American Journal of Environmental Engineering 2015, 5(1): 21-31
DOI: 10.5923/j.ajee.20150501.02

Different Methods of Redistributing Bike among the Station: A Mathematical Solution in Order to Find Critical Stations

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Abstract One of the main encountered issues for transport engineers in order to develop a bike sharing system is redistribution of bikes among the stations. In order to understand the issue, assume that you want to hire a bike from bike sharing system and go to the bike stations which your trip will start from that station but you face that there is not any bike in bike station. Or assume that you used bike sharing system for your trip and want to give it back to the station in your destination but you face with a station with no empty place for your bike. The above mentioned situations should be solved by a transport engineer who is responsible for developing such a system. Different companies around the world suggested and implemented different solutions for this purpose. In this study, different solutions will be explained and defined with their real world implemented examples.

Keywords Redistributing Bike, Critical Stations, Transport Engineers, Sharing System, Bike Sharing, Destination, Public Transportation, Civil Engineering, Environmental Engineering

1. Introduction

One the most famous and successful solutions is given and implemented by Velib System, a famous bike sharing system in Paris, France, which told If a user arrives with a rented bicycle at a station without open spots, the terminal grants another fifteen minutes of free rental time [1-5]. The rental terminals also display information about neighboring Vélib' stations, including location, number of available bicycles and open stands [6, 7]. Also, a special kind of vehicle is used to redistribute bikes among the stations over the night [8].

Some countries such as France, Spain, and Sweden use the same method as mentioned in 3, with a little difference [9]. These countries used specialized vans to redistribute bicycles between the stations [10]. It was useful for short time but by increasing the number of commuters, the number and frequency of vans was not sufficient for appropriate handling during the peak hours, making it very difficult to find critical stations at which to return the bike [11, 12].

Another method is suggested by Germany and Austria is that commuter should return the bike to the rental point [13]. This method is unfriendly for the users since the user prefers to back it to another place where he wants to stay more time than usual [14, 17, 23]. No redistribution is required in this method [14-24].

Netherland introduce another method which users were able to reserve a parking or bikes at any stations that they want for their destinations. By using such a system, the operator of bike system is able to redistribute the bikes between the stations by knowing the exact number of demands between the stations [25]. Unfortunately, this system failed because of high rate of theft [26-29].

Buffalo Blue Bicycle Program (Buffalo, NY) is another bike sharing system with new method for redistributing bicycles [30]. The program relies on its membership. All members must either pay a US$25 seasonal fee for use, or agree to work as volunteer for minimum of six hours of week to help run Buffalo Blue Bicycle [31-50]. Volunteers can also carry out other duties to improve the program, such as: help for maintaining and developing the website and redistributing bicycles between stations [51, 52].

2. Green Transport System

The performances of transportation system and its components are measured based on effectiveness and efficiency. However, the standardizing of environmental impacts of the transportation system should be considered for traffic participants, roads, and infrastructure from planning to operation, due to special attention of the concept of sustainability to this issue. As about 75% of the world's total carbon dioxide emissions from fossil fuel combustion and more than 20% of world energy consumption are related

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Published online at http://journal.sapub.org/ajee

to the road transport and the transportation systems, respectively, solving such environmental problems and the methods for balancing the energy saving and the demand of mobility are significantly under consideration. Today, there is a high attention to the green traffic and green transportation system as sustainable approaches [53].

It is confirmed that green vehicles, smart road, C-2-X communications for green intelligent transportation systems control, and green urban traffic are of significant effectiveness. It believes that green vehicles are more environmentally friendly than conventional internal combustion engine vehicles due to their critical characteristic which is using new alternative energy instead of gasoline or diesel. Various energy types are used in green vehicles such as electricity, hybrid electricity, compressed air/natural gas, biofuel, solar power, and so on. By fast developing of green vehicles in recent years, it is expected that various challenges will be raised in the manufacture, use of vehicles and the service provided by traffic system [54].

The traffic information network is founded by smart road; C-2-X communications including communications between/among vehicles, roadways, roadside, backend infrastructure, and so on; and the assistance systems based on driver-vehicle unit. Its consequence is a smooth, efficient, and accident-free traffic. It hopes that the ongoing information system in ITS and driver assistance systems will be able to not only guide the road users and, but also contribute to the emission control and safety [55].

High traffic demands and deteriorating environment adversely affect densely populated cities. By increasing the value of public transportation for controlling CO_2, air pollution, and noise, walking and cycling traffics are critically motivated. The green urban traffic will be very useful for improving the traffic conditions and in turn, the productivity of cities as it mitigates overcrowded traffic and delay. Moreover, vulnerable road users will have more safety when a user-oriented urban traffic is under operation [56].

The green transportation system (GTSS) is intended to be a key objective for acquiring eco-friendly transportation systems and safety [57].

Figure 1. Redistribution of bikes by truck

3. A Mathematical Solution in Order to Find Critical Stations

3.1. Problem

The below map, which contains situation of a part of bike sharing stations, is given to find critical stations. This map belongs to bike sharing system of Washington DC. The Smart Bike system was originally opened to the public in August 2008, with 60 bikes distributed among seven fixed stations. As the system grew, a total of 1100 bikes were distributed among 110 stations in 2011. This map belongs to area where is next to Ronald Reagan international airport.

Figure 2. Special vehicle using to redistribute the bicycle

Figure 3. A user redistribute bikes among the station as volunteer

3.2. Methodology

A way for handling this problem is using HITCHHIKER method which is so famous among engineers. This method is using two matrixes: first probabilistic matrix which tells us the probability of destination of bicycle and another one is bicycle matrix which tells us the number of bicycles in each station. Then, this method continues to work by multiplying these matrixes together and using the result of this function as the new entry of the next iteration. Finally, by repeating this iteration for at least 10 times, the critical stations will be appeared.

3.3. Solution

At first, the below network is extracted from Figure 4. There are 14 stations and each node represented the bicycle station:

Then, distances between each node and the closest node are determined by using Google Earth: (distances are in Km). Although the line is shown by direct line, the numbers are actual distances not direct ones.

Since the real probability between each node is unknown, the above network (distance network) is used to estimate the probability. It means: the shorter the distance, the more probability the link. By using the mentioned method or using the below formula each probability can be extracted:

The below probabilities are not from above distribution. These are arbitrary assumed values because the above method gave fraction not easy to comprehend as an example application.

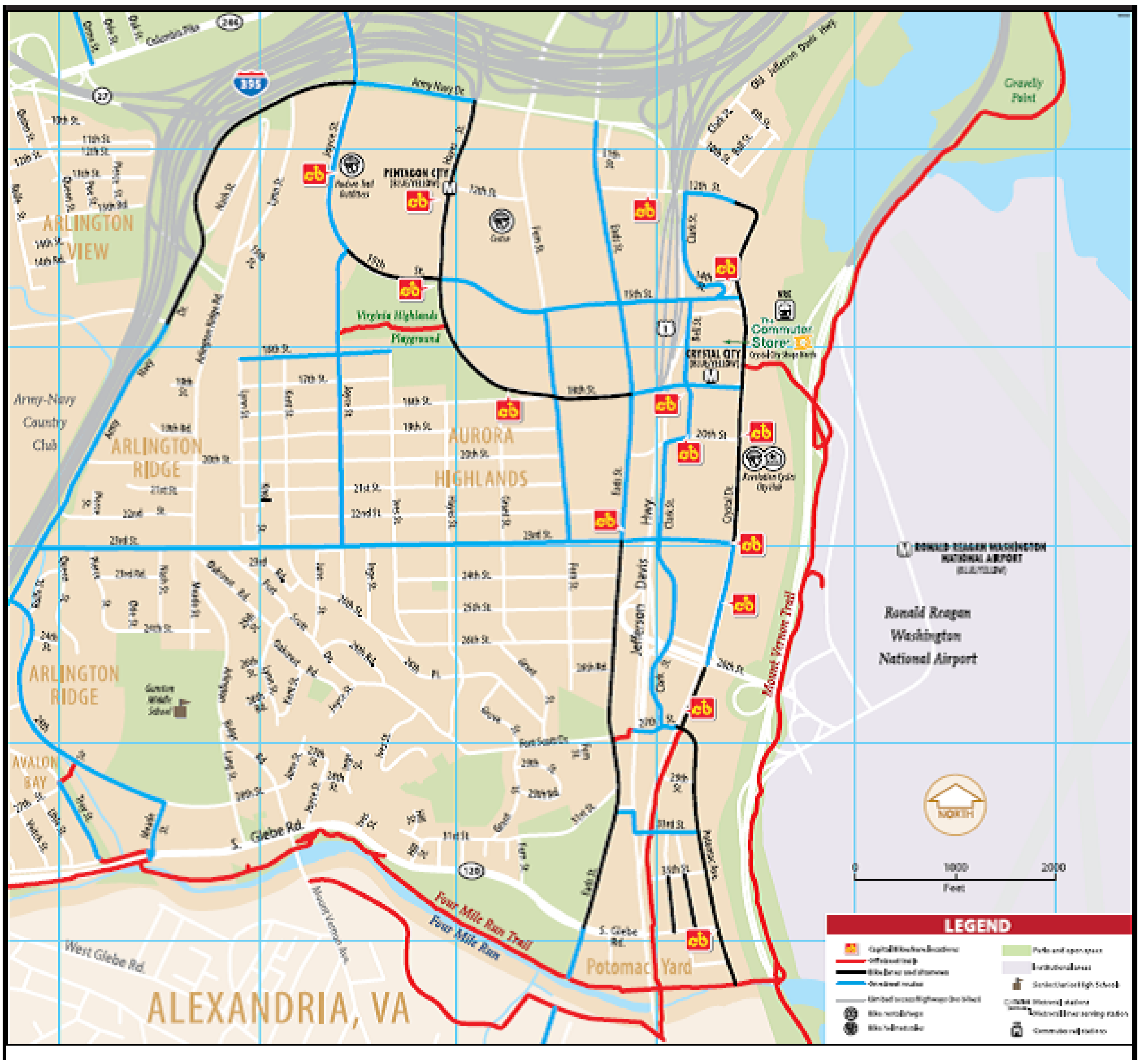

Figure 4. Washington network of bike sharing system

From above network, the below matrix can be extracted:

				Probability matrix										
node	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0.4	0	0.6	0	0	0	0	0	0	0	0	0	0
2	0.3	0	0.3	0.2	0.1	0.1	0	0	0	0	0	0	0	0
3	0	0.25	0	0	0.1	0.25	0.4	0	0	0	0	0	0	0
4	0.3	0.35	0	0	0.35	0	0	0	0	0	0	0	0	0
5	0	0.1	0.1	0.25	0	0.35	0	0.25	0	0	0	0	0	0
6	0	0.05	0.1	0	0.1	0	0.25	0.07	0.25	0.2	0	0	0	0
7	0	0	0.4	0	0	0.2	0	0	0.25	0.2	0	0	0	0
8	0	0	0	0	0.15	0.2	0	0	0.2	0	0.2	0.1	0.15	0
9	0	0	0	0	0	0.2	0.2	0.25	0	0.25	0.1	0	0	0
10	0	0	0	0	0	0.15	0.3	0	0.3	0	0.25	0	0	0
11	0	0	0	0	0	0	0	0.2	0.2	0.2	0	0.25	0.15	0
12	0	0	0	0	0	0	0	0.1	0	0	0.35	0	0.35	0.2
13	0	0	0	0	0	0	0	0.1	0	0	0.2	0.4	0	0.3
14	0	0	0	0	0	0	0	0	0	0	0	0.4	0.6	0

$$p_i = \frac{1/L_i}{\sum_{1}^{14} 1/L_i} \tag{1}$$

The number of bicycles at each station is determined by searching the operation website. So, the below matrix is derived from the website:

node	# of bicycle
1	11
2	19
3	11
4	11
5	11
6	19
7	11
8	11
9	11
10	11
11	13
12	11
13	11
14	11

By applying the HITCHHIKER method, which is mentioned earlier, the below table is derived after ten times:

Table 1. Hitchhiker results after each iteration

iteration	node1	node 2	node3	node4	node5	node6	node7	node8	node9	node10	node11	node12	node13	node14
Initial	11	19	11	11	11	19	11	11	11	11	13	11	11	11
1	9	13.05	11.62	13.15	10.4	16.75	14.65	11.63	15.6	11.35	12.1	13.15	14.05	5.5
2	7.86	12.99	10.9025	10.61	10.489	17.9285	15.361	12.81	16	12.6	14.136	12	11.462	6.845
3	7.07	11.52	11.23	9.935	9.81	18.41	15.82	13.05	17.492	13.49	13.8	12.138	12.349	5.8386
4	6.4365	11.01	10.95	8.999	9.55	18.68	16.64	13.32	17.975	13.98	14.45	12.03	11.77	6.1323
5	6	10.35	11.09	8.45	9.21	18.865	16.839	13.46	18.578	14.45	14.52	12.106	12.056	5.937
6	5.64	10	10.96	7.97	9	18.97	17.2	13.59	18.857	14.69	14.81	12.173	11.99	6.03
7	5.39	9.63	10.98	7.63	8.82	19.02	17.3	13.67	19.129	14.91	14.934	12.269	12.138	6.03
8	5.17	9.4	10.9	7.365	8.68	19.05	17.44	13.74	19.27	15.03	15.09	12.367	12.2	6.09
9	5.02	9.19	10.88	7.15	8.573	19.04	17.485	13.8	19.398	15.13	15.2	12.463	12.3	6.13
10	4.99	9.03	10.82	6.99	8.48	19.04	17.529	13.84	19.468	15.19	15.3	12.551	12.389	6.18
Final	5	9	11	7	8	19	18	14	19	15	15	12	12	6

By comparing the initial number of bicycles with the final result, which derived from more than 20 times of above iteration, the following results are derived:

Table 2. Initial number of bicycle at each station and final result of hitchhiker method

Initial	11	19	11	11	11	19	11	11	11	11	13	11	11	11
Final	5	9	11	7	8	19	18	14	19	15	15	12	12	6

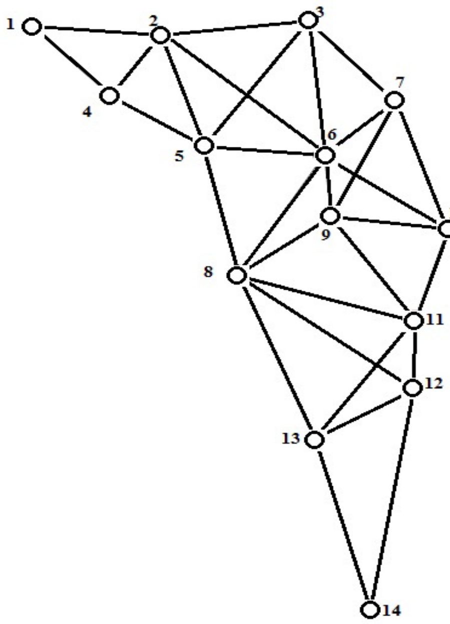

Figure 5. Washington bike sharing network

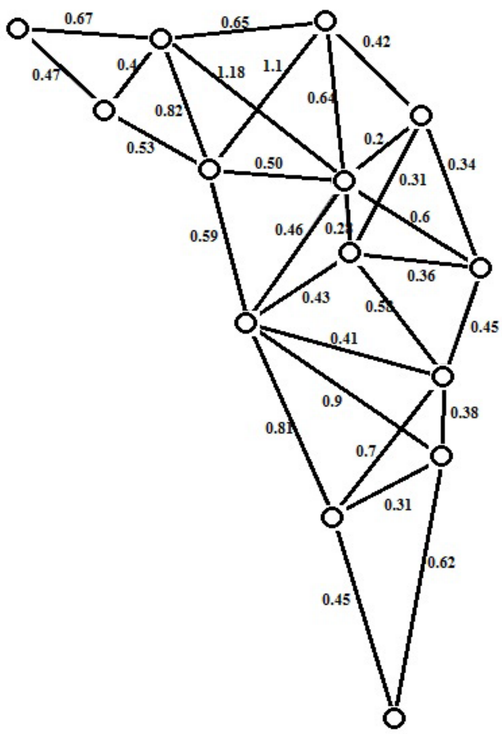

Figure 6. Distances between each stations

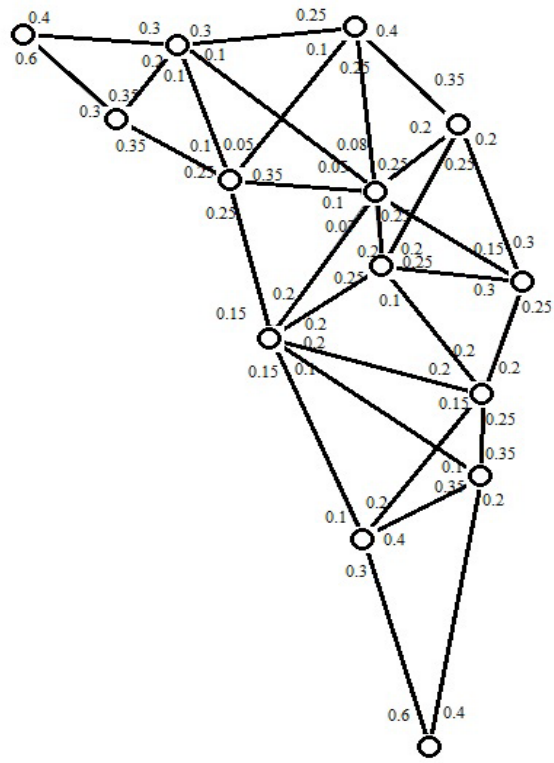

Figure 7. Probability of each links of network

4. Results and Discussion

By looking at Table 2, it is derived that the very big differences are located at stations 2, 7, and 9. In order to solve the problem of these stations, using the truck is suggested to redistribute bikes since these big differences between the initial number of bikes and final number of bikes shows that other methods cannot handle this problem. Therefore, the truck is the best choice for these stations. It means that after seven iterations, the truck should go to stations number 7 and 9, picks up the bikes and then go to station number 2 to put those there.

On the other hand, there are small differences between the initial number of bicycles and the final number of bikes in other stations. So, by applying the encouraging solution which tell If a user arrives with a rented bicycle at a station without open spots, the terminal grants another Fifteen minutes of free rental time or if the user deliver this bike to another station the system will give him 15 minutes free rental time in next time of using bike sharing system.

Also, there are more different solutions for handling of the mentioned problem. The method which is used to handle this problem is also depending on our community which this system is designed for it.

Finally, technical situation, social situation, and many different factors should be mentioned to handle such a problem.

Since 1960s, many bike sharing systems have been installed which can be used as useful references for case study examination. Not only all bike sharing systems do not have the same operational model, but also they didn't face the same problem or they were not successful as the same level. . In order to find an appropriate case study and useful example, some standards should be defined. The chosen standards developed priorities that can be listed as below:

- They installed in appropriate area which has the acceptable level of population or the population density should be in acceptable range in an area which this system was installed.
- These systems implemented in cities that have the same social and economical context with the city which the new system aimed to install.
- Bike sharing system which wants to mention should have enough history or available data for analysis.
- Bike share systems were generally considered to be "successful". For the purposes of this study, "successful" systems were those that continue to be operational at the time of writing, and had received a significant amount of international attention through media reports, academic studies and technical analysis. Other measures of success are the extent to which a system was used, shifted travel from auto trips to cycling, created a cycling culture and/or improvements to cycling infrastructure, raised the profile of cycling, resulted in the avoidance of greenhouse gas and air contaminant emissions, and supported other sustainable transport modes including transit.

In general, European people not only have more psychology of cycling but also have more culture of cycling than other parts of the world. On the other hand, we have some successful practice of bike sharing system in other parts of the world such as north of America. So, the examples are written by corresponding to above filters. All of the examples below are belong to the third generation of bike sharing systems.

Washington's government implemented a bike sharing program, called SmartBike, which inspired from success of bike sharing program in Europe (Bike share Program investigation, 2009). The District Department of Transportation signed a contract to Clear Channel, a US-based media/advertising company that also operates public bike systems in Barcelona, Milan and ten other cities in Europe. Washington has total population of 5.3 million in metro area and population density of 3700 people/km2. Bike sharing system started to work with 60 bikes which distributed among seven stations in 2008 and with growing of the system, the total 1100 bikes distributed among 110 stations.

Each station consists of a rental kiosk and some docking places which the number of bikes in each station depends on the demand for bike on that particular point of the city. The rental kiosk is a vertical pillar, identifying the station, and the docking points are located on a horizontal bar, which includes locking mechanism. Users can collect and drop off bicycles by using credit card or other magnetic strip, known as the smart cart system. Users can rent bicycle from 6 AM to 10 PM and can return it any time they want.

Users should have at least 18 years old and buy $40 annual membership in order to become a bike sharing system member as a user.

The membership allows users an unlimited number of rentals, with a maximum rental time of three hours without any additional charge. After three hours, penalties, such as suspension of rental privileges, may apply. Also if a user did not return the bike during the past 24 hours, the system will fine him $550 as a price of bicycle (Bike share Program investigation, 2009).

Any potential need for redistribution of the bikes among the stations is handled by the service team. Locations for the bike share system terminals were decided upon based on: nearby transit stops, area jobs, population density and proximity to desirable destinations. Survey results also helped direct the choice of bike share system station locations.

The most important aspect of Smartbike system is automatic feature of it since each station is in connection with all other stations to help not only the user to find next station, but also analyze the number of bikes in each station.

The main challenges of setting up the SmartBike DC program to date were: selecting terminal locations; construction and installation of bike share system stops; and installing electronic infrastructure required to power the docking racks.

In contrast to these challenges, the SmartBike DC program appears to be growing in popularity; in October 2008, less than three months after SmartBike DC's launch, the system had 930 registered users and an average of 150 daily users. Because of the steady growth of the user base, an expansion of the system is currently being planned (Bike share Program investigation, 2009).

Velib' is a bike sharing system that operating in Paris, France. This system started to work in 2007 with 450 stations and 12250 bikes. As it grows, the number of stations reached to 1450 with 20600 bikes in less than one year. It was one of the most successful systems around the world since the rate of success was extremely high in compare with other bike sharing systems. Also, the annual members of bike sharing system became 100,000 with the average of ten times per bike per day usage in less than one year. . Now, the system in Paris is well-known over the world as an example of how bike share systems can be introduced to a major urban centre in the twenty-first century.

Recently Paris had chance to complete street furniture including the provision of bike sharing system. After Paris, Lyon, another important city of France, implemented the same bike sharing system around itself.

In both cases, a public-private partnership (PPP) was chosen, and the French advertising Company JC Decaux S.A. was selected since bike sharing system is not profitable by itself.

According to evident usage which is available through a customer survey conducted by the City and performed in early 2008, it has been recognized that on average, users have the following profile:

- Mean Age: 35 years old;
- Gender: More than half of the annual subscribers are men (58%), while the majority of occasional users (weekly and daily subscriptions) are women (65%); and;
- Usage: 71% are using Velib' for professional and other utilitarian purposes (Commuting-to-work, to-school, business appointments and shopping) (Bike Sharing/ Public Bikes, 2009).

Within the first year of implementation, when the system wasn't complete as much as today, the bike usage increased by 70% and it is extremely high among all other bike sharing system affections.

Favorable climate and good cycling conditions, organizational factors (the presence of a local champion) , financial factors, the existence of a suitable urban density, accessibility to service (in terms of price as well as physical proximity of the target market to the infrastructure), and ease of usage are other key components of this successful bike share system.

Bicing is the name of bike sharing program which implemented in Barcelona, Spain, since 2007. This system is so similar to velib' bike sharing program in Paris since all of these programs use the same system as their bike sharing program. Bicing program purpose is to cover the small and medium daily routes within the city in a climate friendly way, almost without pollution (especially the emission of finest particulate matter), roadway noise, traffic congestion, and to reclaim the urban streets with non-polluting vehicles.

User should buy annual membership card if he/she wants to use this system. This system currently consists of 400 stations with 3000 bicycles which distributed among them. All of the stations are situated among the flat area of the city with the maximum distance of 400 meters between each station. The user can borrow the bike from any station and return it to any station that want as his/her destination.

Each station has between 15 and 30 parking slots to fix and lock the bicycle. To rent a bike, one simply swipes the contactless membership card at a service station to be personally identified by the system, and then unlocks a bike from the support frame.

Bicycles can use for first 30 minutes free and after that the user will charge 0.50€ for the next two hours. Use of a bicycle for more than 2 hours at a time is discouraged with a penalty rate of 3 € per hour, but also with the possibility of having your membership cancelled after a certain number of uses in excess of 2 hours.

More than 95% of users return the bike in less than 30 minutes but if a user wants to use bike sharing system again, freely, he/she should wait for 10 minutes to use the bike sharing system for another 30 minutes free. Although there are over 90,000 registered users as of September 2007, only 1/3 of them are using the system on a regular basis.

By the end of the year, Bicing program planned to offer 3000 bicycles at 200 stations and by spring 2008 quadrupling to 6000 bikes at 400 stations to cover approximately 70% of the city area, except areas with slopes of more than 4% and the hilly area of Montjuic and Tibidabo (Students Today, Citizens Tomorrow, 2009).

Stockholm City Bike is the name of bike sharing program which implemented in Sweden. Public and private company are became partner to operate this program. This bike sharing program allows users to hire bike for maximum 3 hours per each day from 6 am to 10 pm.

The membership card is necessary to hire or return a bike. These are obtained by buying a seasonal card (for 250 Swedish kronor SEK) or 3-days card (for 125 Swedish kronor SEK).

The private partner in this program is able to advertise by using the body of bicycle or station. The season card entitles the buyer to receive a free bicycle helmet that is decorated with advertising. The entire system is financed by advertising sold and managed by Clear Channel Communications (private partner).

Figure 8. Washington bike sharing system

Figure 9. Washington smartbike

Figure 10. Paris bike sharing system (velib')

Figure 11. Paris bike sharing system (velib')

Figure 12. Bike sharing system in Barcelona

Figure 13. Bicing program in Barcelona

Figure 14. Bike sharing program in Sweden

Figure 15. Bike sharing program in Stockholm

This system is a little unfriendly since it is hard for foreigners to use this system since the user should know Swedish language to able use the system; if the user doesn't know Swedish language, it became hard for him/her to use this system.

One of the biggest problems of this system is vandalism and theft, since the operator stated that if the vandalism or theft doesn't stop the program is going to become so expensive and then it will be cancelled.

5. Conclusions

One of the main issues that advanced countries are faced these days is green transport systems which don't have any bad effect for our environment. Bike sharing system is one of the green transport systems that attract a lot of attention. The aim of this research was to provide a good help for transport engineers who want to develop such a system for their cities. It is derived that there isn't any complete research in this area by reading different journals and papers. The above aim is achieved by defining all steps that involve in developing a transport system and then, all the steps are linked to the current problem (developing bike share system) and each step is defined in details. Finally, four international outlooks are explained, in details, to make a good resource for reader as successful samples to compare with their own situation and help them to make a best decision. After reading this research, it hopes that reader be able to define bike sharing system, and understand the process of developing bike sharing system. Also the reader will be able to handle redistribution, cost, and partnership problems as explained above.

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