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A GIS-based MCDM approach for the evaluation of bike-share stations

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ABSTRACT

—Several benefits have contributed to the increasing popularity of bike-share systems in cities around the world. In addition to traffic congestion, environmental concerns are also compelling cities to seek more sustainable modes of transportation. A key factor in the efficacy of bike-share networks is the location of bike stations in relation to potential related criteria. Therefore, site suitability analysis for bike-share stations using quantitative methods is essential. This study attempted to evaluate the current status of bike-share stations in Karsiyaka, Izmir, and to locate future station sites by comparing them to existing stations. To do so, different multi-criteria decision-making methods were combined with a geographic information system (GIS) to address twelve conflicting criteria. Specifically, the analytic hierarchy process was applied to obtain criteria weights, and multi-objective optimization by ratio analysis was used to evaluate current and potential alternatives. Our study demonstrates the superiority of the suggested locations compared to the existing stations.

1. Introduction

Converting urban populations from travelling by motor vehicles to travelling by foot or bicycle can provide health benefits, decrease air pollution, and reduce traffic congestion. City planners should conduct sustainable and environmental interventions to encourage people to use public transportation or vehicle sharing systems (Sun et al., 2017).

Bike-share systems are becoming increasingly popular around the world as another solution to the aforementioned problems. A bike-share system consists of a set of rental stations, each with a certain number of parking slots, distributed over a geographical region. Customers (passengers) can rent available bikes at any station and return them at any other station with free parking slots (Chen and Lu, 2016).

The earliest bike-share system dates to 1965 in Amsterdam, Netherlands. Since then, various implementations of bike-share systems have been presented. Coin-deposit systems, seen as the future of bike-share systems, were introduced in Denmark in 1991. Later, a breakthrough occurred when systems began using magnetic cards to rent bikes. This generation of bike-share, known as the IT-based system, started with Bikeabout in 1996 at Portsmouth University, England (Pal and Zhang, 2017). Interested readers are referred to DeMaio (2009), Kahn (2012), and Fishman et al. (2013), for an overview of various generations of bike-share.

Excluding free-floating bike-share systems (Pal and Zhang, 2017), every bike-share system requires specific stations where the bikes are locked in. The decision processes regarding the initial locations and sizes of bike stations or how to extend an existing system by adding stations and/or changing existing station configurations are crucial (Efthymiou et al., 2012). However, developing an efficient bike-share system with proper station locations is a challenging task. To construct a successful bike-share network, the relative station locations within the bike-share network and their relationships with attraction centers, public transport, and passengers must be considered (Liu et al., 2015).

Specifically, there are two major challenges for bike station site selection. The first issue concerns the spatial information of the surrounding human activities, which are reflected in the demand for the bikes. To address the first challenge, the geographic information of the surrounding environment and the station network structure are required. Second, the attributes of the surrounding environment do not have uniform degrees of importance or influence across bike-share systems. For instance, while population

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density was the most meaningful criterion in some studies (Frade and Ribeiro, 2015), other studies (Griffin and Sener, 2016) showed that connectivity to a rail transport system was one of the most important criteria to consider in selecting a bike-share station site. Because of these challenges, the benefits of bike-share systems are not often equitably distributed in the cities in which they have been implemented. Statistics indicate that a large majority of current North American commuters in the United States cannot make use of bike-share systems (Goodman and Handy, 2015).

To overcome these challenges, we first determined the criteria that influence bike-share systems. These criteria included population, recreation areas, cycle line, and public transport networks. Then, a method based on a geographic information system (GIS) was applied to identify their spatial characteristics and assess the geographic values. Next, analytic hierarchy process (AHP) and multi-objective optimization by ratio analysis (MOORA) techniques were combined with the GIS to assign the priorities and rank stations by evaluating the conflicting criteria. The performance of the proposed GIS-based multi-criteria decision-making (MCDM) model was comprehensively assessed on the real-world bike-share system in Karsiyaka, Izmir. The experimental results demonstrated the efficiency of the proposed method.

This paper is divided into five sections following this introductory section. The second section presents a brief overview of relevant literature and the contribution of this study to the topic. The third section describes the methodology used for the considered problem, that is, the MOORA methods used to rank the alternative bike-share stations. In the fourth section, the proposed methodology, which combines GIS, AHP, and MOORA methods, is described. A real-world case with data, application process, and results are provided in the fifth section. Finally, the sixth section presents the main conclusions of this study.

2. Overview of the relevant state of the art

This section contains a brief review of the most relevant and recent literature on bike-share site selection, followed by the contributions of the current study to the literature.

2.1. Prior research

Bike-share station site selection is commonly conducted by the municipalities served by the bike-share network. Recent academic literature has attempted to improve the outcomes of these efforts with various scientific approaches. Researchers have suggested mathematical models, GIS, and MCDM methods. Thus, in our theoretical background section, we focus on the studies that used MCDM techniques, GIS, or hybrid approaches that combine these two techniques.

Leigh et al. (2009) presented a generic model for bike-share station site selection for the Monash University campus, which considered the Australian regulation standards for site selection. Later, in 2010, Rybarczyk and Wu proposed an MCDM and GIS-based exploratory spatial data analysis method to explore the spatial patterns of bicycle facilities. They evaluated their model on Milwaukee, a city in the midwestern region of the United States. Their results demonstrated that their hybrid GIS and MCDM analysis was an effective technique for planning bicycle facilities. In another study, Palomares et al. (2012) proposed a GIS-based method to select bike-share station locations and determine their capacity and demand. They compared their findings with most commonly used location allocation models. An additional accessibility analysis was carried out to calculate the volume of activity to which a station has access. With this additional analysis, Palomares et al. were able to eliminate relatively isolated stations.

In their real-world application, Wuerzer et al. (2012) studied a large bike-share problem that located and optimized the number of bikes and bike-share stations in the downtown area of the United States city of Boise, Idaho, and coordinated their work with the local health department. They used GIS optimization analysis to determine the optimal number of bikes and bike stations. As a result, they found that 140 bikes and 14 stations were optimal for the area. They compared their study with several other bike-share projects and announced that their methodology had been helpful in developing the Boise bike-share network. In 2013, Ghandehari et al. presented a study that attempted to find the best locations for bike-share stations using both mathematical programming and MCDM techniques. They used AHP to determine the weights of each criterion and calculated the final weights for the proposed locations using a simple additive weighting method. They reported that the most important criteria for bike-share station locations were proximity to bicycle paths, transportation and networks, demand, and use type. Using this information, they developed a combined mathematical model with which to determine the final location of bike-share stations.

Unlike most other literature, Milakis and Athanasopoulos included the opinions of cyclists in their 2014 study proposing a four-step methodology for bike-share network planning using multi-criteria and GIS methodology. They incorporated cyclists' views as a support for choosing the network segments. They applied their case study in Athens, Greece because of the city's relatively high demand for bikes. They found their methodology useful for cities attempting to introduce and prioritize cycling infrastructures because it focused on determining where cyclists would prefer to cycle. In another paper, Croci and Rossi (2014) used GIS to determine the locations of bike-share stations in Milan. They also determined which attractors influence the use of bike-share stations. According to their results, the existence of metro stations, restricted traffic areas, universities, cinemas, and museums increased the bike-share usage ratio. In another real-world application, Wang et al. (2016) attempted to enhance the public bike rental system established by the Department of Transportation in Taipei, Taiwan. Their study identified locations lacking bike-share stations using GIS analysis. They also applied retail location theory to determine further rental station sites. Their study demonstrated that spatial-temporal analysis effectively determined the most suitable locations for rental stations and thus improved the public bike system in Taiwan.

In 2017, one of this paper's authors, Cetinkaya, proposed an MCDM methodology to determine the location of bike-share stations in Gaziantep, Turkey. In the study, the selection criteria weights were determined using a fuzzy AHP to manage uncertainty. The potential station sites were also ranked using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method. He reported that this methodology could be applied by policy makers attempting to adopt bike-share systems in any municipality.

Recently, Jahanshahi et al. (2018) attempted to evaluate the present status of Iran's Mashhad City bike-share stations and locate potential future station sites. They determined seven criteria for site selection. They applied an AHP based on GIS to weight the seven criteria and ranked the stations using Multicriteria Optimization and Compromise Solution [VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR)]. Finally, the locations were categorized using the Jenks natural breaks classification method. They reported that 51 of the total 128 stations were unsatisfactory. Thus, they discovered the need for an improved distribution of these bike-share stations. Guerreiro et al. (2018) developed a three-step method to design and compare cycling networks using GIS and MCDM techniques. First, potential users were identified based on real user profiles. Proposed cycling networks were then designed and compared to the networks discussed in this paper and the existing networks of the municipality. Guerreiro et al. (2018) found that the municipality's existing cycling network was ineffective for its bicyclist users. As a result, the researchers confirmed that bike-share networks require further development of scientific methods for the network planning processes.

As observed in the preceding literature review, there are not many hybrid methodologies for bike-share station site selection. Thus, this study proposes a methodology that combines GIS, AHP for criteria weights, and MOORA for rank analysis, to address the challenges of bike-share station site selection. The authors believe that this methodology fills a gap in existing research. To the best of our knowledge, the proposed approach has not been used in any other study on this topic.

2.2. Contributions of this study

Our research effort differs from prior studies because our proposed bike-share site selection method addresses multiple challenges. *First*, prior studies only considered limited criteria when identifying and evaluating potential bike-share station site locations. However, in bike-share systems, the location of a bike station is directly related to multiple factors including other transport networks, user potential, and urban life (Boettge et al., 2017), which are considered in this study. *Second*, in some of the earlier studies, although the considered criteria seem spatial, the data of the criteria are not real or verbal. However, in our study, the twelve criteria considered are explicitly spatial and real data. *Third*, in all the earlier studies that employ GIS-based MCDM, both the prioritizing and ranking processes are implemented using the same MCDM technique. However, while some MCDM tools are suited to prioritizing, others are better at ranking (Zamani-Sabzi et al., 2016). Thus, our proposed methodology applies AHP to obtain the weights of the criteria, whereas MOORA is used to evaluate the current and potential bike site locations in this study.

3. Methodologies

Techniques based on MCDM procedures attempt to help decision makers solve complex decision problems in a scientific and analytical framework. Existing MCDM techniques include AHP, analytic network process (ANP), Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE), decision-making trial and evaluation laboratory (DEMATEL), TOPSIS, MOORA, and COmplex PRoportional ASsessment (COPRAS). Each technique has advantages and disadvantages, and no single technique is superior to the others. Researchers apply them separately or integrate them with other methods in different scientific areas. To our best knowledge, there is no study that uses GIS, AHP, and MOORA for evaluation of alternative bike-share station site locations. Thus, we apply this state-of-the-art hybrid technique to determine the best bike-share station site locations for a city center in Turkey.

After providing a brief description of GIS and AHP and a detailed explanation of MOORA, this section presents the proposed methodology.

3.1. Geographic information system

Geographic information systems are designed to capture, store, analyze, and display data related to positions on Earth's surface. As depicted in Fig. 1, GIS enables the display of multiple layers of information on a single map. Entering information into GIS is known as data capture. Data that are already in digital form, such as

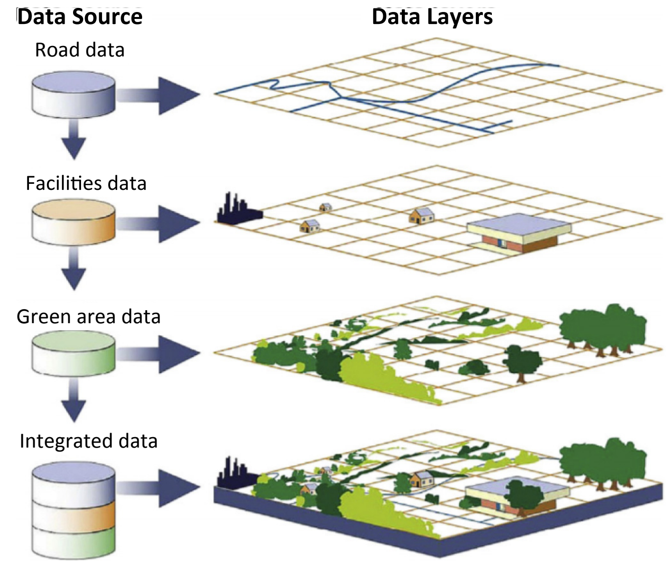

Fig. 1. Geographic information systems (GIS) combine different layers (Lepuschitz, 2015).

satellite images or other, software-created data, are easily uploaded to GIS (Lepuschitz, 2015).

For each type of data, a separate layer is created. For example, one layer shows population density, a second layer indicates bicycle line data, and a third depicts road data. Layers can differ in shape and information with respect to the objects they portray. Furthermore, the shapes of the objects may be raster or vector data. For more details, please refer to Goodchild (2015).

In this paper, ArcGIS software is used to consider the spatial data for the bike-share site selection problem. This is a commercial GIS software product capable of accurately and comprehensively outputting the spatial information and characteristics to users in terms of text or images, according to user-specified needs. The rapid evaluation of unit division and spatial overlay analysis function of ArcGIS can circumvent time-consuming statistical work during evaluation of site suitability, and the evaluating results are roughly accurate (Cheng et al., 2013).

3.2. Analytic hierarchy process

The AHP technique developed by Saaty in the 1970s is a practical MCDM technique that analyzes and solves complex decision problems (Saaty, 1980). It can be used to determine criteria weights or priorities and sort alternatives depending on quantitative and qualitative assessments. Alternatively, AHP can be applied only to determine criteria weights or priorities and act as a support for other MCDM techniques, which require criteria weights.

The primary advantages of the AHP method suggested by the authors are as follows (Ishizaka and Labib, 2009):

(i) It illustrates how possible changes in priority at upper levels influence the priority of criteria at lower levels.
(ii) Its stability and flexibility regarding changes within, and additions to, the hierarchy.
(iii) The values of the weight coefficients obtained using AHP are reliable owing to the consideration of a consistency ratio in the calculation of the weight coefficients.

In this study, the criteria weights determined by the AHP technique were used to construct the suitability map for the bike-share station sites. Details of the AHP method are not explained in this paper as we are not extending the technique and comprehensive descriptions are easily found in various papers (Subramanian and Ramanathan, 2012; Chemweno et al., 2015; Kabak et al., 2016). The software, SuperDecisions, used to execute the AHP method is free, open-source software that can be downloaded from www.superdecisions.com.

3.3. *Multi-objective optimization by ratio analysis*

The MOORA method was originally developed by Brauers and Zavadskas (2006). The MOORA method aims to simultaneously optimize two or more overlapping qualities or objectives under constraints. Although it is a relatively new method compared to other MCDM methods such as AHS, TOPSIS, ELimination and Choice Expressing Reality [ELimination Et Choix Traduisant la REalité (ELECTRE)], and VIKOR, MOORA has appeared frequently in recent literature (Zavadskas et al., 2013; Patel and Maniya, 2015; Paul et al., 2015; Dincer et al., 2017; Majumder and Maity, 2018). Different methods exist under the name of MOORA, namely a Ratio System and a Reference Point Approach. If more importance is required for an objective's response on an alternative, its performance value under the related criteria can be multiplied with a significance coefficient within the process of both algorithms. Adding the full multiplicative form to MOORA produces what is known as MULTIMOORA. This is not a different algorithm, rather, MULTIMOORA includes three or more methods that control each other and orders the alternatives depending on their performance values. Fig. 2 shows the three different methods of MULTIMOORA and their relations. The methods are briefly explained in the following subsection. Additional details are available in the following papers: Brauers and Zavadskas, 2010; Brauers and Zavadskas, 2011.

3.3.1. *Ratio system of multi-objective optimization by ratio analysis*

The ratio system method starts with the determination of criteria and the performance values of alternatives according to these criteria. The matrix below represents this method.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}$$

j 1, 2 … m; m is the number of alternatives
i 1, 2 … n; n is the number of criteria
x_{ij} Response of alternative j on criterion i
x_{ij}^* A dimensionless number representing the response of alternative j on criterion i
y_j^* The total assessment of alternative j with respect to all criteria
g The number of criteria that are maximized
$n-g$ The number of criteria that are minimized

Using Equation (1), the matrix is normalized. The total assessment of each alternative is determined by Equation (2) in which y_j^* is the ordinal ranking of the decision maker who builds the matrix.

$$x_{ij}^* = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^2}} \tag{1}$$

$$y_j^* = \sum_{i=1}^{i=g} x_{ij}^* - \sum_{i=g+1}^{i=n} x_{ij}^* \tag{2}$$

Depending on the intent of the decision maker regarding the relative importance of a criterion's response on an alternative, the dimensionless number can be multiplied by an importance value, as shown in Equation (3).

$$y_j^* = \sum_{i=1}^{i=g} s_i x_{ij}^* - \sum_{i=g+1}^{i=n} s_i x_{ij}^* \tag{3}$$

s_i The importance value/weight of the criterion.

3.3.2. *Reference point approach of multi-objective optimization by ratio analysis*

This approach is based on the normalized data obtained by the MOORA ratio system method. The highest value is taken as a reference value (r_i) for the maximization of the alternatives according to each criterion and the lowest value is taken as a reference value in the case of minimization. The alternatives' distance to the reference point according to each criterion is calculated using Equation (4).

$$r_i - x_{ij}^* \tag{4}$$

The matrix is calculated using the Min-Max Metric of Tchebycheff shown in Equation (5).

$$\min_{(j)} \left\{ \max_{(i)} \left| r_i - x_{ij}^* \right| \right\} \tag{5}$$

Alternatives are sorted from low value to high value, and ranking is determined. The alternative with the lowest value is considered the best. Equation (6), the reference point approach formula, reflects the relative importance assigned by the decision maker to a criterion's response on an alternative.

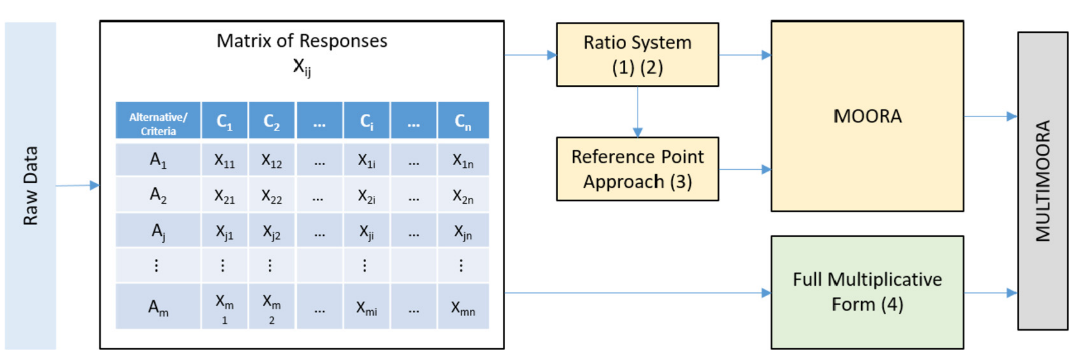

Fig. 2. Diagram of full multiplicative form multi-objective optimization by ratio analysis (MULTIMOORA) (Balezentis et al., 2010).

$$\left|s_i r_i - s_i x_{ij}^*\right| \tag{6}$$

3.3.3. Full multiplicative form

In this approach, the maximization data of each alternative is multiplied and divided by the multiplication of the data for minimization purposes. This approach is expressed by Equations (7–9).

$$U_j = \frac{A_j}{B_j} \tag{7}$$

$$A_j = \prod_{g=1}^{i} x_{gi} \tag{8}$$

$$B_j = \prod_{k=i+1}^{n} x_{kj} \tag{9}$$

j 1, 2 …, m; m is the number of alternatives
i The number of criteria to be maximized
$n-i$ The number of criteria to be minimized
U_j The utility of alternative j with criteria to be maximized and criteria to be minimized

The values of U_j are sorted from high value to low value and the first-order alternative with the highest grade is considered the most appropriate alternative.

3.3.4. The full multiplicative form multi-objective optimization by ratio analysis approach

The MULTIMOORA approach is a general form of the MOORA method developed by Brauers and Zavadskas in 2010. The MULTIMOORA is not a standalone method. After the rankings are determined according to the MOORA methods, ratio system, and reference point approach, the MULTIMOORA carried out a final evaluation based on their dominance. The theory of dominance is based on propositions such as dominance, being dominated, transitivity, and equability. Details of the dominance theory are found in papers by Brauers and Zavadskas (2012) and Hafezalkotob and Hafezalkotob (2015).

4. Proposed approach

Location selection for bike-share stations represents a spatial problem that requires the manipulation of a huge amount of data. The methodological hierarchical model in this paper is based on GIS and MCDM analysis structures. Integrating GIS with the multi-criteria decision analysis (MCDA) techniques for decision-making creates a powerful tool that has been applied to solve various problems including selecting feasible locations for freight villages (Özceylan et al., 2016), refugee camps (Cetinkaya et al., 2016), and wind farms (Villacreses et al., 2017). The AHP and MOORA approaches were tested by means of a MCDM model implemented in two phases:

(1) Determining the weight coefficients of the evaluation criteria.
(2) Ranking of the alternatives.

These approaches use the geospatial data management capabilities of GIS and flexibility of MCDM to combine factual information such as proximity and transport network, with value-based information such as expert opinion or population. The proposed GIS-MCDM model for selecting suitable locations for bike-share stations is described from a methodological point of view as follows:

Once the problem is defined and the model is established, then the evaluation criteria and constraints are determined. The constraints are based on the Boolean relation (true/false) and based on the criteria that limit possible alternatives. The evaluation criteria can also be quantified according to their degree of suitability for all feasible alternatives. The criteria considered are represented in Fig. 3.

Later, evaluation criteria assessment and criteria standardization are conducted. The criteria on the maps are presented in the form of GIS layers in different ways and forms. The weighted linear combination requires all data sets to be standardized or transformed into comparable units. Additionally, the method requires normalization of the weights. AHP is used for calculating the normalized weight criteria. Then, alternative bike-share station site locations are ranked using MOORA. Finally, the best-suited locations are identified. The proposed methodology is explained and diagrammed in Fig. 4.

5. Application of the methodology

In this section, the proposed methodology is applied to the region of Karsiyaka, located at the north of Izmir Bay in Turkey. First, the study area is introduced. Then, the data set and layers of criteria are presented with the GIS-generated maps. Finally, the priorities of each criterion and the rankings of each current and alternative site are provided.

5.1. Study area

The study area, Karsiyaka, is located at the north of Izmir, which is the third largest city in Turkey. In 2017, the population of the Karsiyaka region was 342,062, constituting 8% of the total population of Izmir. Karsiyaka is located at 38° 27′ 19″ North, 27° 7′ 12″ East and covers a total of 25,437 km^2. Fig. 5 maps the study area.

In the region of Karsiyaka, there are currently nine bike-share stations located along the cycle line, as illustrated in Fig. 6.

According to the Karsiyaka Municipality, the total number of bikes for sharing is 130. However, the current system is not sustainable, primarily for three reasons. First, the number of bicycles available is insufficient for the passenger demand. The second and third problems are the location of the cycle line relative to the service area and the distances between current bike-share station sites. As observed in Fig. 6, there are no bike-share stations in the interior of the region. Instead, all stations are located along the coastline. Furthermore, while the stations C1 and C2 are close together, stations C3 and C4 are much farther apart. To overcome these problems, the proposed methodology is applied step-by-step, as described in the following sub-sections.

5.2. Data set and layers of criteria

As mentioned in Section 4, this study used twelve different criteria to evaluate the current stations and select alternatives. The geographic values of each criterion were obtained using ESRI ArcGIS 10.2 software. Table 1 describes the GIS data type for each criterion.

To ensure measurement integrity, the geographic data of each criterion were normalized to [0, 1]. In Figs. 7 and 1 is represented with pure white coloring and 0 is represented with true black. Thus, the desired areas are illustrated in white. Fig. 7 shows map layers of

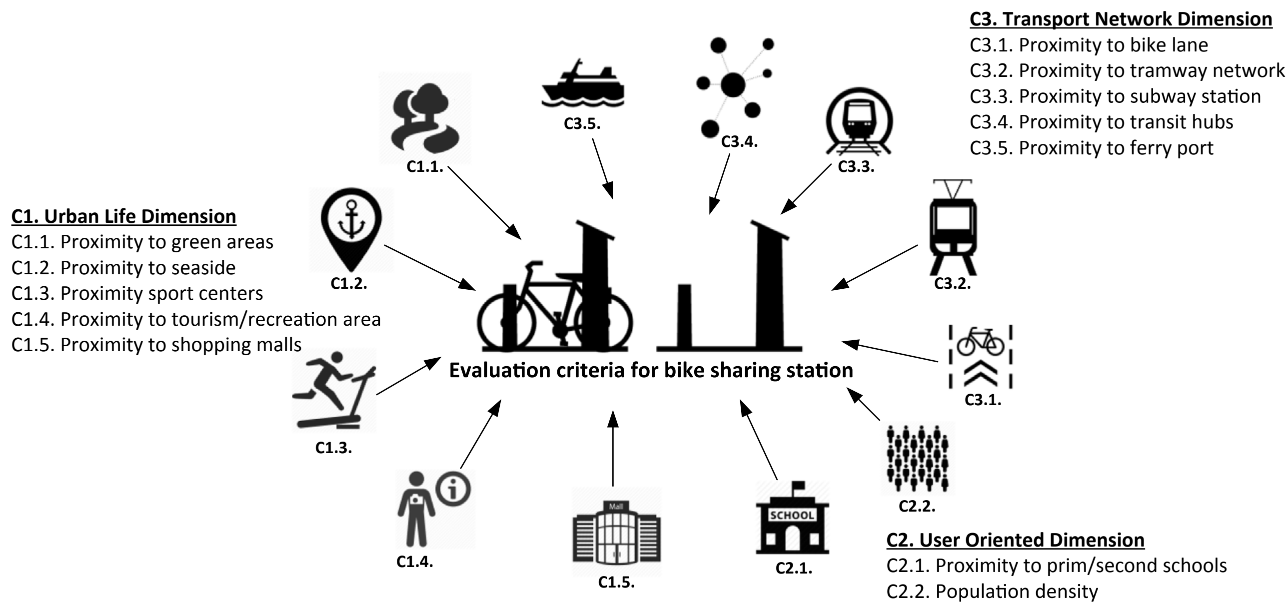

Fig. 3. Criteria for the bike-share station site selection.

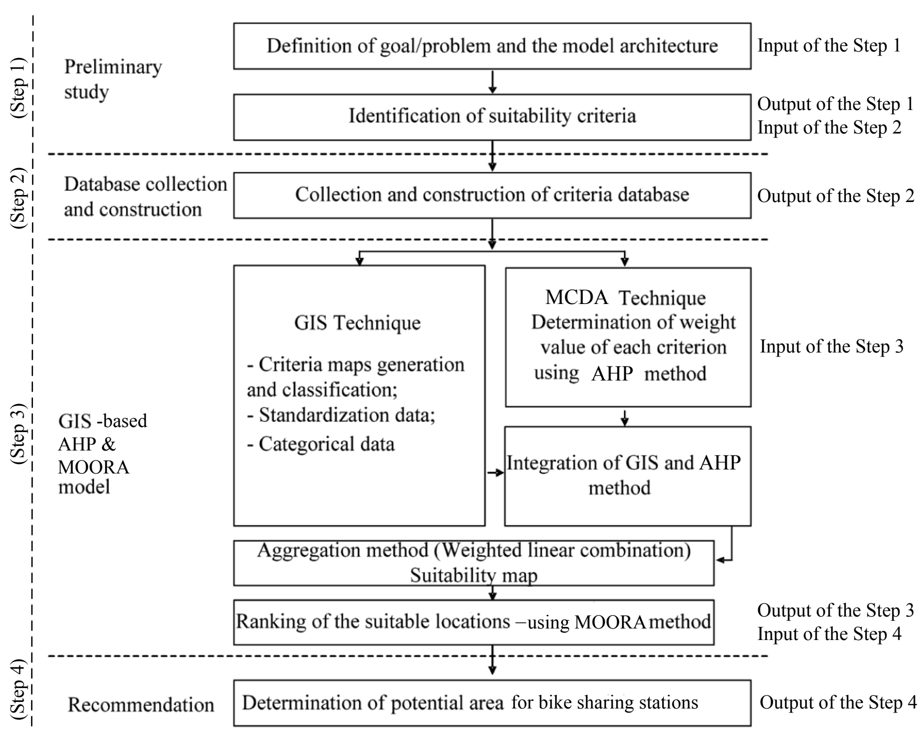

Fig. 4. Methodology for site selection process.

each criterion with normalized values. Data for each criterion is available upon request.

Map layers in Fig. 7 are combined with the corresponding weights calculated in the following sub-section.

5.3. Determination of the priorities and alternatives

In this phase, the experts, the authors of this paper and four citizens using city bicycles, form an individual pairwise comparison matrix using scales of 1–9, which are used within AHP. For example, criterion C31, proximity to bike lane, is compared with criterion C32, proximity to tramway network, using the question “Which is considered more important by the users ranking bike stations, and how much more important is it with respect to satisfaction with the bike site?” If the answer is 3, it means that C31 is more important than C32, but the degree of importance is weak. An answer of 9 also indicates that C31 is more important than C32, but in this case, its degree of importance is absolute. According to the scale, 1 means that two criteria have equal importance, 3 shows that the criterion in the column has a weaker importance than the

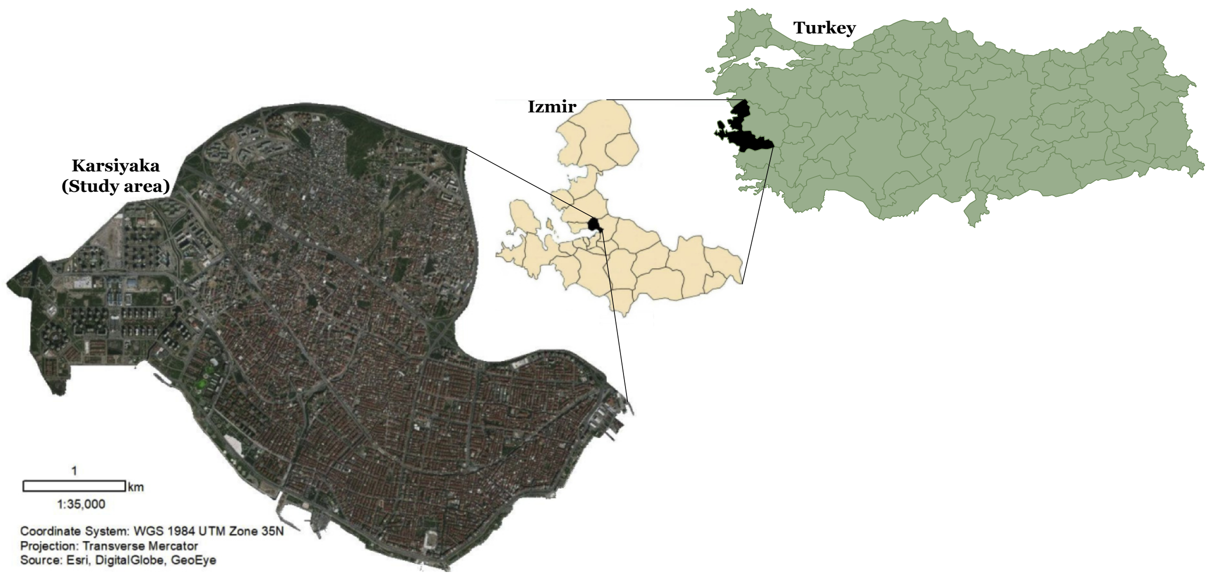

Fig. 5. Location map of the study area.

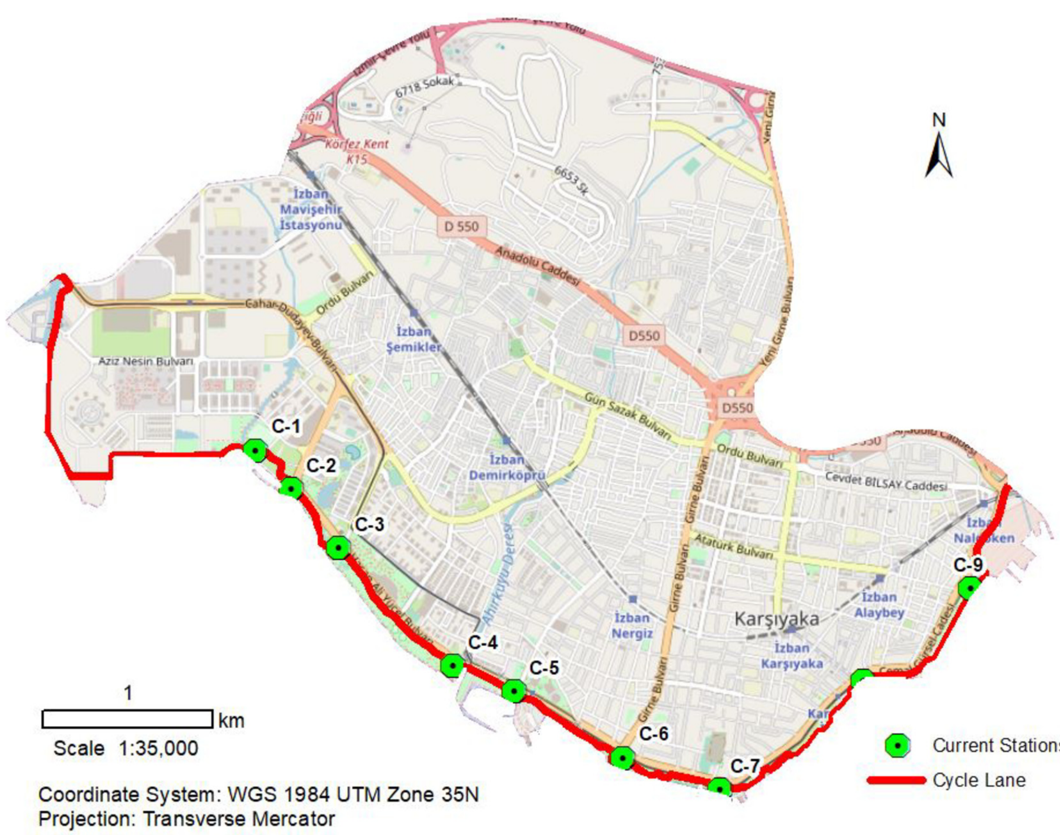

Fig. 6. Locations of current bike stations and cycle line.

criterion in row, and 5, 7, and 9 indicate strong importance, demonstrated importance over the other and absolute importance in the same manner, respectively. SuperDecision software was used to determine criteria weights.

In terms of main criteria, the transport network dimension outweighs other dimensions. The most important factor in the transport network dimension criteria group is C31, proximity to bike lane, as reflected by its overall priority value of 0.298. Other influential factors, ranked by weight, are as follows: C34, proximity to transit hubs, (0.129); C13, proximity to sport centers, (0.115); C22, population density, (0.098). The lowest priority values belonged to C21, proximity to primary or secondary schools, (0.017), and C15, proximity to shopping malls, (0.022).

A suitability map for the bike station sites was obtained by

Table 1
Spatial data and analysis list.

Criteria		Data	Data Source	Analysis
C1.1.	Proximity to green areas (parks)	Park areas	Open Street Map Data	Euclidean dist.
C1.2.	Proximity to seaside	Shoreline	Open Street Map Data	Euclidean dist.
C1.3.	Proximity sport centers	Sport centers	Open Street Map Data	Euclidean dist.
C1.4.	Proximity to tourism/recreation area	Rec. areas	Provincial Directorate of Culture and Tourism of Izmir	Euclidean dist.
C1.5.	Proximity to shopping malls	Malls	Municipality of Karsiyaka	Euclidean dist.
C2.1.	Proximity to prim/second schools	Schools	Open Street Map Data	Euclidean dist.
C2.2.	Population density	Population	https://www.nufusu.com/ilce/karsiyaka_izmir-nufusu	Density
C3.1.	Proximity to bike lane	Bike lane	Open Street Map Data	Euclidean dist.
C3.2.	Proximity to tramway network	Tramway	ESHOT General Directorate	Euclidean dist.
C3.3.	Proximity to subway station	Roadway	ESHOT General Directorate	Euclidean dist.
C3.4.	Proximity to transit hubs	Transit hubs	ESHOT General Directorate	Euclidean dist.
C3.5.	Proximity to ferry port	Ferry ports	ESHOT General Directorate	Euclidean dist.

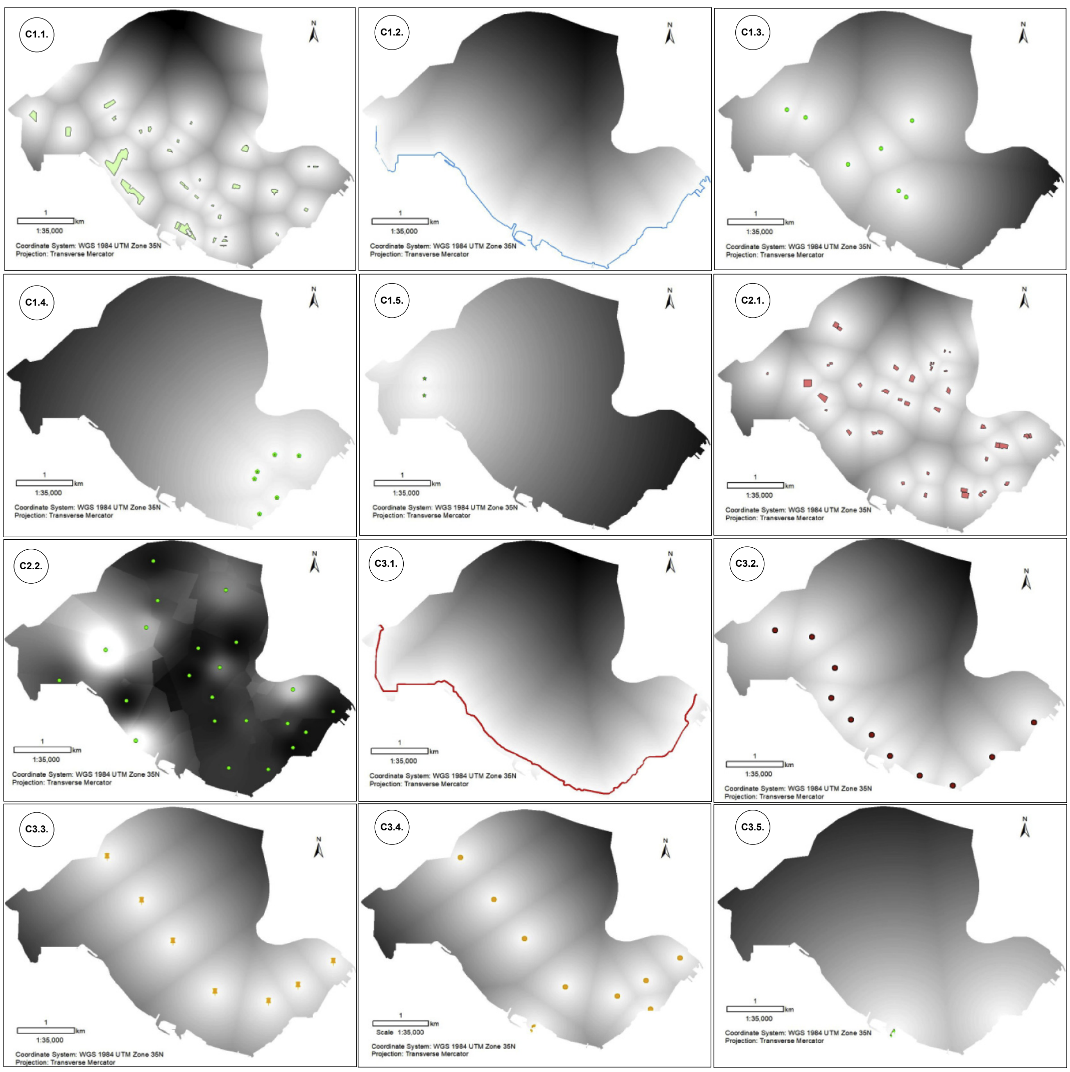

Fig. 7. Map layer of each criterion.

multiplying the weights of each criterion with the values of each pixel on the map. Fig. 8 indicates the suitability of the depicted area for potential bike-share stations. Per Fig. 8, the middle-east and middle-south parts of Karsiyaka are best-suited for bike-share station settlement. Conversely, the northern area has the lowest rates, indicating that area is not suitable for bike-share station locations.

After the suitability map is constructed, it is time to identify alternative locations for new bike-share stations. Although there is no formal approach to determine the alternative locations, the suitability map is classified based on the previously calculated scores, shown in Fig. 9(a). In the suitability map, there are approximately 1000 pixels that indicate suitable points for bike-share stations with values ranging from 0.874 to 0.177. Ranking

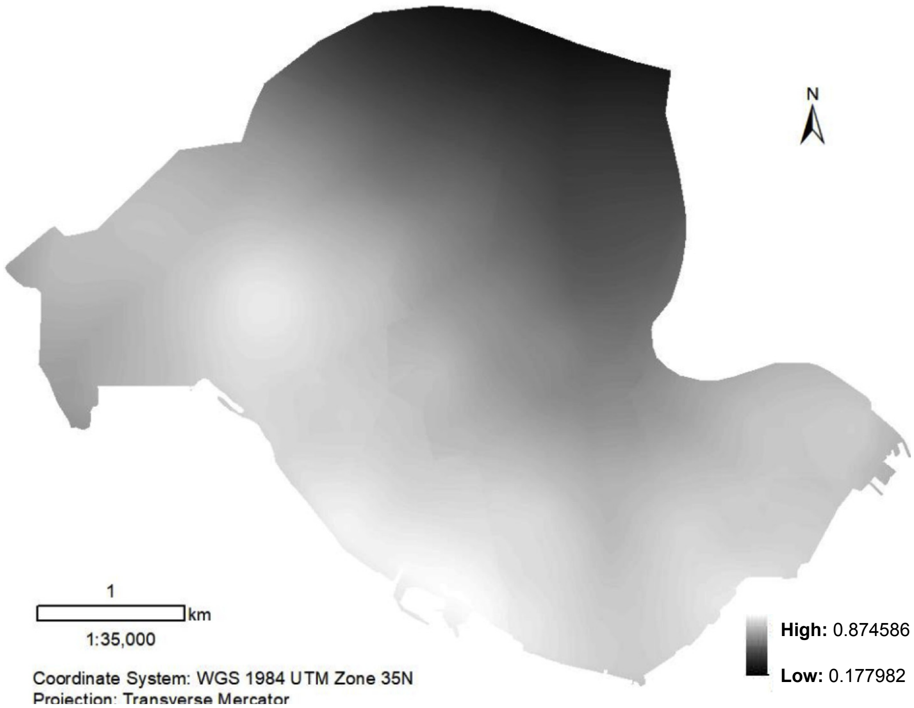

Fig. 8. Normalized suitability map for bike-share stations.

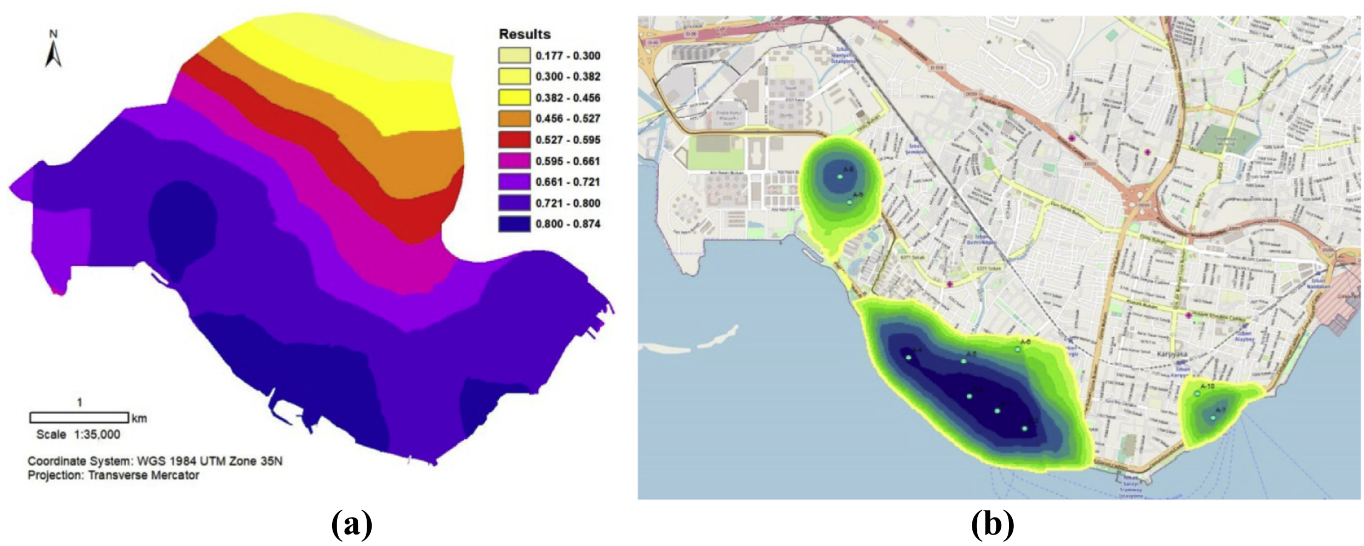

Fig. 9. (a) The classified suitability map; (b) areas with values greater than 0.8.

all the suitable points would be time consuming, if not almost impossible. Therefore, suitable points with low scores were eliminated. When the nine different classifications were investigated, it became clear that the areas with scores greater than 0.8 encompassed the coverage area of the current bike-share stations. Regions with scores greater than 0.8 were considered for the alternatives. As observed in Fig. 9, places with scores of less than 0.8, indicating undesirable station locations, were located in the interior of the city. When the points with values greater than 0.8 in the normalized suitability map were investigated, the region was classified into three sub-regions. Fig. 9(b) depicts these three sub-regions.

While determining the alternative sites, the distance to the current sites was considered and determined to be a minimum of 250 m. According to this information, a total of ten alternative bike-share station sites were identified. It must then be confirmed that the determined points are available for the construction of bike-share stations, meaning that there are no roads, buildings or other physical facilities on the identified sites. The locations of ten alternative sites and nine current sites are illustrated in Fig. 10. Fig. 10 shows that the alternatives occur more frequently than the current sites and their locations are further inland. However, if a new site is built then it may change the suitability map as there would be no point in placing another site in the vicinity of the current site.

Table 2 lists the criteria of each alterative and current site and their final scores that were based on the priorities. According to

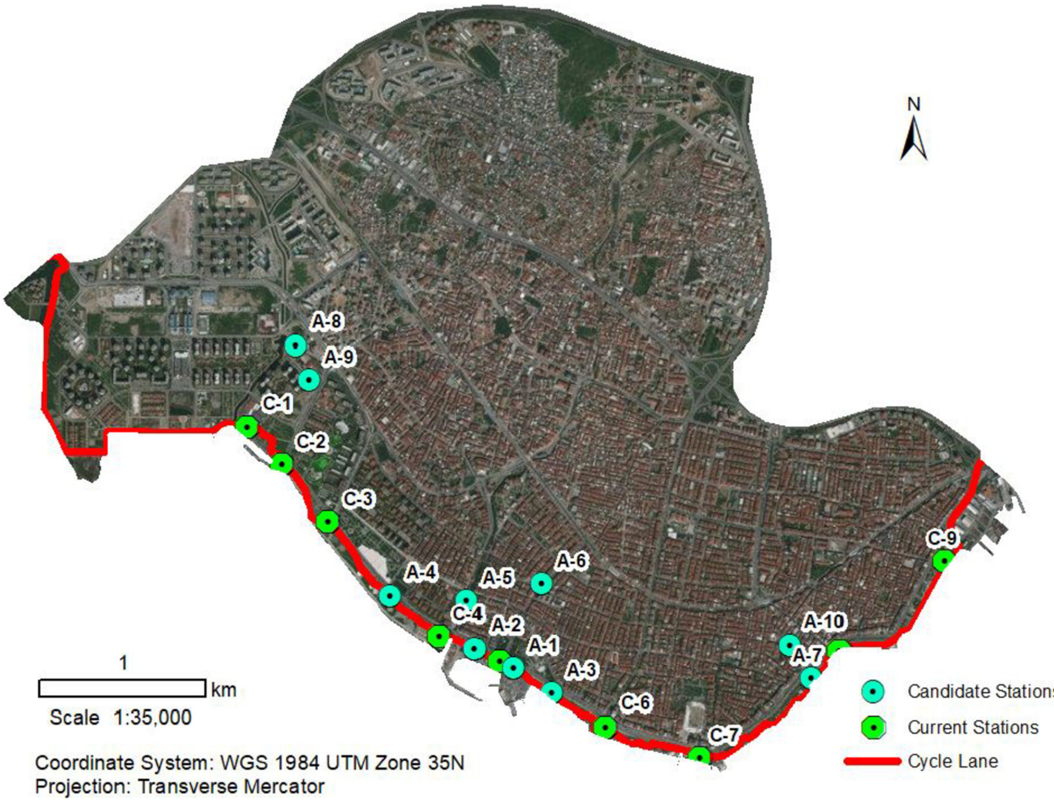

Fig. 10. Alternative (A) and current (C) locations for bike-share stations.

Table 2
Criteria and final values of alternative current bike-share stations.

Sites	Normalized Criteria Value												Final Value
	C1.1.	C1.2.	C1.3.	C1.4.	C1.5.	C2.1.	C2.2.	C3.1.	C3.2.	C3.3.	C3.4.	C3.5.	
A-1	0.984	0.976	0.780	0.761	0.519	0.890	0.480	1.000	0.990	0.768	0.936	0.962	0.875
A-2	0.948	0.980	0.773	0.725	0.563	0.848	0.605	1.000	0.924	0.736	0.864	0.919	0.867
A-3	0.977	0.994	0.751	0.791	0.471	0.862	0.412	0.997	0.921	0.773	0.944	0.967	0.863
A-4	0.960	0.974	0.754	0.637	0.666	0.756	0.894	1.000	0.925	0.661	0.674	0.805	0.856
A-5	0.885	0.933	0.828	0.718	0.604	0.834	0.627	0.931	0.997	0.750	0.779	0.868	0.838
A-6	0.930	0.836	0.939	0.795	0.549	0.924	0.358	0.846	0.865	0.877	0.858	0.865	0.811
A-7	0.971	0.994	0.493	0.985	0.248	0.932	0.277	0.996	0.979	0.856	0.928	0.957	0.825
A-8	0.943	0.830	0.925	0.460	0.875	0.973	0.986	0.841	0.927	0.804	0.773	0.514	0.835
A-9	0.883	0.860	0.863	0.489	0.861	0.990	0.823	0.879	0.911	0.790	0.756	0.556	0.820
A-10	0.951	0.931	0.553	0.969	0.284	1.000	0.266	0.931	0.943	0.921	0.908	0.934	0.807
C-1	0.875	0.986	0.806	0.447	0.903	0.843	0.543	0.993	0.802	0.660	0.605	0.551	0.793
C-2	0.973	0.991	0.808	0.495	0.848	0.854	0.456	0.996	0.880	0.652	0.596	0.611	0.797
C-3	0.977	0.979	0.843	0.560	0.769	0.842	0.377	0.997	0.934	0.677	0.625	0.695	0.805
C-4	0.858	0.985	0.746	0.688	0.599	0.779	0.746	0.993	0.922	0.689	0.797	0.878	0.855
C-5	0.979	0.985	0.778	0.747	0.535	0.878	0.528	1.000	0.968	0.756	0.912	0.947	0.874
C-6	0.919	0.985	0.681	0.849	0.405	0.870	0.329	0.997	0.994	0.743	0.835	0.901	0.825
C-7	0.817	0.994	0.556	0.936	0.306	0.801	0.319	0.991	0.991	0.715	0.669	0.798	0.771
C-8	0.897	1.000	0.465	0.950	0.234	0.952	0.196	0.997	0.948	0.859	0.976	0.985	0.816
C-9	0.843	0.992	0.305	0.912	0.159	0.843	0.209	0.993	0.988	0.863	0.841	0.836	0.764

Table 2, all final values of alternative sites are greater than 0.8. Although the final values of the current sites are not low, suggested alternatives have better scores than do the current sites. In detail, A-1, A-2, and A-4, show a great performance with their proximity to bike lane (C3.1.). On the other hand, A-4 and A-8 have favorable scores with their population density (C2.2.) score. Now, the question is which alternative or current bike-share site is the best. To answer this question, MOORA approach is applied in the following sub-section.

5.4. Determination of the final rank

The final step of the proposed study is to rank the alternatives and compare them with the current sites. To do so, calculations are made according to the Equations (1–9) given in Section 3.3. It must be noted that no software was used for the MOORA calculations. Ranking of alternative bike sites was determined using the ratio system, the reference point approach, and the full multiplicative form, as shown at Table 3. Site A-1 ranked first according to the MOORA ratio systems, followed by C-5, A-3, A-2, and A-7,

Table 3
The ranking of the bike stations based on the MULTIMOORA approach.

	Sites	Ratio System	Reference Point	Multiplicative Form	MULTIMOORA
Alternative Sites	**A-1**	1	3	2	1
	A-2	4	1	8	4
	A-3	3	5	5	3
	A-4	8	9	13	8
	A-5	16	15	9	15
	A-6	18	18	16	18
	A-7	5	7	1	5
	A-8	19	19	14	19
	A-9	17	17	18	17
	A-10	15	16	6	13
Current Sites	**C-1**	14	12	19	16
	C-2	11	13	15	14
	C-3	10	11	12	10
	C-4	9	4	17	7
	C-5	2	2	4	2
	C-6	7	6	7	4
	C-7	13	10	11	11
	C-8	6	8	3	6
	C-9	12	14	10	12

respectively. Site A-1 is the second most preferred site based on the multiplicative form, while it ranks 3rd according to the reference point method. None of the alternatives dominates others according to the MOORA methods. The final ranking based on the MULTIMOORA, the combination of the three preceding rankings, is more compelling. Sites A-1 and C-5, with their proximity to the bike lane, are preferred among others. Site A-8 ranks lowest, despite its favorable population density.

6. Conclusion

The usage and implementation of bike-share programs have increased over the last few years, because of the system's many benefits. The affordability and ecofriendly aspects of the system have enabled cities to integrate the system quickly. Bike-share systems are an effective tool to reduce automobile traffic and the associated stressors, such as traffic and pollution. Bike-share systems may also be tourist attractions. People may explore and visit places using bike-share systems. In addition, cities using these systems find that the bike-share networks enhance their existing intercity transportation networks. As mentioned previously, the most important contributions of bike-shares system are the environmental benefits.

However, there are some critical parameters that must be handled carefully to maximize the positive outcomes derived from bike-share systems. These parameters concern cyclist safety and system productivity. Determination of bike lines, combination of transportation networks, or determining the bike-share station locations are some of these parameters. This paper provides a scientific framework for identifying and evaluating bike-share station sites, as demonstrated using the Karsiyaka region of the popular tourist destination of İzmir, Turkey.

For the solution, first, twelve criteria were determined using existing literature and the insights of municipality experts. Then, AHP was applied to obtain the weights of the criteria, and the MOORA was used to evaluate the current and potential alternatives for bike-share stations. As expected, the transport network dimension weights were determined to be more important than other dimensions. The most important factor from the transport network dimension was C.3.1, proximity to bike lane, and the lowest priority belonged to C.2.1, proximity to primary or secondary schools. Finally, site A-1 was distinguished as the most suitable alternative for a potential bike-share site. From the existing bike-share stations, C-5 appears to be the most effective bike-share site compared to other sites.

To summarize, this study offers both an evaluation for the existing bike-share stations and suggests alternatives sites for additional bike-share stations. Because the implementation of the system is very important the overall productivity of a bike-share network, the implications of this study could be used as a guide by other municipalities. The proposed method is generic, except for a few criteria, and can be adapted to different location selection problems, especially with similar demand types such as automobile sharing stations.

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