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DESIGN AND IMPLEMENTATION OF MACHINE-CONTROLLED SYSTEM FOR PUBLIC BICYCLE-SHARING IN URBAN AREAS

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DESIGN AND IMPLEMENTATION OF MACHINE-CONTROLLED SYSTEM FOR PUBLIC BICYCLE-SHARING IN URBAN AREAS

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Abstract- This paper presents a design of machine controlled intelligent system for public to share bicycles for short distance transportation in urban areas. It allows us to take bicycle from wherever we are and to park at our nearest place of destination. The design schemes used here are automated system for bicycle delivery unit (base station) and bicycle parking unit (substation) and automatic amount collection for the usage from user card (RFID tags) and central administration office (GPS) and solar powered substations (PV solar panels). Moreover, it offers auto-locking racks for bicycles, on-Board vehicle tracking, and battery with solar power management, data logging, and communication with substations and administration. The subscribers can register to this service by administrator of bicycle sharing system. In 2011, the Ministry of Urban Development (MOUD), Government of India, launched the National Public Bicycle Scheme (NPBS) to build capacity for the implementation and operation of cycle sharing systems across the country. This paper outlines the advanced requirements to successfully develop and deploy bicycle sharing system focusing on solar powered battery charging and vending by PV solar panels, rental collection interface, in and out management of bicycles, system equipped with RFID and GPS tracking mechanisms. So bicycle sharing systems has emerged as an innovative form of public transport to provide urban short-distance transportation services by government.

Keywords *– auto-locking racks, rental collection user interface card, solar powered battery-charging and vending, on-board vehicle tracking, smart phone and communication management.*

I. INTRODUCTION

Bicycle sharing systems are an increasingly popular system whereby bicycles are made available on a large scale in a city allowing people to have ready access to these public bicycles rather than their own cycles. Municipal governments and community groups have promoted bicycle sharing systems as part of intermodal transportation by allowing people to shift easily from transit to bicycle and back again. By making alternatives to motorized travel easily accessible, they hope to reduce the carbon footprint of commuting as well as enable residents to become healthier through exercise. Bicycle sharing systems can be divided into two general categories: community bike programs organized mostly by local community groups or non-profit organizations; and large scale public bike programs that are implemented by municipalities or through a public-private partnership as in the case of Paris' Vélib' program[1]. The central concept of many of the systems is free or affordable access to bicycles for city transport in order to reduce the use of automobiles for short trips inside the city thereby diminishing traffic congestion, noise and air-pollution. A secondary goal is to reduce thefts of privately owned bicycles [2].

Bicycle sharing systems in urban areas usually differ from traditional bicycle rental services since they are rather offers for daily mobility than leisure oriented systems. In contrast to those conventional renting schemes, bicycle sharing systems can be used one-way for any trips [3]. As a flexible mobility option they can be considered as an additional part of public transport systems. A long list of possible benefits makes bicycle sharing attractive for municipal organizations as well as for businesses. First of all, the increasing price of natural resources especially for oil necessitates thinking about sustainability, efficient use of resources and development of new innovative solutions. This situation is comparable to the late seventies after the two oil price shocks. Cities like London and Stockholm created a city toll for using the car downtown. Other cities like Rome or Sao Paolo (Brazil) permit car use depending on the number plate [4].

Furthermore, the increasing urbanization brings the necessity to think about alternative transport concepts. Growing density of the population in cities intensifies the problem of insufficient infrastructures. Those infrastructures can only be enlarged to a certain level. Thus, new ways and concepts for an efficient use of the existing infrastructures have to be found. Bicycles require only little space and also reduce the emission of exhausts and the need for fuel in cities [5]. Bike sharing also offers an economic effect for cities and individuals. Bikes are an inexpensive mode of transport with need for only low-tech infrastructures. Therefore, a relatively low amount of investments is needed to create or expand infrastructures. With concepts for bike sharing even the costs for owning vehicles cease to apply [6].

Operators benefit from a change of mobility behavior and the improvement of their image. As cities are competing for tourists and guests they invest a big effort in presenting their city as modern and innovative. In that context bike sharing can be seen as an environmentally friendly service to support the modernity and individuality of a city [7].On July 28, 2011, the city of Boston, Massachusetts launched its 60-station, 600-bike Hub way system, sponsored by the shoe manufacturer New Balance and funded in part by a $3 million grant from the Federal Transit Administration, the contract to operate was awarded to Alta Bicycle Share [8]. Bike-sharing systems have undergone changes which can be categorized into three key phases, or generations. These include the first generation, called white bikes (or free bikes); the second generation of coin-deposit systems; and the third generation, or information technology (IT) based systems. Recent technological and operational improvements are also paving the way for a fourth generation, known as the demand-responsive, multimodal system [9].

Technology-driven bicycle share programs have many common elements including equipment and systems (e.g., bicycle fleets, parking and locking mechanisms, user interface and check-out protocols, and station networks), as well as maintenance and management requirements (e.g., fleet and station maintenance, status information systems and bicycle redistribution systems. Fleet bikes should be distinctive, designed for easy city use, and be clearly branded to increase their visibility. Bicycles typically come with full fenders, chain guards and, in some cases, bicycle locks. Most bicycles come equipped with a Global Position System (GPS) unit, Radio Frequency Identification (RFID) tag tracking mechanism.

This function is typically used in fleet management and location of lost or stolen bicycle Fleet [10]. Bicycle lock to either a rack or kiosk where users collect and drop cycles using a magnetic strip. This is commonly referred to as a smart card system. Smart card systems are found throughout the world. These systems are generally simple to operate, making them accessible to the general public. Bikes are secured using an electronic lock mounted on the bicycle. Users will receive unlock code for bicycle through phone. This is commonly referred to as a dial-a-bike [11]. These systems require very little infrastructure as the necessary mechanisms are mounted on the bicycle itself. Stations using smart card systems generally require:

- Bicycle bar(handle) to lock bicycles between uses
- A microcontroller system to check bicycles in and out
- A solar power source to control check-in/check-out and track bicycles.

The overall system components are given in the Figure (1).it includes Station Hardware, Station Software and Central administration system. The station hardware focuses on auto locking bicycle racks, solar powered battery supply, rental collection card, on board vehicle tracking. Station software focuses on Microcontroller system for user interface, data logging, Communication with admin. Central station focuses on controlling subscriber's registration, smart phone facilities and maintenance of the system.

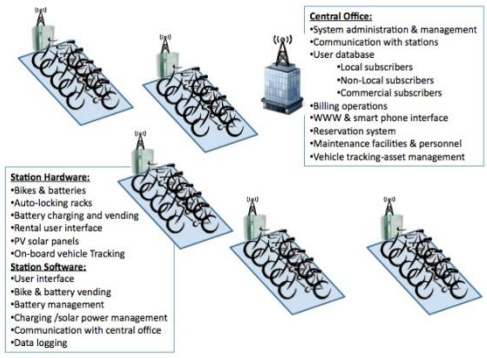

Figure 1: Components of system

II. STATION DESIGN AND USER INTERFACE

All bike share programs require a user interface to collect and retrieve bicycles, through a check-in/check-out system. The interface should be simple and easy to understand. Stations should provide clear directions on how to access and return a bicycle. Other recommended elements and design guidelines include:

- Instructions on where and how to return bicycles
- Cost and pricing information
- Contact information to report damaged bikes or stations
- Maps of nearby stations and recommended bicycle routes
- Damage resistant locking mechanisms
- Quick access to avoid queues and maximize safety

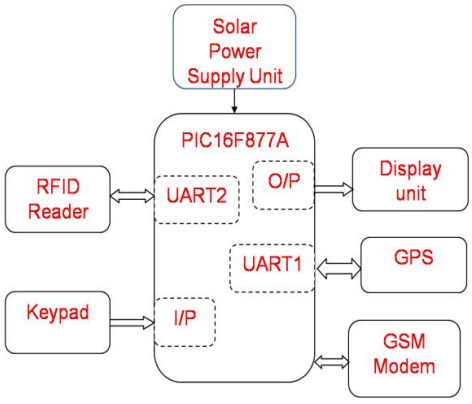

Figure 2: Block diagram Station design

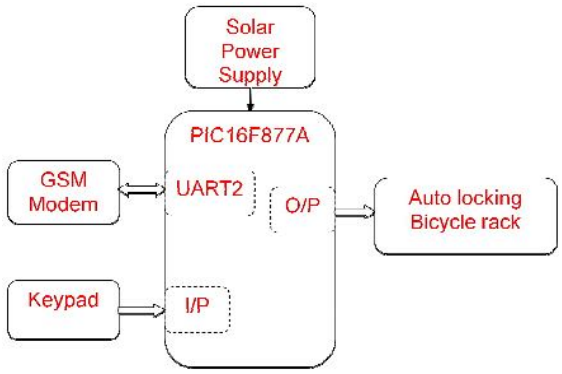

Figure 3: Block Diagram of bicycle delivery unit

To overcome the problems like traffic by more number of two wheeler bikes, usage of cars and other vehicles for short distance more resources are getting wasted in our day to day life. so we go for the automation of the bi cycle sharing system using embedded system design with the microcontroller PIC16F877A and RFID. Imagine a network of bike stations located within a few blocks of one another throughout your community. As a bike-sharing member, you can unlock any of the specially designed bikes at any station and ride it to any other bike station. It is fast, simple, inexpensive. Bicycle relies on the integration of hardware and software to keep track of members and bikes, and all the interactions between users and bikes.

A detailed literature review was progressed and formed a problems in existing system, then the system designed as per following.

- Design of PIC16F877A Microcontroller development Board-Microcontroller system for user interface.
- Design of Keypad interfacing, RFID REDADER, LCD, GSM, GPS with Microcontroller for MENU display user interface.
- Design of Secondary bicycle substation connected with all other stations using GSM, GPS. WWW connection for smart facilities like Maps, Phone SMS service.
- Design auto locking Rack for bicycle delivery unit. When user wants access of cycles it unlocked, when user wants to park it has to lock the cycle.
- Design of automated timer system and rent calculation system from smart card (RFID TAG and READER).

The design schemes of the bicycle sharing system has described in the above steps.

III. BACKROUND AND JUSTIFICATION

1) Current status of transport development in india.

In 2011, the Ministry of Urban Development (MOUD), Government of India, launched the National Public Bicycle Scheme (NPBS) to build capacity for the implementation and operation of cycle sharing systems across the country. As part of the NPBS, this toolkit was prepared for MOUD by a team from the Institute for Transportation and Development Policy (ITDP), an organisation that works with cities worldwide to bring about transport solutions that cut greenhouse gas emissions, reduce poverty, and improve the quality of urban life. The authors wish to thank the Chairperson and all the members of Subgroup 2 of the NPBS for their meaningful inputs and support.

- dense network of stations across the coverage area, with a spacing of approximately 300 m between stations
- Cycles with specially designed parts and sizes to discourage theft
- A fully automated locking system at stations that allows users to check cycles in or out without the need for staffing at the station
- Radio frequency identification devices (RFIDs) to track where a cycle is picked up, where it is returned, and the identity of the user
- Real-time monitoring of station occupancy rates through General Packet Radio Service (GPRS), used to guide the redistribution of cycles
- Real-time user information provided through various platforms, including the web, mobile phones, and/or on-site terminals
- Pricing structures that incentivize short trips, helping to maximize the number of trips per cycle per day.

2) Bicycle sharing system in other countries like china and UK.

Today there are cycle sharing systems in over 200 cities around the globe, and more programs are starting every year. Some of the largest cycle sharing systems is in Chinese cities like Hangzhou and Shanghai. Washington, D.C. (USA), Paris (France), and London (U.K.) have hugely successful systems that have helped re-energize cycling in those cities, providing Based on the battery type and vehicle, Level 1 charging adds about 2 to 5 miles of range to a PEV per hour of charging time. an ideal transport solution for short trips and a feeder to other public transport options. Cycle sharing is a nonpolluting and healthy mode of transport.

Modern cycle sharing systems have the ability to track the identity of the user as a way of preventing theft of cycles. All users are required to furnish identity proof, either at the time of registration or when signing up for temporary subscriptions. Most

systems in Europe and North America rely on credit cards as a security mechanism: if the user fails to return a cycle, a fine can be charged against the user's credit card. The user's account is also blocked to prevent him/her from checking out other cycles. In China, the user is required to keep a deposit in his/her smart card account, and if he/she fails to return the cycle, the deposit is forfeited.

Most cycle sharing systems operate in a public-private partnership structure in which the government carries out planning and oversight activities and the private sector handles day-to-day operations. Successful implementation of a cycle sharing system requires meticulous planning and oversight on the part of the government.

As in most public transport systems, cycle sharing systems generally require supplemental revenue sources to cover operating and investment costs. Revenue streams used in major cycle sharing systems around the world include annual and temporary membership fees, advertising, sponsorships, and on-street parking fee proceeds.

Cycle sharing systems are not a replacement for large scale cycle distribution schemes. These programs, generally aimed at rural users, have a strong focus poverty alleviation orientation. Cycle sharing is an urban transport system designed to appeal to a broad user base.

Figure 4: "HOURBIKE" systems in UK

Bike share programs can provide safe and convenient access to bicycles for short trips, such as running errands during lunch, and transit-work trips. The International community has experimented with bike share programs for nearly 40 years. Until recently, bike share programs worldwide have experienced low to moderate success; in the last 5 years, innovations in technology have given rise to a new (third) generation of technology-driven bike share programs These new bike share programs can dramatically increase the visibility of cycling and lower barriers to use by requiring only that the user have a desire to bike and a credit card or phone.

3) Literature review

- "There is no connection between the drop off point and destination: last mile problems", by shaheen et al in 2010,' a randomized study evaluating the university of oregon bike loan program'
- "2nd generation bike sharing program: with special design for intensive use and assigned location for hiring with a coin deposit", DeMaio, 2009, Bike sharing development in Europe.
- "bike sharing system: solving the static rebalancing problem", daniel chemla, frédéric meunier, and roberto wolfler calvo, hal-00726617, version 1 - 30 aug 2012.
- "There have been three generations of bike-sharing systems over the past 45 years: Family Tree of Bicycle Programs" , Bike-sharing: Its History, Models of Provision, and Future , by Paul DeMaio, Velo-city 2009 Conference .
- "There are two types of mayors in the world: those who have bike-sharing and those who want bikesharing.", by Paul DeMaio MetroBike, LLC,Journal of Public Transportation, Vol. 12, No. 4, 2009.

4) Goals of proposed bicycle sharing system

Before initiating the planning process, it is important to have clarity about the overall goals of the system, as these will serve as the basis for future evaluation of the system's success.

The following goals are common to many cycle sharing systems around the world.

Cycle sharing goals

- Extend the reach of the city's public transport system by solving the "last mile" problem
- Reduce congestion and improve air quality by attracting private vehicle users
- Reduce overcrowding on public transport systems by providing an alternative mode for short trips
- Improve public health
- Increase the mode share of cycling

The system goals should be paired with quantitative indicators that can be used to monitor the success of the project.

Cycle sharing indicators

- Total registered users
- Trips per cycle per day
- Fraction of customers who previously used private motor vehicles
- Fraction of customers who previously used public transport

5) Integration with public trasportation

As a cycle sharing system is one part of the city's larger transport system, integration with existing public transport modes is essential. Components of integration include:

- Cycle sharing stations located at major public transport terminals and stations to facilitate convenient transfers
- Uniform electronic identification and payment systems for public transport and cycle sharing
- Sharing of data networks and other infrastructure operating the cycle sharing system through an existing public transport SPV can facilitate many of these integration activities. If the city chooses to create a new entity to manage cycle sharing, this agency will need to pursue partnerships with the major public transport providers in the city to ensure that the systems work together.

The system requires active and ongoing support from the municipal and state governments. The division of responsibilities is indicated in the diagram Figure (5) below.

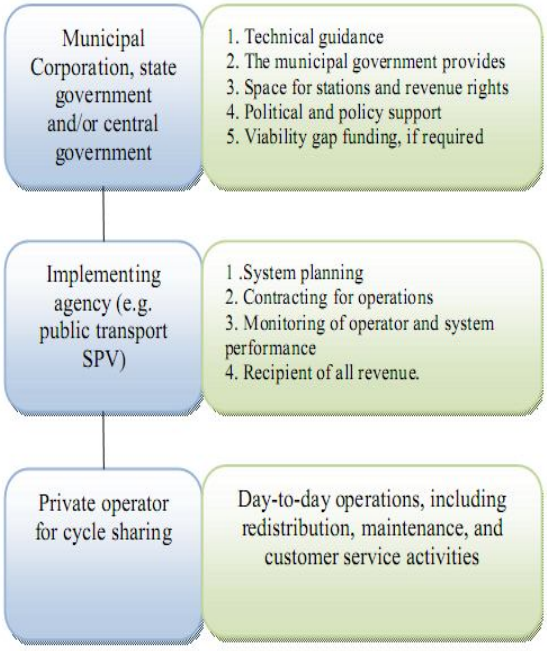

Figure 5: Bicycle sharing Integration with public transportation

IV. PROPOSED BICYCLE SHARING SYSTEM

This section describes the structure and functions of the new proposed bicycle sharing system which provides Intelligent Transportation Systems (ITS) for short distance travel. Bike share programs, such as systems in Paris and Lyon, France, help increase cycling mode share, serve as a missing link in the public transit system, reduce a city's travel-related carbon footprint and provide additional 'green' jobs related to system management and maintenance. In the US, many cities are looking into bike share programs, though they have not yet been widely implemented. These systems are not foolproof; poor design, under utilization and a lack of maintenance are among the potential pitfalls faced when building and implementing a bike share system.

Existing and proposed bike share programs employ a wide variety of technologies, and "lessons learned" are being continually applied to new systems. For a bike program to be successful it is important that the correct technology and package of services involved be mated to the unique challenges that each program faces. For this reason it is strongly recommended that each agency considering implementation of a bike share program have an independent assessment of community needs, economics, technologies, logistical issues, service area, and other challenges faced by a final system.

6) Parking and Locking machanisms

1. bicycle lock to either a rack or kiosk where users collect and drop bikes using a credit card or other card with a magnetic strip. This is commonly referred to as a smart card system. Smart card systems are found throughout the world. These systems are generally simple to operate, making them accessible to the general public.
2. bicycle are secured using an electronic lock mounted on the bike. Users must phone the operating company to receive the code to the lock. This is commonly referred to as a dial-a-bike, or call-a-bike system. These systems are found predominately in Germany. Call-a-bike check-out requires very little infrastructure as the necessary mechanisms are mounted on the bike itself. Stations using smart card systems generally require:

- A bar, post or other physical structure to lock bicycles between uses
- A computerized system to check bicycles in and out
- A power source to control check-in/check-out and track bicycles.

7) Station design, usr interfcae and check-in/check-out protocols

All bike share programs require a user interface to collect and retrieve bicycles, through a check-in/check-out system. The interface should be simple

and easy to understand. Stations should provide clear directions on how to access and return a bicycle. Other recommended elements and design guidelines include:

- Instructions on where and how to return bicycles
- Cost and pricing information
- Contact information to report damaged bikes or stations
- Maps of nearby stations and recommended bicycle routes
- Damage resistant locking mechanisms
- Quick access to avoid queues and maximize safety

Both system styles may require the user to register prior to bike check-out. Any registration process and related technology should be well thought-out and intuitive. The best systems will offer multiple options to register and pay for bike check out (e.g., smart card or credit card.)Smart card systems allow quicker, more convenient bicycle access as users are not required to make a phone call in order to check bikes in or out. Programs using a smart card system generally do not provide users with a lock.

Call-a-bike systems require the user to know and plan for the need to place a phone call in order to unlock the bike, but allow increased flexibility in terms of return locations and provide the ability to temporarily secure the bike during the rental period.

8) Station with Docking points

This type of station consists of a series of docking points and a user terminal. Cycles are checked out by tapping a smart card on the docking point or by using a smart card or credit card at the terminal. While it might be prudent to have personnel on hand during and immediately after the launch, the station should be fully capable of operating without attendants.

- The number of docks determines the station's size, which means there is a great deal of flexibility in adjusting the station size and layout to fit the available space.

9) Cycle Parking areas

These are ideal for larger stations (i.e. over 50 cycles) where there is room in the urban landscape for a secure area for storing the cycles. Cycles are checked in and out through a metro-style turnstile utilizing smart cards. Cycle parking racks can hold more cycles per unit area than stations with individual docking points. The disadvantage is that the parking area needs to be secured by a fence or a wall, which can be visually intrusive. In addition, the station must be attended at all times.

The check-out process itself is automated but the attendants ensure that no one lifts a cycle over the turnstiles.

10) Station placement in urban areas

Choosing good station locations is an urban design art form. Stations should be visible to passers-by but at the same time should make use of underutilized and vacant spaces to minimize interference with other activities and the overall urban landscape. Some options for station location are:

- On-street parking spaces
- Vacant space in roadside landscaping strips
- Areas beneath flyovers and foot over bridges
- Adjacent to bus stops
- Area around metro, BRT, and suburban railway station entrances and exits
- Private property near large commercial and housing developments

11) Operational system for user interface: Microcontroller system

A successful cycle sharing system is designed to provide a positive user experience in order to build long-term customer loyalty and maximize the value of the city's investment in the system. A positive user experience encompasses everything from the registration, the location, usability and appearance of the stations, through to the riding of the cycle (Alta 2011). To accomplish this user must be put first in the operational design of the system. Planners and the operator constantly need to ask themselves, "What would the user prefer?"

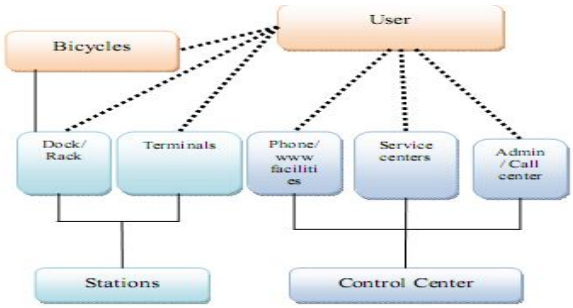

Figure 6: Communication systems and User interface

12) Generations of bicycle sharing schemes

V. PROPOSED BICYCLE SHARING SYSTEM MODEL

Many of the community-run bicycle programs paint each bicycle yellow, white, or another solid color. This is usually done for two primary reasons. First, as a fleet of colored bicycles begin to appear around the city, it helps to get the word out about the program. Secondly, many programs paint over the brand name and other distinguishing features of the bicycle, some

the pedals, shifters, and wheels. This is helpful in deterring theft since the painted bicycle has little resale value. Large scale bike sharing programs, however, have designed their own bike with singular designs of frame and other parts to prevent

disassembly and resale of stolen parts. Another advantage of bike sharing systems is that the smart cards allow the bikes can be returned at any station in the system, which facilitates one way rides to work, education or shopping centers. Thus, one bike may take 10-15 rides a day with different users and can be ridden up to 10,000 km (6000 miles) a year (this figure from the city of Lyon, France). The distance between stations is 300-400 m (1000-1300 feet) in inner city areas. It was found that to have a major impact such as in Paris and Copenhagen— there has to be a high density of available bikes. Copenhagen has 2500 bikes which cannot be used outside the 9 km² zone of the city centre (a fine of DKr 1000 applies to any user taking bikes across the canal bridges around the periphery. Since Paris' Velib program operates with an increasing fee past the free first half hour, users have a strong disincentive of taking the bicycles out of the city centre.

13) Implementing bicycle sharing systems.

For cities which are considering the introduction of bike-sharing schemes, some key conditions for implementation are:

A strong commitment for sustainable urban mobility and the promotion of cycling;

A minimum structure of infrastructure (bike lanes and bike paths) for safe and convenient cycling;

- Sufficient recourses to achieve a real impact.
- Sufficient space for racks/parking to guarantee access to bicycles.

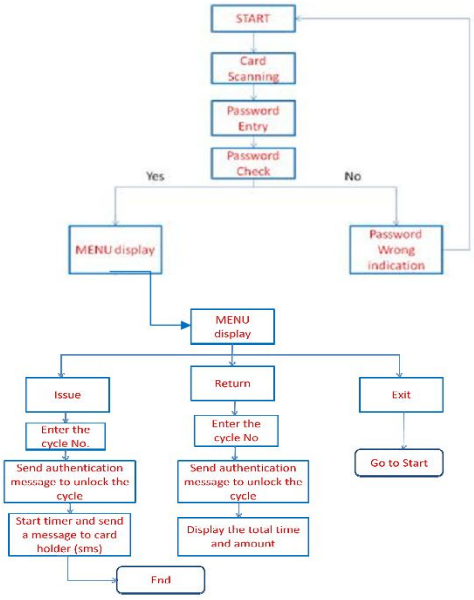

Figure 7: working model of bicycle station

Bike-sharing, or public bicycle programs, have received increasing attention in recent years with initiatives to increase cycle usage, improve the first mile/last mile connection to other modes of transit, and lessen the environmental impacts of our transport activities. Originally a concept from the revolutionary 1960s, bike-sharing's growth had been slow until the development of better methods of tracking bikes with improved technology. This development gave birth to the rapid expansion of bike-sharing programs throughout India and now most other continents during this decade.

VI. CONCLUSION AND FUTURE WORK

Bicycle Sharing combines the simplicity and efficiency of the bicycle itself with new internet-based rental systems and smart facilities. It gives people an alternative for using a car for all trips, as it adds an extra option to public transport. A share bicycle is a kind of virtual bicycle, people can get a bike wherever they want within one minute. The concept of bicycle sharing is booming. Successful bike-sharing programs increase bicycle use and decrease use of cars, petrol bikes and pollution. It is a low-cost manner of transportation, and provides people a way of exercise and stay healthy.

The future of bike-sharing is clear - there will be a lot more of it. Gilles Vesco, Vice President of Greater Lyon, France, quotes his mayor when saying, "There are two types of mayors in the world: those who have bike-sharing and those who want bike-sharing." This certainly seems to be the case as each bike-sharing program creates more interest in this form of transit - call it a *virtuous cycle.*

REFERENCES

[1] "Bike sharing a new public transportation mode: state of the practice & prospects" by Shang Wang; Jiangman Zhang; Liang Liu; Zheng-yu Duan. -IEEE conference publication in the year 2010.

[2] "Station segmentation of Hangzhou public free bi cycle based on improved randomized algorithm" by Hao wu, Xujian Fang,Haitao Xu -IEEE conference publication in the year 2011.

[3] White paper –Bike programs-altera planning & Design(2011).

[4] The bike sharing phenomenon –the history of bike sharing elements-paul DeMaio carbusters Magazine[1], #36,nov 2010.

[5] Jamerson, F.E and E. Benjamin ,Eletric bikes world Reports-100,000,000 light electric Vehicles in 2011.

[6] Online resources-www.wikkipedia.org,www.b-cycle.com,

[7] Shirky, Clay Here Comes Everybody: The Power of Organizing Without Organizations(2008.) Penguin. pg 282-283

[8] Free City Bike Schemes, Søren B. Jensen, City of Copenhagen, Conference Proceedings, Amsterdam 2000

[9] "The Bike-sharing Phenomenon - The History of Bike-sharing", Paul DeMaio Carbusters Magazine[1] #36, November 2008.

[10] Andersen, L., P. Schnohr, M. Schroll, and H.O. Hein. 2000. All-cause mortality associated with physical activity during leisure time, work, sports, and cycling to work. Archives of Internal Medicine. 160:1621-1628. http://archinte.ama-ssn.org/cgi/content/full/160/11/1621/.

[11] Ministry of urban development, government of India, Dec 2012, www.urbanindia.nic.in

[12] DePhillis, Lydia, "R.I.P., Smartbike, Good Riddance." *Washington*, http://www.washingtoncitypaper.com/blogs/housingcomplex/2010/09/16/r-i-p-smartbike-good-riddance/>, (16 Sep 10).

[13] DeMaio, Paul (2009). "Bike-Sharing: Its History, Models of Provision, and Future." *Carbusters*.

BIOGRAPHIES

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