Beyond First/Last Mile Active Transportation – BikeShare@UH

Julio Alonso, Jesus Vargas, Daniel Li[1], Abraham Elizarraras, Tony Hoang, Khanh Vu, J. Patterson, Mohammad Palwala, Marco Maldonado, Masaki Isago, Mark Aranda, Lan Trinh, Tu Huynh, Tie Nguyen, Bao Ly, Jiao Huang[2], Heidar Malki, Xiaojing Yuan
Succeed in Engineering Technology Scholars (SETS)
University of Houston, Houston, TX 77204, USA
xyuan@uh.edu

1. TAMS program, University of North Texas, Denton, TX 76203
2. University of Texas – Dallas, Richardson, TX 75080

xyuan@uh.edu

Abstract

Bike sharing is a new green transportation solution that has been developed and adopted at various cities around the world. In this paper, we present the process and results of the design and prototypes that a group of undergraduate students developed for a BikeShare@UH program during Summer 2017. After presenting the detailed results of four project teams focusing on customer discovery, bike share station (BSS) location identification, cloud-based mobile computing platform for user engagement and bike share program operation and management, smart lock, and alternative energy source based on PV panel. With the phase one implementation at the University planned in Spring 2018, we anticipate gathering real time data and feedback to improve the system.

1. Introduction

As one of the largest city in the USA with a spawning metropolitan area, the Greater Houston Area covers a region of more than 1,285 square miles. Its population is projected to grow from 7 million in 2015 to 10 million in 2040 [1]. In particular, the transit mobility score of the Houston-Galveston metropolitan area is very low (2.9 out of 10) based on a recent report released by the Center for Neighborhood Technology [2], indicating that more than 70% of the residents in the area have poor access to the public transit [2, 3]. It is no surprise that creating an active transportation plan that extend effort beyond first/last-mile strategy to improve access to transit of such diverse population and sustain its growth has been gaining importance in the public policy discussion led by the Greater Houston Partnership (GHP).

Bicycling itself has been an ideal mechanism for short distance point to point travel of general public since late 19th century. Bike sharing, as a green transportation solution [4-11], has been considered an integral part of active transportation planning of many regions. It has witnessed increased interest and traction around the world [12-17] including within the United States in the last decade because of a wide variety of dynamically changing factors, from technology advances, to creating safer and more sustainable transportation venues for upward mobility opportunities and healthier lifestyle of the people.

In Texas and the Greater Houston Area, with sparsely distributed population and transit centers (such as metro distribution centers and bus/light rail stops), bike sharing is a promising solution that goes beyond the first/last mile transportation to ensure all its residence have access to transit stops. For example, Bcycle, as a new branch of Trek Bicycle Cooperation [17], has been leading the national effort on bicycle sharing by partnering with cities and transit systems. Its operation has been expanded to 37 cities around the United States in 2017, including five cities in Texas: Houston [18-20], Austin, Fort Worth, San Antonio, and McAllen.

As part of the first/last mile transportation effort, the BikeShare@UH project focuses on creating and testing innovative and integrated system that will improve mobility in general and access to public transmit on a unique urban campus in particular. In this paper, we present the results of the project from the customer discovery to the need analysis, bike share station location identification, to the innovative hardware and software systems for the bike station and bicycle themselves.

After reviewing existing bike share projects around the world, we presented the rationale of students choosing this as their design project as well as the golden circle approach they adopted to guide the design of the whole project. In the following sections, we detailed the results of the five integral components of the BikeShare@UH system: customer discovery, bike share station location identification, smart lock for smart cycling, and cloud based mobile computing platform, before reaching the conclusion and presenting our future direction.

2. Bike Share Research and BikeShare@UH Project Design

Even with some initial success, wide spread of Bicycle Sharing encounter several obstacles. Some programs failed to scale up, others failed after government pulled out subsidies, still others cannot sustain the program because too many bicycles got lost or damaged. Besides challenges in business and operation model, municipality policies, the most critical technical challenges include the asymmetry of demand and supply at different time throughout the day and geographical locations, security of the bike. Researches are trying to identify mobility patterns of bike sharing patrons in order to solve such challenges and come up with more effective and affordable solution [5-11].

The urgency of transforming and providing safer and more pleasant point-to-point short distance navigation mechanism on UH campus has increased dramatically in recent years due to two main factors. First of all, the ever growing enrollment due to the continuous success of the University. For example, in Fall 2017, a new record of 45,000 student enrolled at UH, with about 9,000 students live on campus and many more live within bicycling distance around it. Secondly, the program expansion and building construction in support of academic, research, student service all resulted in a shortage of campus parking, especially those near the destination buildings (classroom building, library, gym, etc.). Other aggregating factors include limited shuttle service and transit stops; as well as campus expansion to adjacent energy research park. The inconvenience has been felt and experienced by all students, staff, and faculty every day.

Instead of creating the whole system based on the newest and best technology available, the BikeShare@UH team approached the design using the Golden Circle model (Figure 1) [22] and started with "Why." The answer of the "why" question is then used to guide the "How" and "What." The model allows the team to see the big picture from the beginning and gain a deeper understanding of the expected outcome (i.e., purpose) of the effort, before starting the design process and prioritize "how" we want to achieve the expected outcome, and "what" we need to do.

UH students have been wishing for a safe and pleasant bicycling as a transportation option on campus for some time. Their desire has gained attention from more and more stakeholders on UH campus, from faculty and staff, to UH administration, Parking and Transportation division, and office of Sustainability. After collecting feedback from these stakeholders regarding establishing a bicycle sharing program on campus, the BikeShare@UH team agreed that

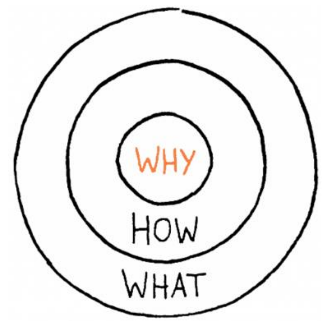


Figure 1 The Golden Circle Model

the project aims to create a transformative transportation solution that addresses the needs of students, faculty, and staff to navigate on campus in a safe and pleasant manner; reduce the uncertainty level and stress managing time traveling from parking spot to their classroom or office; build a healthy lifestyle, and maintain a sustainable campus. They will achieve this ambitious goal by working in an inter-disciplinary friendly environment and creating system level technical solutions to ensure the user satisfaction and efficient operation and management – 'how.'

After establishing collaboration with Houston Bcycle [18-20] and the Office of Sustainability [21], the BikeShare@UH project team established following five tasks ('what') for the first phase feasibility study (Summer 2017) based on their technical competency and career aspiration:

1) Conduct customer discovery by collecting data and analyze the need from students -- to reveal effective incentive mechanisms that encourage bicycling on campus;

2) Explore and determine the process and factors for location identification of bike share stations (BSSs) and provide a set of BSS location recommendations;

3) Create cloud-based mobile computing platform for BikeShare@UH, including mobile app to engage bicycle users and assist them managing their route and account, as well as a unified interface for bike share operation and management;

4) Design smart lock that provide hardware level security and safety; and

5) Create alternative energy solution with power regulation to sustain various system operation without connecting to power grid.

Five sub-teams were formed for each task, as shown in Figure 2. Every student can choose to contribute to at least two sub-tasks based on their technical strength and career aspiration. This practice gives them opportunity to practice working effectively on a multi-disciplinary team and also ensures close collaboration among every team. All teams give weekly progress update before each student provides feedback. In the following section, the results of each team are presented in more detail.

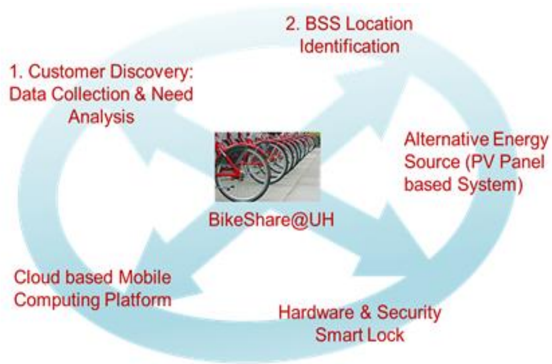


Figure 2 Five Sub-Tasks of BikeShare@UH Project

3. BikeShare@UH Project

3.1 Custom Discovery: Data Collection and Need Analysis

The campus of the University of Houston with its more than 45,000 students has its unique transportation need than many similar sized cities in America. For example, the reason students want to have the bicycle sharing as one transportation option is quite different from those of residents in a city. Like many cities Bcycle has operation in, majority of the subscription and cash members of Houston Bcycle use the bicycle to take sightseeing tours around Houston Downtown area, where more than 46 BSS has been installed. Such trip typically involves more than one bicycle and takes more than 30 minutes. On UH campus, on the other hand, students typical use the bicycles to get to the classroom of their next class, with the travel time less than 10~15 minutes and the class lasts from one to three hours. Such difference renders current business model used by Bcycle – with cash check out starting from 30 minutes per $3 – unattractive for college students. Instead, it makes better sense if the students with semester membership have the privilege to check out the bicycle for certain times per day if they can return it within 10~15 minutes of check out each time. Any additional checkouts or longer duration in between will result in additional fee.

To create a bike share program tailored to students' need, the team decided to conduct customer discovery using online survey to clarify transportation needs (including bicycling) of students, faculty, and staff on UH campus, affordable business model, and attractive incentives. The team decided to first collect the preference and feedback from the major customer group – students – in five categories:

1) Basic demographic information including demographic, class standing, and commuter vs. residence;

2) Students' interest and desire to use bicycle as a transportation option on campus, including current usage and frequency, and changes needed to make the bicycling a more likely option for them to use bicycle more;

3) Top set of BSS location preferences: in addition to general purpose classroom buildings, library, stadium, gym, and residential hall are all possible locations for BSS;

4) Payment preference: what are the students preferred payment mechanism (subscription or no subscription), payment structure (base subscription fee, with increment charge based on time and/or distance), and payment method (credit card, cash, or mobile app); and

5) Incentive preference: reservation privilege for subscription members – advance reservation, and/or reserve for additional bike for friends.

Most of the preference questions allow write in given the provided choices are not comprehensive.

A set of survey questions have been finalized after three iterations during Summer 2017 of refining questions and testing them on small sets of samples. In addition, though various online survey platforms provide similar service with subtle difference, the BikeShare@UH project team choose to use Google Form as the survey platform for testing purpose because: 1) it is free; 2) it is familiar; 3) it uses simple visualization that facilitate the need analysis while providing both raw data and report.

The summary of survey response analysis during our survey testing phase is presented here.

After finalized the survey questions, all BikeShare@UH project team members used social media to reach out to UH students, including various Facebook page of sophomore, junior, and seniors. They also shared the link to survey questions via several student organizations. During Aug. 1 ~ 10, a total of 128 responses was received from UH students across class level.

Among the responses, the basic information about students who took the survey are: More than 98% are students with more responses from junior than sophomore or seniors, with more than 60% choose "She/Her/Hers" as their preferred pronoun. More than 78% commute to school via car, including those using car pool, while about 13% use public transportation including light rail and buses. There is no student live on campus during summer.

Responses to survey questions asking about their interest and desire to utilize bicycle for traveling on campus and their desire to use bicycle share program include: More than 93% of responses believe that bicycle sharing program will improve UH transportation experience on UH campus, while the remaining don't see much difference. Among the responses, more than 12.5% use bicycle more than once per day, more than 45% use bicycle more than once per week, while more than 27% use bicycle once per week. Only about 10% of responses indicate they rarely and/or never use bicycle.

Responses to the survey questions regarding changes needed to improve the bicycling experience around UH campus converges to three main themes: 1) Easy access to bicycles (> 85%); 2) More bicycle lanes (> 64%); and 3) More safety mechanism along bicycle lanes (such as call box, proper lighting, etc.) (> 53%).

Responses to the survey questions regarding payment preferences include: Students are comfortable using credit/debit cards, cash, and mobile app as payment methods. In addition, they prefer subscription method, though more prefer semester subscription (>58%) than monthly subscription (>45%). At the same time, many of them (~29%) want to have cash renting option so that they can try out the program before commit to long-term subscription. Some write-in comments also ask for annual subscription option. Majority of the response (>90%) want to have reservation incentives for semester subscription membership either as making reservation 5 or 10 minutes in advance or reserve additional bicycles for friends to try.

More than 63% of responses indicate their awareness of all economy parking will be moved to adjacent Energy Research Park (ERP), a new mechanism UH transportation and parking division plan to implement starting in Spring 2018 to reduce anxiety and stress of the parking shortage on UH campus. This may also increase the need to provide additional transportation methods from ERP to UH campus besides regular shuttle services.

On the other hand, more than 86% of responses do not aware the Tiger Trail – a new bike trail connecting ERP and UH campus. Such a trail has the potential to make the bicycling experience from ERP to UH campus safer and more pleasant. The project team believes that as more students become aware of the trail, the interest to use ERP parking lot and use bicycle to travel to UH campus will increase, thus reduce the pressure, stress, and time wasted trying to find a parking spot on campus during weekdays.

The responses to the survey question regarding the bicycle station location will be detailed in next section.

In summary, students welcome a bike share program on campus and are excited to try the bicycling as an option to navigate the campus. However, hardware and software of the existing bike share programs were not designed for university campus. Thus the essential functions and options, as reflected in survey responses described above, need to be designed and implemented at both hardware and software level to meet the anticipated quality of service.

3.2 Factors and Process of BSS Station Location Identification

An important component of need analysis is the location identification for the BSS Stations. As an ever growing urban research university, University of Houston is larger than an average city in U.S.A.: from perspectives of both spatial (with approximately 12 MSF (million square feet) mixed occupancy buildings) and population (more than 45,000 enrolled students, with about 9,000 of them live on campus, and more than 11,000 faculty and staff). The BikeShare@UH project directly feed into its transportation transformation process and studying the feasibility as well as providing the recommended implementation tactic of bike sharing program on campus.

There are many factors that need to be taken into consideration when choosing the location to install the BSSs. Standard factors used by our industry partner Houston BCycle include: 1) close proximity to high density residential and/or office space; 2) access to safe and comfort bike facilities (safe bike lane and bike station, green canopy, etc.); 3) proximity to other bike stations; 4) access to public transit; 5) high visibility; 6) access to power source; and 7) easy access for service vehicle.

We are taking into consideration of all these factors and interpret them in the context of UH campus and academic functions. For example, the population density on UH campus during its academic year is much higher than that of many city downtowns during weekend. We also incorporate students' feedback and preference collected from the survey, as well as feedback from both Houston BCycle and UH Office of Sustainability from operation and management perspective. For example, Houston BCycle expressed their desire to have alternative energy solution in support of BSS's operation so that their BSS does not need to be limited by the easy access to power source (i.e., existing grid infrastructure). UH Office of Sustainability shared with the project team the requirement of constructing concrete slab to host BSS and associated cost. Based on all these, we decided to use the following five criteria to identify locations for potential BSS: 1) close to student parking; 2) high student traffic throughout the week day (Monday ~ Friday); 3) students preference (from survey); 4) existing or planned concrete slab; and 5) consistent sunlight throughout the day/year for PV based alternative energy source.

Figure 3 shows the bike station location identification process and results. The yellow star outlined with black indicates the seven locations spatially distributed on UH campus that we selected at the beginning. After collecting feedback, analyzing survey results, and scouting each location several times through the day and the week, the final set of five BSS location recommendation are marked by red triangle outlined with black. The two green diamonds are stations already planned to implement. The blue circle with black outline is the one location desired

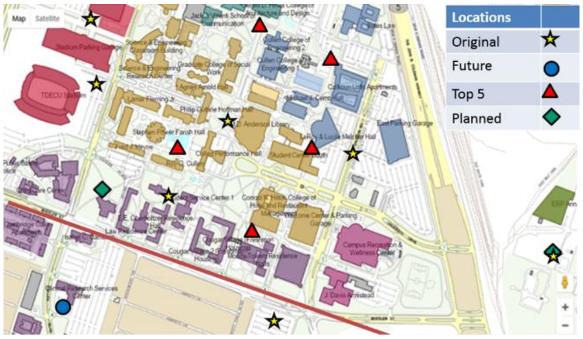


Figure 3 Bike station location identification process and results

from students' survey feedback and recommended for the implementation phase.

Figure 4 shows pictures taken while the team scouting the locations.

Figure 4 Bike station location scouted. Left from Top Left Clockwise: Cougar Village; College of Architecture; ERP (Energy Research Park), and Student Center. Right: newly constructed Tiger trail connecting ERP and main campus for walking and bicycling.

3.3 Cloud based Mobile Computing Platform

To achieve the goal of campus transportation transformation, it is paramount to engage more students in using the bike sharing program as their preferred transportation mode (besides walking) for traveling on campus. Given that this generation of students grew up with all the convenience brought by cloud based mobile computing, it is no surprise mobile phone App becomes the dominant tool they use to interact with the world throughout the day, including keeping in touch with friends and news, taking notes and pictures, and paying bills using digital wallet.

The BikeShare@UH project team decided to create cloud based mobile computing platform for the bike share program on campus. At the front end will be a Mobile App students use to interact with the bike share program: sign up, subscribe, reserve and checkout bikes, and managing their account including their payment and trip trajectory and duration. At the back end is the cloud infrastructure including DBMS (database management system), HTML and CSS (Cascading Style Sheets) script, and PHP (Hypertext Preprocessor) script that supports 1) the operation and management of the bike share program; 2) interfacing with Mobile App and allow the bicycle riders to manage their account; and 3) interfacing with the smart lock embedded system installed on each bicycle as well as PV solar panel energy system.

The team implemented the front end mobile app for Android devices, which can be easily expanded later to other mobile platforms such as iPhone and iPad, Windows phone and tablets. Working closely with both hardware groups: smart lock and PV solar panel, and taking into consideration of students preference from survey responses, as well as feedback from industry partners, the Mobile App team identified following essential functions for the prototype of BikeShare@UH (as shown in Figure 5): 1) sign up and log in; 2) locate and check out bicycle; 3) provide recommended route towards bicycle station (via GPS and Google Map); 4) review trip history (including distance, duration, and even calories count); and 5) using QR code or retrieve pin to unlock bicycle.

Figure 5 shows the logic flow chart of front end Mobile App. First time user will be prompted to sign up and create user name and password. They will also be presented with basic information about the bike sharing program as well as step-by-step guidance on how to use the service. Returning user will sign in and use the Mobile App directly by interacting with Google Map overlaid with nearby BSSs. They have the option to check out one bicycle at a time by scanning QR code or retrieving pin to physically unlock a bicycle.

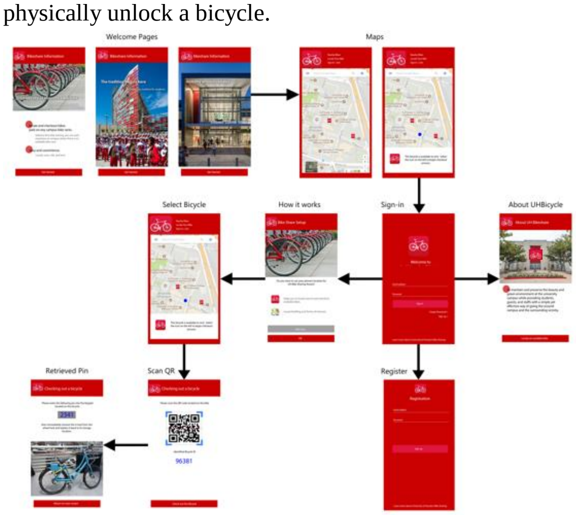


Figure 5 Logic Flow Chart for Front End Mobile Application

To support the operation of such a bike sharing program, MySQL database is used to support storage and retrieval from tables and designed views of users' information, including passwords, trip history, distance, bicycle check in and check out station, and associated cost. These data are periodically pushed from the embedded 'smart lock' system installed on each bicycle and the front end Mobile App asynchronously whenever networking is available. The team decided to collect data from both modalities to separate user account from the account of individual bicycle – each have different behavior pattern – to improve security, protect privacy, and prevent fraud. The database will periodically (e.g., once an hour) pull data from each bicycle in a round-robin fashion to facilitate managing and servicing bicycle. The passwords and other

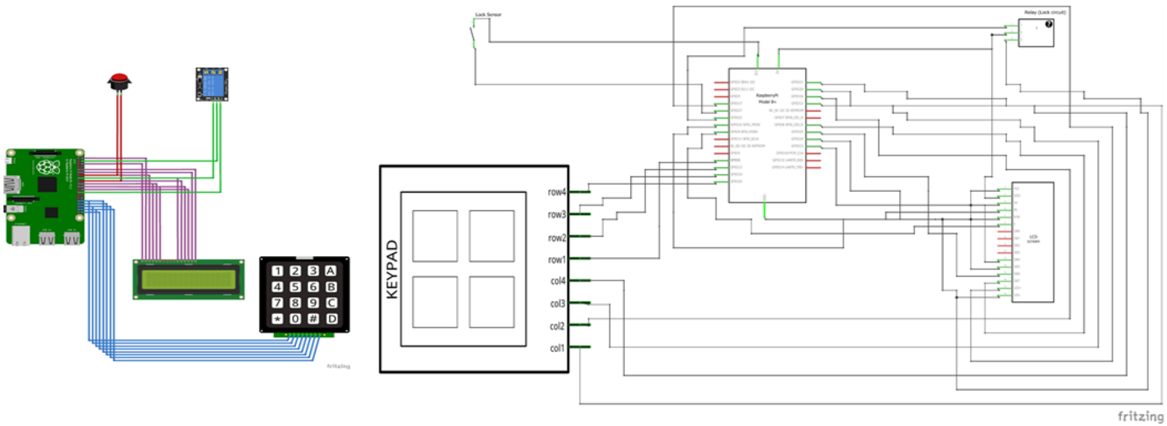


Figure 6 Smart Lock Prototype and Schematics using Raspberry PI B+

sensitive data designated by users are hashed to provide additional layer of security and privacy.

Unified web based interface is designed and implemented using CSS script to support the operation, management, and reporting of the bike share program. Similarly, PHP scripts are used to interact with embedded 'smart lock' to automatically deposit and retrieve user and trip data into and from the database, and display them on webpage and user's mobile device.

3.4 Embedded "Smart Lock" on Each Bicycle

One of the major challenges using bicycle for transportation purpose is the safety of the bicycle itself. In our BikeShare@UH project, we researched about some of the best locks people riding bicycles are using and studied the feasibility of creating an embedded 'smart lock' based on it. The goal of this subtask is to create a 'smart lock' that integrates a secure locking mechanism with physical interface and data collection and user interaction capabilities. The team identified the following objectives of a 'smart lock' to provide physical security as well as openness and flexibility to use it:

1) **Modularity**: Design a 'smart lock' system that can be completely independent of docking station (BSS) and can be accessed from anywhere.

2) **Accessibility**: The 'smart lock' system support easy accessibility of each bicycle by providing two ways to reserve and unlock a bicycle: find and reserve the bicycle from a web browser or mobile device or from the keyboard interface of the 'smart lock' directly.

3) **Flexibility**: Support the flexibility of each bicycle park at a BSS or any existing bicycle rack on campus.

The team built two prototypes using different micro-controller, Arduino Mega 2560 and Raspberry PI B+. Both prototypes work, simple to use and lightweight. Figure 6 shows the Raspberry PI based 'smart lock' prototype with its schematic. The PHP and Python scripts on Raspberry PI support the display on 16x2 LCD and PIN input on 4x4 keypad When the correct PIN is entered, the locking mechanism will be triggered to either 'lock' or 'unlock' it. All functions on both prototypes can be supported with battery and/or a small solar panel, while the Arduino Mega version consumes significantly less power.

With such a compact and lightweight form, the 'smart lock' can be easily mounted on a bicycle. Its user interaction functionality can also be easily expanded given the computational power of Raspberry PI platform. Figure 7 shows the CAD rendering of 'smart lock' case and how it can be placed on the backseat of a bicycle. Similar design can be made to mount the lock on the front wheel.

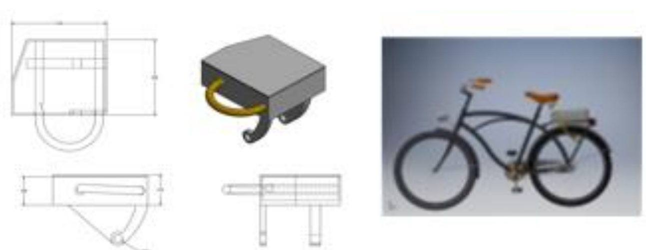


Figure 7 CAD rendering of 'smart lock' case and its mounting on the backseat of a bicycle

3.5 Alternative Energy Source for BSS: PV based solar system

Given the location of the University with respect to downtown Houston, the orientation of most buildings and roads on campus, and the weather pattern throughout the academic year, the team decided to develop photovoltaic (PV) based alternative energy source to give each bike share station (BSS) the choice and flexibility to operate completely off the grid.

The goal of the team designing alternative energy solution for BSS is to research and identify the most efficient photovoltaic (PV) based solar panel system to use and to develop the monitoring and control system for solar tracking. Figure 8 shows the solar irradiation profile on UH

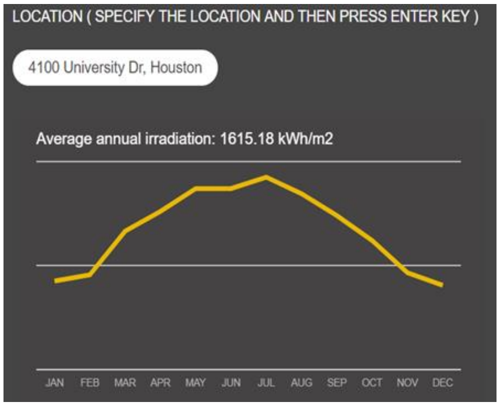


Figure 8 Solar Irradiation Profile on Campus

campus [20]. Solar irradiation rate is a measurement of solar power and is defined as the power per unit area received from the sun in the form of electromagnetic radiation, with the unit as W/m^2. The average annual irradiation on campus is 1615.18 kWh/m^2, while the value varies throughout the year and reaching the peak during summer month, as shown in Figure 8.

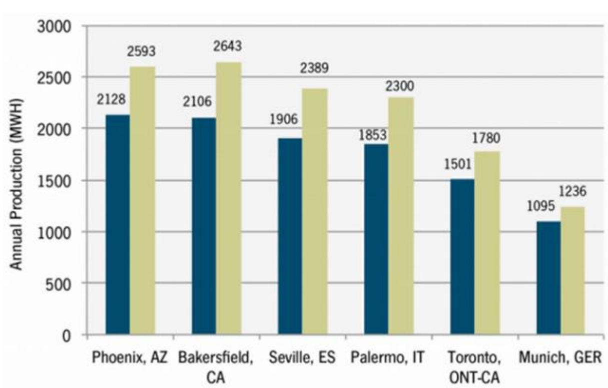
After comparing various PV solar panel types [23-26], ranging from traditional rigid panel and curved rigid panel, flexible panel, to solar tracking system (single vs. dual axis tracking system), we decided to use rigid PV panel with solar tracking system. Comparison on rigid PV panel is conducted based on its functionality, efficiency, durability, and cost. Many online PV system designing tools are available and the team researched each of them and found that recommendation from all of them are the same within the error margin. The team decided to design the PV system using the popular size of rigid PV panel – 13 x 26 inch2 – which provides enough power to support the operation and management functions of a BSS supporting up to six bicycles. Multiple such PV panels can be connected serially to support more bicycles parked there.

All research up to date agreed that tracking solar movement will increase the PV output, as shown in Figure 9 (a) [27]. The team decided to implement a solar tracking system to expand the duration of the PV being exposed to sunlight since the BSS typically are installed either in the shadow of a building or green canopy. Figure 9 (b) shows a prototype of single axis solar tracking system implemented using Arduino UNO, two SG90 servo motors, solar power charge regulator, rechargeable lead acid battery (12V, 7A), and four photo-resistors. The prototype is able to turn to the direction to the higher level light intensity. When the light is blocked from certain direction, the tracking system will start to rotate and identify the direction with highest light intensity until it rotates 360^o.

4. Conclusion and Future Direction

This paper presents the effort of researching and creating a green transportation solution on the campus of an urban university. Under the guidance of faculty mentor, the interdisciplinary BikeShare@UH team approach the project design process based on the golden circle model and started with the question "why." The paper detailed the five essential components of the bike share program to make it a safer and more pleasant experience traveling around campus using bicycles: customer discovery, bike share station location identification, cloud-based mobile computing platform for user engagement and bike share program operation and management, embedded smart lock system, and alternative energy source based on PV panel. The BikeShare@UH team was able to establish collaboration among key stakeholders, learn the research cycle and steps, and implement a working prototype of the system all within a ten-week summer research internship during Summer 2017.

The team is actively involved in the conversation on campus during the implementation and testing phase of the bike sharing program since Fall 2017. The campus-wide survey, adopting all bike sharing related questions the team developed, was conducted using the enterprise level surveying tool and oriented towards undergraduate population. Survey questions regarding basic demographic information are not needed since they are available already.



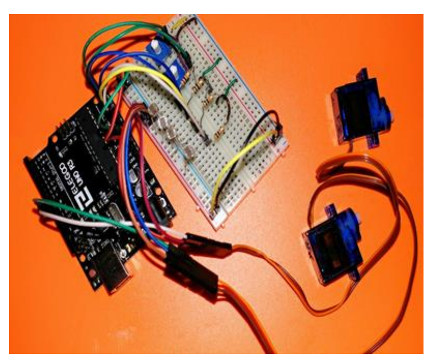


Figure 9 (a) L: Energy Harvest, Fixed vs. One-Axis Tracking [26], (b) R: Two-axis solar tracking prototype

In order to fully implement the bike share program on campus, it is necessary to create middle layer system that provide smooth and transparent interaction between the bike sharing cloud database system with the billing and personnel management system in a secure and safe manner. Some of the team members are researching and developing solution to address the asymmetric demand and supply challenge in bicycle sharing program, given the critical need to rebalance bicycles docked at all stations.

Acknowledgement

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