       |
|               |                        | C4           | 0.292                 | 0.065         | 7       |
|               |                        | C5           | 0.098                 | 0.022         | 16      |
| Accessibility | 0.205                  | A1           | 0.342                 | 0.070         | 6       |
|               |                        | A2           | 0.225                 | 0.046         | 10      |
|               |                        | A3           | 0.317                 | 0.065         | 7       |
| Time          | 0.156                  | T1           | 0.491                 | 0.076         | 5       |
|               |                        | T2           | 0.159                 | 0.025         | 14      |
|               |                        | T3           | 0.350                 | 0.055         | 9       |
| Payment       | 0.165                  | P1           | 0.66                   | 0.109         | 1       |
|               |                        | P2           | 0.13                   | 0.021         | 17      |
|               |                        | P3           | 0.21                   | 0.035         | 13      |
| Safety and security | 0.184          | SS1          | 0.436                 | 0.08          | 4       |
|               |                        | SS2          | 0.484                 | 0.089         | 2       |
|               |                        | SS3          | 0.080                 | 0.015         | 20      |
| Environmental impact | 0.067          | E1           | 0.601                 | 0.04          | 11      |
|               |                        | E2           | 0.296                 | 0.02          | 18      |
|               |                        | E3           | 0.103                 | 0.007         | 21      |

4.4. Ranking of transportation systems using fuzzy TOPSIS

In the final, fuzzy TOPSIS is employed for ranking public trans-
Table 6
Linguistic terms for alternative ratings.

| Linguistic term | Corresponding fuzzy numbers |
|-----------------|-----------------------------|
| Very poor       | (0,0,1)                     |
| Poor            | (0,1,3)                     |
| Medium poor     | (1,3,5)                     |
| Fair            | (3,5,7)                     |
| Medium good     | (5,7,9)                     |
| Good            | (7,9,10)                    |
| Very good       | (9,10,10)                   |

Table 7
Demographic information of the respondents.

| Question                  | Option       | Number observed | % Percent |
|---------------------------|--------------|-----------------|-----------|
| Gender                    | Male         | 219             | 56        |
|                           | Female       | 173             | 44        |
| Age (years)               | 14-19        | 73              | 18.6      |
|                           | 20-29        | 135             | 34.4      |
|                           | 30-39        | 106             | 27.1      |
| Highest level of education| High school degree | 128          | 32.6      |
|                           | Bachelor degree | 174           | 44.4      |
|                           | Master/doctorate | 43            | 11        |
|                           | other        | 47              | 12        |
| Employment                | Full time    | 267             | 68.1      |
|                           | Part time    | 74              | 18.9      |
|                           | Unemployment | 51              | 13        |
| Private car availability  | Yes          | 239             | 61        |
|                           | No           | 153             | 39        |

Table 8
Final ranking of alternatives.

| Alternatives | Closeness coefficient | Ranks |
|--------------|-----------------------|-------|
| Bus          | 0.0220                | 4     |
| BRT          | 0.0226                | 3     |
| Metro        | 0.0249                | 2     |
| Taxi         | 0.0269                | 1     |
| Van          | 0.0156                | 5     |

Decision matrix was computed using Eqs. (13–15) and is presented in Table A2. Next, the weighted normalized fuzzy decision matrix was constructed using Eq. (16) and it can be seen from Table A3. Consequently, the FPIS and FNIS were determined using Eqs. (17) and (18). Then, the distance of each alternative from the FPIS and FNIS was calculated using Eqs. (19) and (20). Finally, the closeness coefficient CC values were obtained by using Eq. (21). By comparing the coefficients of closeness, ranking of all transportation systems was obtained, and the outcomes are illustrated in Table 8.

4.5. Results

The weights of the main criteria and sub-criteria were computed via the BWM and are illustrated in Table 5. A total of 21 sub-criteria were finalized and then grouped into six categories by the decision team. The order of priority of main criteria was given as $C > A > SS > P > T > E$. Further, the final weights of each sub-criteria were obtained by multiplying the preference weights of sub-criteria with the weight of the respective category. Among the sub-criteria, travel cost (P1) was considered as the criterion with the highest priority with a weight of 0.109. Security (SS2) was ranked second among the sub-criteria. Passenger density (C3) was the third sub-criteria that is given the most importance. Safety (SS1) was the fourth most important sub-criteria, and travel time (T1) was the next sub-criteria that is given importance.

After ranking the criteria and sub-criteria, Tehran’s public transportation systems were ranked using the fuzzy TOPSIS procedure. For this purpose, 392 respondents filled an online questionnaire. The respondents were asked to rate public transportation systems with linguistic terms. In this evaluation, taxi was ranked first and followed by metro, BRT, bus, and van respectively. The outcomes demonstrate that taxi had a better performance during the coronavirus pandemic. Compared with similar studies conducted by Ebrahimi and Bridgelall (2020) and Nassereddine and Eskandari (2017), metro was ranked first in both studies, while in this study, taxi ranked highest in passengers viewpoint. It seems that the mentioned difference is under the effect of some criteria such as hygiene and passenger density which have been gotten more attention of riders in the pandemic era.

It should be mentioned that four of the selected criteria (passenger density, hygiene, ventilation, and mode of payment) could directly influence the risk of COVID-19 contagion (Shen et al., 2020; Tirachini and Cats, 2020). Based on the reported data in Tables A1, A2 and A3, by considering each of the mentioned criteria separately, it becomes clear that taxi in passenger density and hygiene, BRT in ventilation, and metro in the mode of payment had a better performance. Also, taking into account all the stated criteria together again taxi had more desirable performance than other transportation modes. These results imply that

Table 9
Weights of all main criteria after varying weight of Comfort.

| Criteria | Normalized weight | Exp 1 | Exp 2 | Exp 3 | Exp 4 | Exp 5 | Exp 6 | Exp 7 | Exp 8 | Exp 9 |
|----------|-------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| C        | 0.233             | 0.1   | 0.2   | 0.3   | 0.4   | 0.5   | 0.6   | 0.7   | 0.8   | 0.9   |
| A        | 0.205             | 0.2375| 0.211 | 0.184 | 0.158 | 0.131 | 0.105 | 0.079 | 0.052 | 0.026 |
| T        | 0.156             | 0.1807| 0.1606| 0.1405| 0.1205| 0.1004| 0.0803| 0.0602| 0.0402| 0.0201|
| P        | 0.165             | 0.1911| 0.1699| 0.1486| 0.1274| 0.1062| 0.0849| 0.0637| 0.0425| 0.0212|
| SS       | 0.184             | 0.2131| 0.1894| 0.1608| 0.1421| 0.1184| 0.0947| 0.0710| 0.0474| 0.0237|
| E        | 0.067             | 0.0776| 0.0690| 0.0604| 0.0517| 0.0431| 0.0345| 0.0259| 0.0172| 0.0086|

Table 10
Ranking of alternatives when the weight of the main criterion increasing via sensitivity analysis.

| Alternatives | Exp 1 | Exp 2 | Normal | Exp 3 | Exp 4 | Exp 5 | Exp 6 | Exp 7 | Exp 8 | Exp 9 |
|--------------|-------|-------|--------|-------|-------|-------|-------|-------|-------|-------|
| Bus          | 4     | 4     | 4      | 4     | 4     | 4     | 4     | 4     | 4     | 4     |
| BRT          | 3     | 3     | 3      | 3     | 3     | 3     | 3     | 3     | 3     | 3     |
| Metro        | 2     | 2     | 2      | 2     | 2     | 2     | 2     | 2     | 2     | 2     |
| Taxi         | 1     | 1     | 1      | 1     | 1     | 1     | 1     | 1     | 1     | 1     |
| Van          | 5     | 5     | 5      | 5     | 5     | 5     | 5     | 5     | 5     | 5     |

It should be mentioned that four of the selected criteria (passenger density, hygiene, ventilation, and mode of payment) could directly influence the risk of COVID-19 contagion (Shen et al., 2020; Tirachini and Cats, 2020). Based on the reported data in Tables A1, A2 and A3, by considering each of the mentioned criteria separately, it becomes clear that taxi in passenger density and hygiene, BRT in ventilation, and metro in the mode of payment had a better performance. Also, taking into account all the stated criteria together again taxi had more desirable performance than other transportation modes. These results imply that
some of the taxi features like its low passenger density and some of the prevention and control measures adopted by taxis like using separators, equipping with hand sanitizer, and mask enforcement were successful.

4.6. Sensitivity analysis

Sensitivity analysis is an invaluable technique to test the robustness of a mathematical model’s outcomes in the case of the existence of uncertainty (Gupta and Barua, 2017; Prakash and Barua, 2015). Sensitivity analysis is described as the study of how uncertainty in the inputs of a mathematical model can cause uncertainty in the outputs (Saltelli et al., 2000). To examine the robustness of the results of the BWM-fuzzy TOPSIS model a sensitivity analysis is carried out. For this purpose, the weight of the most important criterion (Comfort) is varied in the range of 0.1 to 0.9 and consequently, the weight of all the other main criteria is changed. The details are presented in Table 9.

Further, the weights of sub-criteria were computed using the weights of the main criteria for different experiments, and results are presented in Fig. 2. Then, using the weights of sub-criteria, the final weights of alternatives were calculated. The transportation systems were ranked using fuzzy TOPSIS for each experiment, and the outcomes are presented in Table 10. According to sensitivity analysis’s results, it can be deduced that varying the weight of the main criterion with the highest priority will not conclude to meaningful changes in the ranking of alternatives. In all the nine experiments, taxi remained in the first rank and van in the last rank. Also, Bus acquired the fourth rank in all the nine runs. There is a minor change in the two last runs where the ranks of metro and BRT are swapped. This shift does not considerably affect the results of the BWM-fuzzy TOPSIS model. Thus, the results are robust, and the model is validated.

5. Conclusion and discussion

Public transportation plays a vital role in contemporary human life. This kind of transportation provides an economical, environmentally friendly, and safe way to transit within and between cities. Lately, the
BWM procedure was applied to determine the priority of each criterion. Directly influence the risk of COVID-19 contagion. In the next step, the criteria grouped into six main criteria. It should be mentioned that four criteria, namely passenger density, hygiene, ventilation, and mode of payment, were expected to decrease demand and revenue for the public transportation sector. Moreover, there is a risk that the public transportation sector is perceived as unhealthy and unsafe, even after the pandemic. Breaks. During this period, people preferred to use their private cars to avoid overcrowding, especially during the pandemic. This step’s outcomes imply that travel cost is the most significant criterion in the evaluation process, which means if the government considers some sort of discount or economic encouragement for those who use public transportation regularly, people will encourage to use it more. Also, security has the second-highest priority in respondents’ view, which shows that if responsible departments are fond of attracting private car users, they should allocate more resources to improve public transportation security. The third most important criterion is passenger density which shows the necessity of rescheduling in public transportation to avoid overcrowding, especially during the pandemic.

In the final step, the fuzzy TOPSIS technique was adopted to rank public transportation systems in Tehran. This step’s results showed that taxi is the best transport mode from passengers’ point of view and it follows by metro, BRT, and van. Compared with similar studies conducted by Ebrahimi and Bridgelall (2020) and Nassereddine and Eskandari (2017), metro was ranked first in both studies, while in this study, taxi ranked highest in passengers viewpoint. Additionally, about 15% of respondents considered some sort of discount or economic encouragement for those who use public transportation regularly, people will encourage to use it more. Also, security has the second-highest priority in respondents’ point of view, which shows that if responsible departments are fond of attracting private car users, they should allocate more resources to improve public transportation security. The third most important criterion is passenger density which shows the necessity of rescheduling in public transportation to avoid overcrowding, especially during the pandemic.

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Table A3
Weighted normalized fuzzy decision matrix.

| Criteria Alternatives | Alternatives | Alternatives |
|-----------------------|-------------|-------------|
| C1                    | (0.0043,0.0081,0.0127) | (0.0072,0.0115,0.0158) |
| C2                    | (0.0136,0.0218,0.0300) | (0.0201,0.0286,0.0360) |
| C3                    | (0.0036,0.0043,0.0058) | (0.0034,0.004,0.0052) |
| C4                    | (0.0038,0.0154,0.0336) | (0.0052,0.0182,0.0363) |
| C5                    | (0.0106,0.0152,0.0192) | (0.0116,0.0161,0.0198) |
| C6                    | (0.0336,0.0497,0.0646) | (0.0252,0.0415,0.0573) |
| A1                    | (0.0025,0.0099,0.0217) | (0.0176,0.0301,0.0431) |
| A2                    | (0.0338,0.0486,0.0619) | (0.0172,0.0309,0.0456) |
| A3                    | (0.0118,0.0176,0.0232) | (0.0125,0.0183,0.0239) |
| A4                    | (0.0118,0.0134,0.017) | (0.0134,0.0169,0.0239) |
| A5                    | (0.0012,0.004,0.0018) | (0.0018,0.0027,0.0052) |
| A6                    | (0.0158,0.0278,0.0404) | (0.0196,0.0322,0.0449) |
| B1                    | (0.0108,0.0243,0.109) | (0.0093,0.0185,0.0607) |
| B2                    | (0.0056,0.0113,0.0176) | (0.0059,0.0116,0.0179) |
| B3                    | (0.0224,0.0291,0.0341) | (0.0227,0.0295,0.0345) |
| C1                    | (0.0182,0.0377,0.0594) | (0.0324,0.0541,0.0757) |
| C2                    | (0.0368,0.0561,0.0754) | (0.0389,0.0586,0.0774) |
| C3                    | (0.0007,0.004,0.0108) | (0.0060,0.004,0.0109) |
| C4                    | (0.001,0.003,0.0019) | (0.0013,0.008,0.003) |
| C5                    | (0.0029,0.0031,0.0039) | (0.0054,0.0054,0.0067) |
| C6                    | (0.0003,0.0012,0.0026) | (0.0017,0.0032,0.0048) |

Fig. 2. Ranking of sub-criteria when the weight of the main criterion (Comfort) increasing via sensitivity analysis.
contagion results demonstrated that taxis had more desirable performance than other transportation modes. With a closer look at the coronavirus-related criteria, it is obvious that they had a massive impact on the decision-making process (the weight of them together is 0.217), so any action to improve transportation systems in the mentioned criteria could be effective in attracting people to public transportation. Following this, many actions to improve the public transportation service quality during and after the pandemic. The mathematical model could be used to evaluate public transportation of other megacities, and also it could be used several times to determine the improvement of each criterion and transportation mode.

In future research, public transportation systems of other cities can be studied to demonstrate a significant difference in public transportation demand before and after taking countermeasures against COVID-19 contagion. Ride-hailing services as a new transportation mode can be taken into account to measure customer satisfaction as well. Finally, as a future direction, optimization methods can be used to optimize public transportation scheduling according to the pandemic situation.

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.

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