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Location and Coverage Analysis of Bike-Sharing Stations in University Campus

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Abstract

Background: Bike-sharing programmes have become popular in a large number of cities in order to facilitate bicycle use. Determining the location of bike sharing stations is vital to success of these programmes. **Objectives:** In this paper, a case study is applied to the Gaziantep University campus in order to find possible locations of the stations for users (students). The purpose is to minimize the total walking distance. **Methods/Approach:** Set and maximal covering mathematical models are considered to decide on coverage capability of determined 20 demand points and 20 potential bike stations. Then, the mathematical models of P-center and P-median are used to build possible stations and to allocate demand points to the opened stations. Finally, an undesirable facility location model is used to find the bike stations, which have the maximum distance from demand nodes, and to eliminate them. **Results:** In computational results, it is clearly seen that the proposed approaches set the potential bike station covering all demand points. They also provide different solutions for the campus planners. **Conclusions:** The methodology outlined in this study can provide university administrators with a useful insight into locations of stations, and in this way, it contributes significantly to future planning of bike-sharing systems.

Keywords: Bike station, location-allocation, maximal covering, p-center, p-median, set covering, undesirable facility location
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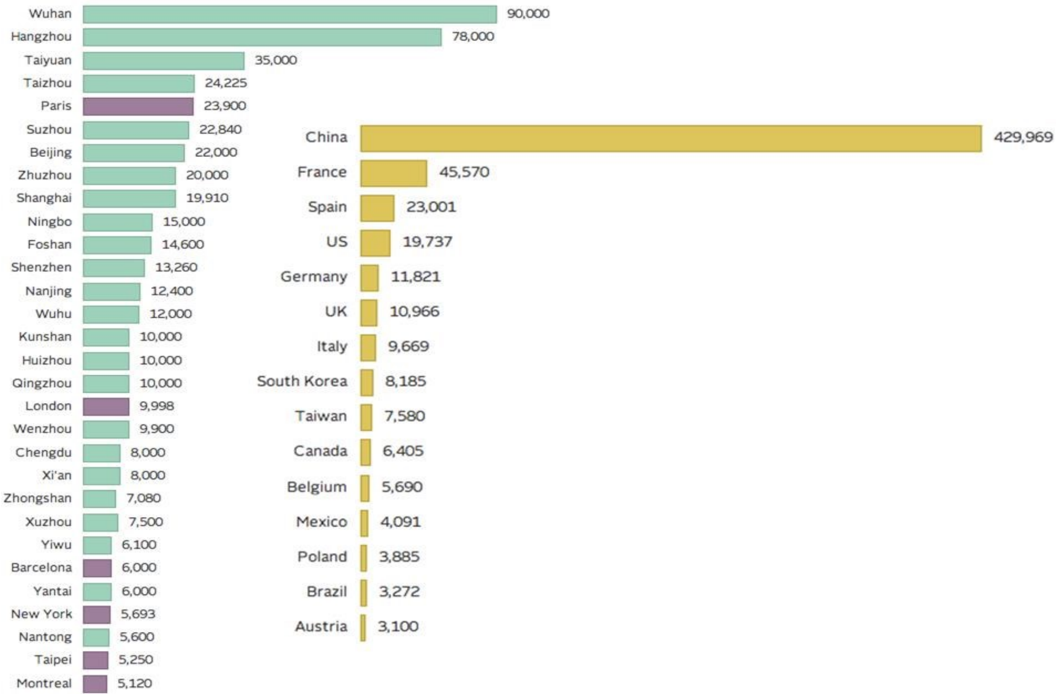
Introduction

Public bike-sharing system popularity has significantly increased in recent years. Bicycle sharing services can be useful when bicycles are offered for use short period and single tours. Bicycle station services are located into different areas with racks where bicycles are locked. Users can take a bicycle from any location, travel, and to leave the same station or other stations (Mattson et al., 2017). The use of bicycles has attracted much more attention in order to reduce using of car. Bike-sharing has developed significantly since its inception in 1965, the first public-use bicycles, with the famous "White Bicycles" system in Amsterdam. It is recommended that approximately 20,000 bicycles were deployed somewhere in the center in order to be used free of charge. Although the proposal was rejected by city council, fifty donated white bikes were distributed by supported for free use around the town. Then, the following initiative about sharing system emerged in La Rochelle, France, in 1993, which offered also a free, but including control system. Other sharing system included 1800 station in approximately every 300 m and more than 20,000 bicycles.

In summarize, bike-sharing system are spared out in more than 600 cities around the world and also it increases significantly every year. China has the most number of bikes in the world and it is following by the France with approximately 45,000 bikes. Detailed lists for the year of 2014 in terms of countries and cities are illustrated in Figure 1. Bike-sharing system has changed according to the city's topography, density, infrastructure, weather, and culture.

Figure 1
Number of bike-share bikes per country and city



Source: Çetinkaya, (2017)

In Turkey, traffic is at the top of the most important problems as in all developed or developing countries. People need for easy transportation in Turkey. That's why the use of bicycles has started to be used in many cities of Turkey. Only Istanbul, Kocaeli, Çanakkale, İzmir, Antalya, Konya and Kayseri out of 81 cities launched a bike-sharing system in Turkey (Figure 2). In Turkey, even if using the bicycle is a sport activity, there is very small place in our lives. According to Turkish Statistical Institute, individuals have spent their free time distribution of sportive activities to evaluate when examined; they 2.2% of them were riding bicycles. In order to removing this situation and solving the other problems, we need to promote using bicycles.

Figure 2
Cities in Turkey with bike-sharing system

Source: Özceylan et al. (2017a).

Research on bike-sharing systems generally has concentrated on operations management, site selection, bike dispatch as well as user preferences and behaviours. (Sallis et al., 2004; Martens, 2007; Lin and Yang, 2011; Broach et al., 2012). We focused on site selection of bike stations in this study. Because one of the main factors is the position of bike stations and relations with demand in order to achieve the programs. The bike-sharing system can be usually set up to appropriate places by municipalities, private companies or universities.

In the literature, different methods are proposed to overcome the problem of location of stations. As an early work, Lin and Yang (2011) emphasizes the strategic planning with service level of public bicycle sharing systems. Later, Martinez et al. (2012) present a mathematical modelling fulfilment through a heuristic approach to optimize the location of shared bike stations. Besides mathematical modelling, Romero et al. (2012) suggest a simulation-optimization method for optimizing the location of shared bicycle stations. To consider spatial information, García-Palomares et al. (2012) propose a geographic information systems (GIS)-based methodology. Ghandehari et al. (2013) present a study to find the best locations of bicycle stations through goal programming and multi-criteria decision-making techniques. Dobešová and Hýbner (2015) provide the analysis of optimal solution of the rental station in Olomouc. For location and allocation analyses, network analyst for ArcGIS was used.

As an artificial intelligence and heuristic application, Liu et al. (2015) presented a prediction model which was based on an artificial neural network for station demand and balance prediction in order to maximize station demand and minimizing the number of unbalanced stations. One of the current studies is proposed by Frade and Ribeiro (2015). An optimization method is proposed in order to develop the bike-sharing system with the objectives of maximizing the demand covered and taking the budget restriction. Strategic decisions are combined to locate bike-sharing stations and to define the dimension of the system with operational decisions. The model of the spatial-temporal analysis is developed by Wang et al. (2016) and also the GIS is adopted in order to detect hot spot lacking-bikes and/or lacking-bike racks. In addition, it is applied retail location theory in order to decide prospective locations for rental stations.

One of the studies which consider uncertainty is proposed by Ali-Askari et al. (2017). They take into consideration a stochastic location-allocation problem, in which bike demand is uncertain, for a capacitated bike-sharing system. They use a sample average approximation method to overcome the uncertainty. Finally, Çetinkaya (2017) aims to determine the location of bike-sharing stations in Gaziantep by using fuzzy AHP and TOPSIS. Although it is one of the first multi-criteria decision-making study about bike station location, lack of mathematical modelling is the main drawback of this study.

There have been many studies which consider bike sharing systems as aforementioned above, there is still a gap to be filled on location and allocation of bike stations mathematically. In view of this, set and maximal covering, P-median, P-center and undesirable facility location models which are well-known and common tools are applied to locate and allocate bike stations in Gaziantep University campus. This paper contributes to the literature in several ways: (i) application of three popular location-allocation models hierarchically –to the best knowledge of the authors it is the first application on bike-sharing site selection, (ii) providing a case study which is in a university campus firstly and finally (iii) generating scenario analysis to answer what-if questions about changing the location of bike stations.

Location-Allocation Models

In this sub-section, the location-allocation models are defined.

Set covering problem

Fully connected network is demonstrated by G (N, A), and "N" is the set of nodes while "A" is set of edges between these nodes. "N", "I", "K" consists of nodes, demand points and potential locations respectively. "d_{ik}" is identified as distance between all node pairs within the network. The problem formulation is given as follows (Beasley, 1987):

Decision variable

$$y_k = \begin{cases} 1, \text{if potential bike station } k \text{ is selected } (\forall k \in K) \\ 0, \text{otherwise} \end{cases}$$

Objective function

$$Min\ Z = \sum_{k \in K} y_k \qquad (1)$$

Restrictions

$$\sum_{k \in K} a_{ik} y_k \geq 1 \qquad \forall i \in I \qquad (2)$$

$$y_k \in \{0, 1\} \qquad \forall k \in K \qquad (3)$$

The objective function (1) is defined as minimizing the number of stations to be opened. Service from at least one opened station to all demand points within the predetermined time is provided by Restriction (2). The decision variable is indicated by Restriction (3), and here, a_{ik} is a parameter:

$$a_{ik} = \begin{cases} 1, \text{if can be reached from } k \text{ to } i \text{ in a predetermined time } (\forall k \in K, \forall i \in I) \\ 0, \text{otherwise} \end{cases}$$

Maximal covering problem

Although set covering problem is a well-known coverage model, the model doesn't differentiate between large and small demand nodes. To overcome this issue, maximal covering model can be used. The model locates p facilities to maximize the covered demands number. This model distinguishes between small and big and permits some node to be uncovered if the exceeds the number of sites p needed to cover all nodes. In addition to the notation described above, z_i is defined as a new decision variable. With this decision variable, the model is given as follows (Daskin, 2008):

Decision variables

$$y_k = \begin{cases} 1, \text{if potential bike station } k \text{ is selected } (\forall k \in K) \\ 0, \text{otherwise} \end{cases}$$

$$z_i = \begin{cases} 1, \text{if demand node } i \text{ is covered } (\forall i \in I) \\ 0, \text{otherwise} \end{cases}$$

Objective function

$$Max\ Z = \sum_{i \in I} w_i z_i \quad (4)$$

Restrictions

$$\sum_{k \in K} y_k = P \quad (5)$$

$$z_i - \sum_{k \in K} a_{ik} y_k \leq 0 \qquad \forall i \in I \quad (6)$$

$$z_i, y_k \in \{0, 1\} \qquad \forall i \in I, \forall k \in K \quad (7)$$

The objective function (4) maximizes the number of covered demands where demand at location i is represented by w_i. Restriction (5) shows that p stations are to be located. Restriction (6) ensures link coverage variables and the location, and last one (7) is integrality restriction.

P-median problem

On the network which is described in set covering problem section, transportation costs per unit among all customers defined as c_{ik} and positive demand defined as w_i are considered. The P-median problem seeks to define the number of P candidate facility (bike stations) to be opened, and which customers (students and staff) will be assigned to each facility. The problem formulation is given as follows (Teixeira et al., 2008):

Decision variables

$$y_k = \begin{cases} 1, \text{if potential bike station } k \text{ is selected } (\forall k \in K) \\ 0, \text{otherwise} \end{cases}$$

$$x_{ik} = \begin{cases} 1, \text{if demand point } i \text{ is assigned to potential bike station } k \ (\forall i \in I, \forall k \in K) \\ 0, \text{otherwise} \end{cases}$$

Objective function

$$Min\ Z = \sum_{i\in I}\sum_{k\in K} w_i c_{ik} x_{ik} \quad (8)$$

Restrictions

$$\sum_{k\in K} x_{ik} = 1 \qquad \forall i \in I \quad (9)$$

$$x_{ik} \leq y_k \qquad \forall i \in I, \forall k \in K \quad (10)$$

$$\sum_{k\in K} y_k = P \quad (11)$$

$$y_k, x_{ik} \in \{0,1\} \qquad \forall i \in I, \forall k \in K \quad (12)$$

The objective function (8) is defined as minimizing total costs. Restriction (9) ensures the allocation of demand point to a bike station, while Restriction (10) ensures the assignment of demand points to the opened bike stations. Restriction (11) defines bike stations numbers which should be opened. Last Restriction (12) is the decision variables.

P-center problem

The P-center problem seeks to define P amount candidate bike stations to be opened and which demand points will be assigned to each bike station while minimizing the demand points' longest distance to the bike station. The P-center problem formulation is given as follows (Narula, 1986):

Decision variables

$$y_k = \begin{cases} 1, \text{if potential bike station } k \text{ is opened } (\forall k \in K) \\ 0, \text{otherwise} \end{cases}$$

$$x_{ik} = \begin{cases} 1, \text{if demand point } i \text{ is assigned to potential bike station } k\ (\forall i \in I, \forall k \in K) \\ 0, \text{otherwise} \end{cases}$$

Objective function

$$Min\ Z = Max(d_{ik} x_{ik}) \quad (13)$$

Restrictions
Eqs. (9) to (12)

A decision variable (MaxL) is added for the linearization of the model. Moreover, the objective function is formulated as $Z = MaxL$ and $MaxL \geq 0$ and $MaxL \geq d_{ik}x_{ik}$ restrictions are added to the model. Therefore, the objective is to minimize the maximal distance for all demand points (Özceylan et al., 2017b).

Undesirable facility location model

The facilities can be classified as desirable or undesirable in a general fashion. Whereas desirable facilities should be as close as possible to the users, undesirable facilities should be as far as possible. Undesirable facilities may contain garbage disposal sites, chemical plants, plants for treatment of residual waters, nuclear power stations, airports, etc. (Rodríguez et al. 2006). However, in some cases, decision makers want to eliminate the potential locations which are not suitable or not accessible. In other words, decision makers may want to eliminate unsuitable locations. In this situation, minimum distance between the demand node and undesirable node is tried to be maximized. In other words, the maximin objective maximizes the distance between the bike station and the closest demand node to it. The formulation of the undesirable facility location model is as follows (Erkut et al., 1989):

Decision variable

$$y_k = \begin{cases} 1, \text{if potential bike station } k \text{ is opened } (\forall k \in K) \\ 0, \text{otherwise} \end{cases}$$

Objective function

$$Max\ Z = Min(d_{ik} y_k) \tag{14}$$

Restrictions
Eqs. (3) and (11)

A decision variable ($MinL$) is added for the linearization of the model. Revised version of the model is as follows:

Objective function

$$Max\ Z = MinL \tag{15}$$

Restrictions
Eqs. (3) and (11)

$$MinL \leq d_{ik} + M(1 - y_k) \qquad (\forall i \in I, \forall k \in K) \tag{16}$$

$$MinL \geq 0 \tag{17}$$

So, the objective function (15) maximizes the minimum distance between bike stations and demand nodes. While Restriction (16) ensures that objective function value ($MinL$) must be equal or less than the distance between demand node and bike station (if it is opened). M value in Restriction (16) is a big number like 10,000.

Study Area

The campus of Gaziantep University is considered as the study area. Gaziantep University is located in Gaziantep with its 1,975,302 population in 2016. University has almost 40,000 population including students, administrative and academic staff on an area with 3,113,084 m2 (Figure 3).

Figure 3
Campus area of Gaziantep University

Source: Authors' work

In the study area, 20 demand points and 20 potential bike station sites are determined as point features and campus roads are vectored as line features via geographic information system (GIS) with ESRI ArcGIS 10.2 software. Demand points (departments, dormitory, cafeteria, etc.) are the places where students/personnel are located mostly according to the student population. Potential locations of bike-sharing stations are determined by the university administration. The main criteria of administration are proximity to demand points and available for possible infrastructure. Selected demand points and number of the students are given in Table 1. In this table, number of student column shows the number of demanding students of each stop.

Table 1
Demand points

Name of the building	No	Demand	Name of the building	No	Demand
Congress center	D1	275	Faculty of Art and Sciences	D11	300
Sport Center	D2	450	Vocational Schools	D12	175
Dormitory	D3	600	Medicine	D13	120
Cafeteria	D4	500	Theology	D14	100
Library	D5	550	Culture Center	D15	150
Market	D6	500	Department of Civil Engineering	D16	200
Techno city	D7	450	Conservatory of Turkish Music	D17	120
Department of Mechanical Engineering	D8	150	Department of Education	D18	200
Department of Electrical Engineering	D9	200	Student affairs	D19	200
Faculty of Economics	D10	150	Department of Food Engineering	D20	130

Source: Authors' work

Figure 4
Demand points (left-side) and potential bike station locations (right-side)

Source: Authors' work

Table 2
Distances (m) between demand points and potential bike stations

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
S1	592.22	1,277.47	1,613.87	586.02	738.24	594.95	1,822.65	514.11	716.62	922.38
S2	179.04	971.94	1,246.69	748.38	900.60	825.09	2,052.78	508.10	710.60	1,152.52
S3	395.48	589.92	864.67	863.02	1,015.24	939.73	2,167.42	537.00	752.66	1,267.15
S4	410.47	597.15	871.89	710.36	873.59	913.26	2,065.58	301.82	517.47	1,258.79
S5	1,215.32	646.89	44.83	1,293.47	1,188.41	1,541.47	2,380.40	1,054.93	1,192.82	1,573.61
S6	897.49	87.92	603.81	780.70	675.63	1,028.69	1,867.62	737.10	633.85	1,060.83
S7	523.17	586.00	860.74	627.21	761.87	830.11	1,953.86	239.02	405.76	1,147.07
S8	807.84	397.86	1,014.64	447.54	430.65	650.44	1,622.63	424.36	226.09	815.85
S9	713.49	576.80	1,051.07	478.00	612.66	680.90	1,804.65	297.60	256.55	997.87
S10	1,065.04	529.87	897.03	441.27	336.20	689.27	1,528.19	722.22	523.95	721.41
S11	613.81	592.91	1,209.69	253.51	423.13	456.41	1,650.57	314.67	27.96	843.78
S12	754.14	637.36	1,207.94	130.37	204.14	410.23	1,396.13	483.14	356.07	589.35
S13	743.92	742.92	1,313.50	222.10	80.26	272.80	1,307.70	497.90	370.83	500.91
S14	740.74	899.00	1,469.58	218.92	236.34	116.72	1,332.13	494.72	367.65	525.35
S15	690.50	1,034.95	1,605.53	354.88	372.30	115.33	1,340.49	612.39	503.61	403.22
S16	1,086.97	1,173.99	1,744.57	761.38	613.25	521.84	1,118.98	1,008.87	910.12	181.70
S17	781.34	1,135.83	1,706.41	455.75	473.18	216.21	1,239.62	703.24	604.49	302.34
S18	2,061.03	1,931.72	2,502.30	1,561.17	1,370.98	1,525.93	77.08	1,882.68	1,755.60	1,069.93
S19	413.51	789.11	1,214.13	294.17	463.80	497.07	1,691.23	114.37	228.26	884.44
S20	1,573.51	1,444.21	2,014.79	1,073.66	883.47	1,038.42	1,119.62	1,395.16	1,268.09	582.41

	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20
S1	821.64	799.97	839.40	592.49	1,101.23	973.14	688.95	717.22	671.85	866.48
S2	557.95	406.29	445.73	822.63	1,253.84	916.73	510.31	947.35	665.83	1,028.84
S3	409.81	140.72	297.59	937.27	1,105.70	768.59	362.17	1,061.99	780.47	1,143.48
S4	174.63	273.15	62.40	952.27	870.52	533.40	126.98	1,076.99	599.68	1,008.22
S5	864.16	960.56	814.72	1,730.62	790.98	876.28	940.36	1,723.20	1,303.59	1,348.62
S6	546.33	642.73	496.89	1,378.58	672.56	317.30	622.53	1,210.42	744.62	835.85
S7	68.51	385.84	114.04	914.70	758.80	421.68	169.28	1,039.43	516.53	922.09
S8	268.31	702.40	430.60	1,000.32	427.57	137.65	354.62	867.73	336.86	590.86
S9	142.08	576.17	304.37	973.29	609.59	272.48	227.86	898.19	367.32	772.88
S10	566.17	1,000.26	728.46	1,039.15	129.72	370.75	652.48	871.00	622.21	496.42
S11	314.89	748.97	477.17	806.29	625.70	288.59	401.19	673.70	142.83	551.37
S12	638.89	961.88	801.18	760.12	440.62	478.24	657.97	627.53	311.30	364.36
S13	653.65	951.67	815.94	622.68	546.18	583.80	672.74	490.09	326.06	208.50
S14	650.47	948.49	812.76	466.60	702.26	624.18	669.56	334.01	322.88	321.19
S15	786.43	898.24	937.68	330.64	838.22	760.13	787.22	198.06	458.84	457.15
S16	1,192.94	1,294.72	1,334.15	586.42	977.25	1,014.87	1,183.70	208.45	865.35	486.00
S17	887.31	989.09	1,028.52	280.79	939.10	861.01	878.07	97.18	559.72	558.03
S18	1,968.02	2,268.77	2,130.31	1,402.24	1,734.98	1,772.60	2,054.33	1,219.51	1,710.84	1,243.73
S19	421.90	621.25	464.90	649.93	809.39	484.79	289.20	714.37	183.49	592.04
S20	1,480.51	1,781.26	1,642.80	914.73	1,247.47	1,285.09	1,566.82	732.00	1,223.32	756.22

Source: Authors' work

In this study, two kinds of GIS data, demand/station points as a point layer and roads as a line layer, are used. Road data is also used as network data set in GIS environment. For this reason, at first, university road map is collected as line data. Then, line-shape road layer is used to generate network between all points. Figure 4 shows the road network of Gaziantep University and demand/station points. Distances between demand points and potential bike stations calculated by GIS are given in Table 2. Distance values in Table 2 are the real values (not a bird's-eye view) which a user can walk.

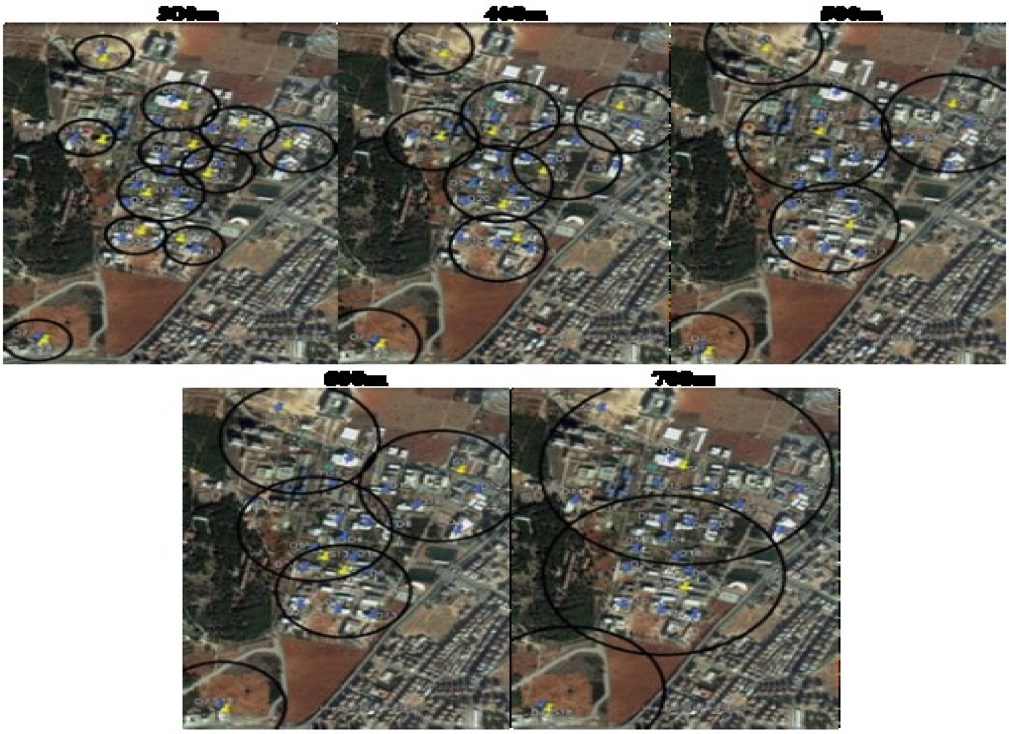
Application of Location-Allocation models

In this part, five different location-allocation models called as set covering, maximum covering, P-median, P-center and undesirable facility location models are implemented to the location problem of bike sharing stations in Gaziantep University campus. All run experiments were conducted on a server 1.8 GHz processor with 4 GB of RAM. The problem is solved with the GAMS-CPLEX and the computation time is required less than 10 CPU seconds.

Results of set and maximum covering problems

Universities should optimize station density to create a reliable network. In this way, the coverage area to provide students (users) may park and bike anywhere conveniently and easily in the area. Moreover, with this parameter ideally scales the intervals of stations, so they are within an acceptable walking distance within the coverage area (Croci et al., 2014). For instance, Paris employed one station each of 300 meters as a guideline for the first stage of its bike-share system, as did New York and London. On the other hand, users can reach a bike station in 250 meters in Mexico City (Cohen et al., 2014). According to this figure, 300 meters coverage area is primarily considered. Then, the model of set covering is solved with four coverage areas, which the ranges are between 400 and 700 meters. The results are illustrated in Figure 5.

Figure 5
Results of set covering model with different coverage limits



Source: Authors' work

As can be seen from Figure 5, all demand points are reached by bike stations in all coverage areas. Only opened bike stations are shown in Figure 5. For instance, while totally 11 bike stations are opened under 300m access distance, this number is reduced to three (stations of 6, 15 and 18) under 700m limit. Due to its location, 18th bike station is the only station which is preferred in all solutions (shown as bold in Table 3).

Table 3
Opened bike stations based on different access limits

Access limit (m)	Stations need to be opened	# of stations
300	S2 – S4 – S5 – S6 – S9 – S10 – S13 – S16 – S17 – **S18** – S19	11
400	S3 – S5 – S8 – S10 – S14 – S17 – **S18** – S19	8
500	S3 – S5 – S8 – S15 – **S18**	5
600	S3 – S5 – S13 – S14 – **S18**	5
700	S6 – S15 – **S18**	3

Source: Authors' work

In addition to set covering problem, maximal covering problem is also considered. Using the demand (w_i) and distance values (d_{ik}), equations (4) to (7) are solved. To make a comparison between set covering problem, the same access limits are used. P values are set as 11, 8, 5, 5 and 3 for each access limit.

Table 4
Results of maximal covering problem based on different access limits

Access limit (m)	Stations need to be opened	*P*
300	S2 – **S3** – S5 – S6 – S9 – S10 – S13 – S16 – S17 – S18 – **S19**	*=11*
	S2 – **S4** – S5 – S6 – S9 – S10 – **S11** – S13 – S16 – S17 – S18	*≤11*
400	S3 – S5 – S8 – S10 – **S14** – S17 – S18 – S19	*=8*
	S3 – S5 – S8 – S10 – **S13** – S17 – S18 – S19	*≤8*
500	S2 – S5 – S8 – S15 – S18	*=5*
	S2 – S5 – S8 – S15 – S18	*≤5*
600	**S1** – S5 – S7 – **S13** – S18	*=5*
	S5 – S7 – **S12** – **S15** – S18	*≤5*
700	S6 – S15 – S18	*=3*
	S6 – S15 – S18	*≤3*

Source: Authors' work

Results of P-median and P-center problems

After showing the effects of coverage areas on potential bike stations, P-median and P-center models are implemented to allocate bike stations to demand points. In this way the total walking distance is minimized. P-median model is performed assuming the demands are different as given in Table 1.

We implement the P-median model with different p values by setting 1 to 10. The results of P-median problem are given in Table 5. To make a fair comparison with P-center problem, total walked man-distance (objective function of P-median) and MaxL (objective function of P-center) values for each model are provided.

Table 5
Results of P-median problem with different p values

	P=1	***P=2***	***P=3***	***P=4***	***P=5***
***MaxL* Value (m)**	1,313.50	1,307.70	740.74	702.26	672.56
Total distance (m)	3,423.61	2,519.17	1,959.43	1,486.69	1,216.49
Opened Stations	S13	S6–S13	S6–S14–S18	S5–S7–S14–S18	S4–S5–S6–S14–S18
	P=6	***P=7***	***P=8***	***P=9***	***P=10***
***MaxL* Value (m)**	546.18	546.18	546.18	403.22	403.22
Total distance (m)	1,040.10	929.14	855.24	792.77	746.90
Opened Stations	S4–S5–S6–S13–S15–S18	S4–S5–S6–S11–S13–S15–S18	S2–S5–S6–S7–S11–S13–S15–S18	S2–S5–S6–S7–S10–S11–S13–S15–S18	S2–S5–S6–S7–S10–S11–S12–S13–S15–S18

Source: Authors' work

With respect to Table 5, all problems of P-median are solved with optimally manner. Results in Table 5 indicate that increasing available bike stations number from 1 to 10, decreases the total travelled distance by 78.18%. Another outcome can be seen from Table 5 that 13^{th} bike station is the closest station to all demand points.

On the other hand, the P-center problem seeks to identify p amount candidate bike stations that is to open, and which demand points will be assigned to each station while minimizing the longest distance to the station. Table 6 offers P-center problem results for different p values.

Table 6
Results of P-center problem with different p values

	P=1	***P=2***	***P=3***	***P=4***	***P=5***
***MaxL* Value(m)**	1,313.50	1,014.64	740.74	622.68	458.84
Total distance(m)	3,423.61	2,868.80	2,120.50	1,629.40	1,488.50
Opened Stations	S13	S8–S18	S6–S14–S18	S3–S5–S13–S18	S4–S5–S8–S15–S18
	P=6	***P=7***	***P=8***	***P=9***	***P=10***
***MaxL* Value(m)**	427.57	410.47	364.36	317.30	302.34
Total distance(m)	1,107.10	1,167.50	1,033.40	847.21	800.76
Opened Stations	S4–S5–S8–S13–S17–S18	S4–S5–S6–S10–S13–S17–S18	S2–S4–S5–S6–S10–S12–S17–S18	S2–S4–S5–S6–S10–S11–S13–S17–S18	S2–S4–S5–S6–S10–S11–S13–S17–S18–S19

Source: Authors' work

With respect to Table 6, increasing bike stations numbers to be opened decreases the longest distance between demand points and stations. While the longest distance between 13th bike station (p=1) and demand points is 1,313.50m, it decreases to

302.34m with a 76.98% improvement in the situation of p=10. If two models are compared, it is clear that P-median model provides less walked distance than the results of P-center model in all situations. On the contrary, P-center model ensures less long distance between users and bike station than the longest distance obtained by P-median model.

Undesirable facility location problem

In addition to finding the closest and suitable bike stations which are presented above, undesirable facility location problem is solved using the same data in this sub-section. Although application of undesirable facility location model seems unreasonable, the main reason of this application is to find which bike stations can be eliminated and which are inaccessible. To do so, the mathematical model of undesirable facility location problem is solved for each p value from 1 to 20. Obtained results which shows opened bike stations (undesirable bike stations) and objective function values are given in Table 7.

Table 7
Undesirable bike stations based on different p values

# of *p*	Stations need to be opened	Value of *MinL* (m)
20	S1 – S2 – S3 – S4 – S5 – S6 – S7 – S8 – S9 – S10 – **S11** – S12 – S13 – S14 – S15 – S16 – S17 – S18 – S19 – S20	27.96
19	S1 – S2 – S3 – S4 – **S5** – S6 – S7 – S8 – S9 – S10 – S12 – S13 – S14 – S15 – S16 – S17 – S18 – S19 – S20	44.83
18	S1 – S2 – S3 – **S4** –S6 – S7 – S8 – S9 – S10 – S12 – S13 – S14 – S15 – S16 – S17 – S18 – S19 – S20	62.40
17	S1 – S2 – S3 – S6 – **S7** – S8 – S9 – S10 – S12 – S13 – S14 – S15 – S16 – S17 – S18 – S19 – S20	68.51
16	S1 – S2 – S3 – S6 – S8 – S9 – S10 – S12 – S13 – S14 – S15 – S16 – S17 – **S18** – S19 – S20	77.08
15	S1 – S2 – S3 – S6 – S8 – S9 – S10 – S12 – **S13** – S14 – S15 – S16 – S17 – S19 – S20	80.26
14	S1 – S2 – S3 – **S6** – S8 – S9 – S10 – S12 – S14 – S15 – S16 – S17 – S19 – S20	87.92
13	S1 – S2 – S3 – S8 – S9 – S10 – S12 – S14 – S15 – S16 – **S17** – S19 – S20	97.18
12	S1 – S2 – S3 – S8 – S9 – S10 – S12 – S14 – S15 – S16 – **S19** – S20	114.37
11	S1 – S2 – S3 – S8 – S9 – S10 – S12 – S14 – **S15** – S16 – S20	115.33
10	S1 – S2 – S3 – S8 – S9 – S10 – S12 – **S14** – S16 – S20	116.72
9	S1 – S2 – S3 – S8 – S9 – **S10** – S12 – S16 – S20	129.72
8	S1 – S2 – S3 – S8 – S9 – **S12** – S16 – S20	130.37
7	S1 – S2 – S3 – **S8** – S9 – S16 – S20	137.65
6	S1 – S2 – **S3** – S9 – S16 – S20	140.72
5	S1 – S2 – **S9** – S16 – S20	142.08
4	S1 – **S2** – S16 – S20	179.04
3	S1 – **S16** – S20	181.70
2	**S1** – S20	514.11
1	**S20**	582.41

Source: Authors' work

Bold values in Table 7 shows the related bike station which provides the objective function value. For instance, there are three bike stations namely S1, S16 and S20 are opened in the case of p=3. Objective function value is 181.70m for this solution. It means that if bike stations of S1, S6 and S20 are established, a user can reach to S16 in 181.70m in the quickest way. So, if three bike stations are needed, S1, S16 and S20 must not be preferred in real.

Obtained results above might appear as a drawback for the campus planners, which may be search, the site selection that minimizes distance. Nevertheless, this can be an advantageous because it offers to the planner various alternatives to select from. For instance, if administration of campus wants to reach a bike station within approximately 400m, they have several options. According to the set and maximal covering problems, the first option is to open 8 bike stations which are S3, S5, S8, S10, S14, S17, S18 and S19 stations. However, according to P-median problem, the second option is to open 9 bike stations which are S2, S5, S6, S7, S10, S11, S13, S15 and S18 stations. In this case, total travelled distance is 792.77 man-km. According to P-center problem, 7 bike stations which are S4, S5, S6, S10, S13, S17 and S18 are enough for 400m limit as the last option. But at this time, total walked distance is increased to 1167.50 man-km. Finally, according to undesirable facility location model, if all bike stations are opened, a user can reach to S11 with a 27.96m distance in the quickest way. As a result, we preferred to provide different alternative solutions for the campus planners instead of deciding on a solution.

Conclusion

This study is designed to find the required number and optimal locations of the bike stations that need to establish in Gaziantep University campus. To do so, five of the well-known solutions technique in location-allocation problem have been investigated, which are, maximal covering, set covering, P-center, P-median, and undesirable facility location models. The P-median solution appears to be more advantageous in terms of accessibility because it produces a uniform coverage. On the other hand, S20 is the only bike station, which covers all demand points in a maximum manner.

The methodology outlined in this study can ensure university administrators with good insight into where bike-sharing stations should be located, and in this way, it contributes significantly bike-sharing systems for the future planning.

Interaction with public transport services, usage of electric bicycles within a framework of internet of things and the cost of the system should be considered in the future studies.

References

1. Ali-Askari, E., Bashiri, M., Tavakkoli-Moghaddam, R. (2017), “A capacitated bike sharing location-allocation problem under demand uncertainty using sample average approximation: A greedy genetic-particle swarm optimization algorithm”, Scientia Iranica Transactions E: Industrial Engineering, Vol. 24, No. 5, pp. 2567-2580.
2. Beasley, J. E. (1987), “An algorithm for set covering problem”, European Journal of Operational Research, Vol. 31, No. 1, pp. 85-93.
3. Broach, J., Dill, J., Gliebe, J. (2012), “Where do cyclists ride? A route choice model developed with revealed preference GPS data”, Transportation Research Part A: Policy and Practice, Vol. 46, No. 10, pp. 1730-1740.
4. Cohen, A., Simons, D., Martignoni, M., Olson, J. (2014), “The bike-share planning guide”, available at: https://www.itdp.org/wp-content/uploads/2014/07/ITDP_Bike_Share_Planning_Guide.pdf (23 April 2018).
5. Croci, E., Rossi, D. (2014), “Optimizing the position of bike sharing stations. The Milan case”, Bocconi working paper series, No. 68, Bocconi University, Milan.
6. Çetinkaya, C. (2017), “Bike sharing station site selection for Gaziantep”, Sigma Journal of Engineering and Natural Sciences, Vol. 35, No. 3, pp. 535-543.
7. Daskin, M. S. (2008), “What you should know about location modelling”, Naval Research Logistics, Vol. 55, No. 4, pp. 283-294.
8. Dobešová Z., Hýbner R. (2015), “Optimal Placement of the Bike Rental Stations and Their Capacities in Olomouc”, in: Ivan I., Benenson I., Jiang B., Horák J., Haworth J., Inspektor T.

(Eds.), Geoinformatics for Intelligent Transportation, Lecture Notes in Geoinformation and Cartography, Springer, Cham, pp. 51-60.
9. Erkut, E., Neuman, S. (1989), "Analytical models for locating undesirable facilities", European Journal of Operational Research, Vol. 40, No. 3, pp. 275-291.
10. Frade, I., Ribeiro, A. (2015), "Bike-sharing stations: A maximal covering location approach", Transportation Research Part A: Policy and Practice, Vol. 82, pp. 216-227.
11. García-Palomares, J. C., Gutiérrez, J., Latorre, M., (2012), "Optimizing the location of stations in bike-sharing programs: A GIS approach", Applied Geography, Vol. 35, No. 1-2, pp. 235-246.
12. Ghandehari, M., Pouyandeh, V. H., Javadi, M. H. M. (2013), "Locating of bicycle stations in the city of Isfahan using mathematical programming and multi-criteria decision making techniques", International Journal of Academic Research in Accounting, Finance and Management Sciences, Vol. 3, No. 4, pp. 18-26.
13. Lin, J. R., Yang, T. H., (2011), "Strategic design of public bicycle sharing systems with service level constraints", Transportation Research Part E: Logistics and Transportation Review, Vol. 47, No. 2, pp. 284-294.
14. Liu, J. et al. (2015), "Station site optimization in bike sharing systems", 2015 IEEE International Conference on Data Mining, IEEE, Atlantic City, USA, pp. 883-888.
15. Martens, K. (2007), "Promoting bike-and-ride: the Dutch experience", Transportation Research Part A: Policy and Practice, Vol. 41, No. 4, pp. 326-338.
16. Martinez, L. M., Caetano, L., Eiró, T., Cruz, F. (2012), "An optimization algorithm to establish the location of stations of a mixed fleet biking system: An application to the City of Lisbon", Procedia - Social and Behavioral Sciences, Vol. 54, pp. 513-524.
17. Mattson, J., Godavarthy, R. (2017), "Bike share in Fargo, North Dakota: Keys to success and factors affecting ridership", Sustainable Cities and Society, Vol. 34, pp. 174-182.
18. Narula, S. C. (1986), "Mini-sum hierarchical location-allocation problems on a network: A survey", Annals of Operations Research, Vol. 6, No. 8, pp. 255-272.
19. Özceylan, E., Mete, S., Çil, Z. A. (2017a), "Optimizing the location-allocation problem of bike sharing stations: A case study in Gaziantep University campus", in Proceedings of 14th International Symposium on Operations Research of Slovenia, pp. 141-146.
20. Özceylan, E., Uslu, A., Erbaş, M., Çetinkaya, C., İşleyen, S. K. (2017b), "Optimizing the location-allocation problem of pharmacy warehouses: A case study in Gaziantep", An International Journal of Optimization and Control: Theories & Applications, Vol. 7, No. 1, pp. 117-129.
21. Rodríguez, J. J. S., García, C. G., Pérez, J. M., Casermeiro, E. M. (2006), "A general model for the undesirable single facility location problem", Operations Research Letters, Vol. 34, No. 4, pp. 427-436.
22. Romero, J., Ibeas, A., Moura, J. (2012), "A simulation–optimization approach to design efficient systems of bike-sharing", Procedia - Social and Behavioral Sciences, Vol. 54, pp. 646-655.
23. Sallis, J. F., Frank, L. D., Saelens, B. E., Kraft, M. K. (2004), "Active transportation and physical activity: opportunities for collaboration on transportation and public health research", Transportation Research Part A: Policy and Practice, Vol. 38, No. 4, pp. 249-268.
24. Teixeira, J. C., Antunes, A. P. (2008), "A hierarchical location model for public facility planning", European Journal of Operational Research, Vol. 185, No. 1, pp. 92-104.
25. Wang, J., Tsai, C. H., Lin, P. C. (2016), "Applying spatial-temporal analysis and retail location theory to pubic bikes site selection in Taipei", Transportation Research Part A: Policy and Practice, Vol. 94, pp. 45-61.

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