Development of locally designed smart bike-sharing system on Thai campus: Lessons learnt of a pilot-scale study

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Abstract.

Campus-wide bike-sharing program is one of the solutions for achieving sustainability in higher education. It also contributes to the UN's Sustainable Development Goals (SDGs). Smart bike-sharing systems have been implemented in some Thai cities and Thai universities since 2012. The systems were provided by foreign companies and developers. A locally designed smart bike-sharing system have been developed and pilot-scale tested at a Thai university. Many problems were found throughout the test-period, while design changes and application modifications were conducted to address the issues. The changes were done to make the system appropriate for the context of Thai university and users' demands. This paper discusses the development process and lessons learnt from this locally designed system. The results can be used by developers and software designers of bike-sharing industry to provide better design and implementation for Thailand market.

Keywords. bike-sharing program, sustainability, sustainability in higher education.

1. INTRODUCTION

Bike-sharing systems have been around for about 50 years. The White Bikes in Amsterdam, the Netherlands was the first system with the first system implemented in 1965 [1]. The purpose of public bicycle is to ride short distances or first or last mile trips. Also, these programs were developed for people who have to connect to other public transportations, for example, subways and buses. Bike-sharing programs reduce personal car usage and traffic jams in peak hours. Shared bikes, also, allow environmentally friendly transport, which is a part of UN's Sustainable Development Goals (SDGs). part of UN's Sustainable Development Goals (SDGs).

Bike-sharing programs have been implemented in more than 700 cities around the world [2]. It showed that people were interested in low-priced and eco-friendly transportation. Many startup companies were established in the 2000s, for example, Ofo

(China), Mobike (Singapore) and Lime (US). Bike-sharing services and accessibility have been continuously improved to support the lifestyle of the younger generation. A second generation of bike-sharing systems added stations and coin deposits for riders, but there were problems with theft and accessibility. Third generation systems allowed easy log in by smartphone or smart cards. Also, Global Positioning System (GPS) was used for identifying bicycles in an area. Some systems were developed to be 'station-free' systems, where users could ride anywhere in a designated area

In 2012, Thailand had a bike-sharing system in Bangkok, 'PUN PUN', which was implemented by the Bangkok Metropolitan Administration (BMA). This program is deemed one of the first step in sustainable transportation. Meanwhile, Thai universities were influenced by UN's Sustainable Development Goals (SDGs). Several Thai universities provided shared bikes on campus including Asian Institute of Technology (AIT), Chulalongkorn University (CU), Khon Kaen University (KKU), King Mongkut's Institute of Technology Ladkrabang (KMITL), King Mongkut's University of Technology North Bangkok (KMUTNB), Kasetsart University (KU), Naresuan University (NU), Phranakhon Rajabhat University (PRU), Prince of Songkla University (PSU), Rajamangala University of Technology Thanyaburi (RMUTT), Thammasat University (TU), University of Phayao (UP) and Huachiew Chalermprakiet University (HCU).

Some studies found that bike-sharing systems were mostly used by younger generation [3]. Many universities supported this sustainable transportation mode and provided shared bicycle for students, staff and visitors. Some universities cooperated with private companies to provide such program. For example, KU has signed Memorandum of Understanding (MOU) with Mobike to launch bike-sharing program on campus. Some of them were coordinated with local government to develop program. For example, CU and BMA have developed station-based bike-sharing program together on campus.

In the United States, there are awards granted for bikesharing system on campus so-called "Bicycle Friendly University (BFU) Award". Examples of BFU awards are presented in Table 1 [4].

Table 1 Examples of BFU Awards

University	BFU since	Awards
Colorado State University	2011	Platinum
Stanford University	2011	Platinum
The University of Arkansas	2016	Gold
University of California, Los Angeles	2011	Gold
The Ohio State University	2011	Silver
University of Illinois at Urbana-Champaign	2011	Silver
University of Massachusetts Lowell	2015	Silver
California State University Northridge	2019	Bronze
Kent State University	2016	Bronze
University of Buffalo	2012	Bronze

Based on BFU Awards list, most universities used a campus bike plan for increasing campus rider numbers. In Thailand, bike-sharing system on campus contributed to the SDGs. Many Thai universities started bike-sharing program in the 2000s. Most of them provided bike-sharing systems by signing contracts with private companies. Some of them created systems themselves: one example of self-system development is KMITL Bike.

KMITL Bike, a dockless bike-sharing program, was first launched as a senior project of International College, KMITL. Three software engineering students were interested in a universal locking system for public bicycles, started in 2017: its purpose was to develop locking system for public bicycles. They aimed to develop the system to provide shared bicycles through mobile application on KMITL Bangkok campus. To overcome different kinds of problems throughout the development and service periods, several changes were made. This study summarizes the development of KMITL Bike in each phase along with the lessons learnt and solutions. The findings can be adopted by bicycle manufacturers and software developers to optimize their design for the broader markets using KMITL Bike as a case study.

2. LITERATURE REVIEW

Campus bike-sharing programs were discussed in many aspects. Some universities developed their own systems. For example, Yi and Nie designed an efficient mobile system based on Android system aiming to improve travel for students at institutions of higher education in China. They claimed that most ofthe younger generations used their phone 4.5 hours per day in China, so their system engaged students with information on bike-sharing and entertainment together [5]. Rachman et al. discussed the distribution system of campus bike sharing for increasing bike service availability in Telkom University, Bandung, Indonesia. They offered a new bike-sharing system based on Internet of Thing (IoT). They used Message Queue Telemetry Transport (MQTT) as a communication method between bicycle and bike station. Riders was noticed about available station via LCD screen on a bicycle [6]. Mete et al. analyzed the possible stations of bikesharing on the Gaziantep University campus, Turkey by using mathematical models. Their purposes were to cover demand on campus and also minimize walking distances. It was used as input for university administrators considering the bikesharing stations, but it did not interact with other public transportations and consider the cost of the system [7]. Kellstedt et al. launched and examined the free-floating bikesharing program on campus; most of riders were students who lived on campus. Cost was a main barrier to cycling. Also, publicity needed to be improved [8]. Kaplan developed a bikesharing program at Kent State University, USA. There were 60% of students who can connect to a shared bike. He surveyed the students for demand and studied the possibility of a third generation bike-sharing program, including financial issues. Finally, he provided options of the third generation bike-sharing program at Kent State University. Also, he compared fixed and variable cost based on several private companies [9].

Some researchers focused on a feasibility of a campus bike-sharing program. Ashley studied bike-sharing programs as alternative transportation in Bridgewater State University, Massachusetts, USA. They started with brainstorming with essential members of campus and explored the bike-sharing program. Students, staff and others on campus were surveyed for interest and usage of bike-sharing program. Most participants were interested in this program and half of them stated that they would ride the bicycle more than ten times a year [10]. Barrier to cycling were also examined. Manaugh et al. analyzed factors influencing the use or not of campus bikesharing programs. The bicycle lanes were strongly related to a frequency of cycling. Meanwhile, a lack of safety was the most important barriers to increase cycling [11]. Nahal and Mitra compared cycling throughout the year and cycling only in autumn or spring. They studied the barriers to cycling in winter on campus. Less than 30% of respondents commuted in winter. An appropriate plan for bicycle infrastructure may encourage the current cyclists to ride in winter [12].

Many researchers studied factors influencing campus demand. Chevalier et al. studied bicycle acceptance in five universities in Shanghai. They surveyed, over 1,100 respondents about built environment and bike sharing. Limiting speed on cycling and suitable infrastructure were the major issues on campuses. As awareness of environmental impact increased, bike-sharing usage increased on campus [13]. Olio et al. examined the most important variables and the most efficient policies for promoting sustainable transportation on campus. They suggested that management policies could contribute to change in transportation patterns such as usage of private cars and parking on campus. Travel times by bus and shared bike were acceptable, which means that they were efficient alternatives [14]. Other factors were also studied, for example, socio-demographic factor, travel behavior, weather and temporal variables [15-18]. Research of factors affecting campus usage continued as is still on-going

Many researchers focused on variables and built environment based on systems, which provided by private companies. Some of them studied feasibility to launch bikesharing program on their campuses. A few studies showed that they developed bike-sharing programs by themselves. In Thailand, there were limited researches on the development of campus bike-sharing program. This research focused on development of a locally designed smart bike-sharing system for the KMTIL campus. The pilot scale development is discussed here. A campus scale is discussed in other work [19].

3. DEVELOPMENT OF KMITL BIKE AND LESSONS LEARNT

3.1. KMITL Bike with InfiniLock

KMITL Bike was founded in 2016, as a senior project. Three students of the Software Engineering Program, International College were interested in a locking system for public transportation. Their first reviewed several locking systems implemented in Thailand and other countries, including MU White Bike, CU Bike, MuniBike, weBike, BitLock and Noke [20]. Table 2 compares local and international bike-sharing systems.

Mobile applications were widely used for log in. KMITL Bike used a secure cloud-based lock sharing system called ‘InfiniLock’. Also, the application had nine user activities including Login, Register, Logout, Borrow Bike, Return Bike, Find Bike and View History. Figure 1 shows the use case diagram of the KMITL Bike application.

Table 2 Local and International Bike Sharing Systems

Name	Authentication Tools	BikeLocating	Powering Method
MU White Bike Bangkok	Physical Key and Student ID card	None	None
CU Bike Bangkok	Membership RFID card	None	Rechargeable Battery
MuniBike California	SMS, phone call,mobile application	GPS	Dynamo battery charger
weBike Maryland	SMS with combination lock	None	None
BitLock California	Mobile application	None	Non-rechargeable battery
Noke Utah	Mobile application	Phone's GPS	Rechargeable battery

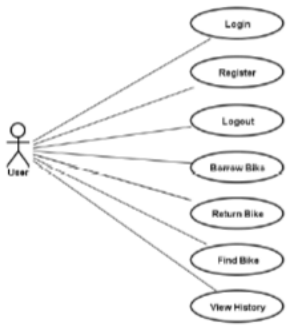


Figure 1 Use case diagram of KMITL Bike application

To lock and unlock the shared bike, they considered that using traditional lock with key or code is not practical. Therefore, automatic wheel lock was developed from scratch. It is equipped with a Bluetooth-based automated locking system. Only authorized users could unlock and ride the bike. Figure 2 shows the first wheel lock design.

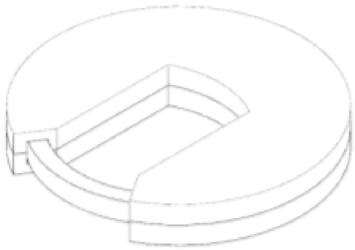


Figure 2 First wheel lock design

The design of wheel lock was reconsidered to adjust some issues. For example, the lock could not detect, if it was locked or not. This was solved by attaching sensor on a bike. Table 3 lists lessons learnt in each of ours three improvements of this design.

Table 3 Design Improvement of Wheel Lock

Design	Description(s)
First design: Cable Locking System	1. The lock could not detect, if it was locked or not 2. It was too fragile to external forces while riding and transporting
Second design: Automated Lock	1. The lock could not detect, if it was locked or not 2. It was too fragile to external forces while riding and transporting
Third design Semi-Automated Lock	1. A new design using teeth-based mechanism was modelled. 2. The battery was used to pull the teeth of the lock package in unlocking process.

Concurrent with the hardware development, they also created an application, ‘KMITL Bike’: its main functions were logging in, borrowing bike, returning bike and finding bike. Figure 3 shows two developments of the KMITL Bike user interface.

Figure 3 First interface of KMITL Bike application

Two types of bicycle were used for initials test, a small bicycle fleet were established. It consists of three city bikes and five commuting bikes. Both kinds of bikes illustrated in Figure 4.

The user must have KMITL email account in order to log in to the system. Then, to borrow a bike, the user must scan barcode on the bike, he wishes to borrow. Then scan barcode on the bike, the application will send unlock command to the lock via Bluetooth connection.

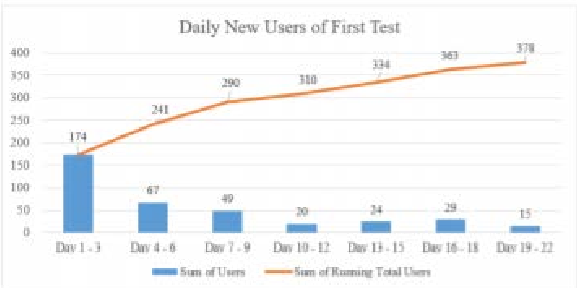
Figure 4 City bike (upper image) and commuting bike (lower image)

Due to the delay in hardware development, the first test adopted passcode to unlock the bike. The second test used barcode to unlock the bike. After tests on the first and the second bike-sharing programs, engineering faculty students and others became interested in the program. Daily users were clearly increased during both tests as presented on Figure 5.

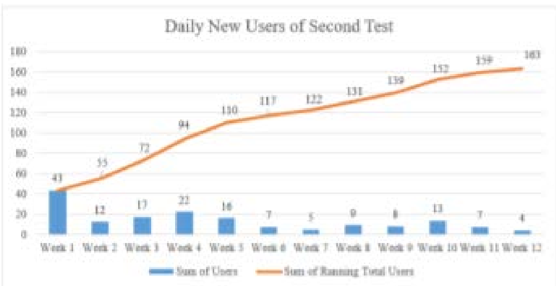
This project ended in June 2017 as it was still part of the senior project course. They have identified several problems and lessons learnt in the first program. For instance, developing maintainable and scalable programs required more experience and examples and was a challenge for inexperience students. Also, designing the application for public use was challenging as each platform had a different guidelines (i.e., Android application follows Google's Material Design guideline and iOS application follows Apple's iOS Human Interface Guidelines). In addition, hardware controlling parts on both kinds of devices are different.

In the hardware development, 3D printing technology was used. The lock prototypes were developed using 3D printer. However, it took at least eight hours to print each sample. To make the matter worse, the plastic locks are not strong enough for intended purposes. The team then turned to aluminum. Nevertheless, the CNC milling cost is rather high and must be done in a workshop. As a result, development cost and time were high, rendering design iterations difficult. Cost per lock was also much more expensive than plastic counterpart.

Another problem that the team encountered is to find and order all necessary components. This is because the bike has limited space and some parts are expected to have higher durability than usual. Some were ordered and shipped from China, so it took several weeks to arrive.



(a) Daily Users – First Test



(b) Daily Users – Second Test

Figure 5 Number of Users during (a) First Test and (b) Second Test

3.2. An Extension System of KMITL Bike

Later in August 2017, KMITL Bike was continued by a next senior generation - three students from the department of software engineering. The objectives of their project were to eliminate the problems and to provide more convenient ways for system administrators and the bike maintenance team. They developed an administration application and real-time monitoring system to prevent users from improper actions, such as overloading and not reading instructions.

After investigating other bike-sharing systems (shown in Figure 3), in many major aspects as well as discussing within the team which are the most important features, they decided to add geo-fencing, near real-time tracking and contact administrator features into the system.

Table 4 International Bike Sharing Systems

Name	Authentication Tools	Bike Locating	Penalty
SG Bike	Scan QR code	Geostation device	Fine via user e-wallet
Ofo	Combination lock	GPS	Phone call
Mobike	Scan QR code	GPS	Receive warning
oBike	Scan QR code	GPS	Deduct user’s credits

They also found that KMITL Bike created by the previous team was not well design and implemented using outdated technology and libraries. This led to difficulty in creating an extension system, so, they decided to re-construct the application (both Android and iOS application), to support system extension and further development.

In addition to KMITL Bike revamp, the team had developed another app, Bike Admin, which is aimed to assist bike-sharing provider. The features of Bike Admin included showing user status, user history, bike status, bike location and contact user. Figure 6 shows the use case diagram of the new system.

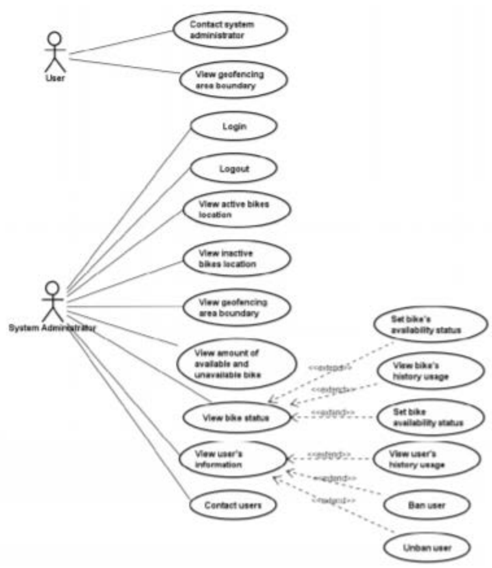


Figure 6 Use Case Diagram of KMITL Bike and Bike Admin Apps

Hardware was also improved. The components in the InfiniLock were replaced several times during the test. In a short period, replacement parts were created by 3D printing, using PLA plastic filament. Figure 7 compares the original and modified mechanism

International College. There was a KMITL team to support users who had problems in using bicycles. This program was developed and discussed in details by Pakdeewanich et al. [19].

4. CONCLUSION AND DISCUSSION

We described development of a locally designed smart campus bike-sharing system, KMITL Bike, as a case study. The use data over the period of 2-year were discussed. The use rates were clearly increased during the pilot study period. The results confirmed that students and staff were interested in sustainable transportation. The admin application and physical assets, especially InfiniLock, were significantly improved.

However, there were a few challenges in the development of a locally designed program, mainly the cost of physical assets and prototypes of the locking system. The design of prototypes of the locking system was analyzed and simulated by programming. This is to be studied further in the future.

In terms of sustainable transport on campus, funding support for physical assets and a number of bicycles should be further studied to provide better use

5. ACKNOWLEDGMENT

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