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Determination of the Size of a Proposed Bike-Sharing Program in Las Vegas, Nevada

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Abstract

Bike-share systems have been installed in cities worldwide as a way to attract travelers to use transit rather than the automobile. This has been proved to be an effective way of mitigating congestion on the road. The objective of this study is to develop a method to determine the size of the bike-share program in terms of the number of bicycles, the number and location of the stations, the number of docks at each station. To achieve the objectives of this study, a literature review was conducted on university bike-sharing systems in the U.S. and abroad. Various cases of bike-share programs were analyzed, in which each case consisted of a different number and location of bike-share stations. The demand corresponding to these stations was used as the input to a simulation model developed in this study to determine the number of docks in stations and bicycles in the system on and around campus at UNLV. These sizing parameters of the bike-share system then were used in a cost and benefit analysis to determine which cases could achieve maximum benefit, given a limitation of the initial costs. It was found that provision of one peripheral station and three internal stations at strategic locations provide relatively higher benefit cost ratio at lower initial cost.

Keywords

Bike-Share System, Simulation Model, Cost and Benefit Analysis

1. Introduction

Bicycles have been used as a mode of transportation for many years. In the beginning, they were owned individually by travelers and used from the beginning to the end of their trips. Because travelers realize that the first or last mile of their trips may involve significantly long distances to walk after they arrive at the bus stop or park in a garage, bicycles can be made available at strategic locations to complete their trips. Using bicycles for the first or last mile trips might entice them to give up automobiles and use public transportation systems for their trips. In this case, a public or private agency could own a fleet of bicycles and distribute them at these strategical locations. Such a system of sharing bicycles is called bike-share program, and is installed in such communities as businesses agencies and academic institutes within a city.

Bike-sharing programs in the United States and Canada have shown great growth in the years since the first program was introduced in 1994. The introduction of programs based on information technology (IT) coincided with significant system growth. By 2009, seven systems existed in the US and Canada, including four conventional reservation systems and three IT-based systems; by 2012, 39 systems were in operation in North America, 17 IT-based program in the U.S. and four IT-based programs in Canada as well as 18 conventional first- and second-generation bike-sharing programs in the U.S. and Canada, which indicates a 229% increase in three years [1]. According to a study by the Toole Design Group and the Pedestrian and Bicycle Information Center [2], Washington, D.C. was the first major city in the United States to implement a modern bike-share program, followed by Denver in 2010. Many studies on bike-sharing focus on such aspects as demand forecasting, location design of bike parking, bike equipment, marketing, and business models [1] [3].

Various studies have identified universities as the main sources and attractors for bike-share trips. A study by El-Assi *et al.* [4] analyzed a station-level commercial bike-sharing program in Toronto, evaluated the effects of the built environment and the weather on bike-sharing demand. It was found that the university campuses outpaced the transit zones, employment density zones, and populated zones in the use of the bike-sharing program. In a study located in the cities of Minneapolis and St. Paul in Minnesota, Wang *et al.* [5] revealed that the average trips taken when using city bike-share stations located within the university campus were at least 42.6% higher than the ones located outside this zone. However, in studying Bike Share Toronto, El-Assi *et al.* [4] noted a higher positive correlation between bike share trips and the zones on university campuses was seasonal, with fall and winter seasons exhibiting higher coefficients and reflecting student use during the academic year. Their finding that university campuses are attractive to bike-share users was consistent with findings by Hampshire and Marla [6] from a study based in the cities of Barcelona and Seville in Spain. Additionally, this study found that the arrival rate of bikes at stations located within the university campuses statistically was significantly higher in the morning.

University of Nevada Las Vegas is the biggest public agency in Las Vegas, and trips to and from the university contribute significantly to the congestion on the roads in the Las Vegas area. To mitigate the congestion on a regional scale, we propose to develop a bike-share system at UNLV that has stations close to bus stops on one end and close to the buildings on campus on the other end. We realize that bicycles that are available for the work trips to UNLV also could be available for trips between buildings on campus, since these two types of trips are generated during different time periods. Additional stations could be added to fully serve the trips on campus. It should be noted that the proposed bike share system at UNLV is isolated from the system in downtown Las Vegas. This setting, in which UNLV is located far from the downtown system makes it different from bike-share systems in other cities, such as New York City, where New York University is part of the downtown system. Due to this difference, there would be no bike-share trips generated between downtown and UNLV.

In this study, following an optimization process, different cases of bike-share system were analyzed, with each consisting of a different number and location of stations. The demand corresponding to these stations was used as input to a simulation model developed in this study to determine the number of docks needed at UNLV for each station, and the number of bicycles in the system, on and around campus. These sizing parameters were used in a cost and benefit analysis to determine which cases could achieve the maximum benefit given the limitation of the initial costs. In addition, the revenue to be generated for each case was calculated based on the estimated demand. The revenue was compared to the costs to determine which cases could generate sufficient funds to make the bike-share system sustainable. This methodology of study is presented in **Figure 1**.

This paper is organized into the following section. The first section provides a literature review on bike-share programs, the demand of the bike-share program, how they are operated and the cost and benefit of the program. How the demands for the proposed bike-share program are derived is presented in the second section. The third section presents the optimization process by which the number of bicycles, stations, and docks are determined. The last section provides conclusions and recommendations for future study.

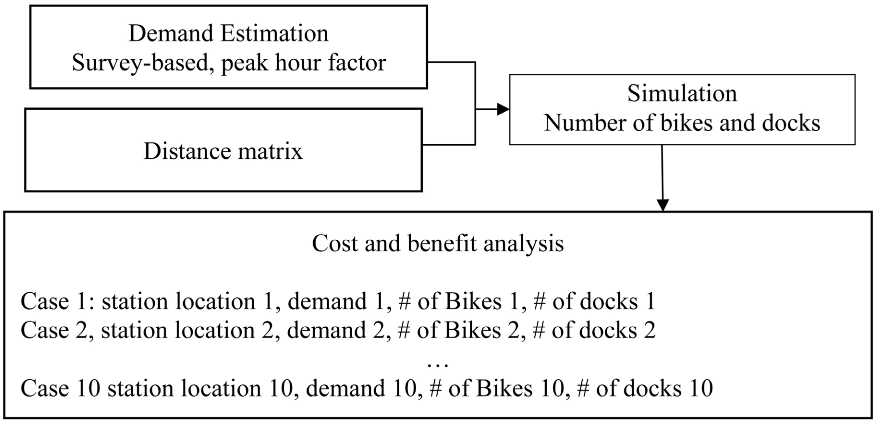

Figure 1. Research methodology.

2. Literature Review

2.1. Technology of Bike-Share Programs

Bike-share systems have gone through several iterations [7]. In 1965, Amsterdam had a free bike program; users were allowed to use bikes from one location to another, and leave them unlocked at the destination point for the next user. Later, in Copenhagen, Denmark offered users bikes from dedicated locking stations that used coins, which were refunded at the end of the ride. Real-time availability and GPS tracking began in 2005 in Lyon, France.

A comparison of these three bike-share systems indicates an advancement in technological solutions for problems observed from the start. For example, in systems similar to Amsterdam's free program, problems encountered included theft. With the invention of a bike access procedure by using coins, thefts decreased and the rate of return of the bikes were high. With the bikes equipped with GPS technology, identification was easy across the bike fleet in use, and the distance traveled and bike conditions could be tracked as well [8]. Currently, established bike programs have more system components when compared to earlier programs [2]. According to a website known as TheCityFix, published by the World Resources Institute, these include "clean docking stations, touch-screen kiosks, additional bike rebalancing technologies, as well as the integration of one unique card allowing a user to ride both bikes and public transportation" [7].

Various programs that currently are established have different fleet sizes as well as service areas. For instance, bike-share programs established for the purpose of serving community members of universities are small compared to those that focus on serving a large area, such as a city or county. The mode of operation and system characteristics are diverse as well. However, there are common system characteristics between small-scale and large-scale bike programs because both programs focus on facilitating short trips, including last-mile trips.

2.2. Operation of Campus Bike-Share Programs

Campus bike-share programs can be owned either by the university, a private company, or jointly [9]. Bikes can be rented by means of traditional renting, a bike library, or the use of smart docks/bikes. Kyung [10] found a significant portion (37%) of bike-share programs were owned by universities and 73% were operated by universities. Traditional renting and the bike library were rental modes applied to most university bike-share programs (45%). Smart bikes accounted for only 5%, and kiosks accounted for 15%. Further, 44% of the universities operated their bike-share programs year-round and 77% of the bike-share programs operated during semester breaks. A significant number of universities stopped operating the program between January and February.

At Purdue University in Indiana, McNamara and Mathew [11] found that 15,259 rentals occurred during the first 14 weeks of their bike-share program. This program had 77 bikes and 13 locations. The most-used bike was rented 450 times within that period, even though some bikes remained idle for as long as 100 days. The peak day had 52 bikes out of 77 that were checked out. Weekends had a very low frequency of bike usage.

On the Danforth Campus of Washington University in Saint Louis, Heda [12] determined that 13 bike stations equipped with 350 - 400 bikes best served student travel. This number of bikes was higher than the average number of bikes reported by Kyung [10], which had found that among the respondent universities, 37% (15) universities had 50 or more bikes, 8% had more than 200 bikes in their systems, and 18% had 50 to 100 bikes. Regarding the number of stations, two extremes were observed: 53% of the universities had less or equal to five bike stations, while the rest had seven or more bikes. Most universities (33%) had 10 to 20 bikes at one station.

2.3. Financial Aspects of Campus Bike-Share Programs

In a questionnaire survey, Jennifer [13] found that faculty, staff, and administrators were willing to pay a higher membership fee than students. Most respondents would prefer a monthly or a yearly subscription-based service with the option to pay using cash or credit cards. Respondents in a study by Bhowmick and Varble [14] mostly indicated they preferred a daily charge of $3 and the yearly charge of $20 - $50. Roughly the same amount for a membership fee was reported by Zonobi and Melara [15], who found that most of the students and employees were willing to pay up to $3 a day and $29 a month for usage. Kyung [10] reported that for most universities (40%), there were no membership fees charged and the university helped subsidize the cost of the program. Only 3% of the universities collected membership fees from the student fees in order to fund the program. Other funding sources included private companies, student congresses, among others.

The initial capital to establish a bike-share program ranged from less than $4000 to greater than $200,000, and most of the universities (53%) were in the range of $0 to $100,000. The annual operating cost for most of existing bike-share programs (57%) was found to be $65,000 or less [10]. Jennifer [13] indicated that an IT-based bike-share system, using cell phones, would cost $1100 per bike for purchase, approximately $100/bike for shipping and onsite assembly, $8/bike/month for wireless connectivity and hosting, and 10% of revenues booked on the platform. With three levels of varying technology options for 32 bikes proposed by Bhowmick and Varble [14], the startup costs and operating costs were estimated to be from $21,896 to $163,668 for high-tech bikes and from $2480 to $5240 for low-tech bikes. The study pointed out that the program revenue would come from a user subscription, with additional sources from sponsors [14]. Work *et al.*, [16] estimated the total cost for 24 bikes to be $118,345, while the expected annual revenue was forecasted at $702,000. Heda [12] estimated the capital cost ranging between $425,000 and $475,000 and the yearly operating cost to be $140,000. The largest portion of the capital cost was estimated to be for equipment purchase and installation.

2.4. Bike-Share Planning Optimization Models

Planning a bike-share system deals with determining the locations of bike-share stations and the number of bicycles and docks. The decision-making of the system variables including bike-share station and the number of bicycles and docks can be made using optimization model. Lin *et al.* [17] applied the hub location problem to the bike-share system where the goal was to determine the location of the BSS stations, bike paths, and fleet of bicycles. Saharidis *et al.* [18] formulated an objective function that included a penalty for individuals not finding a bicycle at a station. The demand is simply a component of a population index subjectively identified. Furthermore, Saharidis *et al.* [18]'s effort was applied to Athens, Greece, which has similarities to other cities in the world, such as Paris, France or New York, U.S.A. These models have several limitations. The spatial and time varying interaction between bicycle demand and supply cannot be well addressed. The estimation of demand for bicycles does not consider the peak period of the bike-share operation.

3. Forecasting the Demand for a Bike-Share Program at UNLV

The demand for a bike-share program at UNLV was estimated based on a stated-preference method. According to Kroes and Sheldon [19], the stated-preference method enables the researcher to extract individual preferences for alternatives with which he or she may not have any experience or else the alternatives do not exist yet. One of the advantages of this method is that it allows researchers to have relatively good quality information at a relatively low cost. In travel demand studies, the stated-preference method has been used to determine commuter behavior with respect to introduced or improved transportation systems [20]. However, use of stated-preference data in forecasting does have some limitations because it is hypothetical and is less likely to account for all types of practical constraints [21].

In this study, a survey was conducted; this involved designing, distributing, and collecting the surveys. After the surveys were collected, they were processed for analysis. Demand was estimated based on UNLV's population of faculty, staff, and students as well as the percentage of the population likely to use the bike-share program. The percentage was determined based on the respondents' statements as to their willingness to use the bike-share system and the uncertainty of those statements. **Figure 2** shows the locations of the potential bike-share stations for both commuting and the on-campus travel that was presented in the survey. The potential stations on campus were identified based on data about student enrollment and building occupancy of the faculty and staff. These data were used to determine the percentage of building utilization falling within the service area of each bike station. The forecasted demand for peak periods was used to determine the station locations and facility capacity. If the forecasted daily demand averaged for 24 hours was used to estimate the capacity of the

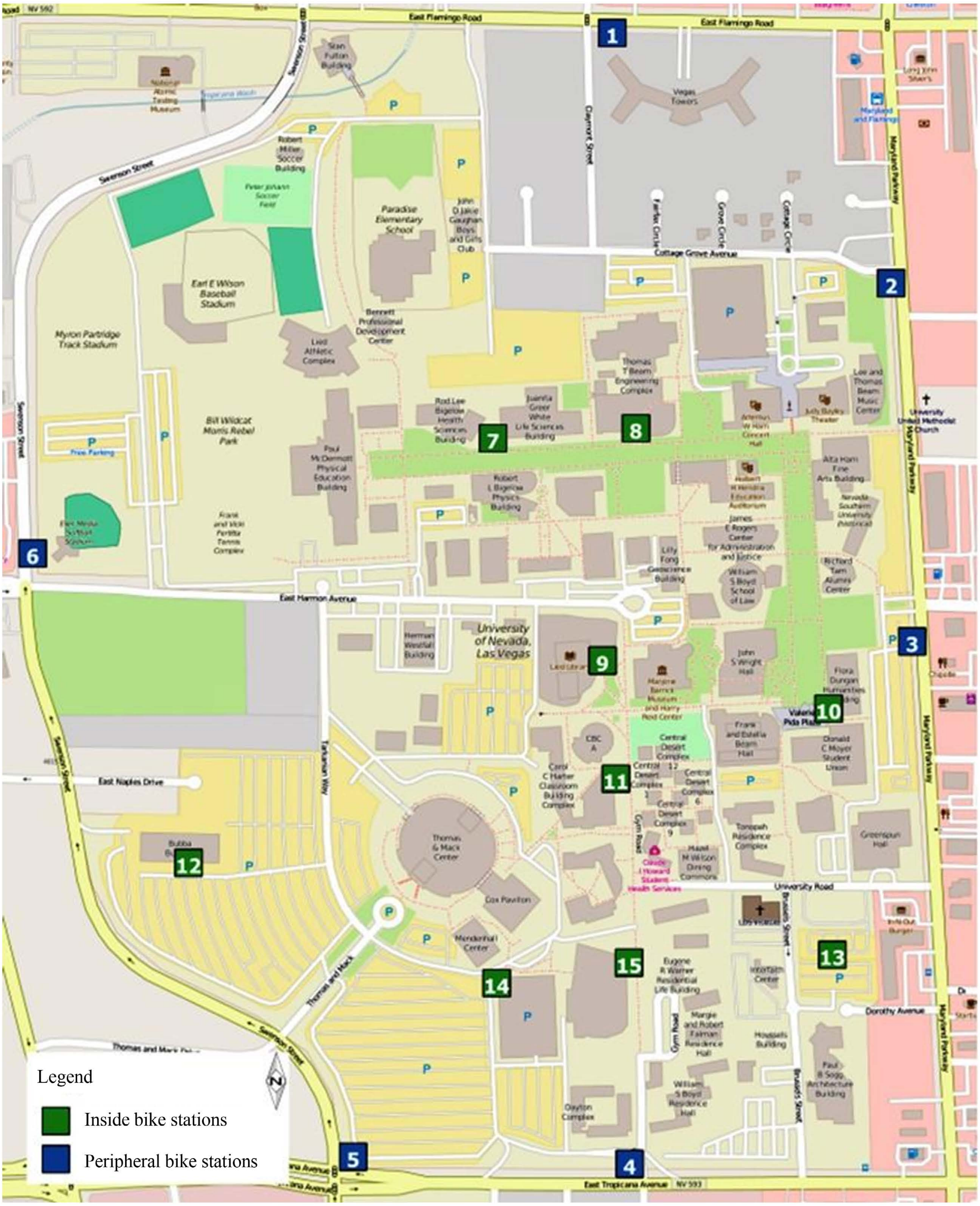

Figure 2. Proposed locations for bike-share stations on the main campus of UNLV.

bike-share system, the system would not be able to accommodate the demand during the peak period. In this case, delays would occur, and users who would have to wait for bikes to be available. This would discourage potential users, and thus reduce the demand. The peak-hours factor was computed based on the utilization of the bike-share system in the City of San Jose at the Bay area of San Francisco where the San Jose State University is located. Five days of data of the utilization of the bike share stations from August 29, 2013 to September 2, 2013 were obtained from the Internet. The peak hour of each of day was identified and the corresponding peak hour factors are calculated. The average of these five peak hour factors is derived as presented in Table 1. Note that the bike-share system in the Bay area is a city bike-share program; this is different from a university bike-share program, and thus the peak periods in these two types of systems differ. Peak periods for both systems would coincide for commuting trips; however, for on-campus travel in a university, the peak periods may be smaller than for that in the city bike-share program.

4. Determination of Locations for Docking Stations on and around Campus

The locations of bike-share stations on and around campus were determined based on the forecasted demand and the evaluation of the cost, benefit, and estimated usage of the system. Obviously the bike-share program at UNLV will build stations that are cost effective. Similar to those presented in the survey,

Table 1. Peak hour flow.

		Destination															
	Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Origin	1	0	0	0	0	0	0	7	50	5	2	0	0	0	2	2	68
	2	0	2	1	0	0	0	7	30	0	14	2	2	0	2	2	63
	3	0	0	1	0	0	0	0	5	11	11	0	0	0	0	0	28
	4	0	0	0	0	0	0	2	9	18	27	20	2	2	0	11	93
	5	0	0	0	0	0	0	0	0	0	7	9	7	0	0	0	23
	6	0	0	0	0	0	0	2	5	2	7	0	0	0	0	0	16
	7	0	0	0	0	0	0	7	5	5	11	2	0	0	0	3	33
	8	1	0	0	0	0	0	5	11	15	31	15	3	2	6	13	101
	9	0	1	1	0	0	0	5	15	9	14	1	3	0	0	2	51
	10	0	2	0	0	0	0	11	31	14	9	6	7	0	2	7	89
	11	0	1	0	0	0	0	2	15	1	6	5	2	1	0	0	33
	12	0	0	0	0	0	0	0	3	3	7	2	0	0	0	3	19
	13	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	3
	14	0	0	0	0	0	0	0	6	0	2	0	0	0	0	0	8
	15	0	0	0	0	0	0	3	13	2	7	0	3	0	0	0	28
	Total	3	20	10	0	0	0	33	100	49	86	32	19	3	8	28	658

some potential locations of these bike-share stations would not attract a significant amount of users to cover the costs for installing a station. This study adopted an optimization process in selecting bike-share stations such that only a set of bike-share stations could generate enough revenue to cover costs.

The cases of bike-share stations considered in this study are listed in **Table 2**. The first case includes all the potential stations, and can be viewed as the baseline that can attract the greatest demand to the bike-share program. The second case removes Station 13, assuming that the existing RTC Transit Center at that location provides all the needed facilities already. The Cases 3 to 10 include at least one location at the periphery of the campus and one location at the core of the campus.

4.1. Number of Bicycles and Docks

The number of bikes needed for different sets of locations for the bike-share stations also varies. Factors include the number of trips generated at each station, the distance between the stations, the exchanges of trips between stations, and how the bicycles are utilized. At certain times of the day, a surplus of bicycles at certain stations could be distributed to other stations that have customers waiting or expecting to arrive. The relation between the number of bicycles needed and the influencing factors are complicated, and cannot be expressed as a simple equation. Therefore, a simulation model was developed that could emulate the interactions regarding the trips between stations and bicycle-utilization strategies.

Table 2. Set of bike share stations considered in the selection process.

Cases	Stations in a Case	Trips	Bikes	Trip/Bike	Docks
1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	1962	286	6.86	343
2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15	1935	284	6.81	340
3	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15	1873	279	6.71	334
4	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 15	1825	264	6.91	316
5	1, 2, 3, 4, 7, 8, 9, 10, 11, 12, 15	1758	242	7.26	290
6	1, 2, 3, 4, 7, 8, 9, 10, 11, 15	1630	237	6.87	284
7	1, 2, 3, 4, 7, 8, 9, 10, 11	1434	221	6.48	265
8	1, 2, 4, 7, 8, 9, 10, 11	1343	194	6.92	232
9	1, 2, 4, 7, 8, 9, 10	1116	171	6.52	205
10	1, 2, 8, 9, 10	925	155	5.96	186
11	1, 4, 8, 9, 10	261	112	2.33	134
12	1, 8, 9, 10	206	59	3.49	70
13	4, 8, 9, 10	202	54	3.74	64
14	8, 9, 10	148	14	10.57	16

The simulation starts with trip table, distance table, and bicycle redistribution strategies. The clock in the simulation progresses second by second. At each second, the model checks whether a user is generated at a station and where the user goes. If a bicycle is available at the station, it is assigned to the user. In this model, a record is kept for each bicycle in order to store the status of the bicycles, whether it is idling at a station or being used for a trip to a destination. As the clock moves forward, a bike can continue to be on the road, taking into consideration the distance between where the bicycle starts its trip and where its current destination is located. It can be on idle again if it is idle at a station and there no new user arrives.

A record is created for each user as well in order to store the status of users over time, whether they are on the road or arriving at a destination. In the simulation, a user does not have to wait for a bicycle. Whenever no bicycle is available for a user at a station, a bicycle is generated at that station right away. The number of bicycles generated at all the stations during the entire simulation period is the number of bicycles needed for the set of stations that generated the given number of users.

By the end of each 10 minutes of one hour, the number of bikes at each station is evaluated, and it is decided whether some bikes at some of the stations need to be redistributed to other stations. To determine this, the distances between the stations that have bicycle surpluses and those expected to have significant users arriving in the near future are considered. The strategies specify when the operation personnel need to move bicycles from certain stations to others; thus, the redistribution strategies differ for each case having different numbers of bike-share stations and their locations.

A flow chart of this simulation is presented in **Figure 3**. The first block of the flow chart shows the inputs to the simulation at the beginning of simulation, including matrices of the trips, distances, and redistribution strategies. The second block, which is at the bottom of the left side of the figure, presents a procedure to generate the number of trips, which are evenly distributed over the peak period. The third block, in the middle of the chart, is for the reuse of a bicycle after it takes a user from a station as well as redistribution of bicycles by operation personnel. The last block illustrates the process of serving the users arriving at the bike-share system.

The bicycles that are needed, derived from the simulation, are listed in **Table 2**. It can be seen that the ratio between the number of trips that can be served by a bike increases with the number of stations in a case. These bicycles are assumed evenly distributed among the stations. 20% more docks are allocated at each station to accommodate the arrivals of bicycles from other stations in operations.

4.2. Cost and Benefits of Bike-Share System

Obviously the bike-share program at UNLV will build stations that are cost effective. The costs of the system include the purchase and installation costs for:

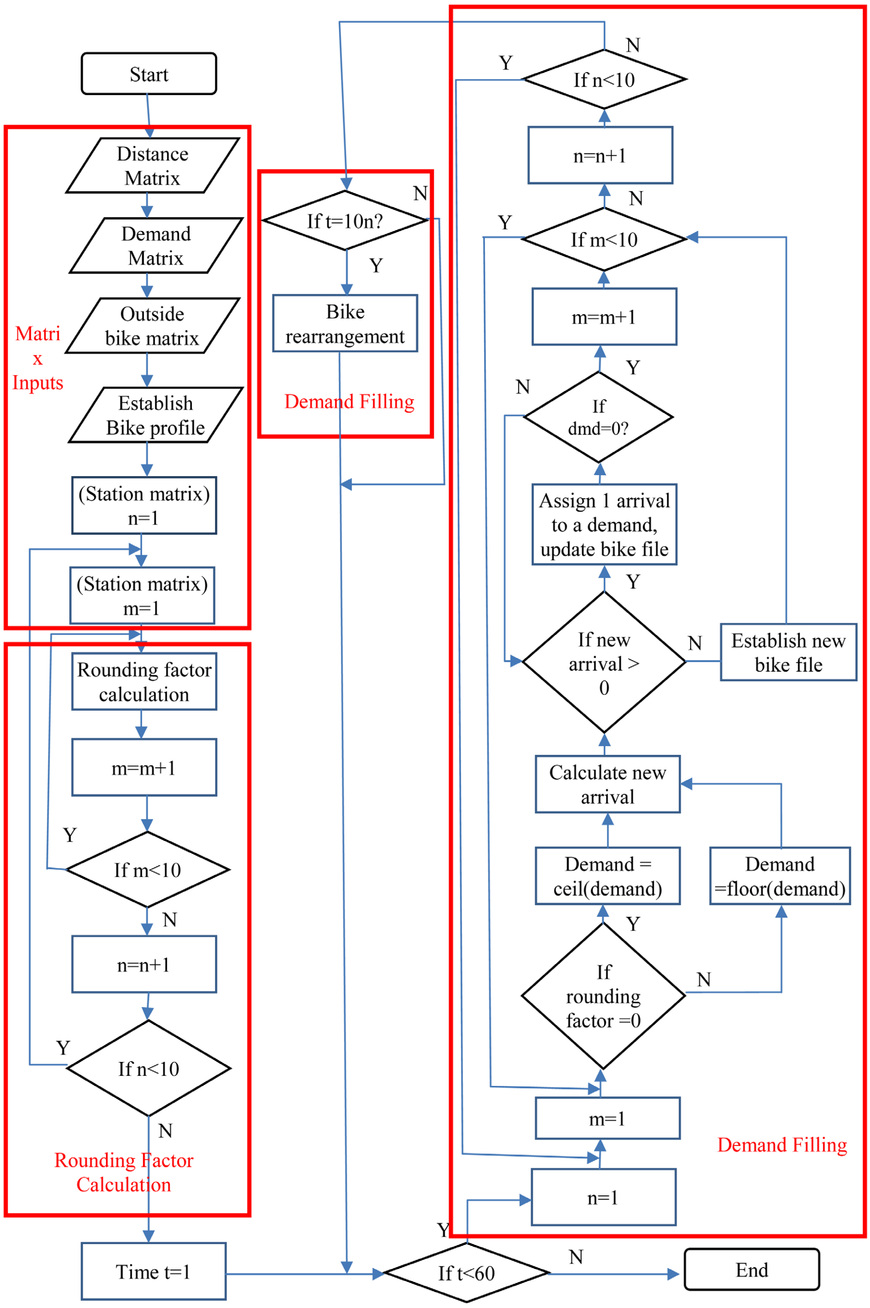

Figure 3. Flow chart of simulation program for the proposed bike-share program at UNLV.

1) Bicycles, dock, and terminals;

2) Vehicles to be used to redistribute the bikes between stations;

3) The cost to hire the personnel to manage the operation of the bike-share program.

The capital and annual operating costs were set as $2000 and $1000, respectively, in accordance to the data obtained from other universities, specifically, the University of South Florida. It was assumed that life cycle of a bike is five years.

Bike-share programs have numerous benefits, which can be grouped on the basis of economics, environmental considerations, and community and user (individual) needs. In this study, saving time during travel due to biking rather than walking was used as the measure of benefit of the bike-share program. Travel-time unit cost (cents per minute or dollars per hour) could be applied to the travel-time savings in order to derive the benefit in dollars.

For commuting, the travel time savings from the peripheral stations to stations in campus is assumed the determining factor that makes the customers to choose using bus rather than automobile, even though there are other factors that may influence their mode choice in commuting. With no the bike share program, the walking from bus stop to their destinations on campus is long that makes them to drive to school. For on-campus travel, the travel time savings from building to building is also considered as a deciding factor in choosing a means to travel on campus. The distances in miles between origin and destination stations were extracted from Google Maps. The shortest distance was 0.07 miles, which was between Stations 7 and 8, while the longest distance (0.68 miles) was between Stations 8 and 12. Savings in travel time was computed as the difference between the travel times by bicycle and walking.

It was revealed that a user could save up to more than nine minutes if he or she opted for the bike-share program for movements on campus. The travel-time unit cost value of $10.55 for non-work travel was applied when converting the travel time to monetary values. The expected minimum value of travel-time savings was $0.16, while the maximum was $1.68 per trip.

The value for total travel-time savings for the entire project will depend on the number of trips made per day as well as the trips origins and destinations. The aggregated value of travel-time savings per day was computed by considering the number of forecasted trips and the value of travel-time savings for that particular trip. In order to include this benefit as a program benefit, the value of travel-time savings for the entire year was determined. Only weekdays were considered, 260 days per year.

In the cost and benefit analysis, the present worth of the cost and benefit used the following formula:

$$PV_{OrdinaryAnnuity} = C * \left[\frac{1-(1+i)^{-n}}{i}\right] \quad (1)$$

where C denotes cash flow per period, i represents interest rate, and n is the number of payments.

The costs for purchasing bikes were converted to the present worth by using the following formula:

$$PV = \frac{F}{(1+i)^{n}} \quad (2)$$

where F denote cash flow per period, i represents interest rate, and n is the number of years. The benefit-cost ratio was calculated by dividing the present worth (values) of benefit to the cost, presented in **Table 3**. The following observations can be made:

First, the benefit-cost ratios increase with fewer stations included in the bike-share program. This is due to the fact that those stations excluded from the program attracted fewer customers and were less cost effective when they were included.

Second, including one peripheral station, either Station 1 or 4, was significantly better than including both of them in the program. The benefit-cost ratios of cases that had one station increased significantly. It is because the peripheral stations such as Stations 1 and 4 involve commuting trips in the morning and afternoon only for which the bikes would be used two times only. The trips between the on-campus stations can be chained by a bike that makes one bike to be used multiple times.

Third, having bike-share stations that were internal only, no peripheral stations, showed the highest benefit-cost ratios. This case particularly presents that a bike can be used multiple times for trips on campus.

Table 3. Costs and benefits.

Cases	Stations in a Case	Equipment and Installation Costs	Approximate Annual Operating Costs	Approximate Operating Costs	Cost to purchase new bikes after 5 yrs	Cost to purchase new bikes after 10 yrs	Travel Time Saving	Benefit – total cost (B-C)	Benefit - Cost ratio (B/C)
1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	572,000	286,000	3,843,840	306,592	328,614	6,569,782	2,090,736	1.47
2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15	568,000	284,000	3,816,960	304,448	326,316	6,470,809	2,023,085	1.45
3	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15	558,000	279,000	3,749,760	299,088	320,571	6,142,938	1,773,519	1.41
4	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 15	528,000	264,000	3,548,160	283,008	303,336	5,861,090	1,726,586	1.42
5	1, 2, 3, 4, 7, 8, 9, 10, 11, 12, 15	484,000	242,000	3,252,480	259,424	278,058	5,532,648	1,742,686	1.46
6	1, 2, 3, 4, 7, 8, 9, 10, 11, 15	474,000	237,000	3,185,280	254,064	272,313	4,866,152	1,154,495	1.31
7	1, 2, 3, 4, 7, 8, 9, 10, 11	442,000	221,000	2,970,240	236,912	253,929	4,141,821	680,740	1.20
8	1, 2, 4, 7, 8, 9, 10, 11	388,000	194,000	2,607,360	207,968	222,906	3,965,707	927,473	1.31
9	1, 2, 4, 7, 8, 9, 10	342,000	171,000	2,298,240	183,312	196,479	3,382,707	704,676	1.26
10	1, 2, 4, 8, 9, 10	310,000	155,000	2,083,200	166,160	178,095	2,866,176	438,721	1.18
11	1, 4, 8, 9, 10	224,000	112,000	1,505,280	120,064	128,688	2,438,110	684,078	1.39
12	1, 8, 9, 10	118,000	59,000	792,960	63,248	67,791	1,665,474	741,475	1.80
13	4, 8, 9, 10	108,000	54,000	725,760	57,888	62,046	1,773,407	927,713	2.10
14	8, 9, 10	28,000	14,000	188,160	15,008	16,086	1,000,770	781,516	4.56

Fourth, it can be observed that Cases 11, 12, 13, have lower equipment installation and annual operation costs comparing with other cases, and they are more acceptable for funding. In addition, these three cases have stations to support both commuting and on-campus travel. Thus these three cases are recommended for consideration in implementation.

It has been observed that the costs for bicycles and docks have been reducing over the past years. This trend makes these feasible cases of the bike share program more attractive.

4.3. Financial Analysis

The financial condition of the bike share program is analyzed by comparing the revenue and cost of the system. This analysis would help determine the fees for using the system. The revenue was computed as the predicted fees collected from the users. There are two categories of users, the casual and regular users. The casual users are those preferred to use the bike share program once a month or a week while the regular users chose to use the program once a day or more than once a day (**Table 4**). The 24 hours fee was set at $8 (for causal users) and annual pass was set at $80 (for regular users). The total revenue is calculated as

Table 4. Costs and revenues.

Cases	Stations in a Case	Equipment and Installation Costs	Approximate Annual Operating Costs	Approximate Operating Costs	Cost to purchase new bikes after 5 yrs	Cost to purchase new bikes after 10 yrs	Total membership revenue	Revenue – total cost (R-C)	Revenue - Cost ratio (RC)
1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	572,000	286,000	3,843,840	306,592	328,614	7,645,568	3,166,522	1.71
2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15	568,000	284,000	3,816,960	304,448	326,316	7,540,354	3,092,630	1.70
3	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15	558,000	279,000	3,749,760	299,088	320,571	7,298,751	2,929,332	1.67
4	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 15	528,000	264,000	3,548,160	283,008	303,336	7,111,703	2,977,199	1.72
5	1, 2, 3, 4, 7, 8, 9, 10, 11, 12, 15	484,000	242,000	3,252,480	259,424	278,058	6,850,616	3,060,654	1.81
6	1, 2, 3, 4, 7, 8, 9, 10, 11, 15	474,000	237,000	3,185,280	254,064	272,313	6,351,823	2,640,166	1.71
7	1, 2, 3, 4, 7, 8, 9, 10, 11	442,000	221,000	2,970,240	236,912	253,929	5,588,045	2,126,964	1.61
8	1, 2, 4, 7, 8, 9, 10, 11	388,000	194,000	2,607,360	207,968	222,906	5,233,434	2,195,200	1.72
9	1, 2, 4, 7, 8, 9, 10	342,000	171,000	2,298,240	183,312	196,479	4,348,855	1,670,824	1.62
10	1, 2, 4, 8, 9, 10	310,000	155,000	2,083,200	166,160	178,095	3,604,562	1,177,107	1.48
11	1, 4, 8, 9, 10	224,000	112,000	1,505,280	120,064	128,688	3,035,626	1,281,594	1.73
12	1, 8, 9, 10	118,000	59,000	792,960	63,248	67,791	2,400,443	1,476,444	2.60
13	4, 8, 9, 10	108,000	54,000	725,760	57,888	62,046	2,357,578	1,511,884	2.79
14	8, 9, 10	28,000	14,000	188,160	15,008	16,086	1,722,396	1,503,142	7.86

$7,645,568 when all the stations are considered in Case 1. The revenue-cost ratio is 1.71. These total revenues and ratios are derived for all the cases considered in this study and they are listed in Table 4. It can be seen that the same trend as for the benefit-cost can be observed. If the 24 hour pass was set at $1 for causal users, some of the cases, especially those with stations with fewer users attracted would not be financially feasible. However, Cases 11, 12, 13, and 14 that where individual stations has highest potential users included in the system are still financially feasible.

It can be observed that it is very critical to set up the fee levels that are both acceptable to the users and the feasible financially to the agencies who will install and maintain the system. Based on both the benefit and cost analysis and the revenue and cost analysis, it is concluded that Cases 11, 12, and 13 are recommended for implementation.

5. Conclusions and Future Study Needed

5.1. Conclusions

This study focused on the determination of the size of a bike-share system. Various cases of the bike-share programs were analyzed, which each case consisting of a different number of bike-share stations. The demand corresponding to the stations in these cases was used as the input to a simulation model developed in this study in order to determine the number of docks in stations and bicycles in the system on and around campus. These sizing parameters were used in a cost and benefit analysis to determine which cases could achieve the maximum benefit at UNLV, given the limitation of initial costs. In addition, the revenue to be generated for each case was calculated based on the estimated demand. Comparing the revenue with the costs, the cases that could generate sufficient funds to make the bike-share system sustainable were determined.

Among the 10 cases considered for a bike-share system at UNLV, one case included two stations on the periphery and three stations on campus; this case was cost effective in terms of costs for initial equipment, installation, and operations (less than $300,000). The revenue generated from this system was greater than the cost. Two cases that included one station on the periphery and three stations on campus were calculated to have initial investment and operation costs of less than $200,000, with revenue being greater than the costs. These three cases are recommended to be considered for implementation.

5.2. Future Study Needs

A sensitivity study should be conducted regarding the effects of the cost of system components on the feasibility of the bike-share system. The cost of bikes has been decreasing over the years, and the cost of the docking station may be decreasing as well. With these major components decreasing in costs, the bike-share program might become even more cost effective.

Only ten cases were considered in this study which is quite limited considering that there are many cases available in terms of number of stations, bicycles and docks. An optimization model can be developed that can include all the decision variables. The simulation model determining the bicycle and docks can be embedded in the optimization model that can incorporate the strategic, tactical and operational decisions in one model.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Shaheen, S.A., Martin, E.W., Cohen, A.P. and Finson, R.S. (2012) Public Bikesharing in North America: Early Operator and User Understanding. MTI Report 11-26. A Publication of Mineta Transportation Institute.

[2] Toole Design Group and the Pedestrian and Bicycle Information Center (2012) Bike Sharing in the United States: State of the Practice and Guide to Implementation. Report for USDOT Federal Highway Administration.

[3] Gauthier, A., Colin, H., Kost, C., Li, S., Linke, C., Lotshaw, S., Mason, J., Pardo, C., Rasore, C., Schroeder, B. and Treviño, X. (2013) The Bike-Share Planning Guide.

[4] El-Assi, W., Mahmoud, M.S. and Habib, K.N. (2015) Effects of Built Environment and Weather on Bike Sharing Demand: A Station Level Analysis of Commercial Bike Sharing in Toronto. Transportation. https://doi.org/10.1007/s11116-015-9669-z

[5] Wang, X., Lindsey, G., Schoner, J.E. and Harrison, A. (2015) Modeling Bike Share Station Activity: Effects of Nearby Businesses and Jobs on Trips to and from Stations. *Journal of Urban Planning and Development*, **142**, Article ID: 04015001. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000273

[6] Hampshire, R.C. and Marla, L. (2012) An Analysis of Bike Sharing Usage: Explaining Trip Generation and Attraction from Observed Demand. 91*st Annual Meeting of the Transportation Research Board*, Washington DC, 22-26 January 2012, 12-2099.

[7] Colin, B. (2013) Four Generations of Bike-Sharing. TheCityFix, World Resources Institute.

[8] Shaheen, S., Guzman, S. and Zhang, H. (2010) Bikesharing in Europe, the Americas, and Asia: Past, Present, and Future. *Transportation Research Record*: *Journal of the Transportation Research Board*, No. 2143, 159-167. https://doi.org/10.3141/2143-20

[9] Kutela, B. and Teng, H. (2019) The Influence of Campus Characteristics, Temporal Factors, and Weather Events on Campuses-Related Daily Bike-Share Trips. *Journal of Transport Geography*, **78**, 160-169. https://doi.org/10.1016/j.jtrangeo.2019.06.002

[10] Kyung, G. (2015) University Bike Share Survey Analysis. Prepared for University of Illinois Institute of Sustainability, Energy, and Environment.

[11] McNamara, M. and Mathew, J.K. (2016) Analysis of a University Bike-Sharing Program and Lessons Learned.

[12] Heda, A. (2012) Implementation of a Campus Bike Sharing Program for Washington University's Danforth Campus.

[13] Jennifer, A. (2012) Bike Sharing as Alternative Transportation at Bridgewater State University. *Undergraduate Review*, **8**, 16-25.

[14] Bhowmick, S. and Varble, D.L. (2015) Bike-Share: A Bicycle Program for Campus.

Journal of Case Studies, **33**, 25-37

[15] Zonobi, E. and Melara, O. (2012) Bike Share Survey Report. Associated Students, San Jose State University Transportation Solutions.

[16] Work, L., Gardner, P. and DeGoey, K. (2013) Boise State University Bike-Sharing Program. Boise State University, Environmental Studies Department.

[17] Lin, J.-R. and Yang, T.-H. (2011) Strategic Design of public Bicycle Sharing Systems with Service Level Constraints. *Transportation Research Part E*, **47**, 284-294. https://doi.org/10.1016/j.tre.2010.09.004

[18] Saharidis, G.K.D., Fragkogios, A. and Zygouri, E. (2014) Multi-Periodic Optimization Modeling Approach for the Establishment of a Bike Sharing Network: A Case Study of the City of Athens. *Proceedings of the International Multi Conference of Engineers and Computer Scientists*, Vol. II, Hong Kong, 12-14 March 2014. http://www.iaeng.org/publication/IMECS2014/IMECS2014_pp1226-1231.pdf

[19] Kroes, E.P. and Sheldon, R.J. (1988) Stated Preference Methods. *Journal of Transport Economics and Policy*, **22**, 11-25.

[20] Louviere, J., Henly, D.H., Woodworth, G., Meyer, R.J., Levin, I.P., Stones, J.W., Curry, D. and Anderson, D.A. (1981) Laboratory-Simulation versus Revealed Preference Methods for Estimating Travel Demand Models. In: *Transportation Research Record* 794, TRB, National Research Council, Washington DC, 42-51.

[21] Louviere, J.J., Hensher, D.A. and Swait, J.D. (2000) Stated Choice Methods: Analysis and Application. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511753831