Evaluation and Relocating Bicycle Sharing Stations in Mashhad City using Multi-Criteria Analysis

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Abstract

The purpose of this study is to evaluate the present status of Mashhad’s Bicycle Sharing (BS) Program's stations, and to locate future stations, taking into account the 7 criteria of “proximity to subway stations”, “proximity to other stations”, “distance from important intersections”, “distance from population centers”, “proximity to educational, recreational and commercial centers”, “slope level” and “proximity to cycling infrastructure (bike lanes)”. The approach employed by the present study is Multiple-criteria decision making (MCDM) and Fuzzy membership maps and Analytic Hierarchy Process (AHP) based on GIS to weight the 7 mentioned criteria, also the stations will be ranked based on VIKOR approach and finally categorized through Jenks natural breaks classification method (JENKS). In order to analyze the data ArcGIS 10 software has been used. The findings show that 26 stations (20.3%) are very unsatisfactory and 25 stations (19.5%) are unsatisfactory among the total 128 stations that have been built so far. The findings also indicate that there are a lot of stations with very unsatisfactory conditions on the borders of the coverage area of the BS program which imply that widespread coverage has been prioritized over efficiency and proper distribution of the stations. Also 22 planned stations that have been stipulated in the contract between Mashhad’s municipality and the beneficiary firm have been located based on the ratings that were assigned. This study, as the first study with the mentioned approach on this subject in Iran shows that priorities regarding the performance of BS program may not be well conceived in different regions and cities, especially in developing countries with their own specific conditions. Thus, in this research we have tried to present the existing problems in locating the stations, and contribute to development of the existing programs and possible future programs in other cities.

Keywords: Shared bicycles, relocating stations, GIS, VIKOR, Mashhad City.

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1. Introduction

In the past years sustainable development has been proposed as the last resort that could solve the problems caused by development. It basically means that we must take into account the needs and interests of future generations as well as the existing population [Nikpour, Malekshahi and Rezqi Rami, 2015]. Reduction and control of pollution, reduction of energy consumption, using public transportation and reduction of urban traffic are among the principles of sustainable urban development [Navabakhsh and Bazrafshan, 2014]. Today, achieving sustainable urban mobility as one of the main principles of sustainable development, is one of the major challenges of rapid urbanization, which in turn leads to serious problems like health problems, financial and social problems and environmental issues [Ahmad and Oliveira, 2016]. Meanwhile in recent years, governments have tried to compensate for some of the problems caused by urban development by encouraging citizens to use bicycles in urban areas by renting bicycles, or in the more advanced form of BS program. The first BS program was established in Amsterdam, Netherland in the 60's, which failed due to theft and vandalism [Shaheen, Guzman and Zhang, 2010]. However, over time and by the advancement of technology, advanced BS programs are offering services in many cities of the world [DeMaio, 2009]. Bicycle sharing programs as a short-distance transportation mode, are one of the innovations of governments for removing the obstacles of using bicycles in cities [Shaheen et al. 2011].

Bicycle sharing programs are programs for short term renting of bicycles from one station to travel short distances to other stations [Fishman, Washington and Haworth, 2013]. However using bicycles in urban areas has its own problems and obstacles. In fact different factors are involved in efficiency and popularity of BS programs. One of the factors that plays an important role in success of these programs is the status of the docking stations. Stations of BS programs as the most important factors in acceptance of such programs have different characteristics. Efficient planning based on these characteristics is of utmost importance.

Many studies have been conducted on the subject of BS programs and a lot of researchers have pointed to the significance of stations, as the most important aspect of infrastructure. Among the studies that were conducted outside Iran, we can refer to the study by Bernatchez et al., (2015) which analyzed the awareness of the citizens about a bicycle sharing program by evaluating the impact of different factors that are mentioned in this research. The result shows that, the distance of docking stations from people's houses has been identified as an important factor in awareness of people about BS programs [Bernatchez et al. 2015]. Also Garcia Palomares, Gutiérrez and Latorre embarked on locating docking stations in Madrid, Spain by using GIS and location-allocation models using different scenarios. With respect to the short history of BS programs in Iran and the limited studies that have been done on this subject, we can point to a study by Javadi et al., (2014) which was conducted on district 7 of Tehran, in which docking stations were located by using GIS and fuzzy approach, considering factors such as accessibility, proximity to main intersections and parking spaces and also distances between docking stations. In another study, Khalili and Heidari Nouri (2014) with the purpose of reducing transportation problems, reaching a dynamic and efficient communication network and achieving better accessibility for the public in district 8 of Tehran; did a site selection and proposed 4 new stations using GIS.

In analyzing effective factors and features in desirability of docking stations, different indices can be taken into account. It must be noted that unbalanced distribution of urban facilities and services can challenge the concept of a sustainable city. In fact, in providing urban services, achieving quantity does not necessarily mean satisfactory service. It is important to distribute services and facilities in a way that all citizens could benefit from them [Khakpour and Bavanpouri. 2009]. This should be kept in mind when planning the locations of stations of BS programs. In fact it can be said that the quality of BS programs is not dependant on increasing the coverage area, but in efficiency [Midgley, 2011].

The number and capacity of stations has a lot of impacts on the acceptance of a BS program. Moreover, increasing the number of stations has been proposed as an effective factor in development of the program too [Tran, Ovtracht and d'Arcier, 2015; Roland Berger Study, 2015; Institute for Transportation & Development Policy, 2013; Shaheen et al. 2011]. In general, increasing the number and capacity of docking stations will have a positive effect on bicycle sharing programs [Tran, Ovtracht and d'Arcier, 2015]. Proper positioning of docking stations is also important for designing an efficient, secure and practical BS program. It also decreases the need for redistribution of bicycles in the stations [Midgley, 2011]. Analyzing the amount of demand plays an important role in ensuring success of a BS program [Tran, Ovtracht and d'Arcier, 2015]. On the other hand it is important to note that the aim of a BS program is not only reducing greenhouse gas emissions and creating a healthy transportation model for short distances, but also accessibility of low income households. For instance, research shows that the BS program of Suzhou, China is less accessible to low income individuals [Karki and Tao, 2016]. On this basis, relocating docking stations based on important factors can lead to more efficiency [Karki and Tao, 2016]. Some of the BS programs like the one in Guangzhou, China have used mobile stations (31 stations) in addition to permanent stations (30 stations) in order to reach a successful model, and then make them permanent [Shaheen et al. 2011]. Also in BIXI program of Canada, mobile stations were analyzed in order to determine use patterns of the users, and move them to the most effective locations [Shaheen, Guzman and Zhang, 2010]. However, in programs that do not use mobile stations, the best way of analysis is relocating and efficient positioning of docking stations.

In this paper different effective factors in desirability of BS programs will be identified by analyzing different studies on this subject. In the following, we will relocate the docking stations of Mashhad's BS program as the first mechanized BS program in Iran based on multiple criteria decision making, AHP and fuzzy approaches in addition to evaluating the present condition of this program. Ranking existing stations based on their ratings in different effective factors by using VIKOR approach and categorizing them based on JENKS approach are the next steps. Finally, with respect to the fact that the stations haven’t still reached the pre-planned number by the municipality, recommendations for efficiently locating other stations will be presented. The process used in this research could significantly help urban managers and planners to successfully carry out similar programs in other cities of Iran.

2. Materials and Methods

In order to carry out a spatial analysis about shared bicycles, important factors in desirability of docking stations were identified using library research and previous studies. Then a Geodatabase of relevant geographical information was collected and GIS layers for the 7 important factors of Table 1 were provided by Mashhad’s Municipality and saved in it. Weights of factors were determined based on AHP approach, as an efficient approach in multiple criteria decision making, and the layers of GIS were fuzzified due to lack of certainty in decision making. Then by allocating weights to the fuzzy layers of the final map, the best locations of the docking stations were marked. Finally, by using VIKOR approach and based on the collected information each of the stations were ranked and categorized through JENKS method in 5 groups, ranging from very satisfactory to very unsatisfactory. Ranking and categorizing stations with this method can show the status of existing stations and recommend substitute stations. Also analyzing desirability in different districts of Mashhad can guide us for constructing the remaining stations.

2.1 Effective Factor in the Status of Bicycle Sharing Stations

2.1.1 Proximity to Subway Stations

One of the important objectives of BS programs is solving “the last mile” problem (a short distance for cycling between transportation stations and home, workplace, university, etc) [Gupta et al. 2014]. In the fourth generation of BS programs, the mentioned issue is of great importance and it is essential for BS programs to be integrated with other transportation modes for efficient transportation. More and more cities are trying to achieve this integrated transportation model [Shaheen et al. 2011]. In fact this integration is one of the main points that could lead to success of a BS program [Roland Berger Study, 2015; Midgley, 2011; Tran, Ovtracht and d'Arcier, 2015], and BS programs are more desirable and popular when they are integrated with other transportation modes [Midgley, 2011].

Meanwhile it is important to note that integration with other transportation modes is not the only factor for the success of BS programs. Efficiency of these transportation modes is what ensures a practical and successful integration. There is no doubt that without an efficient transportation system, a BS program cannot be successful. In this research with respect to the fact that Mashhad has a subway system, the proximity to the subway stations has been one of the important factors in rating docking stations.

2.1.2 Proximity of Docking Stations

Another important factor is locating the stations with proper distances between them. Many researchers have pointed out the importance of proper distancing among the stations of a BS program [Karki and Tao, 2016; Midgley, 2011; National Association of City Transit Officials “NATCO”, 2015; Institute for Transportation & Development Policy, 2013]. In fact, short distance between the stations, in a way that could be walked, is one of the keys to success of a BS program, and a balanced distribution can ensure everybody’s right to access the program [NATCO, 2015]. According to Institute for Transportation & Development Policy, proper distribution of docking stations, with approximately 300 meters between stations, is one of the factors that affect success of a program [ITDP, 2013]. Also the American Public Transportation Association has stated that the number of stations should not be below 28 in each square mile [NATCO, 2015]. It could be said that the distance between stations should be 300 meters to 500 meters [Karki and Tao, 2016]. However, in general the desirable distance between the stations depends on the size and structure of each specific city. For instance in the cities of Paris and Barcelona, there is a docking station every 300 meters [Midgley, 2011]. However, in developing countries, achieving this desirable distance could be challenging.

Another important issue is balanced distribution of relevant urban facilities and services [Khakpour and Bavanpouri, 2009]. Urban facilities must be distributed fairly in a city. There are different opinions on this subject and in some cases proper distribution is prioritized over coverage. However, due to financial shortcomings or political considerations coverage area is often prioritized over satisfactory distribution [NATCO, 2015].

With regard to the mentioned points and considering that economic conditions and approaches of decision makers vary in different countries and regions, the amount of investment in this transportation mode could be different in different societies. Therefore, adequate stations with the mentioned desirable distances may not be achievable due to lack of funding or unwillingness of decision makers. Thus, by considering average speed and average use period of the bicycles, we can estimate the acceptable distances. The average cycling speed is 14 km per hour and the average cycling period is 15 minutes, which means 3500 meters of cycling [Tran, Ovtracht and d'Arcier, 2015]. It is important to note that the distances under 6 kilometers are acceptable in a bike trip due to the fact that it is faster than using other transportation modes [Soltani and Shariati. 1392]. Therefore in this section, in order to define the relations about proper distances between the stations, a 300 meter distance has been considered ideal, and longer and shorter distances reduce the desirability of this index.

2.1.3 Distance from Important Intersections

Distance from important urban intersections as places that are commonly more travelled to, is an important factor in locating docking stations. In other words stations must have proper access to different urban regions and important intersections [Roland Berger Study, 2015; Karki and Tao, 2016; Shaheen, Guzman and Zhang, 2010]. Therefore in this study 41 important intersections have been considered in the analysis based on their importance according to the data collected from Mashhad’s municipality.

2.1.4 Population

A study on the city of Lyon in France shows that population and occupations are among important factors that affect use of BS programs in long-term by permanent users [Tran, Ovtracht and d'Arcier, 2015]. Also in Guangzhou, China it was observed that 40 percent of use belonged to the stations that were near people’s houses [Shaheen et al. 2011]. Therefore, proximity of stations to population plays an important role in locating docking stations. In other words, the population that a BS program covers is of great importance and the more populous a region is, the more docking stations there must be [Bernatchez et al. 2015].

2.1.5 Proximity to Educational, Recreational and Commercial Facilities

Land Use become an essential part of current plans for dealing with spatial problems management across the globe, both by national and local organizations [Minaei and Kainz, 2016]. Studies show that land use in the coverage area of a BS program is a significant factor in the use of the program too. In many studies, proximity to educational, recreational and commercial facilities has been identified as a facilitator for bicycle sharing programs. Research shows that students are one of the main groups that use shared bicycles [Tran, Ovtracht and d'Arcier, 2015]. Also the results of a study by Shaheen et al., (2011) show that in Guangzhou, 40% of use is related to the people whose workplaces are near the docking stations. In a study by Fishman in Australia, which was done in two regions of Melbourne and Brisbane, proximity to workplace had been stated as the most important priority by the users [Fishman et al. 2014]. Therefore, regarding the importance of proximity of docking stations to different facilities, this index has been considered as one of the effective factors in desirability of docking stations.

2.1.6 Slope Level of the Paths

Another important factor, is the topography and slope level of the pathways. In general, people would not be interested in cycling in areas with more than 4 degrees of slope level, and in slope levels more than 8 degrees, they would not be interested in cycling. Usually stations located in heights are empty of bicycles and stations in low altitudes are full of bicycles

[Midgley 2011]. One of the solutions of dealing with slope issues in cities, is practical redistribution in a program. Redistribution is one of the practices followed by many BS programs worldwide. Active and timely redistribution of bicycles in the stations is one of the important factors in efficiency and proper function of the program [Shaheen, Guzman and Zhang, 2010; Shaheen et al. 2011].

Table 1. The effective factors in desirability of docking stations of BS programs

	Factors	Idea behind factors
Docking stations of BS programs	Proximity to subway stations	The closer the better (For desirable integration the docking stations must be close to subway stations).
	Distance between docking stations	300 meters of distance has been defined as a standard. More or less distance is undesirable.
	Distance from important intersections	The less the better.
	Population	More population density necessitates more stations. At least one for every 1000 people.
	Proximity to educational, recreational and commercial facilities	The closer, the better.
	Slope level	Slope levels between 0 and 8 degrees are acceptable. Levels between 0 and 4 are not problematic, between 4 and 8 cycling is challenging, and above 8 degrees no cycling would be done.
	Proximity to cycling infrastructure (lanes)	The closer, the better.

2.1.7 Proximity to Cycling Infrastructures (Lanes)

The feeling of safety on the road is very important in encouraging people to use bicycles [Karki and Tao, 2016]. In fact, if the stations are placed near bike lanes, users are encouraged by the feeling of safety. With respect to all 7 mentioned factors in this section, we can point out the idea behind each factor from the viewpoint of desirability (Table 1).

2.2 Study Area and Mashhad's BS Program

The metropolis of Mashhad with coordinates 36°18′N 59°36′E is located between Binaloud and Hezarmasjed mountains. It is 985 meters above sea level and its distance from the capital (Tehran) is 895 kilometers [Moteallemi et al. 2017]. Mashhad's climate is mild and variable, and the wind usually blows from southeast to northwest [Soqab Isfahani et al. 2013]. The population of Mashhad is around 3 million people based on the 2016 census, and it is the second most populous city of Iran [Mashhad's Municipality, 2017]. Mashhad's BS program was established in 2012 and is providing service with 128 stations and about 2300 bicycles [Mashhad Transportation and Traffic Organization, 2017]. Only men above 15 years old are allowed to use this program, and the service hours of the program are 10 hours a day, from 6:30 to 16:30 based on a contract between the beneficiary firm and Mashhad's Municipality [Mashhad's Municipality, 2017]. Based on the mentioned contract it has been agreed that this program would continue with 3000 bicycles and 150 stations [Mashhad's Municipality, 2016]. All stations have an operator, and are not automatic kiosks. The bicycles are rented by signing up and submitting some personal information and a phone call by the operator to the responsible firm. It is free to sign up in the program, however a 2,500,000 IRR[5] assurance fee is received from the users. The cost of using the bicycles is free for the first 30 minutes and then 2000 IRR per hour. The bicycles of the program are all the same size and in two models, which are not very different in terms of appearance, materials and quality. The study area and the stations of Mashhad's BS program are illustrated in Figure 1.

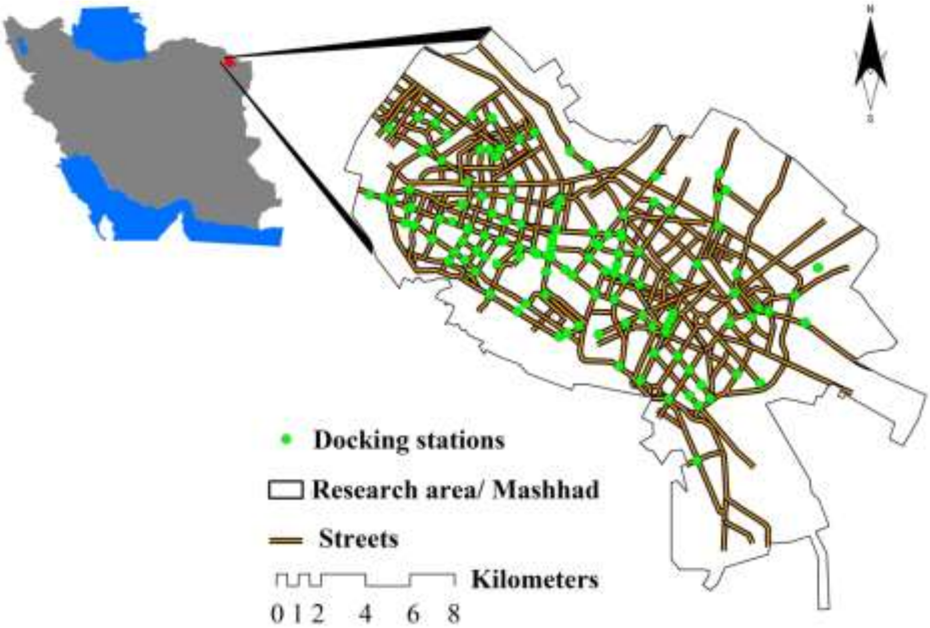

Figure 1. The area under study and the distribution of docking stations in Mashhad.

2.3 Fuzzy and AHP approach

Multiple-criteria decision-making (MCDM) is a sub-discipline of operations research which considers multiple criteria in decision-making environments [Naeimi et al. 2013]. Analytic Hierarchy Process (AHP) is one of the Multi Attribute Decision Making (MADM) and Multi Criteria Decision Making methods, which is very useful in multi criteria decision making issues [Randall et al. 2004]. This method is flexible and yet structured for analysis and solving complicated decision making problems by applying them to a hierarchy framework [Herath G. 2004; Saaty, 1980. Group decision making method includes a series of options $A = \{a_1, a_2, \dots, a_m\}$, a series of dimensions $D = \{d_1, d_2, \dots, d_q$, a series of criteria $C = \{c_1, c_2, \dots, c_n\}$, and a group of experts $E = \{e_1, e_2, \dots, e_n\}$ that are each used in a specific subject. Each expert analyzes their own factors based on different criteria according to their experience:

$$e_k \rightarrow \{u_{11}^k, \dots, u_{t1}^k \dots u_{1q}^k, \dots, u_{1tq}^k\} \quad (1)$$

In which u_{tq}^k is a verbal evaluation that is done by the expert e_k for the criteria c_k, and each criteria c_{tq} belongs to d_q dimension. A comparison is done based on linguistic variable $S_{tq}^k = \{L, X_{a,L}, X_{a,M}, X_{a,R}, R\}$ and for weighting criteria the opinion of each expert is entered in pairwise comparison matrix A, and then the weight is determined based on pairwise comparisons. In simpler terms, AHP approach is necessary in order to formulate intuitions from a complicated phenomenon, using a hierarchy structure. The strength of AHP approach is in its ability to organize a multi attribute decision making issue into a hierarchy of attributes.

AHP approach consists of the following stages: First stage: Making a hierarchy for a multi-attribute decision making issue. Second stage: By pairwise comparisons in a matrix the relative importance of attributes is determined. Third stage: Determining the weight of each element in the matrix that was prepared in the second stage. In this stage, Saati (24, 1980) proposes the geometric average of a row.

A) N elements in a row are multiplied by each other, the square root of the N^{th} root is calculated and a new row is created for the resulting numbers.

B) The new column is normalized (each number is divided by the aggregate of the whole column).

Fourth stage: Each part's share in the final objective is calculated by summing up the final weight vertically [Faraji Sabokbar, 2005; Lee, 1995; Cheng and Mon, 1994].

After defining effective factors in the study and designing the AHP chart, the table of pairwise comparison between the factors was prepared in order to determine the weight of each factor. In this stage, the experts who were familiar with BS programs were invited in a focus group, and they reached a collective opinion about the rating of each factor after discussions and analyses. In fact, in this method, instead of questioning experts individually, the ratings of the 7 factors were discussed, analyzed and agreed upon in a group meeting. Using a focus group in studies goes back to a long time ago, among the benefits of which are cost effectiveness, simplicity of the process, access to more individuals in a shorter period of time and also creating an opportunity for discussions among experts [Marshall and Gretchen, 1999; Collis and Hussey, 2013].

After this stage, the table of comparisons based on the opinions of experts was completed and extracted considering the acceptability of the compatibility ratio of weight of each factor (Table 2).

Fuzzy logic is based on fuzzy set theories [Zadeh, 1965]. Fuzzy logic does not use absolute binary responses, it substitutes zero and one with a range of numbers between them. That's why fuzzy logic and fuzzy decision making methods [Bellman and Zadeh, 1970] that consequently appeared provided a more natural method in comparison with Boolean logic. Fuzzy logic generally means that if an X set of GIS layers are effective X_i (1, 2, 3, …, n) and each layer consists of different values (J = 1, 2, 3, …r), then as a result N fuzzy sets A_i with members (1, 2, 3, …, n) will be defined in X:

$$A_{ij} = \{(x_{ij}, \mu A)/x_{ij} \in X_i\}, \qquad (0 \leq \mu_A \leq 1 \quad (2)$$

The relationship between the distribution methods of docking stations of a BS program with the effective factors (for instance distance from important intersections) could be described through function F. In other words, this function describes the way that different factors affect distribution of docking stations. The most notable fuzzy functions that are usually used in geographical studies are triangular and trapezoidal functions. We can also mention Gaussian fuzzy functions, S shaped functions, and Z shaped functions, which are more compatible with geographical and environmental phenomena and should be optimized in accordance with effective factors (Figure 2). In Gaussian functions the effective factor consists of an optimized value or values that have the membership 1 and by increasing distance, the desirability of the factor on the subject decreases and membership functions decrease as well. Meanwhile, in S shaped and Z shaped functions, the desirability of the factor and consequently membership function increase and decrease respectively [Zhu et al. 2014]. In the present study after processing the GIS based layers, fuzzy membership functions were used to describe the *f* function for each of the effective factors of distribution of docking stations (for instance the distance from subway stations). And in conclusion, fuzzy maps of each of the effective factors were prepared. For distance based factors, 600 meters was used as the threshhold of walking in defining fuzzy functions, and regarding the population factor, the fuzzy function was defined based on the density of one docking station per 1000 people.

The factor of slope level was defined based on the maximum threshhold of 8 degrees. At last, the final maps were prepared using Simple Additive Weighing method (SAW), which is one of the most popular methods used in spatial multi attribute decision making (Minaei, 2009). These methods are based on weighted average which is formally used in decision making about each factor or A_i with the following formula:

$$A_i = \sum_j w_j x_{ij} \qquad (3)$$

where X_{ij} describes the rating of member i in relation to attribute j, and w_j is a standardized weight; in a way that $\sum w_j = 1$.

Table 2. Rating table of effective factors in AHP method.

	Proximity to subway stations	Distance between the stations	Distance from important intersections	Population	Proximity to facilities	Slope level	Proximity to bicycle lanes	Geometric average	Eigenvector
Proximity to subway stations	1	3	7	5	5	7	5	4.031	0.4192
Distance between the stations	0.333	1	2	1	0.5	4	2	1.1492	0.1195
Distance from important intersections	0.142	0.5	1	0.5	0.333	4	4	0.7894	0.08210
Population	0.2	1	2	1	0.333	3	3	1.026	0.1067
Proximity to facilities	0.2	2	3	3	1	5	4	1.8354	0.1908
Slope level	0.142	0.25	0.25	0.333	0.2	1	0.333	0.2976	0.0309
Proximity to bicycle lanes	0.2	0.5	0.25	0.333	0.25	3	1	0.4863	0.0505

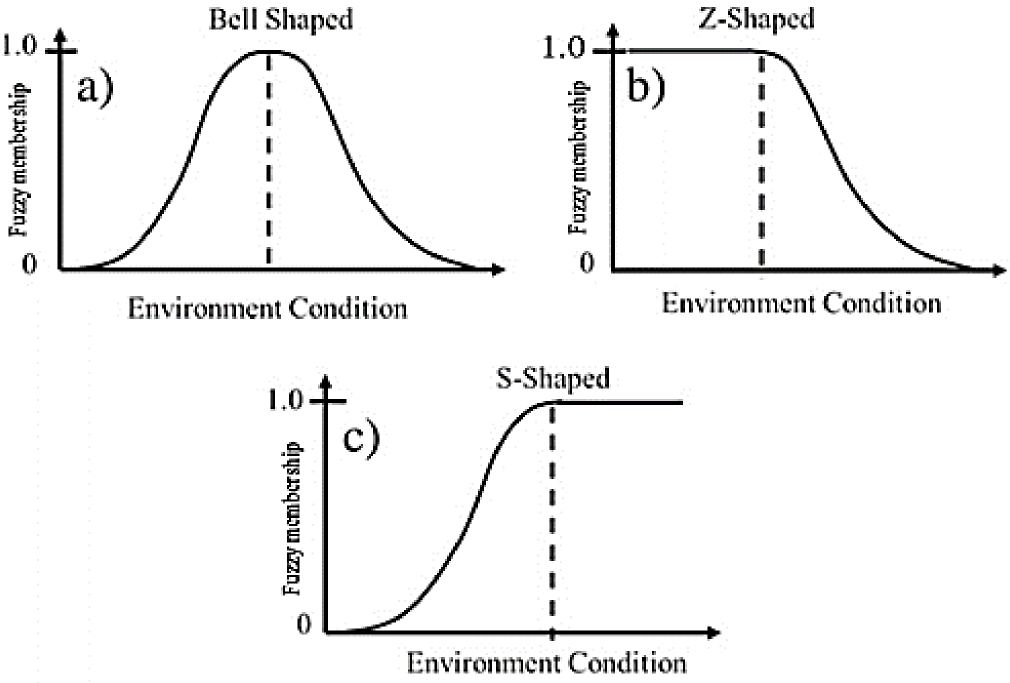

Figure 2. The initial diagram of fuzzy Gaussian, Z shaped and S shaped membership functions that must be optimized based on factors in each study [Zhu et al. 2014].

Weights show the relative importance of each attribute. By determining the maximum value of A_i (i =1, 2, ... , n), the member with the highest priority will be chosen. [Hwang, 1995; Li, Chen and Hung, 2001; Asgharpour, 2004]. At last, the final map of optimization of location of stations is achieved.

2.4 Ranking and clustering stations by using VIKOR and Jenks methods

Finally, by using VIKOR approach the existing stations were rated and ranked. VIKOR approach was presented as a practical method for Multi criteria decision making, and extended as a method for multi criteria decision making for solving problems with contrasting and inconsistent criteria [Opricovic and Tzeng, 2004; Opricovic and Tzeng, 2007]. The difference between this model, AHP and network decision making models is that in this model, pairwise comparisons between criteria are not made, as opposed to those models, and each factor is analyzed and evaluated based on a single criterion. After implementing VIKOR model on the data regarding existing docking stations of the BS program, the results were categorized into 5 groups, by JENKS method (1967) or Natural breaks method. Which is a statistic based method for making maps [Basofi et al. 2015]. JENKS method is used because it provides an optimized number of classes with a desirable fitting of variance [Gili, Álvarez and Noellemeyer, 2017].

In other words, natural breaks algorithm not only seeks to find the minimum difference of distance between members and center of cluster, but also it tries to maximize the variance between centers of clusters, which means

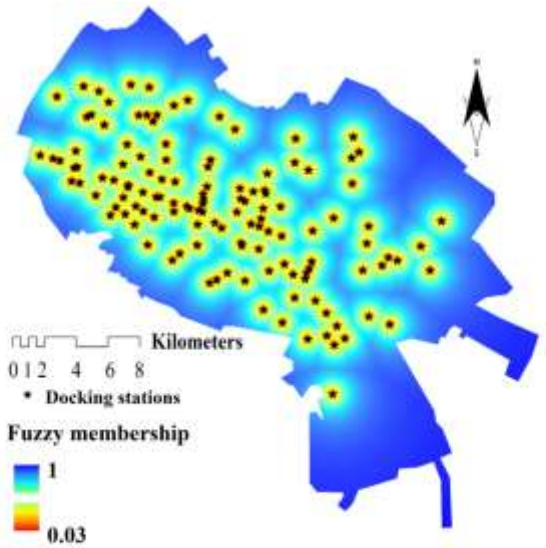

Figure 3. Map of distances between stations.

difference between clusters and categories [Khan, 2012]. The results of categorization have been presented in the findings section.

3. Findings

After weight allocation in AHP method, it is time to prepare a geographical database and fuzzy maps of each factor. The distance between the stations is an important factor and if it exceeds the standard limit, it will discourage people from using the program. In this respect the map of distances between stations has been prepared using fuzzy functions (Figure 3). The desirability of geographical space regarding access to bike lanes as the main cycling infrastructure has been presented in Figure 4. In many countries, bike lanes between the stations are mandatory, however, bike lanes in Mashhad are not very well located. Another important issue is the extent to which bike lanes are acknowledged and respected by the drivers and pedestrians, and according to prior studies, citizens do not pay much attention to bike lanes [Jahanshahi, Kharazmi and Ajza Shokuhi, 2018].

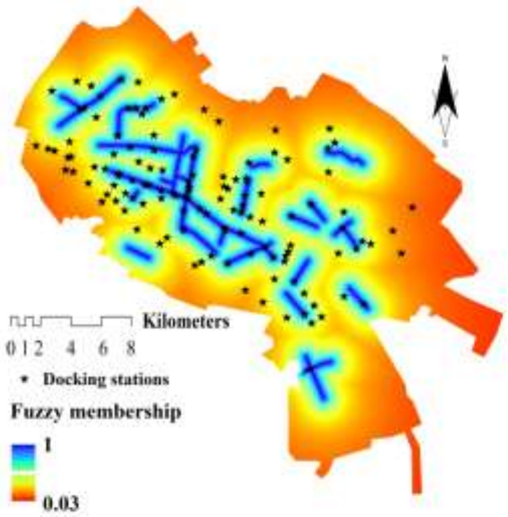

Figure 4. Desirability of stations based on proximity to bike lanes.

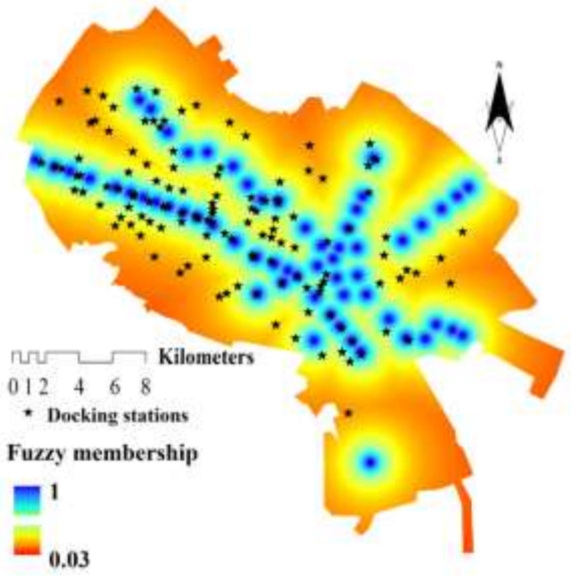

Figure 5. Map of desirability of stations based on proximity subway stations.

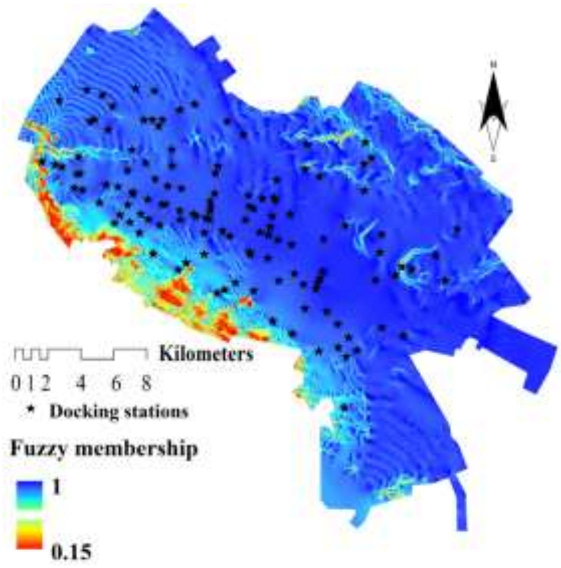

Figure 7. Desirability of stations based on slope level of Mashhad's regions.

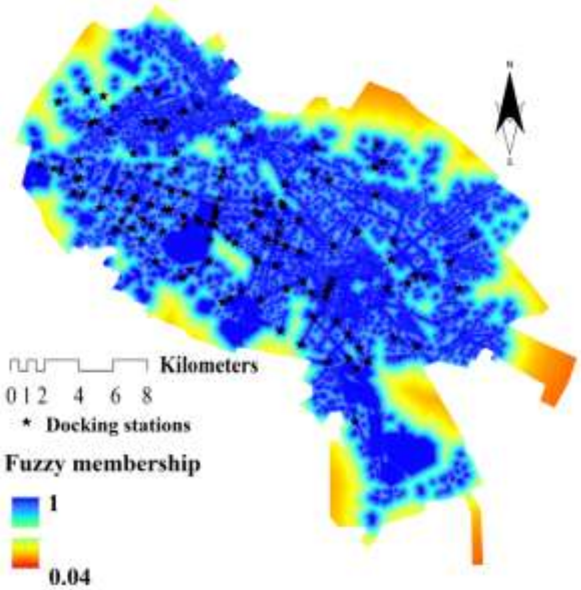

Figure 6. Map of desirability of stations based on proximity to different facilites.

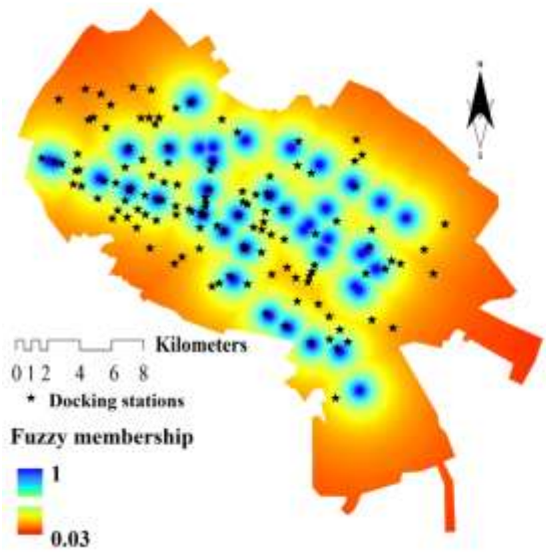

Figure 8. Desirability of stations based on proximity to important intersections.

Users of a BS program in each city, are the citizens of that city. And considering the numerous commutes to educational, recreational and commercial facilites, one of the important factors in desirability of stations is proximity to these facilities. In the following, the desirability map of the stations was prepared with the importance of proximity of stations to different facilities in mind (Figure 5). Also in Figure 6, the desirability has been illustrated with respect to proximity to subway stations. In Figures 7, 8 and 9 the maps of desirability of the stations are illustrated based on proximity to important intersections, slope level, and proximity to population. Finally, by adding up all fuzzy layers and relevant weight allocations to each, the desirable spatial distribution map in the studied area was achieved (Figure 10).

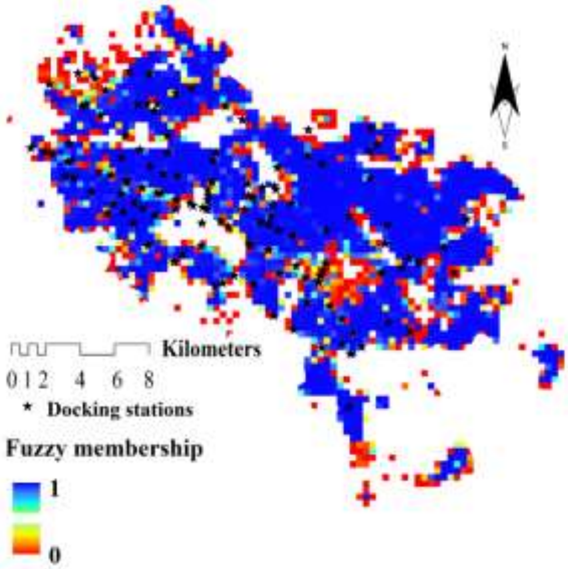

Figure 9. Desirability of the stations based on proximity to population.

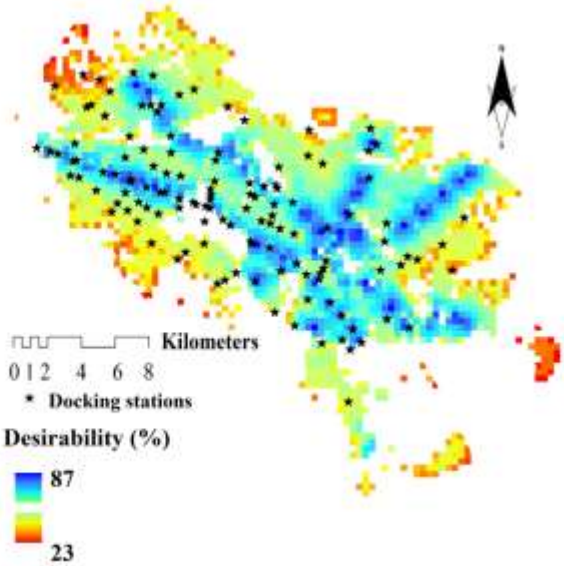

Figure 10. Final map of desirability of the stations of Mashhad's Bicycle Sharing progarm.

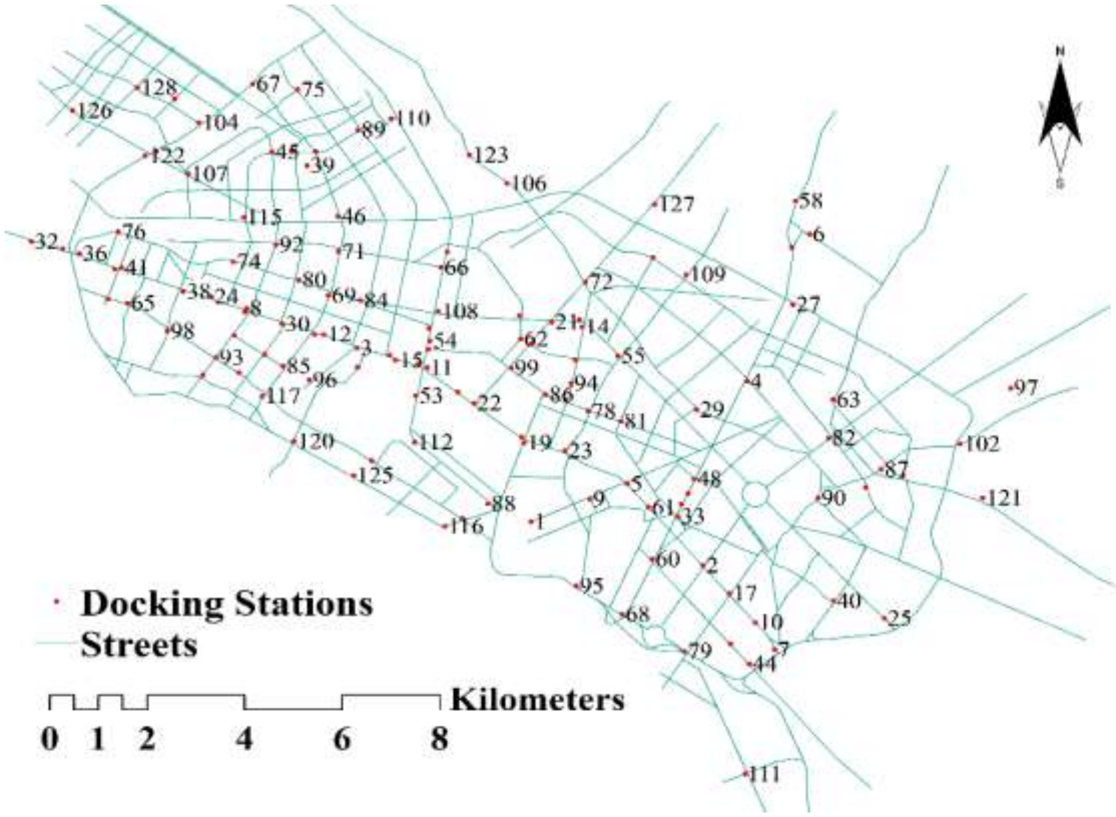

Figure 11. Ranking of the docking stations of Mashhad's Bicycle sharing program

After preparing the map of spatial distribution of desirability of constructing docking stations, VIKOR approach was used to evaluate, compare and finally rank the stations by extracting the data regarding each station with respect to different studied factors. The rankings of the stations are presented in Figure 11 and table 3.

Table 3. VIKOR rating (V.Rate) and ranking of desirability of 128 stations of Mashhad's BS program.

Station N.	V. Rate	Rank	Station N.	V. Rate	Rank	Station N.	V. Rate	Rank	Station N.	V. Rate	Rank	Station N.	V. Rate	Rank
1	0.543	67	27	0.374	34	53	0.179	14	79	0.672	94	105	0.709	100
2	0.968	128	28	0.443	42	54	0.312	30	80	0.682	97	106	0.867	121
3	0.596	75	29	0.575	71	55	0.295	28	81	0.569	70	107	0.643	90
4	0.935	124	30	0.380	36	56	0.148	12	82	0.630	86	108	0.107	9
5	0.948	126	31	0.770	113	57	0.485	50	83	0.807	117	109	0.509	57
6	0.763	110	32	0.579	74	58	0.700	98	84	0.528	63	110	0.523	61
7	0.753	104	33	0.540	66	59	0.527	62	85	0.600	77	111	0.635	88
8	0.636	89	34	0.378	35	60	0.501	54	86	0.490	53	112	0.000	1
9	0.851	119	35	0.438	41	61	0.480	49	87	0.223	22	113	0.360	33
10	0.869	122	36	0.763	109	62	0.064	3	88	0.601	78	114	0.754	105
11	0.485	51	37	0.606	80	63	0.397	37	89	0.300	29	115	0.799	116
12	0.458	45	38	0.577	72	64	0.663	93	90	0.613	81	116	0.515	60
13	0.892	123	39	0.403	38	65	0.577	73	91	0.856	120	117	0.049	2
14	0.473	47	40	0.563	69	66	0.162	13	92	0.767	112	118	0.673	95
15	0.419	39	41	0.245	24	67	0.503	55	93	0.211	20	119	0.193	17
16	0.760	107	42	0.616	84	68	0.485	52	94	0.614	82	120	0.433	40
17	0.755	106	43	0.643	91	69	0.324	31	95	0.205	19	121	0.550	68
18	0.511	58	44	0.282	27	70	0.180	15	96	0.729	102	122	0.265	25
19	0.948	127	45	0.537	65	71	0.507	56	97	0.243	23	123	0.115	10
20	0.788	115	46	0.105	8	72	0.700	99	98	0.814	118	124	0.104	7
21	0.470	46	47	0.198	18	73	0.122	11	99	0.635	87	125	0.451	43
22	0.599	76	48	0.762	108	74	0.623	85	100	0.936	125	126	0.604	79
23	0.099	6	49	0.212	21	75	0.778	114	101	0.715	101	127	0.454	44
24	0.329	32	50	0.193	16	76	0.729	103	102	0.477	48	128	0.767	111
25	0.656	92	51	0.513	59	77	0.675	96	103	0.080	5			
26	0.281	26	52	0.616	83	78	0.066	4	104	0.529	64			

Note: Red cells show 26 stations with very unsatisfactory condition placed in the end of VIKOR rate list.

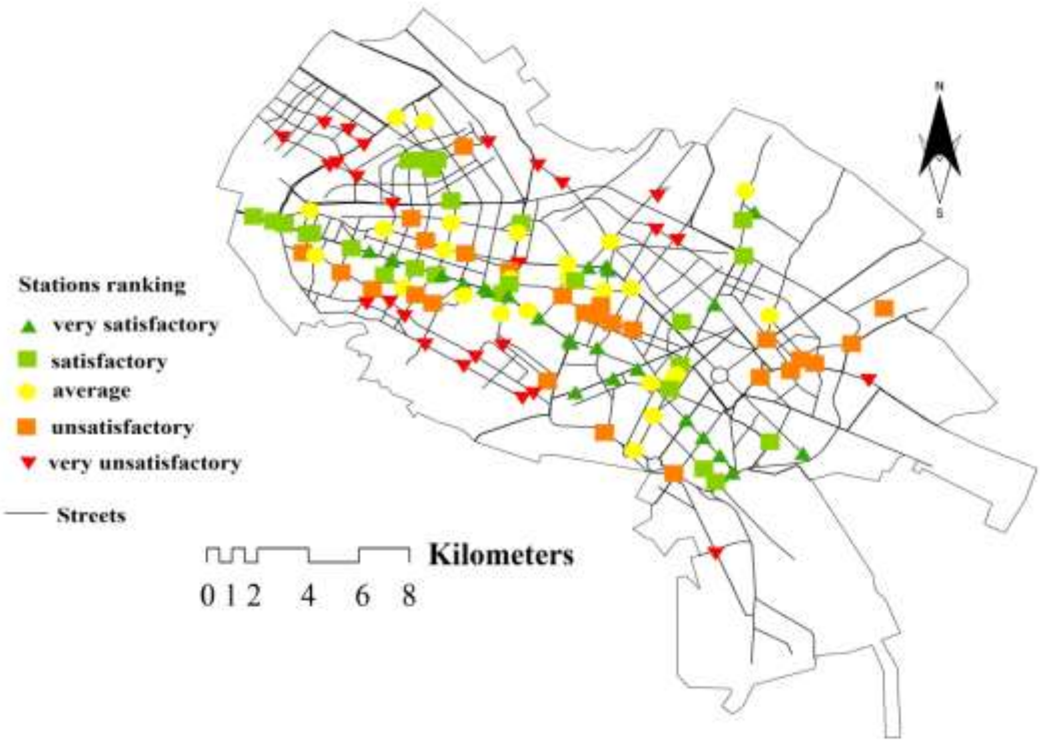

Figure 12. Desirability of the stations based on JENKS method

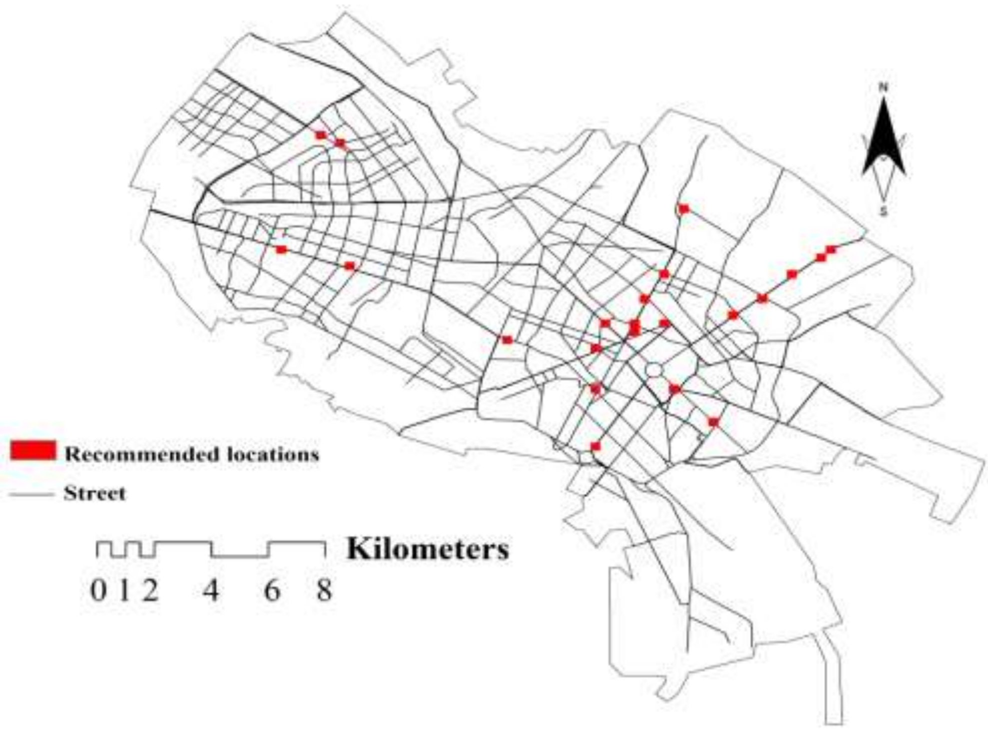

Figure 13. Recommended locations for the remaining 22 stations of Mashhad's Bicycle Sharing Program.

Based on the mentioned table, the 128 active stations of Mashhad's BS program could be compared with regard to the 7 discussed factors. The results of clustering the stations in 5 clusters, ranging from very satisfactory to very unsatisfactory based on JENKS method, also known as Natural breaks method, are presented in Figure 12. With respect to this categorization, 25 stations are very satisfactory, 26 satisfactory, 25 average, 26 unsatisfactory and finaly 26 very unsatisfactory.

Considering that the existing 128 stations have already been built and cannot be moved, and 150 stations were planned to be built in total, it is recommended that the remaining 22 stations be built in accordance with Figure 13.

4. Discussion and Conclusion

Success of a Bicycle sharing program can depend on various social, cultural, infrastructural and practical factors. In this research we have focused on the infrastructure and specifically on docking stations. Proper positioning of the stations can greatly impact dynamicity and efficiency of a BS program. It has been established in many studies that one of the important factors in acceptance or otherwise of a BS program by the citizens is location of the stations [ITDP, 2013; NACTO, 2015]. Generally, it can be said that increasing stations in the coverage area of the program would have a positive effect on the rate of use by the citizens. However, the challenge for developing countries, poor countries, and the countries that do not prioritize this matter in terms of investment is properly locating the limited stations to achieve the highest efficiency. For this purpose, proper positioning of the stations is very significant.

In the present study, we have presented the most desirable locations for the remaining stations, we have also prioritized the existing stations based on the factors that affect desirability of the docking stations of BS programs. As it was already mentioned in the findings section, 26 stations have very unsatisfactory status, and could be replaced with new stations. The notable point is that among the 26 stations with very unsatisfactory status, stations such as 106, 128, 36, 31, 19, 17, 13, 5 and 91 are merely built to extend the coverage area and cannot practically be integrated with other stations.

Another important factor in locating stations in a city, is the priority of coverage area or density of the stations. Each of these priorities have a lot of pros and cons. However, it's obvious that an efficient program in a smaller scale is better than an inefficient program in a large scale. [Midgley, 2011]. The problems that usually exist on this subject are wrong policies and decisions that are made based on political reasons rather than practical reasons, which results in programs that are apparently designed to cover a city or a region but are very inefficient in practice [NATCO, 2015]. Therefore, it is recommended that for other cities and future programs, the density be prioritized over coverage area. The commercial aspect of this transportation mode is another significant factor. One of the most popular sources of income for these programs is through advertisement. It is important to note that in many cases, BS programs are designed and managed by big advertising agencies, therefore proper positioning of the stations could be overshadowed by advertising potentials. Mashhad's BS program is not an exception to this, and the locations of the stations could have been determined based on financial reasons, considering the advertising billboards on each station. It can be said that due to financial status of developing countries, proper and scientific positioning of the docking stations can save a lot of costs by preventing waste of resources.

As it was already mentioned, the existence of 26 very unsatisfactory and 26 unsatisfactory stations indicates a 40% inefficiency in planning the docking stations. And in order for this inefficiency to be rectified, a lot of the stations must be destroyed in not very far future, which would mean waste of massive resources. The results of this study indicate the fact that proper planning before starting urban projects can save a lot of resources and lead to much more efficiency. As a beneficial suggestion for the mentioned program we can refer to a solution that has been tried in many programs worldwide; today the stations of BS programs are designed in the two forms of permanent and mobile. Mobile stations, especially at the beginning, can help a lot in properly defining the best locations for permanent stations. A method that was used in Guangzhou, China, where permanent stations were built after the best locations were determined [Shaheen et al. 2011]. BIXI program in Canada was another example of this method [Shaheen, Guzman and Zhang, 2010]. Therefore, it is suggested that for the remaining stations of Mashhad’s BS program and for potential future programs in other cities, mobile stations be considered as well as permanent stations. Of course it is important to note that theft and vandalism rate can also affect the planning of docking stations in different societies and regions.

5. Endnotes

[5] 1 US$ = 32950 IRR

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