Sigma J Eng & Nat Sci 9 (4), 2018, 427-436

Publications Prepared for Transist 2017,
10th International İstanbul Transport Congress

Research Article

A BICYCLE SHARING SYSTEM DESIGN FOR ITU AYAZAĞA CAMPUS

Dilay ÇELEBİ*[1], Aslı YÖRÜSÜN[2], Hanife IŞIK[3]

[1]*İstanbul Technical University, Management Engineering Dept., İSTANBUL;* ORCID:0000-0002-7103-3868
[2]*İstanbul Technical University, Management Engineering Dept., İSTANBUL;* ORCID:0000-0002-4415-9510
[3]*İstanbul Technical University, Management Engineering Dept., İSTANBUL;* ORCID:0000-0001-7084-0767

Received: 19.09.2018 Revised: 06.12.2018 Accepted: 25.01.2019

ABSTRACT

This study presents design of a bike-sharing system developed for Istanbul Technical University Ayazağa Campus. The key design decisions considered are: the number and locations of bicycle stations in the system, the inventory levels of sharing bicycles to be held at the bicycle stations, and the pricing scheme to be used in operating the system. The station location problem is formulated as a hub location model. Considering stochastic arrival and departure rates, the optimal number of bicycles in each location is then determined by a queuing model. Finally, feasibility of different pricing schemes is analysed in the account of demand elasticities and investment, maintenance and operational costs.
Keywords: Bicycle sharing, location selection, optimization, queuing models.

1. INTRODUCTION

Transportation constitutes a considerable part of our life. The necessity of using motor vehicles in long distances combined with increased population density and desire of private car ownership, increase the number of motorized vehicles in traffic dramatically every day. This situation causes environmental, economic, social problems, creates congestion, and decreases the quality of life. It is stated that about 90% of the global transport sector depends on oil and around 49% of oil production is consumed alone by transportation, transportation itself is swift consumer of the world's energy [1]. The unavoidable impacts are negative externalities such as climate change, augmentation of CO2 emissions, bad air quality, high noise levels and road accidents. Thus, many countries take actions to encourage the use of public transportation and more environmental friendly transportation modes. The principle is to provide an alternative or complementary form of public transport to cover short journeys within city limits [2]. In this sense, Bicycle Sharing Systems (BSS) are ideal for short distance point-to-point trips providing an sustainable alternative for transport.

The success of BSS is determined by the convenience of locations of the bicycle pick-up and drop-off stations. To improve operations efficiency, BSS should ensure that the distance between centres is short enough that it is convenient to pick up, return, and transfer bicycles between centers [3]. This is not a straightforward task, because demand for bicycle pick-up and returns are random. Hence, demand patterns must be identified, and accurate forecasts must be made for each

* Corresponding Author: e-mail: celebid@itu.edu.tr, tel: (212) 293 13 00 / 2056

centre to maximize the level of customer satisfaction. Each bicycle station must carry enough capacity to increase the probability that users can find a bicycle or a docking station when needed. Therefore, BSS must be well designed and planned.

The purpose of this paper is to design an efficient and effective BSS for ITU Ayazağa Campus. In the first phase, we estimated potential demand at alternative locations and developed a set covering model for obtaining best bicycle station locations on those points. Then we used queuing theory to calculate the optimal capacities in each location such that a predetermined service level is satisfied both for pick-up and return demand. The remainder of the paper is organized as follows: Section 2 reviews the use and benefits of BSS and provides a short overview of bicycle use in Turkey and İstanbul. Section 3 gives an overview of the system, presents the model for determining best station locations and capacities, including estimation of bike sharing demand. Section 4 concludes the study and outlines perspectives for further research.

2. LITERATURE REVIEW

2.1. Sustainable Transportation

Sustainability concept became prominent in recent years although its history dates back to old times. A widely accepted definition of sustainability was given at Bruntland Report in 1978. According to that report, sustainability was defined as meeting the today's requirements without endangerment of the posterity's meeting requirements resources [4]. Based on that definition, sustainable transportation was described as meeting the today's transportation requirements without endangerment of the posterity's transportation meeting requirements resources [5]. Sustainable transportation is concept of transportation that does not damage to environment beyond to its capacity of self- perpetuation is economically viable, socially fair, politically responsible and accountable [6].

In recent years, sustainable transport policies have taken by hundreds of cities and locations. The innovative strategies for sustainable transportation are divided into four groups: (1) new mobility, (2) city logistics, (3) intelligent system management, and (4) liveability [7]. New mobility strategies offer the alternatives to private car usage by developing new technologies and business models. City logistics strategies aim to decrease empty vehicle travels in congested urban centres and to increase the yield of urban freight operations without damaging environment. Intelligent system management is about pricing and system management techniques for sustainable transportation. Liveability strategies pay particular attention to connection of transportation system to society.

2.2. Benefits of Bicycle as a Means of Transportation

Bicycle is the most environment friendly mode of transportation. Its only source of energy is manpower. Even when CO2 consumed by man power and calories burnt during cycling are added, bicycle accounts for about 21 g of CO2 emissions per kilometer which is more than ten times less than an automobile [8]. Bicycle enhances the mobility of users in urban transport as a fast, convenient and responsive mode of transport. It is inexpensive and does not require large amount of maintenance expenses. It does not lead to noise pollution and supports the well-being of the users by providing a good form of exercise. Research findings are striking. Cycling to work was associated with a 41% lower risk of dying overall compared to commuting by car or public transport. Cycle commuters had a 52% lower risk of dying from heart disease and a 40% lower risk of dying from cancer. They also had 46% lower risk of developing heart disease and a 45% lower risk of developing cancer at all [9].

Bicycle sharing systems are conducive to familiarize new people to urban cycling, which eventually reduces congestion at peak hours, decreases self-owned automobile usage, and improves liveability of cities [9]. BSS use less space than other modes of transportation. On the average five public bicycle consoles correspond to 15 users, while one car parking lot correspond to six users per day [11]. If BSS are integrated to other modes of public transportation, it will have significantly positive effect on reducing motorized traffic and its environmentally unfavourable effects [10]. Another survey results show that 20% of bicycle commuters in Paris replaced their self-owned vehicles with city's bicycle sharing system for daily commuting [12].

2.3. History of Bicycle Sharing Systems

A BSS is defined as a system offering short-term urban rental bicycles available at a network of unattended locations in public spaces. Passengers can take the bicycles whenever they need them and leave them behind when they reach their destinations [13]. Bicycle sharing is an innovative mode of transportation that stands readily available at bicycle sharing points. These bicycles can be used for a fee without the worries of owning one. BSS are ideal for short distance point-to-point trips providing users the ability to pick up a bicycle at any self-serve sharing point and return it to any other sharing point located within the sharing system's service area. In order to encourage the use of bicycle for transportation, it is generally free or inexpensive. BSS differentiate from bicycle rental systems in the respect that they do not require long term commitment of user and the user is free of maintenance costs and theft [14]. BSS are generally introduced by a private company with the collaboration of a local authority. Improvement, application and introduction of these system sometimes can be performed by civil society organizations that formed by certain group of urban cyclists [15].

Three (and a half) generations of bicycle sharing systems can be identified [16]: The first generation originates in Amsterdam in 1965. The initiative was called "White Bicycles" where bikes in circulation were provided free to be used for one trip and then leave them unlocked for someone else to use. Second-gen BSS emerged in Copenhagen, under the name "Bycykler Kobenhavn". The system introduced the coin-deposit model to deter theft and to foster bicycle returns. Yet, the program still had an issue with theft due to the anonymity of the users. The third generation replaced coin-access with smart card access. It was first launched in Rennes as "Velos a la carte". It also started the restricted usage time scheme, generally providing minutes of bike use for free. The next generation (3+) of bicycle sharing systems was smartened with real-time availability and GPS tracking. These systems signal the appearance of flexible, clean docking stations, touchscreen kiosks, additional bike re-balancing technologies, as well as the integration of one unique card allowing a user to make use of both bikes and public transportation. Currently, there are around 1000 cities equipped with BSSs around the world [17].

BSS has been receiving growing attention from researchers and policy makers for achieving more sustainable urban transport [18]. Over the past decade, bike sharing has become more common, consequently a good inventory of research has been developed for the analysis of BSS in towns and cities around the world.

2.4. Bicycle Use in Turkey and İstanbul

Despite the high potential of bicycle usage in Turkey shown by previous studies, use of bicycles in urban transport in Turkey is limited to a very small domain. Among the reasons are the lack of a common cycling culture and consideration of bicycle as a means of transportation, and absence of relevant infrastructure. An example is the "Istanbul General Bike Path Plan", which is developed in 2002 [19]. Even though this plan is comprehensive in providing the planning principles, specifies constraints and identifies some pilot regions, all identified regions are green areas or coastal lines with unconnected lines, which indicates that cycling is mainly deemed as a means of entertainment but not transportation.

Around 92% of urban transportation in the city of İstanbul is over road, and almost half of the all journeys are made by pedestrians [20], which can easily be diverted to cycling. The demand for cycling may also be increased by integrating bicycle systems with other types of transportation. Bicycle sharing systems makes up a good option for increasing cycling demand by providing an environmentally sustainable and socially equitable mode of transportation, which can be used as part of an intermodal public transport system. For the bicycle-sharing system to become a sensible alternative to other modes of transportation, it has to be reliable in providing available bicycles and lockers when demanded. The system has to be planned and managed to maximize the level of customer satisfaction. Even though lack of bicycle lanes and ill-structured traffic creates danger and inconvenience for cyclists in İstanbul, BSS are convenient in providing an alternative or complementary form of transport to cover short journeys, particularly in traffic restricted areas, such as parks, university campuses, and historic city centres. Next section presents an example of BSS design for such an area, İTÜ Ayazağa Campus, for determining optimal station locations and capacities.

Figure 1. ITU Ayazağa Campus map

3. A BICYCLE SHARING SYSTEM DESIGN FOR ITU AYAZAĞA CAMPUS

3.1. Analysis of ITU Ayazağa Campus's Geographical Situation

ITU Ayazağa Campus is located in İstanbul Maslak over an area of 247 hectares as the map in Figure 1 illustrates. The majority of the population are students of the university, ITU has approximately 30,000 students. At present, ITU does not have the infrastructure to make cycling a preferred mode of transport in an optimized way. The campus lacks a sufficient network of bike lanes and other supporting facilities for bicycles. However, as more than 70% of the road network is suitable for cycling using normal bikes [21], the road network within the campus can easily be used for cycling, due to the grading and extent of the road network.

According to Midgley [22], slopes within the range of 4% and 8% can be a limiting constraint for the implementation of a bicycle sharing system. We conducted a spatial examination of slopes in the area and height profiles show that despite the high level of elevation differences between a number of points within the campus, the maximum altitude difference is moderate. The slopes of the two most inclined paths vary between 2% and 8%. With the lengths of both slopes being less than 300 meters, together with the high percentage of daily trips of less than 2 km and restricted vehicle traffic on campus, ITU Ayazağa is a potentially suitable site for a bicycle sharing system.

3.2. Method

In this work, we propose a model, which considers both the location decisions and capacity allocation to determine the best configuration of a bicycle sharing system. One distinction of this approach is its sequential behavior as depicted in Figure 2, and the definition of service level measured by the amount of unsatisfied demand for both bike pick-ups and returns. We therefore used a set-covering model to assign the demand locations to stations with a queuing model to measure the relevant service levels.

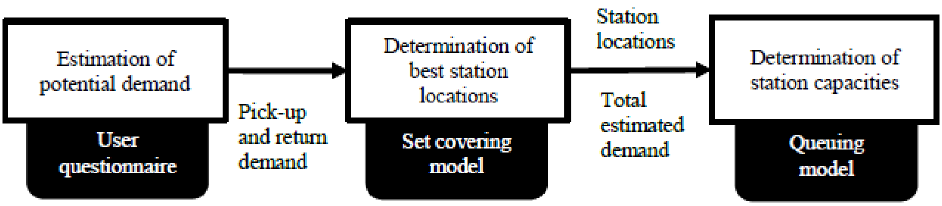

Figure 2. Schematic representation of the method

3.3. Distribution of potential demand

The geographical distribution of demand is a fundamental element in finding optimal locations of stations. Obtaining potential station demand starts with the determination of potential points containing the travel demand and number of students associated with each building and calculating the expected number of trips generated and attracted for each potential point. We conducted a survey to understand daily transportation requirements of students, academic or administrative staffs in ITU Ayazağa Campus. Table 1 summarizes respondents' demographics.

Table 1. Survey statistics

	Total population		Survey respondents	
	Number	Percentage	Number	Percentage
Acd. staff	2043	5,96%	87	23,32%
Adm.staff	424	1,23%	4	1,07%
Students	31786	92.81%	282	75,61%
Total	34253		373	

We have identified 48 potential demand points and asked the respondents their most frequently used origin and destination points in five different time slots of a typical day. We also questioned respondents' willingness to use a bicycle sharing system if built, and maximum amount of fee they will be willing to pay for such a system. Figure 2 shows the number of respondents who are willing to pay a monthly subscription fee for given price levels. We assumed people who are willing to pay a certain amount is also willing to pay some other less amount and used this information to estimate the demand at each origin point. As an example, the resulting total number of trips generated from selected origin points at all time slots and no subscription fee (minimum) is given in Figure 3, by a number besides each point.

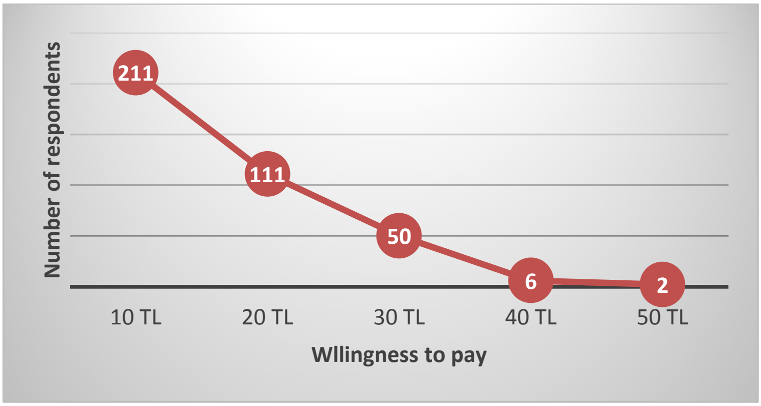

Figure 1. Willingness to pay at different price levels

3.4. Determination of station locations

In any bike-sharing program, one of the keys to success is the location and distribution of bike stations [23]. In proposed model, the stations are located such that coverage is maximized while the total number of stations are limited. Accordingly, the stations are located such that as many demand points as possible are allocated to solution facilities within the impedance cut-off. In this 'maximize coverage' model, the impedance cut-off considered was 200 m, deemed as a suitable distance for pedestrian access to bicycles. The mathematical model for choosing the minimum number of stations to maximize the flow between the stations is formulated under following assumptions:

1. There are N different potential locations, determined by demand analysis.
2. Each buildings and locations are named as candidate station or as a centre.
3. Flows between two candidate locations reach highest value during a day, therefore the flows between 00:00 and 06:00 are assumed as zero.
4. Users are willing to walk to any bike station within the distance of D meters.

Prior to introducing the system structure and presenting the formulation of the model, the notation and symbols are listed below:

Subscripts and Sets

N	Set of demand points (k) and alternative stations (i), $i,k \in N$
Parameters	
α_{ik}	Indicator of potential assignment of point k to station i
V_k	Demand at point k
θ_i	Total demand at alternative station i
M	Total number of stations
Variables	
x_{ik}	Binary variable indicating point k is assigned to station i
y_i	Binary variable indicating selection of station i

The formulation of the station location model as an application of set covering is given below: Objective Function:

$$\max \sum_{i=1}^{N} \theta_i y_i \tag{1}$$

subject to

$$\sum_{k=1}^{N} \alpha_{ik} V_k = \theta_i, \quad \forall i \tag{2}$$

$$\sum_{k=1}^{N} \alpha_{ik} x_{ik} = 1, \ \forall k \tag{3}$$

$$x_{ik} \leq y_i, \qquad \forall k, i \tag{4}$$

$$\sum_{i=1}^{N} y_i \leq M \tag{5}$$

$$\alpha_{ik} = \begin{cases} 1, if\ d_{ik} \leq D \\ 0, otherwise \end{cases} \tag{6}$$

$$y_i = \begin{cases} 1, if\ ith\ station\ is\ selected \\ 0, otherwise \end{cases} \tag{7}$$

$$x_{ik} = \begin{cases} 1, if\ kth\ point\ is\ assigned\ to\ ith\ station \\ 0, otherwise \end{cases} \tag{8}$$

In the model, Equation (1) gives the objective function, maximizing total flows within the system. θ_i is the total flow in i^{th} station. First constraint defines the value of θ_i and calculates the total expected demand of each station assigned to station *i*. Second constraint (3) ensures that any demand point k, assigned to station *i* is in the distance of *D* meters. Here, a_{ik} is the indicator of a potential assignment. Third constraint (4) is the covering constraint. Last constraint (5) limits the total number of stations.

By setting *N*=48, *M*=12, and *D*=200 meters, solution of the model is obtained with CPLEX algorithm. Optimal locations of stations are determined as follows: Faculty of Mines (i=6), IMKB Student Dorms/ITU Borsa Istanbul Gate (i=8), Faculty of Naval Architecture and Ocean Engineering (i=11), Rectorate (i=13), Swimming Pool (i=19), Ferhunde Birkan Student Dorm (i=15), ITU Etiler Gate (i=23), Arı Teknokent 3 (i=24), Simmit (i=25), Ayazağa Housing A Block (i=28), Energy Institute (i=37), Dorms and Scholarships Office (i=40). The findings are illustrated in Figure 3, by grouping station assignments in identical colours.

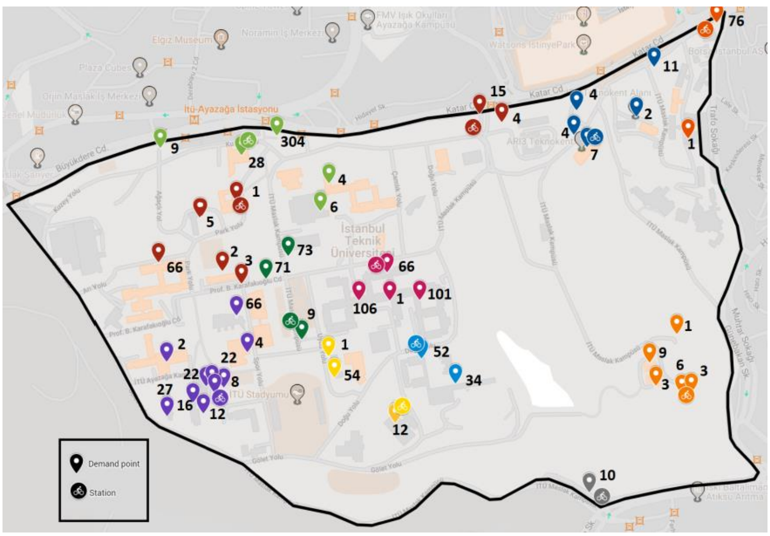

Figure 3. Demand at origin points and location of stations

3.5. Determination of station capacities

The system at station *i* can be modeled as an M/M/1/K queuing system [24], where the number of customers in the queue representing the bicycles (maximum K). This implies that the customer inter-arrival times (for bike returns) and service times (i.e. inter-arrival times for bike pickups) are exponentially distributed with rates λ_i and μ_i, respectively, at each station *i*. While some students arrive simultaneously (compound Poisson process), we assume this effect is negligible.

Let K_i be the capacity of station i, that is the number bicycle slots in the station, referring to the maximum number of bicycles in the station or under service. The number of bicycles in the system is a birth-death process with rates $\lambda_{ik} = \lambda_i$, $k = 0,\ldots,K_i - 1$, $\mu_{ik} = \mu_i$, $k = 1,\ldots,K_i$.

The M/M/1/K queue is well-studied [25] and closed-form expressions for the transient probabilities *(P)*, given a starting state are available. For the steady-state distribution we have:

$$P_k = \frac{\rho^k}{\sum_{n=0}^{K_i} \rho^n}, \quad k = 0, \ldots, K_i \tag{8}$$

that is

$$P_0 = \frac{1}{\sum_{n=0}^{K_i} \rho^n} = \begin{cases} \frac{1}{K_i+1}, & \rho = 1 \\ \frac{1-\rho}{1-\rho^{K+1}}, & \rho \neq 1. \end{cases} \tag{9}$$

Bike sharing systems are subject to a net demand process, with an empty station preventing users from picking up bikes and a full station preventing returns. Therefore, the number of unsatisfied users are proportional to fraction of the time when all slots are empty and all slots are full. Therefore, we can implement a measurable type 2 service level: the fraction of demands satisfied directly should be larger than β_i^- for pickups and larger than β_i^+ for returns.

The service level requirement at station i is then:

$$\begin{aligned} 1 - P_k &\geq \beta_i^+ \\ 1 - P_0 &\geq \beta_i^-. \end{aligned} \tag{10}$$

By requiring a $\beta_i^- = \beta_i^+ = 95\%$ service level at each station *i*, we calculate K_i using Eq. 8-10 for 10 TL, 20 TL and 30 TL monthly subscription fees. Note that both λ_i and μ_i decreases with increased cost of monthly subscription fee. Accordingly, minimum number of bicycle slots for each station under different monthly subscription prices are provided in Table 2.

Table 2. Optimal station capacities

	Subscription Fee		
Stations	10 TL/month	20 TL/month	30 TL/month
i=6	17	9	5
i=8	10	4	3
i=11	8	4	3
i=13	22	10	5
i=15	14	7	5
i=19	9	4	3
i=23	3	3	3
i=24	6	4	3
i=25	25	13	6
i=28	4	3	3
i=37	4	3	3
i=40	8	6	3
Total	130	70	45

As it can be seen from the table, the impact of increasing the subscription fee from 10 to 20 is highest at stations i=6,13,15, and 25, the stations with the highest demand of students. As expected, stations *i*=28 and 37 are located close to residential area of academics and business centres (Teknoparks) have the lowest price sensitivity. The total number of bicycles required almost halves when the fee is increased from 10 TL to 20TL but the rate of change is lower between 20 TL and 30 TL. Accordingly, to better understand the impact of monthly fee changes, in the final stage, a financial analysis for proposed bicycle sharing system is performed by a cost evaluation technique where each cost item is estimated under different pricing scenarios. Income statements of the three options are constituted for two years and evaluated over net present value, internal rate of return, and discounted payback period at the end of 2 years according to Gorden growth model.

For system costs we considered fixed capital investment costs, comprising costs of project development, station equipment (kiosks, bike stands), infrastructure, office, software and installation costs, and working capital investment costs, comprising costs of bicycles, stand-by bicycle equipment, and operating costs of maintenance and management. Revenue expectations are generated according to the survey results. Based on this analysis, first scenario with 10TL subscription fee is identified as the best option with 11% internal rate of return and 10 months discounted payback period, though all alternatives are found financially feasible. Calculation of payback period is straightforward by basic accounting techniques, so it has been excluded from the paper. Interested readers may contact the authors to obtain details of this step.

4. CONCLUSIONS

Bicycle sharing system is an appropriate mode of transportation for campuses where young population exist. This study shows that ITU students, who spend time in the campus are ready and willing to use a BSS. Therefore, such type of bicycle sharing system can be a solution for campus transportation in an efficient and environmentally friendly mode and even can be extended to other parts of the city if safety and comfort of riding is ensured. The method outlined here can be directly used to identify the station locations and capacities so as to maximize service levels with respect to investment constraints. The model can also be helpful to analyse the impacts of different configurations of an already planned Bicycle Sharing System

For implementation of such a system in real life some further steps may be required. Our findings are based on demand expectations from the survey responses which may be different than real life usage after implementation. Moreover, bicyle demand is subject to change as a function of service quality, changing passenger habits, and bicycle availability after the implementation of such a system. Hence some future work is planned to obtain a more accurate prediction of demand in relation to other factors, including the impact of relocation of bicycles on service levels.

The method used in this paper gives a good allocation of stations and bicycles, yet it does not guarantee optimality. Future research will involve development of an integrated optimization system that simultaneously determines the number of stations and capacities that minimizes costs and maximizes service quality for bike planning. We also plan to conduct a sensitivity analysis to observe marginal effects of rental costs, operational parameters and service penalties.

REFERENCES

[1] Maniatopoulos, P., Andrews, J., & Shabani, B., 2015, Towards a sustainable strategy for road transportation in Australia: The potential contribution of hydrogen. Renewable and Sustainable Energy Reviews, 52, 24-34.

[2] Lihong Zhang, Jun Zhang, Zheng-yu Duan, and David Bryde. 2015, Sustainable bike-sharing systems: characteristics and commonalities across cases in urban china. Journal of Cleaner Production, 97:124-133.

[3] Shu, J., Chou, M. C., Liu, Q., Teo, C. P., & Wang, I. L. (2013). Models for effective deployment and redistribution of bicycles within public bicycle-sharing systems. Operations Research, 61(6), 1346-1359.

[4] United Nations., 1987, World Commission on Environment and Development. Our Common Future. Oxford, UK.s

[5] Black, W.R., 1996, Sustainable transportation: A U.S. perspective. Journal of Transport Geography, 4:3, sf 151-159.

[6] Elbeyli, Ş., 2013, Kentiçi Ulaşımda Bisikletin Konumu Ve Şehirler İçin Bisiklet Ulaşımı Planlaması: Sakarya Örneği (Doctoral dissertation, Fen Bilimleri Enstitüsü).

[7] Goldman, T., Gorham, R., 2006, Sustainable urban transport: Four innovative directions. Technology in society, 28(1), 261-273.

[8] OECF, 2013. how much CO2 does cycling really save?, URL: https://ecf.com/news-and-events/news/how-much-co2-does-cycling-really-save [Online; accessed 19-September-2018].

[9] Celis-Morales C. A., Lyall D. M., Welsh P., Anderson J., Steell L., Guo Y., 2017. Association between active commuting and incident cardiovascular disease, cancer, and mortality: prospective cohort study, British Medical Journal; 357 :j1456.

[10] Ying, Z., 2011, Evaluating performance of bicycle sharing system in Wuhan, China. Master Thesis. Faculty of Geo-information Science and Earth Observation of University of Twente, Enshcede, The Netherlands.

[11] Niches, N.D., 2012, New seamless mobility services: Public bicycles. European Commission Sixth Framework Programme Policy Notes.

[12] Midgley, P., 2009, The role of smart bike-sharing systems in urban mobility. Journeys, 2, 23-31.

[13] George, David K and Cathy H Xia. Fleet-sizing and service availability for a vehicle rental system via closed queueing networks. European Journal of Operational Research, 211(1):198-207, 2011.

[14] Palomares, J.C.G., Gutiérrez, J., Latorre, M., 2012, Optimizing the location of stations in bike-sharing programs: A GIS approach, Applied Geography, Volume 35, Issues 1–2, November 2012, Pages 235-246

[15] Buis, J., Lobo, Z., 2011, The role of CSO's in the implementation of public bicycle systems. Civil Society Organisations Advancing Cycling Reflections on the Bicycle Partnership Program Experiences.

[16] Vogel and Dirk Christian Mattfeld. Modeling of repositioning activities in bike-sharing systems. In World conference on transport research (WCTR), 2010.

[17] Wikipedia. Bicycle-sharing system, 2017. URL https://goo.gl/ifjAaW. [Online; accessed 25-September-2017].

[18] Lovelace, R, SBM Beck, M Watson, and A. Wild. Assessing the energy implications of replacing car trips with bicycle trips in she_eld, uk. Energy Policy, 39(4):2075-2087, 2011.

[19] Kös, M., 2015, Kentiçi Ulaşım Problemlerine Alternatif Entegre Bisiklet Ulaşımı Planlaması, Masters Thesis, İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü, İstanbul, Turkey.

[20] İBB, 2017. İstanbul Yıllık Ulaşım Raporu, URL: https://tuhim.ibb.gov.tr/media/2171/%C4%B0bb-ula%C5%9Fim-raporu-2017-tr_son.pdf [Online; accessed 17-September-2018]

[21] Ines Frade and Anabela Ribeiro, 2014. Bicycle sharing systems demand. Procedia-Social and Behavioral Sciences, 111:518-527.

[22] Peter Midgley, 2011. Bicycle-sharing schemes: enhancing sustainable mobility in urban areas. United Nations, Department of Economic and Social Affairs, pages 1-12, 2011.

[23] Lin Jenn-Rong, Yang Ta-Hui, 2011, "Strategic design of public bicycle sharing systems with service level constraints", Transportation Research Part E, Vol. 47, pp. 284-294, 2011.

[24] Kendall, M. G., 1953, The analysis of economic time-series, Part I: Prices, Journal of the Royal Statistical Society. Series A (General) 116(1), 11–25.

[25] Morse, P.M.,1958, Queues, Inventories and Maintenance, New York Wiley.