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Planning of Public Bicycle (bike) Sharing System (PBSS): A Case Study of Surat City

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Abstract

In recent years cycling has seen as a new beginning, triggered by the thrust towards greater environmental consciousness. In cities where cycling shares are low, efforts are being made to promote cycling as a viable mode of transport. As an emerging economy, city like Surat is now facing urban challenges that are more complex than other cities of India especially the central Business District (CBD) area of Surat. Due to congested streets and other limitations, it is not feasible for the provision of other transportation facilities in the central area of it and for this reason city planners are now planning to provide Public Bicycle Sharing System (PBSS) in Center zone. To understand factors starring to bike sharing adoption and hindrance to adoption, the IUTI-SVNIT Team conducted an intercept survey in the Central zone during January-March 2017. The House Hold (HH) survey reveals that about 75% two-wheeler users and 78% car users are willing to use PBSS if implemented. The results from analysis give an idea about if PBS system is launch then daily commuters, Pedestrian etc. get benefits & use this types of NMT facility in their daily trips. The study identifies total 81 potential docking station with 1920 bicycle fleet size in three phases using maximum coverage area method and minimum impedance method using ArcGIS platform. Author expect that practitioner and researchers will find this study useful to overcome the various issues of densely urban areas such as roadside short-term parking issues, reducing vehicular congestion, increase cities' livability.

*Keywords:*Public bicycle sharing, Sustainable transport, Nonmotorized transport, bicycling

1. Introduction

From the time when the beginning of Public Bicycle Sharing System (PBSS) in Amsterdam, Netherlands, in 1965,

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the public Bike share system has been well-known as an alternative fastest green transportation mode in the family of sustainable transportation systems. Initially, in 1965 the system is started and introduced in Amsterdam which generally known as the first generation PBSS is now expanded to a latest fourth-generation system which has a fully automated dock less system, real-time big data, and many more features. Within five decades, PBSS got a huge success and take their own space in an urban environment in world's cities as an only option as a sustainable mode of transport. Up to the Year 2008, PBSS is very limited spread only a few European cities then exponentially the growth of system is increasing in last 1 decade and spread in worlds' five continents(Asia, Europe, South America, North America, and Australia).

The principle of bicycle sharing is simple: persons use bicycles on an "as-needed" basis without the costs and responsibilities of bicycle ownership (Shaheen et al., 2010). Moreover, PBSS system is not having financially burdened to the individual, and so it could be a motivational advantage to the users. Therefore, Bicycle sharing system is the most excellent option out of all other potential ways such as bicycle rental scheme and bicycle loan scheme to provide bicycle usage. According to bike sharing world map as on Dec-2017, there are more than 370 cities operating bicycle-sharing schemes and around 250 being planned in more than 30 countries covering every region of the world having approximately 6,88,163bicycles.

In recent years several of the Indian urban transport planners have to pay attention to a great extent on promoting to bring into play of bicycles as a substitute option to the exhaustive car and two-wheeler (2W) use. Additionally, about 35% of the vehicular trips in Indian cities are short trips (Tiwari, 2008) and also most of the medium and large cities in India has 56% to 72 % trips which are short trips having less than 5 km trip length(Dhingra & Kodukula, S., 2010), which presents an enormous potential for bicycle use. Looking to this, the present research was conducted to plan and design Public bicycle sharing system in CBD of Surat.

For the study 856 household surveys were carried out to get the idea about travel characteristics, willingness to use and socioeconomic profile of citizens. The data of major activity centres, routes of intermediate public transit, Public transit stops, land use, road network, population density, traffic generating activity map were collected and analysed in GIS software. Based on the analysis, Spatial Location was freeze and long term, medium term, short term system design was carried out. The proposed PBS system will help in decongesting the CBD area and attract more people to shift from personnel mode to NMT.

This paper is structured as follows. Section 2 provides a brief literature review summarizing the current state of the art. Study area profile and geographic details are detailed in Section 3. Section 4 demonstrates Readiness to use PBS in which HH survey analysis discussed. Finally, Section 5 summarizes in depth for the main contributions of this study, discusses the methodology of PBSS system design, criteria for design, and finally gives the Optimal potential location of Bicycle station, size of each station and numbers of bicycle requirement.

2. Literature Review

In general, the allocation of bicycle stations is dependent on the size and pattern of the city. The methodological guide to designed bicycle-sharing in Spain differentiates based on the size of city, density of the city and the type of loan system (IDAE, 2007). Some studies recommend that the PBSS is initially introducing in the zones with the highest density, which is generally the city centres, and then gradually extending it to reach the peripheral areas (IDAE, 2007). One of the keys to the success of PBS programs is the location of bicycle stations and their relation to trip demand (Lin and Yang, 2011). To gain user acceptance, the distance between stations and the origins and destinations of trips should be small. The numerous methodology is adopted to identify the potential location of bicycle station like maximum likelihood method, Hub and Spoke method, Location-allocation method, GIS-based methods etc. Various researchers apply the different methodology to find out the potential docking station. There are usually different approaches in all of the methods, but the research articles do not compare different approaches and claim that the approach adopted for a particular study is superior to the other. One reason for such inference is because of the fact that the results of all approaches are identical in general. To identify cycling station location, one should choose one simple method which has not more complex procedure.

Most favourable location tools known as location-allocation models have been implemented in a GIS background, which may be of enormous apply to locating potential bicycle stations with relation to the distribution of potential demand (García-Palomares et al., 2012). This model consists of finding where services of a given type should be located and what their capacity should be to meet several predefined objectives while fulfilling demand as of a given number of centres. Once the coverage area has been considered, the location of the bike-stations should be adapted to the objectives of the public bike program and the demand that it aims to satisfy (García-Palomares et al., 2012). Various obstacles are carefully monitored for the successful operation of the cycling system, efforts are made to make PBS successful using various optimization models. Various optimization tool/software such as Lingo, MATLAB, C^{++} programming, Express, ArcGIS are used to make accurate decision-making in this entire process.

Frade and Ribeiro, (2015) attempt planning of PBSS using an optimization method in such that it maximizes the demand covered and takes the available budget as a constraint. A model combines strategic decisions for locating bike-sharing stations and defining the dimension of the system with operational decisions (Frade and Ribeiro, 2015).

The "steady-speed power equation" published by Wilson (2004) is used to estimate the total energy expressed in Joules in the study of Tingstrom, (2013).Study consider a bicycle rider would have to pass through each the street segment as well as street distance, slope and characteristics of bicycle and a bike rider taking as inputs for analysis. Final output by different 5 methods gives an optimum place of bicycle station as well as a location of bicycle shed area in the region.

Study addresses by Lin and Yang, (2011) for strategic planning of public bicycle sharing systems with service level considerations. In the study considering the interests of both users and investors and output of the proposed model determine the number and locations of bike stations, the optimal requirement of bike paths connected between the pair of origins and destinations (Lin and Yang, 2011).

Hub-location inventory model which is popularly known as a Hub-spoke location model, has been enacted by Lin et al., (2013)and the number of cycling stations, places of bicycle stations, bicycle lanes and cycle path between origin and destinations, etc. have been taken as the main design decisions.

All these works provide the background for our study, but they all fail to notice a few points in the actual implementation of these systems. The proposed model combines strategic decisions in the location of bike-sharing stations and establishing the system's size. More precisely, the model defines the most favorable location of the bicycle stations, the fleet size, the capacity of the stations, and the number of bicycles in each station.

To identify a potential location for bicycle stations in the central zone of Surat, the location of the important attractions points like commercial hubs, schools, government offices, shopping complexes, PT-IPT points, junction of important commercial activity, parking complex, trip generation point identified in ArcGIS software. After finding all points, minimal impedance tool in ArcGIS software which works as an Optimization Tool gives the best potential locations for bicycle station which connect all the trip generated points and trip attracted points. Section 5 gives an in-depth idea about operation and result of the PBS system design.

3. Study Area Profile

Surat which was popularly known as "THE SILK CITY", "THE DIAMOND CITY", "THE GREEN CITY" is a city located in the western part of India in the state of Gujarat. It is one of the most dynamic city of India with one of the fastest growth rate due to immigration from various parts of Gujarat and other states of India. According to the census 2011, Surat city has 2nd highest population among other cities in Gujarat with around 45 lac.

The central zone of Surat city is highly congested zone. Due to concentrated commercial and business activities, CBD attracts numerous visitors daily for various purposes. Short duration parking for the visitors is a critical requirement along with long-term parking for employer and employees. The CBD is facing a lot of traffic problems in terms of congestion, pedestrian-vehicular conflicts etc. Central Zone is also delineated by adopting existing ward system of Surat Municipal Corporation. Total 12 wards of CBD are grouped together. Table 1 represents a geographical area, total population and a population density of each ward while figure 2 represent density map for central zone.

Figure 1Central zone of Surat city

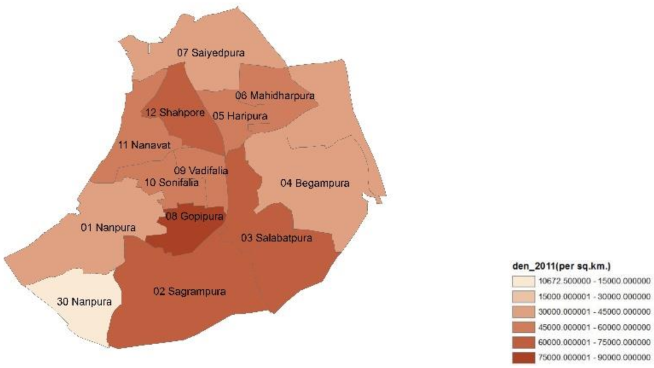

Figure 2 Population Density map of Surat city as on census 2011

Table 1 Ward-wise demographic details of the central zone as on census 2011

Ward No.	Name of Area	Area in Sq. km	Total population	Density(Persons/Sq.km)
1	Nanpura	1.28	52421	40954
2	Sagrampura	1.31	81554	62255
3	Salabatpura	0.84	53684	63910
4	Begumpura	0.93	41768	44912
5	Haripura	0.23	11378	49470
6	Mahidharpura	0.36	17027	47297
7	Saiyadpura	1.69	56006	33140
8	Gopipura	0.22	18795	85432
9	Wadifalia	0.14	8089	57779
10	Sonifalia	0.24	13499	56246
11	Nanavat	0.46	21022	45700
12	Shahpor	0.39	24979	64049

(Source: Surat Municipal Corporation, Census 2011)

4. Analysis of Household survey

To understand the feasibility of this system the citizen's involvement and their perception is a must to be captured and in line with this Household (HH) survey was undertaken to understand travel behaviour and demand of Central zone. An intercept survey in Central Zone was carried out between January-2017 to March-2017. In total, 7 teams and around 50 Student collected 856 valid surveys samples. Based on the survey HH Characteristics, the Socio-economic character of stakeholders, O-D travel pattern of the study area etc. are analysed and used for the PBS System Design. This section discusses the different results and travel demand statistics for Central zone. The results from analysis give an idea about if PBS system is launch then there is a good impact on mode shift from personalizing vehicle to PBS system whereas, various PT users, IPT users get benefits and willing to use this types of NMT facility in their daily trips for first and last mile connectivity.

Table 2 HH survey data and results (Socio-economic characteristics)

Variable	Descriptions	Value
Number of respondents	Total Male and female	856 No.
	Male	75%
	Female	25%
Age of Respondents	Range (in Years)	
	0 – 18	26 No 4%
	18 – 25	119 No 14%
	25 – 40	322 No 37%
	40 – 60	331 No 38%
	Above 60	58 No 7%
Occupation	Government job	7%
	Semi-government job	5%
	Private job	32%
	Business	33%
	Not employed	09%
	Housewife	14%
HH income	Total Family Income in thousand ₹ (INR)	
	<10	3%
	10 to 20	18%
	20 to 30	30%
	30 to 40	21%
	40 to 50	14%
	>50	10%
	No answer	5%
Willingness to use PBSS	2-w users	
	Yes	76%
	No	24%
	Car users	
	Yes	78%
	No	22%

4.1 Survey Analysis for Central Zone

The household survey was conducted in different wards of Central Zone. The survey took a total of 856 HH samples covering total 3826 individuals. Samples are collected from all the 12 zones in the proportionto their population so as to have a rational understanding of the characteristics of people's travel behavior.

4.1.1 Gender of respondents

It is necessary to know about travel preferences of males and females. In the present survey, out of a total sample of 856, 75% respondents are male who will be the dominant users of the system whereas 25% are female.

4.1.2 Occupation of respondents

The respondent occupation helps in deciding the particular types of the facility and how effective it will be after implementation. Table-2 shows that 46% households are having jobs whereas 33% respondents are having business as occupation. The PBS system will be more benefiting to service class people (33%) and Housewife (14%) category of travelers.

4.1.3 Household income characteristics

A household income characteristic is also an important part to get an idea about the socio-economic condition of the area. On the basis of that, planners can get the idea about which type of System/facility gives the best performance in the prevailing socio-economic environment. Table-2 shows monthly income distribution, ranging from less than INR 10,000 to more than INR 50,000.About 65% households have monthly income in the range of INR 20,000 to INR 50,000 whereas only 3% households have monthly income less than INR 10,000.

4.1.4 Family size distribution

The number of members in a family directly generates the demand for PBS uses specifically for middle income and low-income families. Table-3 shows the distribution of family size varying from 1 to more than 10 per household. From Table-3, it is evident that in the central zone 80% of households have family size 5 or less, out of which 30% households are having a family size of 4.

Table 3 Ward-wise Family size distribution of central zone

Family Size	No of HH	Relative Frequency In %	Cumulative %
1	11	1	-
2	77	9	10
3	165	19	30
4	247	29	58
5	181	21	80
6	84	10	89
7	48	6	95
8	24	3	98
9	5	0	98
> 10	14	2	100
Total	856	100	

4.1.5 Vehicle ownership per HH

Vehicle ownership is essential data to judge the potential use of public transportation and from this data, it is possible to predict the number of different types of vehicle availability per HH in the study area as well as the pattern of growth of vehicles individually. Figure-3 shows the ward-wise vehicular ownership per household and Table-4 shows the vehicular characteristics at zonal level.

From table-4, it is evident that 2W ownership is almost 2 per HH, for the car, it is 0.41 per HH which means 500 cars per 1000 HH and bicycle ownership is only 0.27 per HH which is very less compared to car and 2W. As per Figure-3, ownership of 2W, Car, bicycle and other vehicles is 73%, 16%, 10% and 1%, respectively.

Table 4 Ward wise average vehicle ownership

	Average Vehicle ownership per HH		
Location	Cars	2 W	Bicycle
Ward 1	0.38	1.44	0.63
Ward 2	0.62	2.05	0.20
Ward 3	0.57	2.16	0.06
Ward 4	0.44	2.08	0.39
Ward 5	0.28	1.84	0.16
Ward 6	0.52	2.16	0.48
Ward 7	0.13	1.40	0.00
Ward 8	0.40	1.94	0.26
Ward 9	0.36	2.08	0.36
Ward 10	0.35	1.83	0.05
Ward 11	0.71	1.83	0.36
Ward 12	0.21	1.52	0.30
Zonal Level	**0.41**	**1.86**	**0.27**

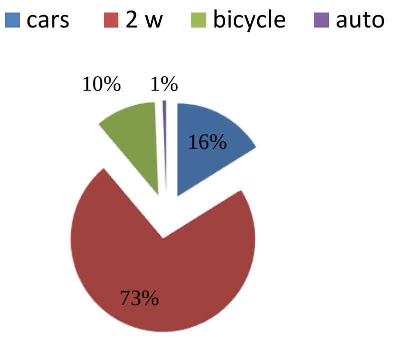

Figure 3 Vehicle ownership of central zone

4.1.6 Willingness to shift

The willingness of the residents to adopt the new mode of travel will make the proposed project successful. Two types of willingness were asked from the respondents 1) walking distance for cycle stand preferred by users and 2) Up to what distance users prefer for cycling. From the WTS analysis presented below, the planner can get the idea about at what distance users want docking station and up to what distance people would prefer bicycling. On the basis of this, a planner tries to accommodate bicycle stands and gives the expansion of the PBS system or connectivity to various locations of the urban area. The planner also gets the idea about certain benchmark to the new PBS system according to the users' preferences. Figure-4 Radar plot shows ward-wise preferred walking distance by the respondents. However, it is clearly understood that the users can walk up to a distance of 500m.

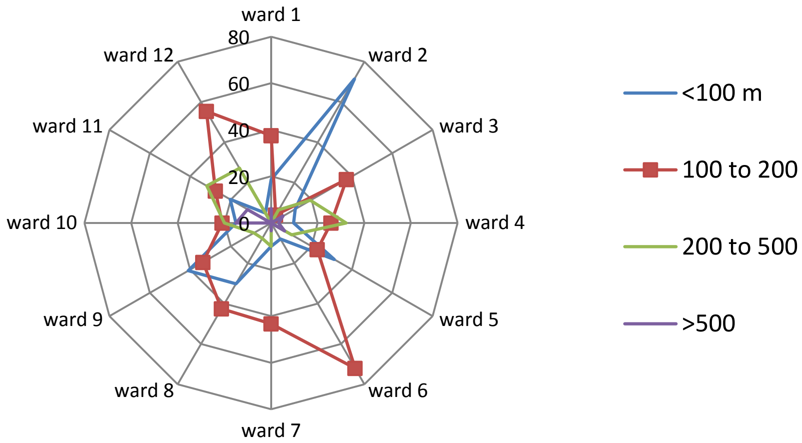

Figure 4 Radar plot for distance preferred to walk for PBS system

4.1.7 Trip distance preferred with PBS system by users

The trips preferred by the users will decide the density of the docking station and hence the analysis of the distance likely to be traveled by respondent play vital role.
Figure-5 shows preference of trip distance travel by respondents. It can be seen that maximum respondents prefer travel up to 100 m to 2.5 km distance range.

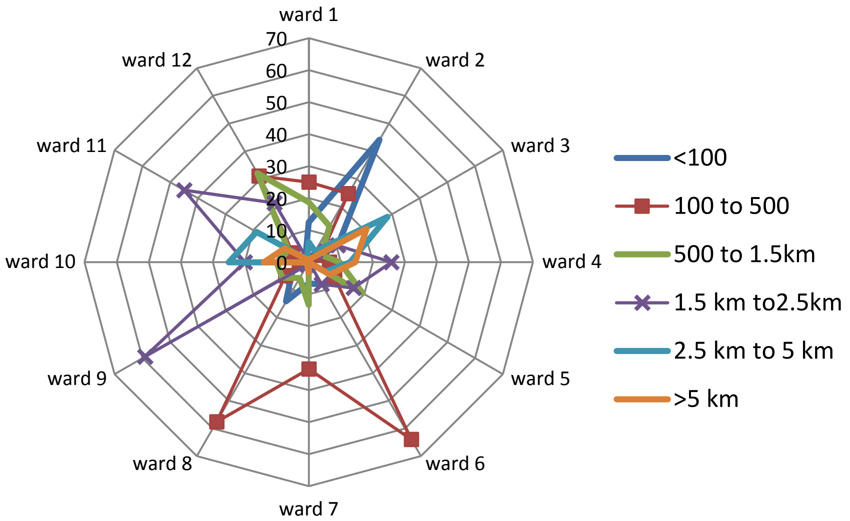

Figure 5 Radar plot for trip distance preferred by cycling

4.1.8 Demand Assessment

Total demand is decided on specific considerations based on past studies and available literature. With the help of above HH survey, demand assessment is carried out. By the survey total daily trip was count approximate 2,51,120 then after considering 90% trip made by 2-W and cars total 1,75,784 trips are estimated. Out of that 90% trips 40% trips were considered as a short trips by 2-W and cars and in that 40% trips peak hour demand is considered as 10% only and finally 4920 trips are taken as full demand trips for PBSS design as a benchmark. Table-5 below shows demand assessment on the basis of respondents' survey. It is estimated that total daily demand of 4920 trips will have to be catered by PBS system out of total daily trips in the CBD.

Table 5 Assessment of trip demand by PBSS in peak hours

S. no	Assumption	Estimated Demand
1	Total Daily Trips	2,51,120
2	Total trips made by 2W and Car (90%)	1,75,784
3	Trips from (2) that are shorter than 5km (40%)	70,314
4	Peak hour demand (10% of total daily trips)	7,031
5	Catering to 70% of Full Demand	4920
6	Total Demand For Phase 1	4920

5. PBS SYSTEM DESIGN

An important consideration while designing the PBS System for the city should be the accessibility of bicycle and PBS Stations to the potential users, which would impact the acceptance of the system largely. To address this, the station density should be such that a bicycle is available at all potential origins and destinations across central zone also enough bicycles are presently based on the area under PBS such that potential users need not walk for more than 4 to 5 minutes in search of a PBS Station anywhere in the coverage area.
Even though the detailed plan for the entire area has been prepared, but due to budgetary constraints, a phase-wise implementation would be, more result oriented and successful in long term.

5.1 Criteria for phasing

The overall delineated study area is divided into various phases for PBS implementation due to technical and financial reasons. The selected Phase I especially, should have a huge potential for a PBS system, which can pave way for the subsequent phases by showcasing success. Criteria to phase the project have been considered as under:

1. Areas connected to major attraction and production nodes.
2. Areas proximate to existing transit routes.
3. Areas accessible from Rajmarg, Kotsafil road, and Ring Road.
4. Availability of land for the core PBS Stations and the distributed PBS stations

5.1.1 Proposed phasing

Central zone's proposed PBS system has been divided into three phases based on the desired timeline for implementation short-term, mid-term, and long-term. To delineate the phases, population, land use, road network, PT stops and routes, IPT stops and routes and traffic generating activity map are overlaid and the potential areas that overlap, with maximum production and attraction of trips possible, are considered for the first phase, Phase II includes areas with the high potential of growth and phase III includes rest of the central zone to ensure PBS network for the whole area.

5.2 Station Location Criteria

The result of HH survey gives a very brief guideline and clear vision to the planners for design configuration of any system with respect to citizens' perception. With the help of respondents' response and standard guidelines provided by international practices planners finalize various parameter of the system. According to the standard guideline for station distance, 300 m is preferable by users and in our results, 100-200 meters are preferred by most users. But the reason behind this is respondent may not judge walking distance directly so we consider 300 m as station distance. The distance between stations is directly affecting the system coverage. With this regards, we taking Minimum coverage includes 10 PBS stations per sq km which are standardized by international guidelines. Stations location will be near mass transit stations or IPT/transit stops and near bicycle lanes/tracks if present.
Stations should be located preferably near or on SMC/ Government property, Multi-Level Parking, Below Flyover, On major arterials like Ring Road, Rajamrg, and Kotsafil Road and places along the street that are safe to access by bicyclists.
Stations should be located inside residential cores and near important public institutions or places like school, colleges, parks, markets, commercial areas and other activity nodes.
Following the above-given guidelines, PBS station locations are delineated on the basis of population density, road network, transit nodes and activity map.

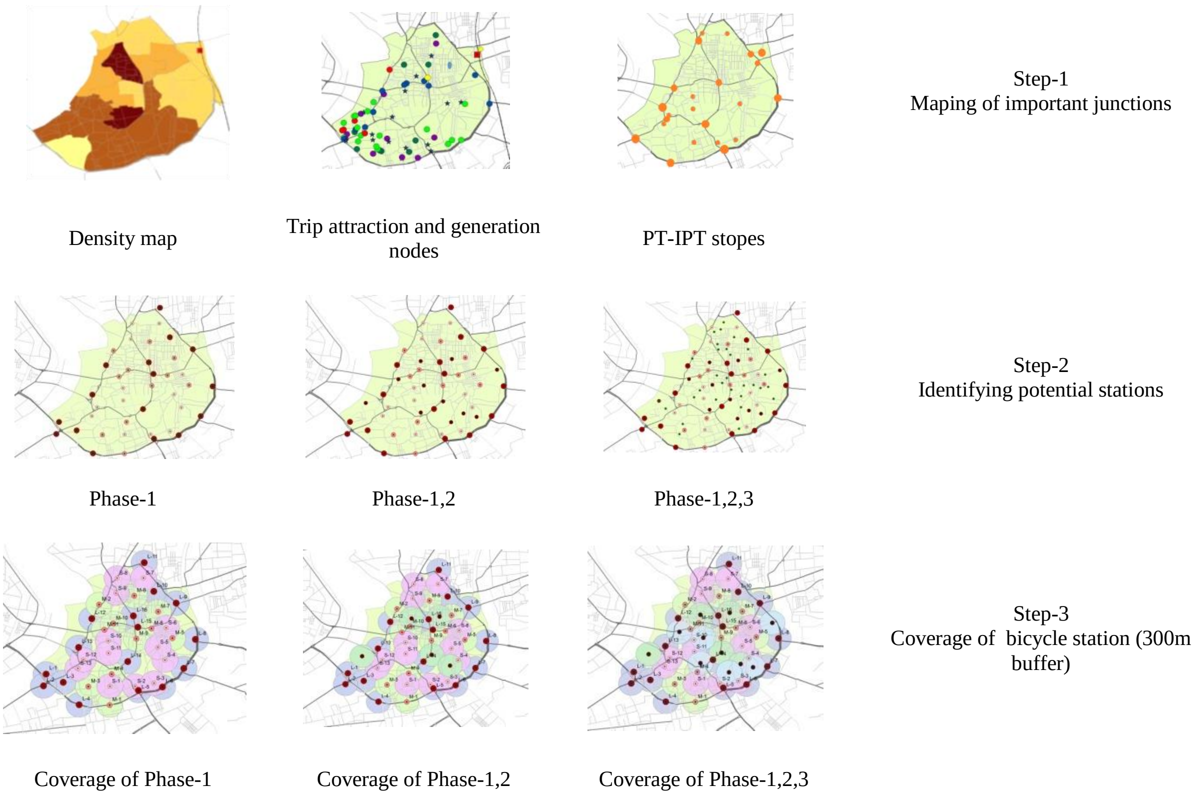

Figure 6 Planning Sequence to design PBS system by ArcGIS

Preliminary identification has resulted in 81 stations out of which 40 stations are within the Phase I area, to maintain a density of 10 stations per sq.km. The proportion of large, medium and small stations have been developed to accommodate the required fleet size of 1920 bicycles. Large, medium and small stations are proposed for the docking capacity of 40, 20 and 15 cycles respectively.

The study is conducted to identify the major areas of attraction in the central zone which are the possible locations for the PBS station. The identified areas include Government buildings i.e SMC, Collector office, Bahumali Building etc, Major Commercial areas like ChowtaPull, Bhagal, Chowk, PT and IPT interchanges and Bus Station, railway station as well as recreational places like Gopitalav, chowk etc. Based on the identified area trips O-D is carried out to understand the quantum of bike demand.

Based on the detailed study following PBS system size for phase I to III and station types is worked out.

Table 6 Phase wise PBS system design

Phase	Coverage Area (Sq.km)	No of Stations	No of Bicycles
1	4.0	40	1160
2	1.18	11	210
3	3.0	30	550
Total	8.18	81	1920

6. Conclusion and Recommendation

A study demonstrates the planning of PBSS in the central zone of Surat city by Integrating two methods i.e. minimum impedance and maximum coverage in ArcGIS platform. The Phase-1 is considered as a pilot project so to identify station location, the concept of minimum impedance method in ArcGIS adopted while for Phase-2 and phase-3 probable trip generation activity points and coverage of the area is taken as constraints and by using Max coverage approach in ArcGIS bicycle station are identified. Overall PBS station locations are delineated on the basis of population density, road network, transit nodes and activity map. Preliminary identification has resulted in 81 stations out of which 40 stations are within the Phase I area, 11 stations are within the Phase II area, and 30 stations are within the Phase III area. The proportion of large, medium and small stations has been developed to accommodate the required fleet size of 1920 bicycles. Large, medium and small stations are proposed for the docking capacity of 40, 20 and 15 cycles respectively. Results from mode shift analysis bring a very optimistic information for the planners, analysis shows that 72%, 2-W users & 76%, Car users are willing to shift from their private mode to PBS if it implemented. This mode shift from personalized mode to the PBS will lead the cities towards sustainable transportation and make the cities climate resilience.

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