國立交通大學

運輸與物流管理學系

碩士論文

台北公共自行車租賃系統使用型態之分析

Better understanding the Taipei public bikesharing system: Exploring activity patterns

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中 華 民 國 一 〇 三 年 七 月

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碩 士 論 文

A Thesis

Submitted to Department of Transportation and Logistics Management

College of Management

National Chiao Tung University

in partial Fulfilment of the Requirements

for the Degree of

Master

in

Traffic and Transportation

July 2014

Taipei, Taiwan, Republic of China

中華民國一〇三年七月

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ABSTRACT

City-wide urban infrastructure are increasing reliant on information and communication technology (ICT) to improve and expand the service. Therefore, by taking advantage of passive sensors and Open Data policy, large scale of human behaviour data can be sensed and become more easily accessed independently. Data mining plays a vital role in helping to discover the patterns of human behaviour. In this study, we focus on the emerging urban transport infrastructure: public bikesharing system of Taipei City: YouBike. YouBike is launched from August 2012, operated by Giant, recognised as the world's largest bicycle manufacturer. Besides, it was the first large-scale public bike sharing system to be implemented in Taiwan. Currently, there are 166 bike station is operation. This study has shown that how bikesharing usage data which mainly focuses on the changes of the number of available bicycles across all stations not only reveals the station activity patterns but also explores the underlying temporal and spatial dynamics of a city. The clustering results indicate that station activity patterns could be categorised into three groups: which are daytime origins nighttime destinations, daytime destinations nighttime origins, and combined origins and destinations. Each cluster groups reveal the different activity patterns throughout the day. We believe that the visualisation of average temporal activity patterns and the clustered results could easily lead to a better understanding of the bicycle availability information. In addition, it is expected to improve the Taipei YouBike service itself, avoiding a future empty or full station through an improved redistribution of bicycles via rebalancing trucks. As a result, it would help to improve user satisfaction with the enhanced service and it is possible to attract more people to use YouBike as an enhanced green transport system.

Keywords: public bikesharing system, station activity pattern, data mining, cluster analysis

Acknowledgements

論文的結束，另一階段的起始。從入學至畢業的這三年中(密集緊湊的一年北交生活、一年的英國留學生活以及近一年的替代役生活)即將畫上圓滿的句點。這一路走來眾多貴人的提攜與幫助，謹以此篇表達對各位的感謝!

能夠順利完成此篇論文，首先要感謝我的指導教授汪進財老師，不管是在問題的釐清、邏輯思路的理清，在與老師會談後均豁然開朗; 此外老師也不時耳提面命地提醒除了專業能力的培養，養成獨立思考、解決問題的重要性，方是個人在現今競爭社會中立足的根本。其次要感謝的是我的口試委員胡守任老師與葉文健老師，提出了許多寶貴的問題與建議，讓本篇論文臻於完善與健全。此外，也要感謝所上老師的教導，馮正民老師、陳穆臻老師、邱裕鈞老師、溫傑華老師、黃寬丞老師以及轉任至台大商研所的許鉅秉老師於申請英國里茲 ITS 提供的幫助。感謝網路無遠弗屆，特別感謝 Shane Lynn 提供接取程式的基礎以及林 yume 的撥空指導；也萬分感謝認識多年的好友中閔的熱情幫忙，加速資料的的處理，是順利完成論文的一大功臣。也感謝共同奮鬥的汪家小夥伴們敬莘、涵恩、弼元、憲天，以及研究所的各位榕芳、怡心、紹谷、得政、筱茜、修豪、思遠等人，讓研究生活充了笑顏與樂趣。

也感謝各位在金瓜寮的同袍們的包容與幫助，感謝育賢與瓜子對於投影片的建議，柏勛的餅乾、八寶粥，中閔大廚每天中午的張羅，何泓的神奇寶貝紓壓與無限咖啡供應、涵郁活寶、志遠提供的各種零食，釗暉的人性化管理和 CS 開打，還有每天下午大家一起做運動聊天打屁的時間，溜溜小黑，讓寫論文時的各種高壓、煩躁得到了宣洩，能在這一年中在金瓜寮一片群山環繞清幽的環境裡完成論文，實屬天大之幸福。

最後感謝我的父母與家人背後的包容與支持，在未來的日子裡，必定讓你們驕傲以及無憂。祝各位平安喜樂。

群彥 謹致於

國立交通大學交通運輸研究所

中華民國 103 年八月

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List of abbreviations

API	Application Programming Interface
BN	Bayesian Network
BoE	Bureau of Energy, Ministry of Economic Affairs (Taiwan)
CO	Carbon monoxide
CO_2	Carbon dioxide
CSV	Comma-Separated Values
DoT Taipei	Department of Transportation, Taipei City Government
EM	Expectation Maximisation
EU	European Union
GHG	Greenhouse Gas
GIS	Geographic Information System
ICT	Information and Communication Technologies
IDE	Integrated Development Environment
IOT	Institute of Transportation, MOTC
ITS	Intelligent Transport System
JSON	JavaScript Object Notation
KlOE	Kilolitre of Oil Equivalent
KM	K-means
Km^2	Square Kilometres
MOTC	Ministry of Transportation and Communications, R.O.C.
Mt	Million tonnes
NAB	Normalised Available Bicycles
NO_x	Nitrogen Oxides
PBIC	Pedestrian and Bicycle Information Centre
PBS	Public Bike Sharing
PPP	Public-Private Partnership
SIB	Sequential Information Bottleneck
SO_2	Sulphur dioxide
SSE	Error Sum of Squares
TDG	Toole Design Group
TEO	Traffic Engineering Office
TFEA	Taipei Friendly Environment Association
TfL	Transport for London
TRL	Transport Research Laboratory
TRTC	Taipei Rapid Transit Corporation
WCED	World Commission on Environment and Development

1. Introduction

This chapter briefly describes the background to this dissertation and briefly highlights the important role of bike-sharing systems in daily mobility and achieving sustainable transport. It also demonstrate these issues by contributing to defining the research questions, the aims and objectives, the structure and research process, and the scope of the dissertation. Finally, it concludes with a brief outline of each chapter.

1.1 Background and motivation

1.1.1 Motivation: the trends of adopting sustainable transport in transport policy

The need to achieve sustainable transport is evident. While transport system underpins the basic daily life, maintaining and delivering activities of different sectors in society, it is critical to think that what cost or long term effect that transport sectors may bring about, especially in terms of the environment impacts and externalities. Sustainable transport is based on the context of sustainable development which Brundtland Report defined it as "*development meets the needs of the present without compromising the ability of future generations to meet their own needs*" in three perspectives of sustainability: economic, social, and environmental (WCED, 1987). More specifically, World Bank (1996) defined sustainable transport in terms of three pillars in sustainability where:

1) economic sustainability: to make transport more cost-effective and can respond to growing demands by competition and the enhancement of user participation;
2) social sustainability: to provide universal access to transport and meet the needs particularly of the poor; and
3) environmental sustainability: to address adverse impacts that transport brings about in terms of land use, energy consumptions, water, air quality etc. for more liveable environment

Noted that sustainable transport is not only in accordance with ecology-friendly of sustainable development which satisfies current transport and mobility needs and still being functional by future generations but also being avoidance of institutional failures (Zuidgeest et al., 2000; Chapman, 2007).

For example, generally speaking in 2011 transport accounts for 22% of energy related carbon dioxide (CO_2) emissions globally[1] (IEA, 2012). Hence, it achieves 6.9 Gt CO_2 emissions[2], as the largest end-used sector source, and more than half the oil used (IEA, 2012). It is widely accepted that increasing mobilisation and reliance on motorcars associated to increasing urban traffic leads to higher demand on energy consumption, greater CO_2 emissions and brings about externalities (Plaut and Shmueli, 2000; European Commission, 2004). These incorporate air pollution, noise and vibration, and traffic accidents at local level whereas climate change at the global level. Emissions from transport not only refer to CO_2 but also incorporating particulates (PM_{10} and $PM_{2.5}$), Nitrogen oxides (NO_x), carbon monoxide (CO), Sulphur dioxide (SO_2) etc., resulting in harming human health as well as environment. Notably, it would also cause negative impacts on urban quality of life in term of equity, economic efficiency, visual intrusion, severance and competitiveness (European Commission, 2004).

Growing concerns about climate change, global warming, energy security, and unstable fuel prices have caused a large number of policy makers and experts to explore sustainable travel solutions (Shaheen et al., 2010). As a result, a variety of non-motorised transport modes has been promoted by transport planners, professionals and policy makers in recent years, which are often considered as vital elements in sustainable transport (Rietveld and Daniel, 2004).

Promoting active transport from motorised travel towards walking and cycling would expect to yield environmental benefits, such as limiting greenhouse gases (GHG) emissions (e.g., CO_2 emissions), reducing air pollution, noise, and alleviating traffic congestion (Rabl and de Nazelle, 2012; Woodcock et al., 2014). Moreover, it is increasing recognised that cycling and walking represent practical opportunities for people to integrate physical activity into daily life and yield positive impacts on public health (Cavill et al., 2008; Dill, 2009).

Based on the concerns described above, more and more policy planners and transport planning researchers have increasing interested in sustainable transport alternatives which could be seen as possible solutions to combat those challenges. Specifically, reducing carbon emission to mitigate climate change and adapting to the potential impacts of climate change have become a major policy in many countries in the world (Wadud, 2014).

[1] including international aviation and bunkers
[2] Gt = 1,000,000,000 tonnes

Accordingly, one possible way could be adopted to deal with these problems is the promotion of cycling through implementing public bikesharing scheme, which is economical, eco-friendly, healthy, ultra-low carbon emissions and more equitable.

1.1.2 Increasing attention of public bikesharing system

Public bikesharing systems (PBS), also known as public bikes or bikesharing or shared bicycle system, have received increasing attention in the last decade and have rapidly emerged in many cities all over the world. In addition, it could be considered as an innovative scheme in the realm of urban transport (Parkes et al., 2013; Zaltz Austwick et al., 2013; Bührmann, 2007).

Bikesharing schemes are networks of public use of bicycles operated in urban areas for use at low cost and accessed from a fixed number of stations which are distributed around a city (NYC Dept. City Planning, 2009; Lathia et al., 2012). Travellers can pick up bicycles at any self-service bike station and return them to any of the stations' parking slots, making it ideal for point-to-point trips (NYC Dept. City Planning, 2009). The bikesharing usage is limited by time rather than the usage in terms of origination and destination (Lathia et al., 2012). For example, the first 30 minutes is free which is an often fare structure in many cities, and penalty fare would occur if the bicycle is not returned within given time for ensuring circulation rate at certain level.

The prosperity of bikesharing system may be mainly because that it "*provides the missing link between existing points of public transportation and desired destinations*" (Midgley, 2009). It also covers the issue that bridging the gap between distances that are deemed too far to walk, but too close to justify a car/public transport trip (Casiello et al., 2013). In this role, bikesharing systems increase transit accessibility. Accordingly, it could be an alternative and complementary transport mode, even as part of green and versatile public transport in cities (Borgnat et al., 2011; Faghih-Imani et al., 2014).

Over the past ten years, public bikesharing schemes have developed from being pilot experiments in urban mobility to mainstream public transport options in cities as large and complex as Paris and London (Midgley, 2011). Currently, there are almost 700 cities in the world have implemented bike-share systems till at the end of April 2014 and more than 200 cities are planning to install public bikesharing (DeMaio and Meddin, 2014).

This system is intended to generate the benefits associated with cycling while providing users with free or rental bicycles particularly suitable for short distance journey in urban areas (Bachand-Marleau et al., 2012; Etienne and Latifa, 2012). A public bicycle sharing scheme enables users to ride bicycles whenever needed rather than maintaining cost and taking responsibilities for owing a bicycle since bicycle theft is a common issue in urban regions (Rietveld and Daniel, 2004; Shaheen et al., 2010; Bachand-Marleau et al., 2012; Faghih-Imani et al., 2014). In addition, It allows more people experiencing health benefits, cost savings, flexibility, and enjoyment while cycling across the city (ITDP, 2013; Fishman et al., 2013).

Not only a bikesharing system can be interpreted as an individual mode for short trips but also served as a vital segment of an intermodal route for longer trips (Nair et al., 2013). If it serves for an "extension" of the existing transit system, public bikesharing system could be construed as a first-mile or last-mile connection (DeMaio, 2009; Liu et al., 2012; Casiello et al., 2013). In fact, it is suitable for its fast, convenient and flexible characteristics in short term trips whereas for long term trips it would be suitable for bridging the gap among using multimodal transport options. As a result, commuters in urban area could use shared bicycles to connect to their desire destinations from their homes, working places, schools, transit stops or other places. It implies that bikesharing systems play the role in increasing transit accessibility, which is strongly aligned with integrated transit systems explored in the past that also aims to increase the catchment area of transit (Nair et al., 2013).

All these characteristics have provoked a growing number of cities to carry out public bikesharing programmes with initiatives to promoting cycling, addressing the first-mile/last-mile connection to transit, and eliminating environmental impacts.

1.1.3 The potential benefits and drawbacks of public bikesharing

To some extent, the advantages of bicycle sharing schemes are similar to those of cycling in general (Wiersma, 2010). For example, there are several advantages of public shared bicycle systems from the view of system implementation. It includes *(a)* low cost of implementation, *(b)* ease of installation, and *(c)* less infrastructure required than other modes (DeMaio, 2009; Heinen et al., 2010). Additionally, it also provides a number of potential benefits that implementing bikesharing system.

Generally speaking, public bikesharing may offer environmental, social, economic, transport benefits, and other benefits. For instance, it offers users increased travel utility through flexibility and cost (Nair et al., 2013). Travellers can pick up the bikes at any time at any bike stations, choose the route and destinations based on their desires. Compared to other modes, public bikesharing is attractive by its low cost. Shaheen et al. (2010) point out that it has the potential to play an important role in bridging the gap in existing transport networks for solving the first/last mile issue where the short distance between home and public transit or transit stations to work place would be too far to walk. Also, it encourages travellers to use multimodal transport options, and creates larger cycling population. It implies that some personal car trips would be replaced by public bikesharing and it forms the basis of environmental benefits that bikesharing provides. For example, cycle mode share in Barcelona was increased to 1.76% from 0.75 % during the year that Bicing was launched in 2007 (Romero, 2008 as cited in DeMaio, 2009).

However, it could be argued that bikesharing schemes also have some drawbacks attached in terms of riding itself. It includes riding skill required, a great physical effort, the difficulty of carry loads while cycling, being at the mercy of weather, travelling more slowly in outside urban area than motorised transport, and etc. (Heinen et al., 2010). A wide range of potential benefits and drawbacks are summarised in Table 1 below.

Table 1 Potential benefits and drawbacks of public bikesharing system

Potential benefits	Drawbacks
Added benefit of exercise provided to users (public health improvement)	Can be used in ways unsafe to riders and pedestrians
Additional mobility provided	Difficulty of carrying loads
Air quality improvement	May be difficult to ride in some topography
Environmentally friendly	May be inaccessible to people with certain disabilities
Extending the public transport catchment area	Most appropriate for short distance
Freedom from fear of bicycle theft	Riding skills required
GHG emissions reduction	More likely to be affected by the weather while cycling
Have potential on creating larger cycling population	Travelling more slowly than motorised transport outside urban areas
Improved connectivity to other modes of transit	Usage strongly depends on weather and topography
On-demand transport provided	
Possible generalised travel cost savings	
Reduce the burden on a crowded public transport system	
Reduction in energy consumption	
Reduction in fuel use	
Savings on individual finance	
Strengthened local identity	
Support for multimodal transport connections	
Traffic congestion alleviation	

Source: Adapted from DeMaio (2003); DeMaio and Gifford (2004); Bührmann (2007); DeMaio (2009); Heinen et al. (2010); Shaheen et al. (2010); Wadud (2014)

1.2 Statement of the problem

There is an increasing demand of leisure activities since Taiwan has practiced the “weekend” policy for labours since 2001. In addition, the importance of keeping physical activity receives increasing attentions by more and more people, and meanwhile life style has been starting to alter. Thus, it provides the great opportunity for government to establish leisured-based public rental system in the attraction points, encouraging more people to use it.

According to MOTC (2010), the main purpose of riding bicycles would be for leisure use, exercise, and travelling, which accounts for 60.5%, followed by community activities for 26.4% such as buying groceries, visiting friends and relatives, shopping etc., and commuting purpose accounting for 12.5%. Notably, for those using bicycles to commute to work, most of users (88.2%) commute less than 30 minutes and only 10% of users would spend time between 30 minutes and 60 minutes for commuting (MOTC, 2010). By 2013, modal split in Taipei city of active transport and public transport for all trips accounts for 19.7% and 37.5% respectively whereas for commuting purpose, public transport accounts for 41.8% and active transport for 10.7% (MOTC, 2014). The transformation of YouBike bikesharing scheme seems to be successful through altering the operational strategy in terms of more bike stations supplied, simplified registration and competitive price. As Lathia et al. (2012) found that simper access to the systems in association with not only greater weekend (i.e., recreational) usage but also reinforcing the weekday commuting trend.

However, recently the survey done by Taipei Friendly Environment Association (TFEA) reported that publics reckon that there are six issues should be addressed in higher priority: *(a)* more bike stations integrated with New Taipei City (46.2%), *(b)* cannot pick up and return the bikes due to imbalanced distribution (36.3%), *(c)* higher broken rates of bikes (10.5%), *(d)* broken docks(9.3%) and *(e)* uncomfortable saddle (6.6%) and *(f)* fare (6.6%) (黃福其, 2014). Similarly, there are also two biggest problem in Barcelona’s public bikesharing system which results in user frustration, are *(1)* unable to find a bike while trying to start their journeys and *(2)* unable to return the bike in the desired destinations due to full stations occupied with bicycles (Kaltenbrunner et al., 2010).

Bikesharing operators have to ensure the sufficient bike availability to satisfy customers. The problem of impossibility to pick up/return bikes due to imbalanced distribution seems to be a universal feature and is one of the main issues raised by many users in cities where have implemented bikesharing (Kaltenbrunner et al., 2010; Shaheen et al., 2010; Vogel et al., 2011; Shaheen and Guzman, 2011; Zhang et al., 2012; Liu et al., 2012; Nair et al., 2013). It is believed that the shared bikes designed for short-term and one-way use resulting in the imbalanced spatial distribution of bikes at stations over time (Vogel and Mattfeld, 2011). Normally, this issue could be addressed through design and management measures in terms of different of planning horizons shown in Table 2 below:

Table 2 Measures for alleviating imbalanced distribution of bikes by planning horizons

Planning horizons	**Measures**
operational (short-term)	- providing redistribution of bikes from full to empty stations; practically, it would cost $3 approximately for repositioning a bike in the case of *Vélib* bikesharing in Paris - informing the users in advance about the closest stations where could be pick up/return bikes through mobile applications
tactical (mid-term)	providing incentives for customers for helping redistribution of bikes. For instance, 15 extra minutes are granted for retuning bikes at uphill stations in the case of *Vélib*, Paris
strategic (long-term)	network design which incorporates the location, number and size of stations

Source: DeMaio (2009); Kaltenbrunner et al. (2010); Vogel et al. (2011)

Addressing imbalanced bicycle distributions is one of the research topics on public bikesharing system. Since the short history of modern bikesharing systems, researches on such system and their impacts are still quite few though growing rapidly in recent years. There are number of studies of bikesharing systems have mainly focused on *(a)* optimisation of bike station locations (Lin and Yang, 2011; García-Palomares et al., 2012; Martinez et al., 2012; Sayarshad et al., 2012; Hu and Liu, 2013; Lin et al., 2013), *(b)* user perception and satisfaction of such system (Bordagaray et al., 2012), and *(c)* exploring spatial and temporal characteristics or spatiotemporal trends from the station hire data (Froehlich et al., 2008; Froehlich et al., 2009; Kaltenbrunner et al., 2010; Borgnat et al., 2011; Vogel et al., 2011; Lathia et al., 2012; Borgnat et al., 2013; O’Brien et al., 2014).

1.3 Aims and Objectives

Based on the above premise, the primary aim of this dissertation is ***to contribute to the solution of imbalanced distribution of bikes, i.e. unable to pick up/return bikes due to empty/full stations through the analysis of spatio-temporal station activity patterns.***

In order to achieve the research aim, the objectives of this dissertation are as follows:

1. To identify and understand the role of bikesharing system playing in urban mobility;

2. To identify, study and analyse spatial and temporal activity patterns of bike stations,

3. To help gaining the insights into classifying bike stations; and

4. To explore spatial relations between bike usage and location of stations and how station activity data can be used to infer cultural and geographical layout of Taipei City.

By better understanding the role of pubic bikesharing systems in urban mobility, it helps cities search for ways to increase cycling population, meet increasing mobility demands and mitigate adverse environmental impacts (Midgley, 2009). As the ubiquitous ICT embedded in transport systems and higher penetration rate of smartphones, it not only enables users to acquire real-time information about bicycle availability but also amenable to investigation for researchers. Taking the advantages of ICT and Open Data, this research provides the potential of a novel way of retrieving real-time bike station data as a data source in urban transport research particularly. The bike stations usage data reveals spatial and temporal bikesharing patterns; moreover, these patterns reflect the culture and the spatial layout of the city (Froehlich et al., 2009). For instance, station activity patterns may disclosure relations with certain type of customers using certain stations depending on the stations' surroundings. It is believed that the contribution of this dissertation would have implications for the design and operation of existing bikesharing system in Taipei City as well as future public bikesharing schemes deployment in other cities of Taiwan. Additionally, the findings would also have impacts on three different stakeholders depending on their roles: *(1)* bike users interest in finding available bicycles or docking slots, *(2)* transport planners cope with the imbalanced distribution problem and other issues while in operation, and *(3)* urban planners decide the land use and spatial layout of the city (Lathia et al., 2012). Hence, it leads to a better service of bikesharing afterwards.

1.4 Scope of the dissertation

Our study area Taipei City, the capital city of Taiwan, has the largest mode share of public transport and active transport (walking and cycling) either for all purposes or commuting among the cities in Taiwan. With 2.67 million people by 2012 where live in only 272 square kilometres (Km^2), resulting in extremely high population density for about 9800 people per Km^2 (DoT Taipei, 2013a).

YouBike which has been discussed in the following sessions refers to the second bikesharing system however the first large scale of bikesharing system deployed in Taiwan since 30 August 2012 (YouBike, 2014d). Although there is another public bikesharing system in Kaohsiung, located in southern Taiwan, which launches since 1 March 2009, this dissertation only covers the study of spatio-temporal activity data among stations in Taipei YouBike system. There are 165 stations of data collected in this study and shown in below Appendix A: YouBike station list by administration region. More detailed station information such as station capacity, id number, establishment time, etc… is presented in Appendix B: description of stations. Notably this study focuses on the temporal analysis and clustering of bike stations through retrieving data of bicycle availability collected at a fixed timespan automatically rather than collecting flow data of bikes at stations. Therefore, it demonstrates another way of looking human mobility data in an urban area instead of identifying changes in travel behaviour over space and time via OD matrix.

Public bikesharing schemes mentioned in this research would be mainly refer to the third generation of bikesharing system.

1.5 Dissertation framework

Below Figure 1 illustrates the overall dissertation framework, beginning from literature review which includes introduction of public bikesharing system, identifying the factors influencing bicycle use and studies about station activity and temporal patterns. Followed by three main parts: (a) data collection: retrieving data from Taipei Government Open Data source; (b) station activity pattern analysis based on bicycle availability; and (c) discussions and implications: discussing the bicycle redistribution in the view of operation managements towards stakeholders.

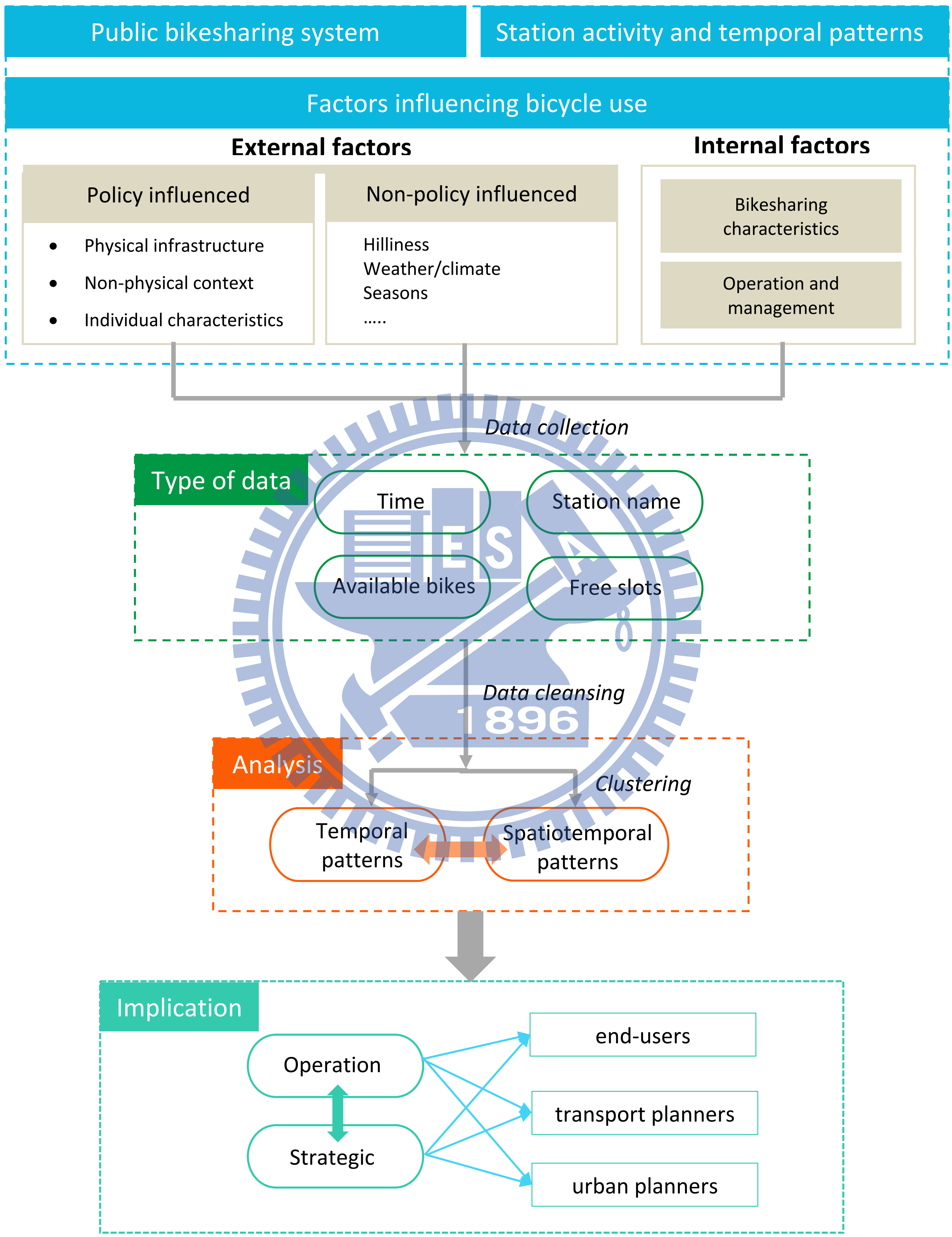


Figure 1 Research framework

1.6 Dissertation structure

This dissertation is divided into six stages including this introduction. The remainder of this dissertation is organised as follows and research flow diagram is shown in Figure 2 below:

Stage 2: Literature Review – It provides an overview of public bikesharing in urban mobility through its characteristics, potential benefits, components, business model and evolution. It is followed by the reviews of the determinants of bicycle use as to discover the factors influencing public bikesharing system usage. This gives us the insights on promoting shared bicycles usage in terms of planning and strategic measures. Researches on station activity and mobility pattern are also reviewed, helping to clarify provide the analysing basis of station usage patterns. Additionally, related works on bikesharing system are discusses, allowing us to cover multiple aspects of this system.

Stage 3: Taipei YouBike overview – It provides the detailed description of Taipei public bikesharing system: YouBike, by means of *(1)* cycling development in Taiwan and how it transforms to fulfil the goal of green transport by Taipei Government, *(2)* transport characteristics in Taipei City, *(3)* basic YouBike characteristics, including design and planning concept

Stage 4: Data collection and processing – By taking advantage of open data and open source code, the station activity data (e.g., available bikes and free slots) in a given time is collected in an automatically based. Consequently, the collected data is required to be pre-processed, enabling to analyse later.

Stage 5: Analysis and results – To explore temporal and spatiotemporal patterns of station activities in the YouBike system, highlighting how these patterns reflect the underlying cultural and spatial layouts and characteristics of the City. When taking account of geographic distribution of these patterns based on clustering results, it enables to visualise the mobility patterns of Taipei city.

Stage 6: Conclusions and suggestions – It contains the limitation of this dissertation, suggestions for future works and conclusions.

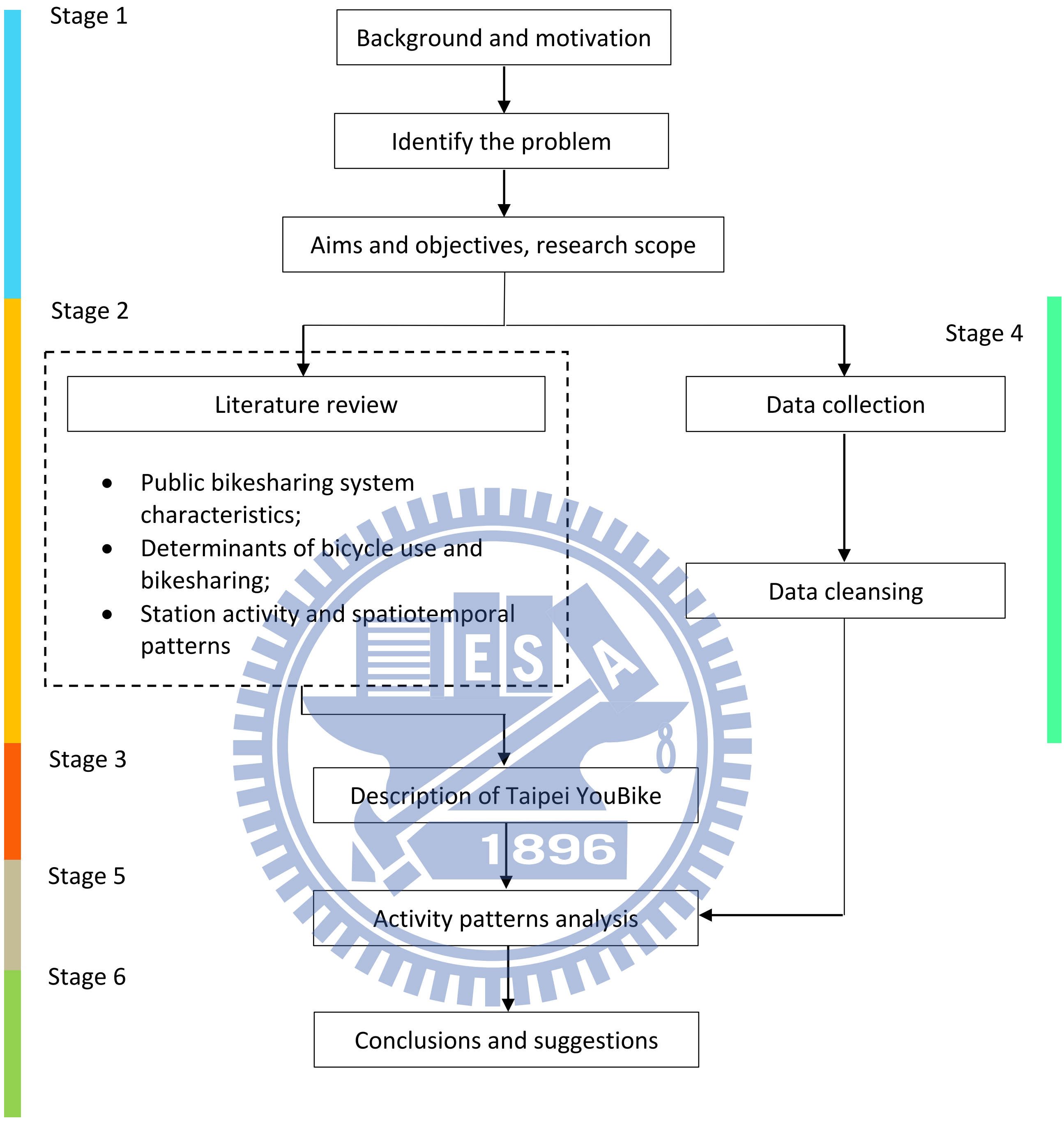


Figure 2 research flow diagram

Source: this study

2. Literature review

This literature review in this chapter can be divided into five parts. Firstly, it provides an overview of public bikesharing in urban mobility through its characteristics, potential benefits, components, business model and evolution. Then followed by the reviews of the determinants of bicycle use as to discover the factors influencing public bikesharing system usage. Thirdly, researches on station activity and mobility pattern are also reviewed, helping to clarify provide the analysing basis of station usage patterns. Consequently, related works on bikesharing system are discusses, allowing us to cover multiple aspects of this system. Finally, it concludes with key findings and remarks for this chapter.

2.1 Public bikesharing system

Bikesharing, generally speaking, is the shared use of a bicycle fleet. Since it is the comprehensive citywide system which designed for shared use for publics, it is also known as shared bicycles, public bikesharing scheme, etc. Such systems go by a variety of names around the world: such as "bicycle sharing" or simply "bike-share" in North America, "cycle hire" in the United Kingdom, "cycle sharing " in South Asia and "public bike" in China (ITDP, 2013). It has received increasing attention recently and rapidly emerged in many cities across the globe. Note that in this study, we usually the term of bikesharing.

Pucher et al. (2010) identify that there are three main actions for promoting cycling: travel related infrastructure, measures for integrating bicycles with public transport, and programmes and legal interventions to promote cycling. Bikesharing is the programme for promoting cycling aiming to reducing vehicle travel through shifting to transit, walking and cycling. The primary goals for bike-sharing system are reduction of congestion, pollution and other environmental externalities such as GHG emissions, improvement of public health, promotion for bicycle usage and integration to wider transport system ultimately (Vogel et al., 2011; Murphy and Usher, 2013). It is one of the sustainable transport alternatives that could help to address growing concerns about global motorisation, global climate change, energy security, and unstable fuel prices (Shaheen et al., 2010). In other words, it allows individuals to meet their transport needs in an environmentally sound manner (DeMaio, 2003). Additionally, it seems to be important for social inclusion, which provides sufficient supports for access public transport or carries out the whole journey. It enables people to have access to participate in life opportunities, and in reaching activities and services such as education, work, shipping and recreational activities (Daniels and Mulley, 2013).

The principle of bikesharing is simple. Bikesharing schemes are networks of public use of bicycles operated in urban areas for use at low cost and accessed from a fixed number of stations which are distributed around a city (NYC Dept. City Planning, 2009; Lathia et al., 2012). Travellers can pick up bicycles at any self-service bike station and return them to any of the stations' parking slots, making it ideal for point-to-point trips (NYC Dept. City Planning, 2009). The bikesharing usage is limited by time rather than the usage in terms of origination and destination (Lathia et al., 2012). For example, the first 30 minutes is free which is an often fare structure in many cities, and penalty fare would occur if the bicycle is not returned within given time for ensuring circulation. Such system enables users to ride bicycles whenever needed rather than maintaining cost and taking responsibilities for owing a bicycle since bicycle theft is a common issue in urban regions (Rietveld and Daniel, 2004; Shaheen et al., 2010; Bachand-Marleau et al., 2012; Faghih-Imani et al., 2014). In addition, It allows more people experiencing health benefits, cost savings, flexibility, and enjoyment while cycling across the city (ITDP, 2013; Fishman et al., 2013).

It is essential to distinguish between general bikesharing scheme and traditional, mostly leisure-based bicycle rental system. In essence, it differs in the following ways (Midgley, 2009):

- can be fast and easily accessed at one location and either returned there or at another location;
- they have diverse business models;
- ICT technology embedded and make use of applied technology; for instance, smart cards for fast access and integration with public transport and mobile phone apps for informing available bike at stations; and
- they are often designed and integrated as part of public transport system.

Moreover, bikesharing bike stations normally "*located in close proximity to major transit hubs (e.g., metro stations) and in both residential (origin) and commercial or manufacturing (destination) neighbourhoods*", enabling it ideal for a short-term, commuter transport system (NYC Dept. City Planning, 2009).

2.1.1 Potential benefits of public bikesharing

Bikesharing has a lot of potential benefits not only for individuals but society in terms of social, environmental and even economic benefits. One of the main contributions of implementing public bikesharing scheme would be that it plays a vital role in fostering the use of bicycles in cites (García-Palomares et al., 2012). In other words, to explore the potential benefits of bikesharing is actually the synonym of identifying the contributions of cycling it brings about in some extent. Basically, the potential benefits of bikesharing can be concluded and derived from two ways: modal shift and riding itself. These benefit are discussed in the following in terms of four aspects: transport, social, environmental, and economic benefits.

1. transport benefits

   The transport benefits which bikesharing brings about may refer to enhanced accessibility and mobility, providing complementary services to public transport, behaviour changes and modal shifts. Since bikesharing systems provide the missing link between existing points of public transport and desired destinations, it bridges the gap between distances that are deemed too far to walk, but too close to justify a car/public transport trip (Midgley, 2009; Casiello et al., 2013). DeMaio and Gifford (2004) mention that the proximity of bikesharing stations to downtown transit stations tends to be ideal for transit customers. As a result, it not only allows users to have greater access to place that are beyond their reach on foot but enhance users' mobility in a cheaper way.

   In fact, bikesharing system is suitable for its fast, convenient and flexible characteristics in short term trips whereas for long term trips, it would be suitable for bridging the gap among using multimodal transport options. It offers an alternative for short trips that people would have otherwise made on transit (ITDP, 2013). If it serves for an "extension" of the existing transit system, public bike share could be construed as a first-mile or last-mile connection (DeMaio, 2009; Liu et al., 2012; Casiello et al., 2013). For instance, about 10% of *Velo'v* users also take public transport in trip chains (Bührmann, 2007).

   Behaviour shifts also can be identified after the introduction of public bikesharing system. It is reported that during the first year of *Velo'v*, there is a 44% increasing in bicycle riding in Lyon (Bührmann, 2007). According to Rojas-Rueda et al. (2011), Bicing has increased the number of cycling trips by 30% since inception. In addition, modal shifts could also be identified after the introduction of bikesharing. For example, Bührmann (2007) reports that in the case of *Velo'v*, 7% of trips of private car is replaced by public bikes and 37% of walking, 50% of public transport, 4% of private bicycle trips are also replaced by public bikes respectively. Following Table 3 summarises some bikesharing programmes impact on modal shift.

Table 3 Type of trips replaced by bikesharing by cities

Type of trips replaced	Bicing (Barcelona)	BIXI (Montreal)	Vélib' (Paris)	Velo'v (Lyon)
Bus / Metro	51%	33%	65%	50%
Car / Motorcycle	10%	2%	8%	7%
Taxi		8%	5%	
Walk	26%	25%	20%	37%
Bicycle	6%	28%		4%
New users		4%		2%

Source: Midgley (2011)

2. social benefits

The social benefits of shared bicycles may include addressing the parking issue that cyclist faced, increasing public awareness of bikesharing, and improving a city's image and branding. There is a common issue that although cycling lane has been added and extended longer than before, it is still used not well. For instance, Paris government identified the biggest deterrent was the lack of bicycle parking, especially once they reached their destinations (ITDP, 2013). Implementing bikesharing seems to be able to address the needs for bicycle parking as well as increase cycling populations. In terms of enhanced public awareness of bikesharing, Shaheen et al. (2010) found that according to a 2008 Vélib′ survey, 89% of Vélib′ users agree that riding with Vélib′ makes travel easier in Paris. This phenomenon also happens in Washington D.C, where approximately 79% of users consider using Capital Bikeshare (former: SmartBike) is faster or more convenient than other transport options (Shaheen et al., 2010); and 70% said that t has been important in helping or encouraging them to cycle more often (LDA Consulting 2012 as cited in ITDP, 2013). It is believed that for those cities implement bikesharing system would strengthen its image as green or innovative city; for example, Paris' *Vélib*' won the British Guild of Travel Writers' Best Worldwide Tourism project (ITDP, 2013).

3. environmental benefits

As bikesharing provides a low carbon solution for the first/last mile of a short-distance trip, linking trips between home and public transit or transit stations and the workplace that are too far to walk to, even as a many-mile solution (Shaheen et al., 2012). In terms of environmental benefits, it would come from modal shifts due to more bikesharing users and increased cycling level; hence bikesharing trips replace automobile trips. Additionally it also generates positive impacts not only on environment but also individual health and fitness in a number of ways, incorporating congestion reduction, improved air quality, noise pollution reduction, CO_2 emissions reduction, physical health improvements (DeMaio and Gifford, 2004; Bührmann, 2007; DeMaio, 2009; Shaheen et al., 2010; ITDP, 2013). Although the contribution of cycling to pollution and congestion reduction is highly depended on substituting car use for cycling trips, it is more likely to be most effective as part of a wider set of transport measures (SQW, 2007). Below Table 4 clearly demonstrates several examples of bikesharing system impacts on CO_2 emissions reduction.

Table 4 Impacts of public bikesharing on CO_2 emissions reduction

Bikesharing	Year of Data	Trips per day	Km per day	CO2 reduction
Bicing (Barcelona)	Rojas-Rueda et al. (2011)			9M Kg/year
BIXI (Montreal)	DeMaio (2009)			3M pounds/year
Hangzhou	2009	172,000	1,032,000	191,000/day
Vélib' (Paris)	2009			
Velo'v (Lyon)	DeMaio (2009)	25,000 (by 2011)		18.6 M pounds[3]
Boulder B-cycle	2011	18,500		47,174
Denver B-cycle	2011	202,731	694,942	280,339
Boston	2011	140,000		
Madison	2011	18,500		46,805
San Antonio B-cycle	2011	22,709		38,575

Source: adapted from Shaheen et al. (2012); DeMaio (2009); Rojas-Rueda et al. (2011)

[3] since inception

Notably, researches have shown that there is a strong link between physical activity and health. Furthermore, physical and mental health benefits of shared bicycle use are well investigated (see (Fraser and Lock, 2010; Rojas-Rueda et al., 2011; Woodcock et al., 2014). There is an evidence shown that spending 20 minutes on a bike everyday causes a significant positive impact on mental health (Obis 2011 as cited in ITDP, 2013). It may be argued that the using bikesharing would be likely to exposure to traffic-related pollutants than other modes. However, cyclists may be less exposures to these pollutants than motorises actually, assumed that these pollutants concentrate inside automobiles. For instance, the amount of exposure to CO and nitrogen dioxide (NO_2) by cyclists only accounts for about 40% and 56% of that pollutants faced by motorists respectively (Gris Orange Consultant, 2009).

4. Economic benefits

The main economic benefits of introducing bikesharing would be that it generates investment in local industry, the cost of implementation and infrastructure maintenance and footprint are substantially lower with comparison to motorised vehicles and public transport (Gris Orange Consultant, 2009; ITDP, 2013). It has the potential to support this system through service providing, demand for hardware and software. However, the research of studying economic benefits is scarce.

Note that a wide range of potential benefits and drawbacks of bikesharing has been disclosed and summarised in previous chapter (see Table 1 in chapter 1).

2.1.2 History and evolution

Over the past decades, public bikesharing could be categorised into four generations in terms of characteristics and components, which are discussed in the following.

Bikesharing system has evolved significantly over decades and is firstly emerged in 1965 while Amsterdam introduced the world's first large scale public bikesharing scheme called "*white bikes*", known as the first generation of bikesharing (DeMaio, 2009; Shaheen et al., 2010). The common characteristics of first generation system are that bicycles are typically painted in one colour, unlocked bikes, and distributed around the city for anyone for free use. Note that in some of the systems, the bikes are locked and have to get access key from a local business and deposit required; however the usage of bikes is still free (Shaheen et al., 2010; Shaheen et al., 2012). There were lots of cities implemented a free bike system; for example, La Rochelle, France implemented bikesharing system in 1974 where was considered as successful and continued to operate till today. In the contrast, Cambridge (UK) in 1993 ended with failure due to theft and bicycle vandalism (Shaheen et al., 2010).

The general failure of first generation of bikesharing leads to the emergence of a second generation, known as coin-deposit systems which adopt a more structured and improved secure approach to the system (Parkes et al., 2013). Initially, 2nd generation systems were both emerged in Farsø and Grenå, Denmark, but until 1995 that the first large scale of 2nd generation was opened as Bycyken in Copenhagen (DeMaio, 2009). The main differences of 2nd generation bikesharing system are *(a)* designated docking stations where bikes can be borrowed, locked, and returned; and *(b)* deposit required to unlock the bikes (Shaheen et al., 2010). Theft is the main issue as well which is partly because of low cost of deposit (generally about US$4), likely to be used for a long time period or not return at all (Shaheen et al., 2010).

Bikesharing system in Rennes (France) introduced in 1998 was the first bikesharing scheme using smartcard technology; and it was the introduction of a variety of technology improvements that facilitates 3rd generation bikesharing scheme (IT-based system) and gains popularity worldwide (Midgley, 2011; Shaheen et al., 2010). A number of new characteristics which differentiate from previous generations are: improved bicycle designs, ICT embedded for bicycle pickup, drop-off, locking and tracking, sophisticated docking stations, improved user accountability through the use of credit/debit card or mobile phone numbers (Shaheen et al., 2012; Parkes et al., 2013; Bachand-Marleau et al., 2012). In addition, mobile apps and website are also used to provide real-time information about bike availability for users and as a portal for them to manage their accounts (Parkes et al., 2013). Until 2005 Lyon introduced "Vélo'v", 3rd generation bikesharing system starts to bloom worldwide. Following Figure 3 shows a system diagram for a typical third generation public bikesharing system and demonstrates the rental process while using the system.

Shaheen et al. (2010) propose the concept of 4th generation bikesharing and is still evolving and yet to be fully deployed. Generally speaking, it is demand-responsive, multimodal systems that builds upon the third generation with enhanced features and emphasis on mobile, clean docking stations or solar-powered stations; bicycle redistribution innovations (e.g., demand-responsive, and value pricing for encouraging self-rebalancing); multimodal access with smartcard integration with other modes; GPS tracking, real-time transit integration and system data dashboards; and electric bikes (Shaheen et al., 2010; Shaheen et al., 2012). Montreal bikesharing system could be seen as 4th generation for example (Bachand-Marleau et al., 2012).

Figure 3 Typical third generation bikesharing system

Source: this study

Recently, there is an experimental bikesharing scheme called "*shike*" in Stockholm where is unlike the concept of 3rd or 4th generation bikesharing system. This system totally embraces ICT technology with mobile phone and its exclusive app. For example, the available bikes would be located and users check the nearest bike then reserved the preferred with the app (Shike, 2014). "Shikers" can pick up everywhere and anywhere and keep the bike for how long they would like and pay with mobile phone. More importantly, they can even drop-off the bike wherever they like (Shike, 2014). Hence, the last-mile problem is really solved.

2.1.3 The present

Public bikesharing system has become a significant trend worldwide. According to Shaheen et al. (2010), at that time approximately 101 public bikesharing schemes are in operation with almost 140,000 shared bicycles across about 125 countries throughout the world. By 2012, it is reported that the number of bikesharing schemes are more than 150 in Europe and almost 30 in North America, respectively. Below Table 5 clearly demonstrates part of bikesharing schemes in the world currently.

Table 5 Worldwide bikesharing systems overview

City	Country	Scheme name (system)	Operator	Operator type	Launched date	# of stations[4] (or active)	# of bikes[4] (or active)
			Europe				
Barcelona	Spain	Bicing	Clear Channel	Private	22th March, 2007	421	10,280
Bordeaux	France	VCub	Keolis Bordeaux	Private	20th February, 2010	149	1,700
Brussels	Belgium	Villo!	JCDecaux	Private	19th May, 2009	329	7,868
Dublin	Ireland	Dublinbikes	JCDecaux	Private	June, 2009	75	2,104
Gothenburg	Sweden	Styr & Ställ	JCDecaux	Private	10th August, 2010	58	1,278
Lille	France	V'Lille	Keolis	Private	16th September, 2011	203	4,097
London	U.K.	Barclays Cycle Hire	Serco Group	Private	30th July, 2010	734	10,000+
Ljubljana	Slovenia	Bicikelj	JCDecaux	Private	2011	33	646
Luxembourg City	Luxembourg	Vel'oh!	JCDecaux	Private	2008	70	1,327
Lyon	France	Vélo'v	JCDecaux	Private	19th May, 2005	340	4,000
Milan	Italy	BikeMi	Clear Channel	Private	3rd December, 2008	188	5,120
Oslo	Norway	Bysykkel	Clear Channel	Private	2002	97	1,442
Nice	France	Vélo Bleu	Veloway	Private	18th July, 2009	168	2,984
Paris	France	Vélib'	JCDecaux	Private	July 15th, 2007	1,800	20,000+
Rennes	France	STAR	Keolis	Private	6th June, 2009	80	1,635
Saragossa	Spain	BIZI	Clear Channel	Private	May, 2008	129	2,611
Sevilla	Spain	SEVici	JCDecaux	Private	July, 2007	259	5,069
Turin	Italy	ToBike	Bicincittà	Private	6th June, 2010	133	1,813
Valencia	Spain	Valenbisi	JCDecaux	Private	21th June, 2010	276	5,497
Vienna (Wien)	Austria	Citybike Wien	Cyclocity	Private	May, 2003	117	2,913
Warsaw	Poland	VETURILO	Nextbike	Private	August 1st, 2012	175	2,500
			Australasia				
Brisbane	Australia	CityCycle	JCDecaux	Private	October 1st, 2010	144	3,000
Melbourne	Australia	Melbourne Bike Share (BIXI)	Alta Bicycle Share	Private	May 30th, 2010	51	886

[4] Most of the figure based on the end of April 2014 statistics

***Cont.* Table 5**

North America							
Boston	USA	Hubway (BIXI)	Alta Bicycle Share	Private	28 July, 2011	134	2,284
Chicago	USA	Divvy (PBSC)	CDOT	Public	June 28th, 2013	300	5,184
Denver	USA	Denver B-Cycle	Denver Bike Sharing	Non-profit	22 April, 2010	81	1,210
Miami Beach	USA	Deco Bike	DecoBike, LLC	Private	15 March, 2011	96	1,420
Minneapolis	USA	Nice Ride (BIXI)	Nice Ride Minnesota	Non-profit	10th June, 2010	169	3,020
Mexico City	Mexico	Ecobici	Clear Channel	Private	16th February, 2010	273	7,335
Montreal	Canada	Bixi (BIXI)	PBSC Urban Solutions	Public	12th May, 2009	450	8,864
New York City	USA	Citi Bike (BIXI)	Alta Bicycle Share	Private	27th May, 2013	330	11,467
San Antonio	USA	San Antonio B-Cycle (B-cycle)	San Antonio Bicycle Share	Non-profit	26 March, 2011	52	781
Toronto	Canada	Bike Share Toronto (BIXI)	Public Bike System Company (Bixi)	Public	3rd May, 2011	80	1,437
Washington, D.C	USA	Capital Bikeshare	Alta Bicycle Share	Private	20th September, 2010	319	2,600+
South America							
Buenos Aires	Argentina	Mejor en Bixi	City Government of Buenos Aires	Public	1st December, 2010	28	750
Rio de Janeiro	Brazil	Bike Rio (Serttel Samba)	mobilicidade	Private	November 2011	63	784
São Paulo	Brazil	Bike Sampa (Samba)	mobilicidade	Private	23rd May, 2012	137	1,648
Asia							
Daejeon	South Korea	Tashu (HongChui)	DaeJeon Metropolitan City	Public	2009	144	1909
Guangzhou	China	Guangzhou Public Bicycle	Guangzhou Public Bicycle Operation Management Co.	Public	22th June, 2010	50	4,840
Hangzhou	China	Hangzhou Public Bicycle	Hangzhou Public Transport Bicycle Service Development Co.	Public	1st May, 2008	2,177	66,500
Kaohsiung	Taiwan	City Bike	Kaohsiung Rapid Transit Corp. (KRTCO)	Public	1st March, 2009	149	4,130
Shanghai	China	Shanghai Forever Bicycle	Shanghai Forever Bicycle Co.	Public	October, 2011	594	19,000
Taipei	Taiwan	YouBike	Giant Manufacturing Co. Ltd.	Private	11th March, 2009	165	5,350
Zhongshan	China	ZSBicyle (Changzhou Eversafe)	changzhou Eversafe Public Bicycle System Co., Ltd	Public	10th October, 2011	483	11,886

Source: this study; the figure is collected from official website; O'Brien (2014); DeMaio and Meddin (2014)

2.1.4 Components

Generally speaking, a typical public bikesharing system (3rd generation) would have numbers of essential elements which are demonstrated in the following (Midgley, 2011):

1) bicycles:

The design concept of bicycle amis to provide users a comfortable riding experience, hence it should be adaptable to different users in terms of height and weight, mechanically reliable, resistant to theft or vandalism and distinguishable in appearance. Bicycles in most of bikesharing system (3rd or latest generation) are equipped with ICT equipment such as GPS, RFID tag or other tracking technology, facilitating the operation management.

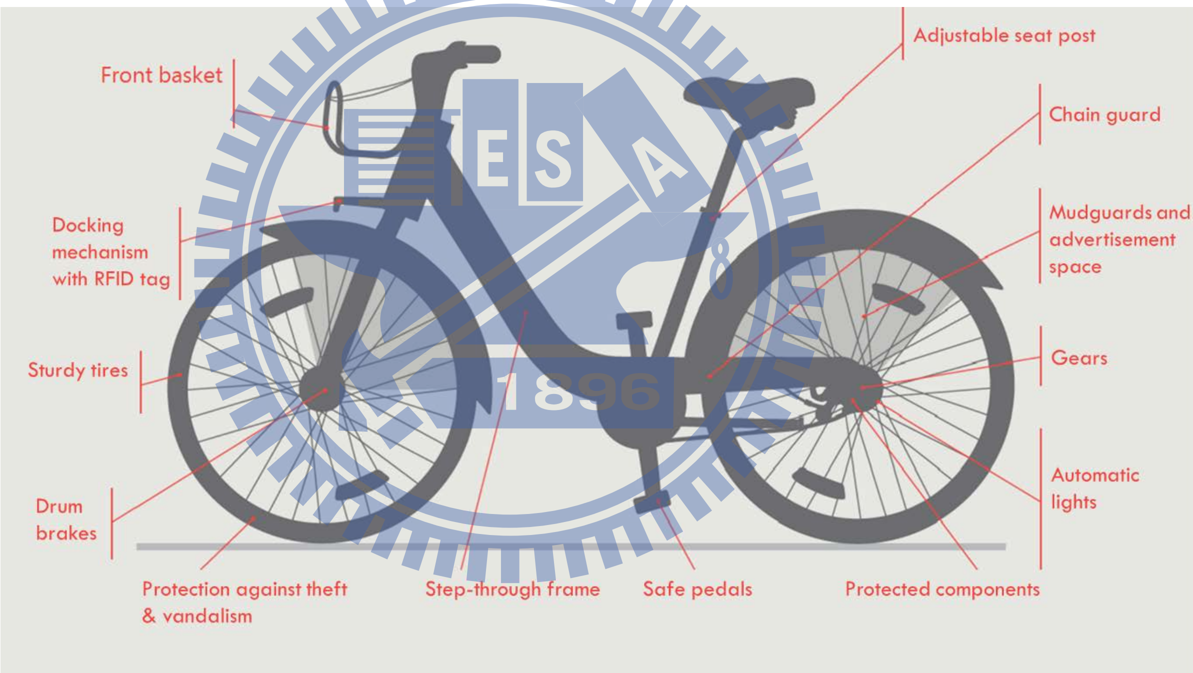


Figure 4 Bicycle elements

Source: ITDP (2013)

2) docking stations:

It is suggested by Gris Orange Consultant (2009) that there are three types of docking stations: fixed permanent, fixed-portable (modular) and flexible, respectively. The difference between fixed permanent and modular docking stations is mainly on the mobility of service terminals, the bike stands as well as the support of self-powered (solar power) for providing service. Thus, modular station has more flexibility in terms of installation; once the desired location is determined, it can be installed in a very short time (Gris Orange Consultant, 2009). One typical example of using modular station is Montreal bikesharing system, BIXI. In contrast, the flexible station has larger differences than the other two types. There is no need that bicycle should be locked in the docks; instead, it can be locked to any stationary object when not in use. Such flexible dockings used to be adopted by Copenhagen (Bycyklen); however, such system was abolished in October 2012 was launched again in 2014 with electronic bikes and fixed bike stands (DeMaio, 2012; Bycyklen, 2014). Below Figure 5 demonstrates fixed and mobile type of docking stations; note that some of bike stands in London also adopt mobile type. In addition, there are two types of station design which accommodate check-in and check-out: docking spaces and bike parking areas (ITDP, 2013). Normally each dock is for one bicycle; however two bicycles are for one dock in Taipei YouBike. Regarding bike parking area, bikes are stored together in a secured area, on racks.

(a) London Barclays Cycle Hire (b) Montreal BIXI

Figure 5 Types of docking stations

Source: (a) image by swanksalot, http://goo.gl/PVdXjM; (b) image by spacewaitress, http://goo.gl/rSN4nv

3) System access and user registration

Most of bike stations provide kiosks for users to register with debit/credit card or mobile phone to gain access to bicycles. The payment is usually processed through using smartcard or credit/debit card. There are number of ways for unlocking bikes, such as pin code, key fob or smartcard with an electronic user interface for bike check-out.

Advanced ICT not only facilitates the rental process but enabling to track bicycle usage and user information and helping to curb bicycle theft (TDG and PBIC, 2012).

4) System status information systems

Real time information about availability of bikes at stations, empty or full stations are provided on website and shown on mobile apps which is usually visualised presented.

5) Bicycle redistribution mechanism

It is expected that it would have asymmetric demand and supply among stations due to a wide range of factors such as geography layout of bike stations, weather etc. Therefore, redistribution mechanism is essential to ensure to meet the demand as possible, reducing the situation of empty or full stations. Redistribution is broadly defined as the rebalancing bicycles form stations which at low capacity or close to empty and is one of the greatest challenges in operation, accounting for around 30% of operating cost in European systems (ITDP, 2013). The redistribution mechanism used by YouBike is discussed in the next chapter (Chapter 3) afterwards.

2.1.5 Business model

The business model defines "the asset ownership and revenue flow between the government and the operator", aiming to balance service provision with resource allocation (ITDP, 2013). Normally, there are three main types of contracting structure as defined by the ownerships of the assets: (1) publicly owned and operated, (2) publicly owned and privately operated, and (3) privately owned and operated. Note that regardless of these structures, the government still take responsibility of overseeing the system, managing the contracts and monitoring the level of service. In terms of operators of bikesharing systems, it can be categorised into five main varieties: government agencies, public transport authority, or private entities which include for-profit companies and non-profit organisations (ITDP, 2013). Table 6 below provides an overview of bikesharing business models by types of providers.

Operating public bikesharing is generally not profitable since revenues from membership and usage fees are not sufficient to cover operation costs (Gris Orange Consultant, 2009). Therefore, a continuous steam of external funding is needed, which mostly come from the public sector or the private sector, or a combination of these two sectors depending on the business model. There

Table 6 Bikesharing business models and examples

Model (type of operators)	Standard operating model	Revenue source	Programme example
(1) <u>publicly owned and operated</u>			
Local governments and public authority	Directly design and operate a bikesharing programme or local government purchases bikesharing service provided by others and maintains the liability for the programme	Municipality funding Membership and non-member usage fees Ads and sponsorships on bikes and bike stations	Mejor en Bixi (Buenos Aires, Argentina) City Bikes (Copenhagen, Denmark, abolished 2012) OV-fiets (Netherlands) Shanghai public bicycle (China)
Public transport agencies	Provide bikesharing under the guidance of a public authority to enhance the public transport system	Government subsidies Membership and non-member usage fees Ads on bikes and bike stations	Hangzhou public bicycle (China)
(2) <u>publicly owned and privately operated</u>			
Advertising company	Provide bikesharing service in exchange for rights to advertise on city street furniture and billboards; service often operated as public-private partnership (PPP) with advertising company	Advertising funding from public space such as city street furniture, billboards, bus shelters, bikes, kiosks, and bike stations Membership and non-member usage fees	Bicing (Barcelona, Spain) Dublinbikes (Dublin, Ireland) Vélo'v (Paris, France)
(3) <u>privately owned and operated</u>			
For-profit sector	Provide profitable bikesharing services with minimal government involvement	Membership and non-member usage fees Ads and sponsorship on bikes and bike stations Private investment	Deco Bike (Miami Beach, USA)
Non-profit business	Provide bikesharing services under the support of public agencies or jurisdiction	Membership and non-member usage fees Public-private partnership (PPP) funding Local/national foundation grants Local business sponsorship	BIXI (Montreal, Canada) Wuhan public bicycle (China) Denver B-Cycle (USA) Nice Ride (Minneapolis, USA)

Source: adapted from Shaheen et al. (2010), TDG and PBIC (2012) is another way of financing bikesharing programme where advertising companies provide the services in exchange of the right to advertise on public space such as billboards, bus shelters, bike stations, kiosks etc. (DeMaio, 2009). It is also one of the most prominent funding sources (Shaheen et al., 2010). However, it is argued that advertising company may not put much effort to operate bikesharing since revenues generated by system operation usually does not benefit advertising companies (DeMaio, 2009). Each business model has its own pros and cons which are illustrated below (see Table 7). While these business models differ, there are still several characteristics in common as following (TDG and PBIC, 2012):

- station space permitting issues although some business models allow for more efficient expedition of public space permitting;
- funding for bikesharing programmes may be subject to additional regulations; and
- cross-jurisdictional agreement is needs to help dived the proportionality of costs and revenues between jurisdictions and the operator.

Table 7 Strengths and weakness by type of operators

	Advantages	Disadvantages
Government	Maintains great control of legislative and public assets necessary to make bikesharing successful; has no ulterior motive other than to operate a high-quality system	initial lack of expertise in bikesharing
Public transport authority	Has experience in managing transport-related service; facilitates cost sharing with existing assets such as customer service, maintenance personnel and depots	Difficulty in accessing and working with other transport providers due to being seen as competitors by others
Advertising company	Convenient and cost-effective for local governments that could not afford to provide the bikesharing service otherwise	Advertising company may not put much effort to operate bikesharing since revenues generated by system operation usually does not benefit advertising companies
For-profit sector	Generally achieves a high level of efficiency	Profit-oriented may conflict with maximising the utility of system for users; may reduce its efficiency due to financial constraints or suboptimal contractual conditions; limited ability to push for policy and planning changes in government
Non-profit sector	Prioritises the utility of the bikesharing system on the user	Frequent financially constrained; normally below-average business focus which may lead to financial unsustainability

Source: ITDP (2013); DeMaio (2009)

2.2 Determinants of bikesharing use

While there are some literature on the evolution of bikesharing system, bike station location planning, characteristics, impacts, ridership trends, inventory management as well as mobility and activity patterns, few studies have explored the characteristics of users using public bikesharing systems and the reasons why they use or not to use shared bikes. Little is known about the influence of socio-demographics and behavioural characteristics of bikesharing system users, attitude factors or environment or the attributes of system itself (supply side) such as station location, bike availability, pricing, etc., which should be investigated further. This section commences with discussing the factors affect the odds of cycling (mainly focusing on cycling to work), then further exploring those factors influence the use of shared bicycles in particular. Finally, it gives a short remark at the end of section.

2.2.1 Insights from factors influencing cycling

Identifying the factors affecting bicycle demand or cycling to work may give us some insights on investigating what factors affect the uses of bikesharing though literature are still quite few. There are a wide range of factors may influence individual's choice to cycling such as demographic and socio-economic, cultural and societal, environmental as well as policy-related determinants. Here provides an overview of these factors as discussed below.

Dill and Voros (2007) point out demographics and environmental factors which incorporate both objective-oriented (e.g., climate and topography, land use, and infrastructure) and subjective-oriented (such as attitude on travel, safety perceptions, convenience, cost, and time valuation) would have impacts on the level of cycling based on the survey conducted in Portland, USA. It reveals that demographic characteristics vary between types of adult cyclist and the desire to cycle more but the impact of income and vehicle ownership on cycling seems to be unclear. It is also found that built environment in terms of both objectively and subjectively has impact on cycling to some extent. Additionally, positive perceptions of more bike lanes is related to higher cycling level and the desire to cycling more; and higher level of street connectivity is related to more cycling for utilitarian trips as well. However, it should be noted that the influences of some socio-demographic characteristics on cycling are still uncertain. For instance, age and income are negatively related to cycle to work in some studies while having a positive or even no impact in others (Handy and Xing, 2011).

Several studies believe that providing bicycle infrastructure, particularly bicycle lanes and paths, can increase cycling. Dill and Carr (2003) highlight the importance of bicycle infrastructure, indicating that higher levels of bicycle infrastructure are positively and explicitly associated with higher rates of bicycle commuting. However, it does not indicate that there has a cause-effect relationship since people may cycle more for commuting because of more bicycle lanes or paths. Alternatively, it is the higher cycling level that leads to build more bicycle infrastructure. Buehler (2012) explores the role of bicycle parking, cycling showers, free car parking and transit benefits as determinants of cycling to work, which is based on the Washington, DC context. It indicates that bike parking and cycling showers at workplace are associated with higher bicycle commuting; additionally, if combined these two facilities together, it is significantly that it has greater influence on bicycle commuting compared with only bicycle parking provided. However, the results show that transit benefits provided by employer seems to be not related to bicycling commuting. Zhao (2013) examines the effects of the built environment on bicycle commuting in Beijing through using multinomial logit (MNL) model for estimating workers' travel mode. It is surprised that residential density has no significant effects in Beijing for bicycle commuting in comparison to Europe and North America. A higher level of public transit service is likely to decrease bicycle use in this case due to more new metro lines strengthening the pull effect and the competitiveness of low price. It is also interesting that even though higher level of exclusive bicycle lanes relates to more cycling to work, but the elasticity analysis shows the impacts are smaller than mixed environment. Thus it implies that integrated bicycle facilities with urban design would encourage cycling to work more effectively. Traffic safety and air pollution are also the major factors influencing bicycle commuting.

Climate (long-term) including the weather (short-term) conditions is widely confirmed that it would have influences on the individual choice to cycling. Koetse and Rietveld (2009) present an overview of empirical findings from various literature on the impact of climate change and weather on transport. It is found that changes in temperature, precipitation and wind have impacts on bicycle use in the view of utility; for instance, rainfall and both very hot and cold weather decrease cycling trips. This finding is also in line with the research by Dill and Voros (2007). Noted that temperature and precipitation are the most significant factor for those cycling to work in summer rather than winter. In addition, recreational cyclists are more likely to be affected by bad weather than utilitarian cyclists. Miranda-Moreno and Nosal (2011) investigate the use of urban bike facilities in Montreal to identify the impact of weather conditions on cycling ridership and to identify temporal trends of cycling ridership up to hourly scale through both absolute and relative ridership models. It is found that temperature, humidity, and precipitation have impacts on cycling ridership as expected; nevertheless, the impacts vary significantly across facilities and different time periods. Moreover, while temperature has a positive impact on ridership in most of time (if less than 28℃), the effect of humidity is negative. The combination of heat and humidity would decrease cycling ridership as well. Flynn et al. (2012) quantify the impact of weather conditions on individual decisions to cycle to work among a diverse panel of adult bicycle commuters for at least 2 miles. They find that temperature and precipitation are more likely to influence the likelihood of bicycle commuting, which is in line with other studies. In contrast, higher wind speed decrease the odds of cycling to work; moreover, snow depth seems to have a dampening effect that most respondents does not cycling to work in wither months. Noted that the survey focuses on morning commuting condition and neglects the likelihood of other work schedule. Saneinejad et al. (2012) explore the impact of weather conditions on active transport travel behaviour in the city of Toronto through using MNL model on five transport modes; and the interaction between weather and age as well as gender are also investigated through two sub models. It is found that the utility-based cycling decreases in the situation of temperature below 15 °C while cycling becomes insensitive if temperature higher than 15 °C. Wind speed and precipitation are found that negatively influence cyclists more than pedestrians However, Nankervis (1999) suggest that neither weather nor climate would be a strong deterrent to bicycle commuting, and this is generally based on which the rider groups surveyed response. There are several more subtle factors in association with social or psychological act as deterrents to bicycle commuting. For example, the perception of the effect of weather conditions particularly in the traffic dominated by cars, or road conditions, traffic patterns, etc.

It is suggested and concluded that there are several main determinants of bicycle use based on the findings from various studies: demographic and socio-economic, cultural and societal, environmental including weather, urban spatial structure, and infrastructure, and policy-related determinants (Vandenbulcke et al., 2011). Similarly, Handy and Xing (2011) also propose a cross-sectional study of bicycle commuting in six small U.S. cities to explore the relationships between bicycle commuting and individual factors (e.g., socio-demographic characteristics and attitudes), physical and social environment of the work place. It is suggested that individual attitudes and constraints are the most important determinant of bicycle commuting while physical environment is likely to have only a marginal effect directly. It is also found that females are substantially less likely to cycle to work than males, as consistent with previous researches. It is surprising that providing bicycle facilities such as racks, showers, etc. close to the workplace does not indicate a significant influence on bicycle commuting. It implies that the provision of facilities may be a welcome amenity, but it seems not to be a main deterrent for bicycle commuting which is in contrast with the findings by Buehler (2012).

Winters et al. (2013) build a spatial tool through mapping "bikeability" to identify areas that are more facilitative or less facilitative to cycling in terms of opinion survey, travel behaviour studies, and focus groups to forming the bikeability index and their relative importance. It is reported that bicycle facilities, aesthetics, topography, traffic and trip distance are the main built environment factors influencing cycling. While travel behaviour survey indicates that bicycle facilities, connectivity, topography, and land use are the domains for cycling, the focus groups provide useful information on the relative importance of built environment factors. Bicycle facility is the most important among built environment factors, which are about twice the score as traffic. Followed by street network, topography, environment, travel distance and neighbourhood land use. Population density is the least importance among these factors.

Rietveld and Daniel (2004) give a general framework of factors that have a potential impact on bicycle use, which includes: (1) *individual features*: income, gender, age, and activity patterns; (2) *generalised cost of bicycling*: travel time, physical needs and comfort, traffic safety, risk of bicycle theft, monetary cost of bicycle use, and personal security; (3) *generalised cost of other transport modes*: such as parking cost, fuel tax; and (4) *local authority initiatives*: quality of capacity of bicycle dedicated infrastructure, spatial design of city and etc. However, the gap of the factors influencing the uses of bikesharing and cycling between bikesharing users and traditional cyclists does not addressed in this research.

Heinen et al. (2010) perhaps offer a comprehensive overview of academic literature on bicycle commuting so far to the author's knowledge; and focus on empirical results in particular from various aspects such as travel behaviour, transport planning, psychology and health science, as shown in following Table 8. This study also examines the individual's daily choice toward cycling or not in terms of frequency. It is found that using conventional mode choice models may be insufficient and not be able to address some determinants; hence, other kinds of knowledge should be introduced and help to investigate the gap between for those currently available for motorised forms of transport and active transport.

Table 8 Overview of determinants of cycling (to work)s

Determinants	Influence mode choice	Frequency	Preference	Comments
Built environment: (1) urban form				
Trip distance	increase results in less cycling; (according to 27% of non-cyclists, compared with 2% of cyclists)	No studies found on how access and egress distance affect cycling frequency		• The built environment affects a person's choice to commute to work by bicycle;
Network layout	No significant effect on cycling	People living closer to city centre cycle more		• Cycling share is influenced by the following factors: distance, function mixture, storage facilities, block size and density, the presence of bicycle infrastructure and its continuity, traffic lights and stop signs, land use, parking facilities and showers at workplace; and
Density	Higher density relates to more cycling	people living close to city/town centre cycle more (decrease from 56% to 46% of non-cyclists closer to the centre)		
Function mixture	Residential densities have no effect; higher density increases bicycle share	people living close to city/town centre cycle more		• Of these factors, distance seems to be the most important factor; and
Built environment: (2) cycling infrastructure			separate facilities (safety issue)	• The presence of infrastructure might not only result in more cycling, but a higher cycling frequency could also stimulate the construction of bicycle infrastructure.
Adjacent to parking			Roads with no parking perceived to be safer	
Continuity of cycling infrastructure		Unclear	Preference for continuous facilities	
Number of bicycle paths	More cycling infrastructure results in more cycling (increase of 1-2%, but probably depending on location	No effect		
Traffic lights	More traffic lights in a city associates with lower cycling levels		Experienced cyclists perceive them more negatively	
Built environment: (3) facility at workplace				
Bicycle parking	No significant effect on cycling		important to cyclists	
Shower at workplace	If present more cyclists	Seems not to result in higher cycling frequency	important to cyclists; Bicycle locker mostly preferred	
Locker at workplace	No effect	No effect	important to cyclists	
Natural environment				
Hilliness and land scape	Less cycling with hills			• A climate with moderate temperatures and little rain increase the share of bicycle commuting; and
Season	More cycling in summer and autumn (differs between locations			

Temperature	Unpleasant temperature corresponds with less cycling	Unpleasant temperature corresponds with less cycling	Less influential for commuting; more influence on women	• Bad and uncertain weather negatively affects a person's decision to cycle.
Precipitation	Cold more unpleasant than heat; negative effect on cycling	May have effect	Mentioned by cyclists as most negative weather aspect	
Socio-economic variables				
Gender	No Effect; Men cycle more than women	Men cycle more than women		• The relationship between socio-economic factors and cycling is unclear.
Age	No effect; Women cycle more than men; Cycling declines with increase; Age is not significant			• In most countries, men cycling more than women; in those countries where cycling is very common, such as Belgium and the Netherlands, women cycle more;
Income	Positive connection between income and cycling; Negative connection			• Car ownership has a negative effect on cycling; logically, bicycle ownership has a positive effect; and
Employment status	No significant connection	Part-time workers commute more frequency by bicycle		• Most research merely mentions or examines the relationship between socio-economic factors and cycling, but does not allow us to make any inferences about the causality of this relationship.
Car ownership	Car ownership decreases cycling Car ownership has no effect	Car ownership decreases cycling; having few cars increases cycling frequency		
Psychological factors				
Attitude	Cyclists have a more positive attitude towards cycling			• There is a relationship between commuting by bicycle and people's attitude as well as perceived values. More cycling may result from positive perceptions of cycling or negative perceptions of car use. If people's social surroundings have a positive opinion of cycling, then higher chance of cycling
Perceived social norm	Cyclists have a higher perceived social norm; No effect on being a cyclists			
Habit	A cycling habit increases the cycling share	A cycling habit increase the cycling frequency		
Cost, time, effort and safety				
Cost of other means of transport	It higher, more cycling			• It is thought that people sometimes decide whether cycling to work with other transport options in terms of cost, travel time and safety. Negative factors relating to car use or public transport could lead them to develop a more favourable view of cycling; and
Travel time			Experienced cyclists prefer short travel time	
Safety	A reason not to cycle		Subjective safety does not always correspond with objective safety	• Travel time and safety seem to be more important for cycling than for other modes of transport.

Source: Heinen et al. (2010), Kim et al. (2012)

2.2.2 Factors influencing the use of shared bicycles

Krykewycz et al. (2010) identify the potential primary market area of bikesharing in Philadelphia, Pennsylvania (USA) through a raster-based GIS analysis which is represented as bike share score for each location in the raster grid. There are three main factors, including trip origin, trip attraction, and network and facility factors, used in this study to illustrate the potential use of bikesharing system. These factors are mostly associated with spatial layout and land use pattern such as locations of tourist attraction or bus stops, proximity to parks and recreation areas, rail stations, and street with bicycle lanes, etc. However, the factors of demographics, behavioural characteristics of users, user's attitude, and system characteristics are neglected in this study. Noted that bikesharing trips in the primary market area are estimated in terms of three demand scenarios through observed bikesharing diversion rates in other European countries, which may only provide the overview of bikesharing usage.

Bachand-Marleau et al. (2012) investigate that the likelihood of using bikesharing system (BIXI, in Montreal) in terms of three main types of variables: socioeconomic characteristics, transportation habits, and spatial characteristics based on a survey conducted in Montreal in the summer of 2010. Furthermore, the factors influencing frequency of using shared bikes are identified as well. It is found that while many of factors influencing the likelihood of using shared bicycles are associated with transportation habits, the proximity of home to bikesharing docking station has the greatest effect. Followed by those people combined cycling and transit already, owing a driver's license[5], destination being proximity to bike stations and being a bus user are more likely to be bikesharing system users. In terms of frequent use of shared bikes, owing a yearly membership has the greatest impact on the number of uses of shared bikes, followed by using BIXI for avoid bicycle maintenance and its distinct design, and avoid theft. It indicates that the factors influencing the use of shared bikes may not be the same as those that increase the frequency of use. While transportation habits and spatial factors play a key role in prompting users to use shared bikes, users' motivation dominates the frequency of use actually (Bachand-Marleau et al., 2012).

Campbell (2012) identifies the difference between the factors influencing the choice to shared bikes or shared e-bike system in Beijing, which is answered by conducting stated preference (SP) survey. This study indicates that the choice of using shared bikes is largely influenced by

[5] It is because most of BIXI users in Montreal have a driver's license; therefore, it has greater chance that adult BIXI users also have driver licenses.

distance, environmental conditions and user's transportation habits whereas the choice of using shared e-bike is rather influenced by "taste heterogeneities", namely social class, age, gender and environmental concern.

Kim et al. (2012) address the factors influencing travel behaviour in bikesharing and determine their impact on the frequency of bikesharing usage. Five variables are chosen that may significantly influencing bikesharing usage: the floor area of nearby residential and commercial buildings, parks, schools, and subway stations. Additionally, weekdays and weekdays; precipitation (rainy or non-rainy days), and departure point and destination are also considered to have different riding patterns on bikesharing. However, this study only focuses on the effect of specific land use and facilities on bikesharing usage in the view of demand forecast; notably, socio-economic variables or other built environment factors or environmental factors are neglected in this study.

Buck et al. (2013) investigate user travel behaviour of bikesharing system in Washington, D.C. to see the differences to regular cyclists and develop a profile of user demographic among short-term (1-day) users, annual member and area cyclists. The factors such as demographics, income, car ownership, bicycle access are examined; in addition, trip purpose, mode shift and helmet use of Capital Bikeshare are identified as well. Both short-term users and annual members are more likely to be female and younger, to have lower household incomes, and to own few cars and fewer bicycles and are more likely to cycle for utilitarian purpose. Note that short-term users would be more likely to cycle for recreational purpose if compared to annual members.

白詩榮 (2013) in his master dissertation identifies the factors influencing the use of bikesharing based on Taiwan context in terms of main four aspects: city characteristics, system friendless, environmental friendness including riding environment and riding convenience, as well as individual behaviour and preference. He proposes a survey to infer the usage characteristics and behaviours of public bikesharing in Taipei City (YouBike) on the grounds of people's cognition, preference, perception resulted from these factors and explores the demand model of YouBike. If is found that overall use of bikesharing and for commuting by bikesharing are affected by the perception, socio-economic variables and individual cognition. It is also shown that students and other groups of YouBike users are actually not different significantly.

2.2.3 Remarks and key findings

Better understating the factors that influence the use of bikesharing system and the frequency of use would provide useful information in policy formulation for promoting the use of shared bicycles. Location of bikesharing stations, transportation habits of current bikesharing system and potential users, the fear of bicycle theft, and the status and perceptions regarding to shared bicycles are the four major aspects for encouraging shared bicycles usage (Bachand-Marleau et al., 2012). However, what influences the frequency of bikesharing usage seems to be dominated by other factors such as weather conditions, daylight time, habit, motivation, land use and facilities such as parks, metro stations (Stinson and Bhat, 2004; Heinen et al., 2010; Bachand-Marleau et al., 2012; Kim et al., 2012). The key findings of factors influencing bikesharing usage and frequency of use from literature is as follows:

- Generally speaking, the factors influencing bikesharing usage can be categorised into following five aspects: built environment (spatial context), natural environment, socio-economic characteristics, psychological factors, and cost, time, effort and safety;
- Factors influencing the use of shared bikes may not be the same as those that increase the frequency of use;
- While the provision of shower facilities influences the choice of cycling to work positively, the presence of shower facilities does not seem to result in higher frequencies of cycling to work;
- The natural environment has a large influence on both the decision to cycle and frequency; weather conditions mainly affect the frequency of bicycle commuting; and
- Habits both affect mode choice and frequency of cycling.

The results of these research would provide some useful information and direction for transport planners to promote cycling. Towards better understanding of determinants of bicycle use, it is expected that the effectiveness of strategies can be secured by providing directions as to which factors are likely to have influences.

2.3 Station activity and spatiotemporal patterns

Human mobility patterns have received increasing attentions recently. This section builds on reviewing literature on station activity and spatiotemporal patterns of public bikesharing system. In addition, the way how they collect data to identify these patterns is also covered. Finally, the applications of these station activity patterns to predict the number of available bike for any station at a given ahead are examined as well.

Froehlich et al. (2008); Froehlich et al. (2009) examine and analyse Barcelona bikesharing system, Bicing, through an extensive 13 weeks of bike station usage data to uncover patterns of human behaviour. Temporal and spatiotemporal patterns among bike stations are explored; in addition, clustering is applied in terms of "activity" and "bicycle" cluster category to illustrate how these patterns associate with location, neighbourhood, and time of day. Results shows that neighbouring stations are likely to share similar usage patterns. Four predictive models are implemented to predict the near-term availability of bicycles at each station; it is found that Bayesian Network (BN) performs best to predict as smallest average error of 0.08 normalised available bicycles (NAB). The factors that have impacts on predictability of the station usage are discussed as well. This study shows the potential of bike station usage as one source of human movement dynamics in the city, helping to uncover underlying mobility patterns and inferring attributes about neighbourhood. It also indicates that 10 to 15 weekdays are enough to build station models.

Kaltenbrunner et al. (2010) also perform an analysis of human movements of Bicing in Barcelona by means of exploring and predicting trends of the bikesharing system during the 7–week period between May 15th and July 3rd, 2008. Local activity cycles among stations are used to aggregate these cycles to infer global mobility cycle of Barcelona. It is observed that different patterns in different stations, depending on the station location and time of day. In terms of global activity cycle of Barcelona, while the standard deviation in weekdays is quite stable throughout the data collection period, the weekend deviation is slightly greater than weekdays. It may because of larger number of working days than weekends (35 vs. 14) and more flexible time on weekends. Mobility patterns are illustrated for different times of the day by local activity cycles with the station's geo-coordinates and the difference of available bikes compared to a given time (i.e., 5:00). This study also applies prediction of activity in terms of several simple prediction models and more advanced time series model (auto-regressive moving average, ARMA) which not only takes into account the recent history of current station but also its surroundings. The results highlight the importance of the dynamics of neighbouring station for predicting bicycle availability at a given station.

Borgnat et al. (2011) use data mining methods to analyse spatial patterns of station activity of Lyon's public bikesharing system, Vélo'v. Temporal patterns of the bikesharing system usage are examined. It reveals that there are three parks on weekdays (i.e., 8am – 9am, 12am – 1pm, and 5pm – 7pm) and two peaks on weekends (1pm – 2pm and 4 pm – 6pm). Furthermore, spatial patterns are examined as well in terms of clustering flows of activity between stations, which clearly shows the dynamics on the network in space and time. The communities are found to be mostly grouped by geographical proximity in the city, indicating a preferred short distance use of the shared bicycles. This study also addresses a statistical model for the prediction of the number of bicycle rentals on a daily or hourly basis.

Vogel et al. (2011) also use data mining techniques to obtain insights into station activity patterns. This study hypothesises the bike station activity as well as the type of customers depending on station location and the surroundings. It is examined by cluster analysis in terms of three aspects: (1) pickup and return activity of stations; (2) customer behaviour, as leading to customer segments with different rental behaviour; and (3) location factors of stations. Results show that there are five different activity patterns based on their temporal pickup and return activity at stations. For example, cluster *Pickups Morning Returns Evening* (PMRE) refers to stations which are likely to have higher pickup activity in the morning and dominant return activity in the evening. The visualisation of these clusters geographical distribution helps to clarify these activities whether depends on spatial factors; for instance, stations in cluster PMRE are found to be more likely located at the periphery with residential buildings.

Lathia et al. (2012) investigate how the access policy change (from key required to allow for casual usage in a simple way) would affect the usage of Barclays bikesharing system. Hence, the data of pre- and post-policy change on bicycle usage are collected. The impacts of opening the London shared bicycle scheme to casual users are measured in terms of average system-wide temporal trends on weekdays and weekends, spatiotemporal differences between these two datasets, and the differences between the datasets at the station level. It is found that quicker access to the system reinforces the two peaks of the morning and the evening commuting trips whereas the weekend usage has a specific peak during the mid-afternoon hours (around 4pm). Hierarchical clustering algorithm is used to group the stations based on their usage patterns and the results are mapped to see how station activity relates to the city's geography. Six clusters are generated and represented as three typical types of behaviour among stations: *Day-Time Origins*, *Day-Time Destinations*, and *Combined Origins/Destinations* for both pre-and-post datasets. The results indicate neighbourhood stations tend to have similar usage behaviours. It is found that some changes occur due to the broader access policy such as some stations change their cluster however the overall behaviour remains the same; hence departure station becoming an arrival station and vice versa. A more detailed analysis is provided for station activity changes. It concludes that although important variations in bikesharing usage across policy changes and the surroundings of changing stations are observed, these only give little explanation of why changes occur. Therefore, it can be addressed by qualitative work on bikesharing usage for telling why people opt for bicycles.

O'Brien et al. (2014) may be the first comparative study of using data mining on bicycle sharing data across 38 public bikesharing systems in Europe, the Middle East, Asia, Australasia and United states. It aims to discuss various metrics and obtain insights into and classify each bikesharing system. Like other similar studies which have been done previously, aggregate, spatial and temporal characteristics and their changes in bicycle distribution are examined. Additionally, the non-spatial and spatial characteristics of bike stations in terms of locations are discussed for comparison as well. Load factor, used as a key measure for examining aggregate characteristics at bike stations, is the proportion of docking points in each bike stations that currently available bikes at each station for hire. Results show that while average maximum load factor is around of 48% worldwide whereas a bit lower in Europe's average (45%) and slightly higher in America's average (50%). Compactness ratio (or circulatory ratio) and Z-score are the two measures of describing system shape and layout respectively. Generally speaking, bikesharing systems in Europe tend to have higher compactness ration and higher Z-score, which is largely because of European systems being more likely to concentrate in the traditionally compact areas of the cities. In terms of temporal characteristics across different bikesharing systems, it could be categorised into six qualitative classifications and corresponding predicted demographic of the system. For example, YouBike, Dublinbikes and Vélo'v are dominated by the pattern of more than two commuter peaks on weekdays and users are mostly expected to be commuters with some utilitarian purposes. Wards' Hierarchical clustering is used to reveal spatial similarity among different bikesharing systems in the world, offering a useful basis for operators to anticipate activity patterns and gain some insights from similar systems. Below Table 9 illustrates the reference table relates to activity patterns.

Table 9 Reference table relating to activity patterns

Study	Study context	Methods	Data duration	Results and findings
Froehlich et al. (2009)	Bicing, Barcelona	Hierarchical cluster analysis (Ward's method as dendrogram clustering); station behaviour prediction	collect at 2 minutes interval; from Aug.27, 2008 for 13 weeks	• A repeating three-pronged spike in station activity during the weekday, morning, lunch and evening commutes; • Simple predictive model are able to predict station usage data with only average 2 bicycles error and able to classify station state (full, empty, or in-between) with 80% accuracy up to 2 hours ; and • 10 to 15 weekdays of historic data are enough to build station models.
Kaltenbrunner et al. (2010)	Bicing, Barcelona	Prediction and time series analysis (auto regressive moving average model)	2 minutes collection interval; from May 15 for 7 weeks	• It reveals that the dynamics of neighbourhood stations certainly have an important incidence on the ability of predicting bicycle availability at a given station;
Borgnat et al. (2011)	Vélo'v, Lyon	Hierarchical clustering for communities; Non-hierarchical clustering (K-means) for flows between stations; Statistical model for prediction	From May 2005 to the end of 2007; the records of all bicycle trips	• Five hierarchical communities of stations are clustered where mostly grouped by geographical proximity; close stations exchange more bicycles than distant • The clusters of flows of activity between stations reveal the dynamics on the bikesharing system network in space and time
Vogel et al. (2011)	Citybike Wien, Vienna	Geo BI approach; Clustering analysis (non-hierarchical method)	ride information including pickup and return station; 2008 to 2009;	• To examine the relationships between spatial factors and station activity patterns; and • Exploratory and cluster analysis reveal that spatiotemporal dependencies of pickup and return activity patterns at bike stations
Lathia et al. (2012)	Barclays Cycle Hire, London	pre-post comparison; Hierarchical cluster algorithm	scraping data every 2 minute; pre-casual data: Oct.17, 2010 to Dec. 3, 2010; post-casual data: Jan 2, 2011 to Feb.22, 2011;	• The clusters of stations are likely to be rings of activity patterns surrounding central London; and neighbouring stations tend to share similar usage behaviours; • Six clusters are generated to represent three types of behaviours among various stations; and some stations change their membership between pre-and-post datasets; and • Average changes of activity patterns are not huge and not spatially uniform;
O'Brien et al. (2014)	Various bikesharing systems in Europe, the Middle East, Asia, Australasia and United states	Comparative analysis; Hierarchical clustering	Collect every 2 minute; Data throughout September, 2012	• Typical maximum load factor would be just under 50% for most of systems; • There are six classifications of worldwide bikesharing system based on the temporal characteristics and also four types of demographic characteristics of the cyclists are stated; and • To reveal activity patters which infer the typical working hours of a city

Source: this study

2.3.1 Clustering algorithm

Cluster analysis only group samples based on the provided information that describes the objects and their relationships. The goal of clustering is that the objectives within a group are similar to each other and different from the objects in other groups (Tan et al., 2006). There are various types of clustering but the most commonly discussed would be hierarchical (nested) and partitional (or non-hierarchical) clustering. K-means is a typical partitional clustering technique that attempts to find a specified number of clusters (*k*), represented by their centroids. The algorithm of K-means is that forming K clusters by assigning each point to its closet centroid firstly and the centroid of each cluster is updated based on the points assigned to the cluster. Then followed by re-computing the centroid of each cluster until no point changes clusters or the centroid remain the same (Tan et al., 2006). There are various agglomerative hierarchical clustering algorithms holds the same concept where starting with individual points as clusters, successively merge the two closest clusters and update the proximity matrix to reflect the proximity between the new cluster and the origins until only one cluster remains (Tan et al., 2006). Ward's method is one the most common hierarchical clustering approach; it measures the proximity between two clusters in terms of the increase in the SSE resulted from merging two clusters. It also attempts to minimise the sum of the squared distances of points from their cluster centroids (Tan et al., 2006).

Froehlich et al. (2009) use a hieraarchical clustering method (dendrogram clustering) and generate two clusters to investigate Bicing usage patterns geographically distribitrd in the city. In addition, the distance between clusters is measured by Dynamic Time Warping (DTW) based metric with a one-hour Sakoe-Chiba band becaouse of interest in comparing overall temporal patterns and allowing for up to one hour of tempotal shifts in the data. Activiy Cluster is based on how active a staion in a given time on weekdays, which is calculated by the absolute value of changes of the number of bicycles in a given time. The other is Bicycle Cluster based on weekday available bicycles. Note that the information of station geolocation, surroungding geographical layout or other information are not included in forming clusters.

Borgnat et al. (2011) use hierarchical clustering to group stations in communities which share similar behaviours to understand the impact of the inhomogeneity of the city on the long-run activity of stations. The results are applied to one year of data and visualised; it reveals that the grouped communities of stations are spatially close, even though there is no geographical information involved. The flows between stations at finer time-scales are also clustered by using

K-means algorithm to explore spatial patterns; and Silhouette measure is used to estimate the similarity among pairs of stations in its own cluster vs. pairs in other clusters.

Vogel et al. (2011) use non-hierarchical cluster analysis to group station based on their normalised bicycle pickup and return activity in terms of three algorithms: K-means (KM), Expectation Maximisation (EM), and Sequential Information Bottleneck (SIB) to evaluate the different outcomes for choosing a desirable number of clusters. Note that there is still no extra information considered by these measures and the clustering tendency of the data is validated by Hopkins-Statistics (0.73), suggesting that the data is suitable for cluster analysis. The number of clusters is evaluated by three index: Davies-Bouldin-Index, Dunn-Index, and Silhouette-Index. The higher value of Dunn and Silhouette Index the better whilst Davies-Bouldin-Index holds opposite. Results indicate that 5 clusters would be best suggested by all these algorithms; moreover, EM is better than the others. Therefore, EM is chosen for 5 clusters to examine temporal and spatial patterns of station activity.

Lathia et al. (2012) also use hierarchical cluster algorithm to group the stations according to their usage patterns which are represented by normalised available bicycle, NAB proposed by Froehlich et al. (2009), and visualised onto a map to examine the relationship between usage and geography. Similar to other studies mentioned above, there is no geographic information involved in the clustering process. This clustering process can be divided into three steps: firstly, a 3-side moving average to smooth the data; secondly, similarity measure is used to compare cluster using Euclidean distance; and finally, merging clusters with a weighted average until the average intercluster-to-intracluster distance is maximised. O'Brien et al. (2014) use hierarchical clustering algorithm (Ward's method) to evaluate 38 bikesharing systems in the world through a number of factors based on geographical footprint and location, and bicycle occupancy of daily variations. Results illustrate that further understanding of demographics of the system users in each city is identified, revealing communities of users and showing significant spatial similarity between different system characteristic as well. Moreover, it is also suggest that location is not being an input during the clustering process normally.

As mentioned above, most of literature associated with exploring station activity patterns use hierarchical algorithm for grouping similar station based on their usage patterns while there are some choosing non-hierarchical algorithm (i.e., K-means) to generate the best number of clusters. Both methods have their advantages and disadvantages; thus using two-stage clustering algorithm would be a better choice.

2.3.2 Urban sensing and Open Data

Traditionally, the data of mobility pattern studies are obtained either from sensing device (e.g., GPS handset, mobile phone) or observational mechanisms such as questionnaire (Etienne and Latifa, 2012). However, the development of information and communication technology (ICT) as well as the advent of new observations and tracking capabilities have enabled the data availability more easily than before. Actually, ICT underpins the data flow of daily life. While ICT applications in transport system varies, ICT basically not only links the transport sectors with complementary sectors and facilities but connects different types of technologies and functions to provide services to users (Grant-Muller and Usher, 2014). It is widely accepted that ICT can potentially be a power driver to affect travel behaviours, improve efficiency, enhance safety and reduce environmental impacts on urban mobility, enabling it as a sustainable solution (Grant-Muller and Usher, 2014; Baptista et al., 2012; van Geenhuizen, 2011).

The development of "Open Data" (mainly refer to public sector information[6]) facilitates the opening up of government information to public access, aiming to provide free of restrictions on use or redistribution (Bakıcı et al., 2013; Heimstädt et al., 2014). Generally speaking, open data means data that is technically and legally made available to the public for reuse and redistribution; moreover, it is accessible (normally via the internet) at marginal cost and without discrimination, and available in a standardised format (Heimstädt et al., 2014; Lindman and Nyman, 2014). The use of open data and discussions is already commonplace among biological science for instance, yet it is not fully discovered and still has a large potential in other fields of studies (Jäppinen et al., 2013; Lindman and Nyman, 2014). Jäppinen et al. (2013) model the potential effect of shared bicycles on public transport travel time in Greater Helsinki through using open data approach to access urban transport information for travel time analysis, helping to analyse multimodal urban mobility patterns. It shows the possibility of application such as journey planner which is benefited from open data has been explored recently on the research front.

In addition, open data is also very helpful and easily in collecting data since it is open-access and seems to be perfectly solve the privacy issue. The collected data are usually in a large scale; thus using data mining is a common approach to help to examine and discover the facts behind the big data. There are several bikesharing system studies facilitated from this approach.

[6] However, open data also includes data released by private sectors

Normally the data are collected automatically at a fixed time interval through the link provided by the operator and generally include the information of bike station locations, capacity, current availability of bikes and number of empty spaces (see Froehlich et al., 2008; Froehlich et al., 2009; Kaltenbrunner et al., 2010; Vogel et al., 2011; Lathia et al., 2012; O'Brien et al., 2014). There also some similar studies using data-centric approach for analysing bikesharing systems. For example, Jensen et al. (2010) sense usage data from Lyon's bikesharing system stations and find that shared bicycles now compete with car usage in terms of travelling speed in downtown Lyon. The data also help to compare Vélo'v trips distance between stations to car and pedestrian distances and calculate spatial patterns in Vélo'v use on all streets. Therefore, it is useful information for designing cycle paths network. Nair et al. (2013) analyse data from Paris' bikesharing system, Vélib' from several aspects such as system characteristics, utilisation patterns, the casual relationship between transit proximity and bike stations, and flow imbalances between stations. It is suggested that proximity to transit stops indeed leads to higher bikesharing usage; and multimodal trips with shared bicycles can provide value-addition to users, thus giving insights into multimodal integration.

2.3.3 Prediction of bike stations activity

There are some studies interested in the prediction of station usage as more details described following. In addition, predicting bike station usage is expected to have following advantages (Froehlich et al., 2009):

- Allowing for more accurate load balancing of the stations;
- Providing expected station activity information to operators and stakeholders; and
- Allowing for new mobile services to users to inform possible station activity.

Both studies of Froehlich et al. (2009) and Kaltenbrunner et al. (2010) focus on predicting the number of available bicycles at a given station at a given time. In the contrast, Borgnat et al. (2009) however predict the number of shared bicycles hired per hour taking into account external factors to the cycle patterns. According to Froehlich et al. (2009), four simple predictive models are used which are last value (LV), historic mean (HM), historic trend (HT) and Bayesian network model (BN. Note that all of these models have three input parameters: (1) the current time t_0; (2) the current number of bicycles at time t_0 , denoted as B_{t0}; and (3) a prediction windows (PW) ranging from 10 minutes to 120 minutes. Three weeks of historic data are used to form the three history based predictors, LV, HM and HT. In terms of BN model, extensive experiments with two pilot stations as to determine the optimal dimensionality[7] of three observed (input) nodes which are *time*, *bik*e (normalised available bicycles, NAB), and *PW* with six possible values in the future, and one hidden (output) node, *delta*[8]. Therefore, prediction of bikes are made through the current available bikes plus the value of *delta* node. Each BN is trained by computing a posterior over the parameters from the observed data in terms of *time, bikes, PW* and *delta* where *time* covers the three-week period of training data in five minutes increments. Results show that BN model performs the best among these models with smallest average error of 0.08 NAB (e.g., average error of 2 bicycle if corresponds to a station capacity of 25) whereas HM predictor has the worst performance, implying station daily activity is quite varied in comparison with historic mean. Station state of full or empty are taken into account as well. Similarly, BN model still perform the best if up to 2 hours prediction in the future with 80% accuracy either for empty station or full station state prediction in the most challenging scenario (i.e., PW for 120 minutes). However, HM and HT predictors are replaced by decision tree classifier (ID3) and support vector machine classifier (SVM) due to poor estimation. Practically, most bikesharing users tent to be interested in the available numbers of shared bicycles within next 60 minutes in the future. And LV, HT, and BN models are actually able to provide sufficient accuracy only within one bicycle error.

Kaltenbrunner et al. (2010) use two basic predictors which are baseline model and gradient-based prediction, and advanced time series analysis method, i.e. auto-regressive moving average (ARMA) model. More specifically, baseline model is to predict the current state of the problem for any time in the future whereas the other is based on inferring from the current state using only data tendencies of the same day of the week. These two models are compared in terms of mean error for different time offsets such as 10 minute, 30 minutes or more in the future. Notably there is no significant difference for predicting in a very short period of these two models; however, a greater performance of prediction using the gradient of the average activity cycle. In terms of ARMA model, a history of 20 minutes (i.e. 10 samples) usage data are used to generate for both AR (auto-correlated nature) and MA (information from surrounding stations) components, resulting in the same order of 10. The optimal number of surrounding station used for MA component is tested through examining the average absolute error for a set of different ten stations with different number of surrounding stations. While

[7] The optimal dimensionality is based on the prediction error
[8] All observed data of *time, bikes* and *PW* are the parents of the *delta*

using 15 surrounding stations achieves the least mean absolute error, actually the performance of the number of surrounding stations ranging from 5 to 20 have no significant differences. Additionally, the prediction error over the time intervals ranging from 2 minutes to 60 minutes is evaluated with consideration of 5 closest surrounding stations. Results show that the average prediction error is below 1 bicycle at a 30-minute prediction interval while the error increasing to around 3 bicycles at one hour prediction interval. Although there are smaller prediction errors in the prediction interval of less than 20 minutes, it may be resulted from the low-pass filtering applied to the data. It seems that ARMA model can provide better prediction performance over simpler methods and the important role of the number of surrounding stations play to improve the prediction.

Unlike these two studies mentioned above, Borgnat et al. (2009) propose a statistical model to describe the daily and weekly patterns of Vélo'v bikesharing system in Paris in terms of cyclostationarity manner and possible non-stationary evolutions in larger time-scales. This study is further developed in the study of Borgnat et al. (2011). In addition, linear regression model is combined with this model is developed to predict the number of bicycles hired hourly. Weekly temporal patterns are identified firstly to study non-stationary patterns on time scale larger than the day and the cyclic mean for the number of bicycle rentals over the week is estimated in terms of the periodic average. Prediction of the number of bicycles hourly can be divided into two parts[9]: firstly, the prediction of the non-stationary amplitude $A_d(d)$ for a given day; and secondly, the prediction of the fluctuations $F\,(t)$ at a specific hour. Factors of the weather in terms of the average temperature over one day and the volume of rain during the day are considered; the number of registered users and the number of bicycles available and the dummy variables in terms of holidays and specific days or strikes are also taken into account. In terms of prediction of hourly fluctuations, it is modelled by an auto-regressive process of order 1 with exogenous input. It should be noted that the prediction of the number of bicycles hired is estimated for the whole system rather than each station. This study only evaluates the prediction in terms of the standard deviation of the error, namely 120 bikes per hour; however, the difference between estimated and actual number of bicycles hired per hour is not examine. As a result, it is hard to evaluate the performance of this model and only can be understand the temporal pattern globally.

[9] Estimated the number of bicycles hired hourly is represented as $L\,(t) = L_{mod}\,(t) + F(t) = A_d(d)\frac{<L(t)>_c}{A_{mod}(d_7)} + F(t)$

2.4 Remarks

In this section, a number of studies associated with PBS have been investigated in terms of system evolution and planning, components, business models, potential benefits. Determinants of cycling and bikesharing system usage are examined as well. Furthermore, station activity in the view of temporal and spatiotemporal patterns is extensively explored. And using station activity data helps to predict the number of available bicycles in the near future time. It is expected that a statistical analysis of the public bikesharing scheme data (e.g., station activity) would contribute to leverage the development of new and innovative approaches for better understanding of urban mobility as well as the use and performance of PBS (Etienne and Latifa, 2012).

Most of spatiotemporal studies of bikesharing system use clustering algorithms to group stations based on their usage patterns as previous studies mentioned to discover the relationship between stations which share similar usage patterns and the surround spatial layout. Once the stations are clustered, a visualisation map of clustered stations can be illustrated. However, it should be noted that these clustering results are highly specific and independent for each system and hard to compare among different systems though specific usage patterns would share similar surrounding spatial layout or attributes. For example, for those stations returning morning pickups evening (RMPE) are mainly located in the inner city area, offering higher working places. Better understanding of station activity according to the specific city context may not only help transport planners and operators to evaluate the underlying temporal and spatial dynamics of a city but also facilitate daily operations.

Bayesian network model used in Froehlich et al. (2009) only consider three observed input without external factors and one hidden output i.e., delta; and the information for prediction is obtained from the system itself. ARMA used in Kaltenbrunner et al. (2010) however covers the external information from surrounding stations to gain better prediction result. It seems that either BN or ARMA model could have better prediction performance of the number of available bikes in comparison with using basic models such as baseline model. Using ARMA at a 30 minutes prediction interval has smaller average prediction error than BN model (below 1 bicycle vs. around 1.7 bicycles) whilst using BN model at a 60 minutes interval is slightly better than ARMA model (around 2.5 bicycles vs. maximum 3 bicycles).

3. Public bikesharing scheme in Taipei - YouBike

This chapter commences with the necessity of achieving sustainable transport and embracing the concept of green transport. The reason of implementing green transport is explained, followed by the cycling evolution in Taiwan. Consequently, the role and efforts of Taipei City government plays in cycling promotion will be discussed. Simple but comprehensive transport characteristics of Taipei City is provided, hence helping to understand specific transport context more clearly. Then the design and planning concept of YouBike and its evolution is introduced. Finally, a detail description of YouBike regarding to pricing, operation management e.g., bicycle redistribution mechanism, and characteristics of YouBike users are explored.

3.1 Cycling development and policy context

3.1.1 Government policy on promoting cycling

Sustainable transport, being ecology-oriented of sustainable development, could be defined as "satisfying current transport and mobility needs and it would be still functional by future generation" (Black, 1996; Zuidgeest et al., 2000). Accordingly, it has become an important goal in transport planning and research recently. It is widely accepted that transport is seen as a major use of carbon-based fuels e.g. fossil fuels. Therefore, reducing the CO_2 emissions, which are the main contributor of greenhouse effect, seems to be beneficial for alleviating climate change impacts (Hickman and Banister, 2007). By 2012, transport is the second largest sector for energy consumption in Taiwan followed by industry sector (52.38%), accounting for 16.32% of energy consumption, i.e. 13.26 million KlOE[10] (BoE, 2013b). In addition, Transport sector accounts for 14.48% of total CO_2 emissions in Taiwan, i.e., 35.26 Mt CO_2 emissions[11] (BoE, 2013a). Note that most of CO_2 emissions in transport (95.53%) comes from road transport (BoE, 2013a).

To achieve a sustainable transport network, alternative transport mode should be accessible, perceived as safe, and desirable. In response to the negative environmental externalities brought by climate change, Taiwan Government proposed the comprehensive White Paper of transport policies incorporating six categories: green transport, transport safety, shipment, public transport, intelligent transport and aviation in 2012. With regard to White Paper: green transport,

[10] KlOE is an abbreviation for kilolitre of oil equivalent.
[11] Emissions of electricity consumption is included.

the purpose is to mitigate the growing trend of energy consumption in the short time and to reduce energy consumption and CO_2 emissions in the long run.

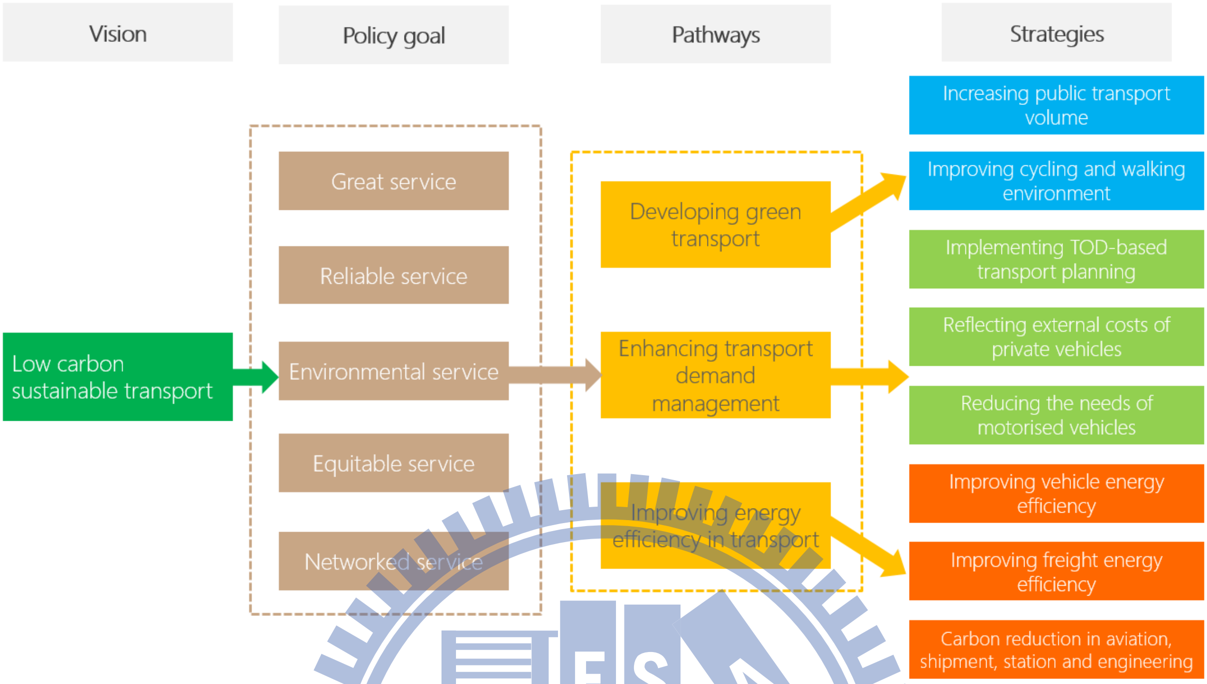


Figure 6 Policy structure of green transport development in Taiwan

Source: Adapted from IOT (2012)

Figure 6 above clearly shows that the green transport development structure in Taiwan. It shows that "*low carbon sustainable transport*" aims to achieve great service, reliable service, environmental service, equitable service, and networked service through three pathways: developing green transport, enhancing transport demand management, and improving energy efficiency in transport to form nine strategies. Notably, increasing public transport volume, and improving cycling and walking environment are the two suggested strategies for developing green transport system, enabling more people to use green transport mode to reduce energy consumption and GHG emissions generated by cars and motorcycles. It is expected that the improvements of cycling and walking environment should be integrated with the connection among residential and commercial area, transport hubs and stops, and the walking area along the road; and moreover, these improvements are achieved by the involvement and cooperation of the local and central authorities.

According to MOTC (2014), current mode share for all trips of cycling in Taiwan is around 5% by 2013 whilst for commuting purpose, cycling only accounts for 3.6 %. In order to increase cycling usage, the rate of bicycle commuting should be further improved; however, it takes time to be altered to choosing bicycles for commuting since it is accompanied by the travel behaviour changes and the efforts of bicycle infrastructure e.g. bicycle exclusive lanes that have made (IOT, 2012). Therefore, it is suggested that the goal of more cycling usage can be achieved by multiple stages. Through improving the cycling climate firstly in terms of leisure-based cycling infrastructure implementation and "slow movement" is explored. Benefits from the improved cycling climate, enhancing the bicycle commuting infrastructure are needed and it consequently helps to attract more people use bicycle for commuting. This concept is partly achieved by the "Challenge 2008 – National Development Plan" since 2002 in order to connect urban greenways and local network with leisure-based bicycle lanes as forming national wide cycling network. Note that the national bicycle lane network is still evolving. IOT (2012) suggests a number of measures to improve cycling and walking built environment including PBS promotion. For example, constructing seamless cycling network in the city helps to attract more leisure-based cyclists altered to bicycle commuting. It also highlights the importance of bicycle parking space around transport hubs, stations or even stops. Recent bicycle infrastructure development plans are displayed in the following Table 10.

Table 10 Bicycle infrastructure development plans

Development plan	Type	Time	Belonged projects
Bicycle infrastructure as core plan			
National Bicycle Lane System Plan	Leisure and sports	2002-2007	Challenge 2008 – National Development Plan
		2008	2015 Economy Development Vision First Stage: 2007-2009
		2009	Over One-tenth Billion Public Infrastructure Plan
Bicycle Lane Network Planning and Develop Plan	Leisure and sports	2009-2012	The i-Taiwan 12 Projects
Bicycle infrastructure as part of plan			
Existing Urban Network Landscape and Walking Environment Improvement	Commuting	2006-2008	2015 Economy Development Vision First Stage: 2007-2009
		2009-2012	-
Eastern Taiwan Bicycle Lane Pilot Scheme	Leisure and sports	2009-2011	Economy Revival and Public Infrastructure Expansion

Source: 王義川 et al. (2011)

3.1.2 Cycling development in Taipei City

In the early days of Taiwan, the use of bicycle is originally for travelling however currently using bicycles takes account of around 60% for leisure and sport activities and dedicated to integrate with tourism industry (張勝雄 et al., 2008). The first establishment of bicycle exclusive lane is dated back to 1991 where located on the safety island of Dunhua North Road. By 1997, the leisure-based bicycle exclusive lane is planned along from Tamsui *River* to *Xindian River*; on the same year of March, the first leisure-based bicycle exclusive lane (i.e. Guanshan bike path) has been implemented and operated (張勝雄 et al., 2008). Note that the success of Guanshan bike path in Taitung takes the trend of building bike path and bicycle lane to develop township. The role of bicycle plays in Taipei transport systems have experience several changes over time and it can be examined through certain specific measures, policy or events in that times. 張勝雄 et al. (2008) have identified four stages in Taipei's cycling policy evolution and associated measures displayed in the following Table 11. It illustrates the bicycle popularity changes from flourishing to decline but obtains attention again during the last decade; for example, cycling path along numbers of Riverside Park have been extensively built and the cycling network in urban area is still expanding.

Table 11 Cycling policy context evolution in Taipei City

Time	Policy context	Specific measure, policy or events
1960s	• Motorised vehicles are the major mode of urban transport; • Bicycles are symbolised as backwardness	• Tricycle and pedicab drivers are transformed to taxi drivers; • Cycling is prohibited in main arterial roads
1980s – 1990s	• Cycling should be included in urban transport; • Bicycle exclusive lane underpins the development of cycling in a city	• Implementing the first bicycle exclusive lane on the safety island of Dunhua North Road claims that Taipei as a modern city
1990s	• Cycling receive attention again due to growing awareness of green transport; • Road capacity is not sufficient to support the implementation of bicycle lanes; • Cycling is developed mainly for leisure use and support for metro	• Establishment of Riverside Park cycling path; • Cycling network planning plan is proposed; • Taipei City Bicycle lane design manual is proposed; • Establishment of commuting-based bicycle lanes; • More participants in Car Free Days
1997 – current	• Leisure and sport use transformed to commuting, everyday life-based gradually	• Ongoing expansion of cycle path along the river, and urban cycle path network;

Source: 張勝雄 et al. (2008)

It concludes that bicycle infrastructure development such as establishment of riverfront cycle path in Taipei has engaged in promoting cycling since 1997. In the past Taipei government focused on developing recreational-based cycle paths along the river; however until 2003 the urban cycling network establishment has been started. Accompanied by the Car Free Day activities, these measures aim to encourage bicycles as a means of short-haul transport mode as well as being a part of daily life. By 2004, 100 Km of bicycle lanes have been completed (DoT Taipei, 2005). Furthermore, in coordination with the development of Xinyi Development Zone, greenbelts and walkways are built in its surrounding areas to encourage bicycle usage. And the first downtown cycle path network (Xinyi Business DISTRIC Bike Lanes) of total 10.5 Km was completed in 2004 as well, aiming to facilitate commuting and shopping activities (DoT Taipei, 2005). Connection and expansion of various bicycle routes such as Riverside Park cycle path and urban cycle path network are continuous growing. By 2013, the length of urban cycling path network has reached 323.3 Km where bicycle exclusive lanes and shared-used footpath account for 38.6 Km and 284.7 Km respectively as shown in below Figure 7. The high quality of riverfront cycle paths since 1997 and the continuous work on building urban cycle path network bring about the gradually increasing rate of cycling and enable more people start to use bicycle. Therefore, cycling gradually transforms from leisure, recreation or sport use to commuting and short-haul uses.

Other several measures and facilities are also introduced, accompanied with the emergence of PBS. In order to accommodate the PBS, Taipei City Traffic Engineering Office (TCTEO) began establishing cycling-friendly routes around bikesharing stations and bike lane markers, logos and indicators. In addition, these instalments are also include in the enhancement of connectivity of cycling routes between riverfront bike lanes and urban bike paths. Therefore, the connectivity of bike lanes and road-user information system, and the linking of various bike lane networks could be enhanced. At the end of 2012, there are 130 bike lane markers and indicators have been installed around 33 bikesharing stations and in Nangang, Dazhi, Dadaocheng, Minsheng, Wanhua and Gongguan (DoT Taipei, 2013a). Urban bike lane networks is planned to establish in stages starting 2012 within 3 years. At the end of 2012, the bike lane networks in business areas of Nangang, Xinyi, Gongguan and Wanhua have been completed (DoT Taipei, 2013a).

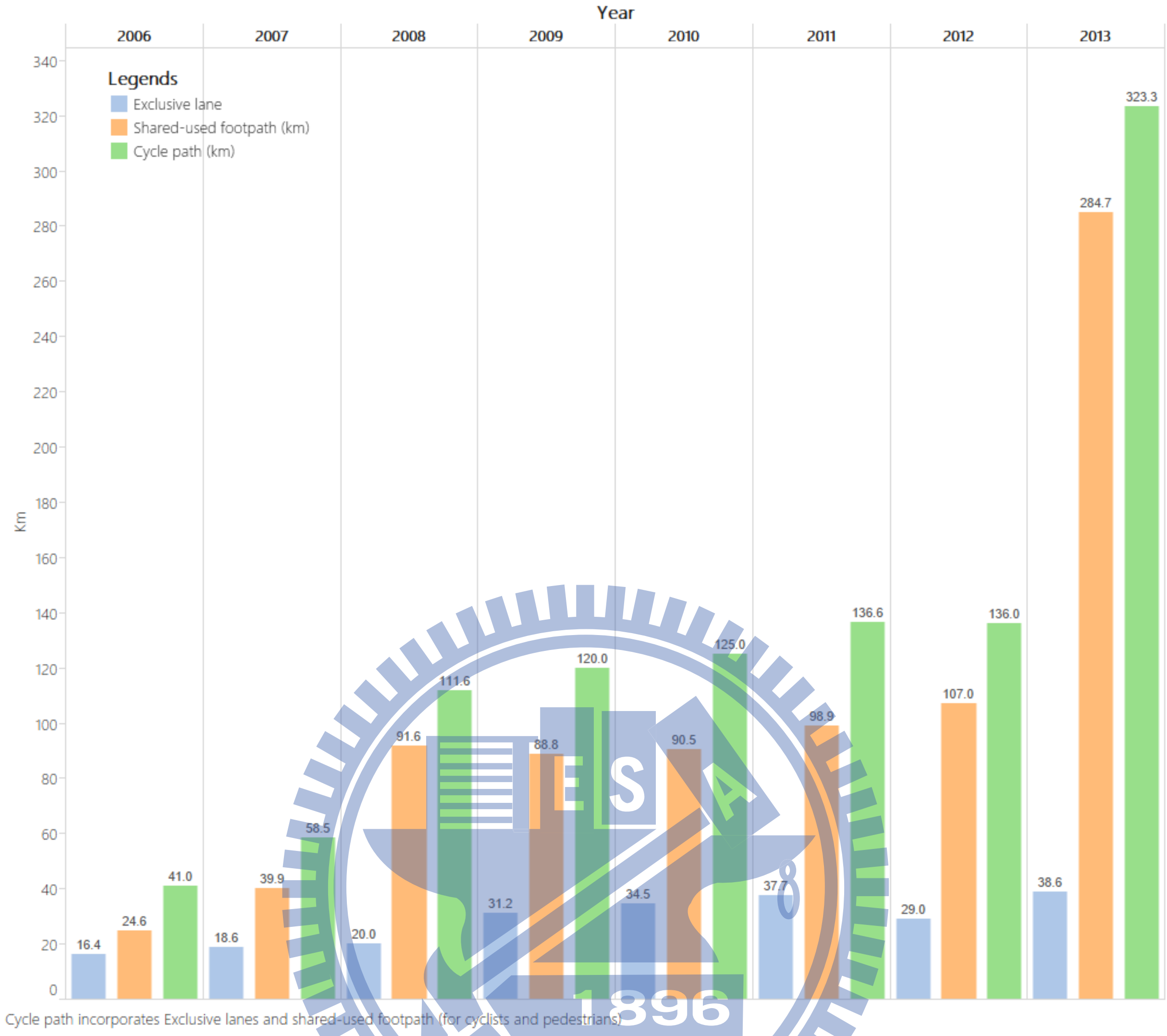


Figure 7 Cycling path in Taipei City

Source: this study; data from DoT Taipei (2014d)

3.2 Transport characteristics in Taipei City

Following Table 12 illustrates the overall facts and figures of transport services in Taipei City in terms of four categories.

Table 12 Facts and figures of transport services in Taipei City

Category	**Index**	**Description**	
Geographic characteristics	Location	At the northern part of Taiwan island, located in southeast Asia	
	Topography	Basin and dissected by numbers of rivers	
	Geography	Located in a seismically active zone with soft sediments	
	Climate	Monsoon-influenced, humid subtropical climate; mean annual temperature: 23.4°C	
	Territory	272 Km^2 (square kilometres)	
Population	Population	2,673,000 people	
	Number of residents	1,017,000 residences	
	Density	About 9,835 people per Km^2	
Travel condition[Ψ]	Roadway area	22,521,347 m^2, accounting for 8.29% of Taipei area	
	Number of cars[Ψ]	772,209	
		- including bus, heavy truck, private car, and light truck	
	Car ownership	283 vehicles/1000 persons	
	Number of motorcycles	1,038,141	
	Motorcycle ownership	411 vehicles/1000 persons	
	Number of parking spaces	For cars: 637,315	
		For motorcycles: 660,068	
	Roadway network layout	Roads in Taipei City centre are laid out like a chessboard	
		13 designated exclusive bus lanes	
Transport services[Ψ]	Bus	No. of operators:	14
		No. of routes:	295
		Average No. of passengers per day:	1,614,958[12]
		Average No. of operating vehicles per day:	3352
		Average kilometre per bus per day:	159.73
	Metro	No. of stations:	109
		No. of routes:	10
		Operating kilometre:	121.3
		Daily average ridership:	1,739,619 [12]
		Daily average of bi-direction transfer discount:	484,357 [12]
	Bicycle infrastructure	Bicycle exclusive lane:	38.6 Km [12]
		Shared-used footpath:	284.7 km [12]
		Bicycle racks:	21,426
		Riverside Park cycle path:	159.7 km
		No. of Riverside Park cycle path:	6

Source: Adapted from DoT Taipei (2013a), Taipei City Government (2013), DoT Taipei (2014a)

[Ψ] till at the end of February 2014
[12] data of 2013

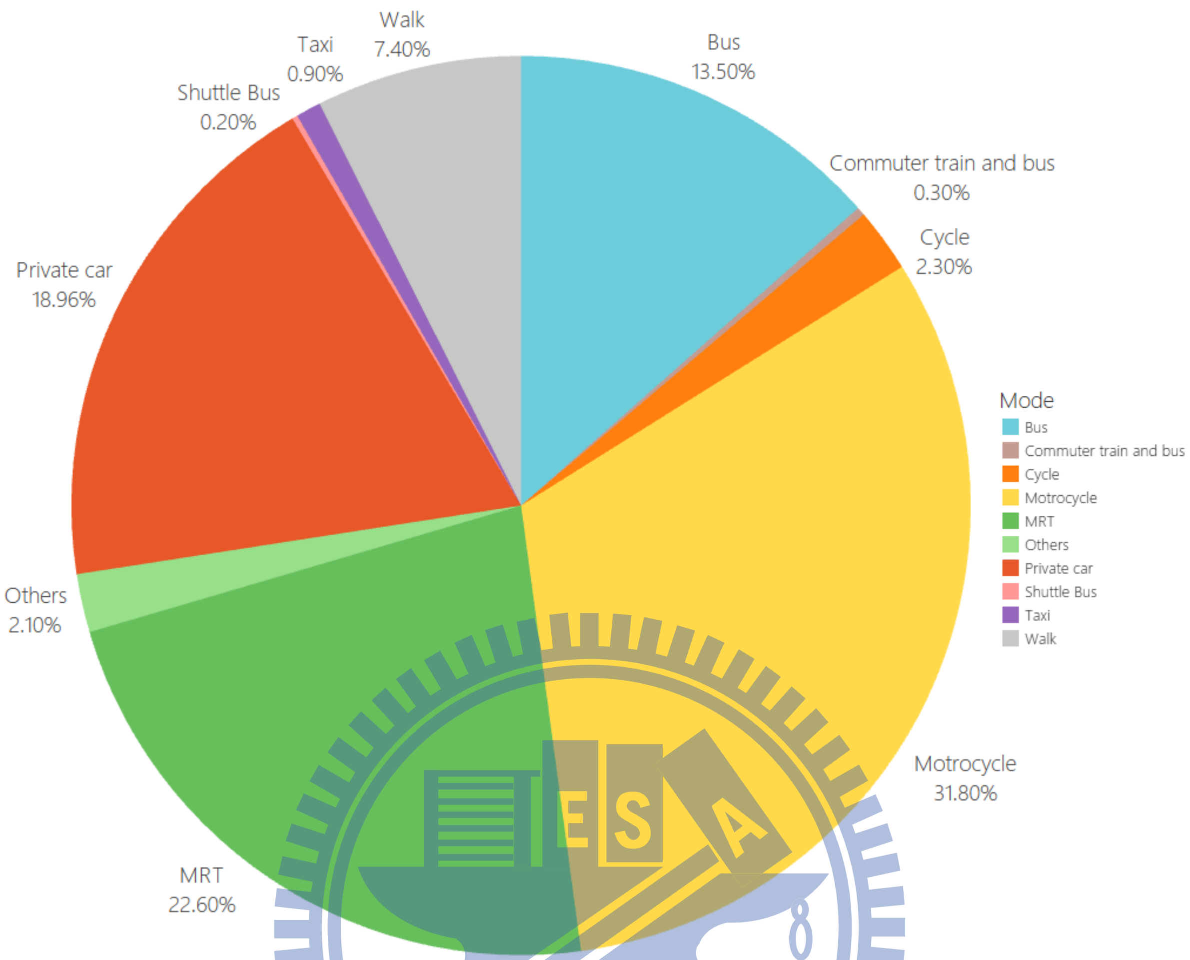


Figure 8 Mode split for commuting purpose in 2012

Source: Adapted from DoT Taipei (2013a)

Figure 8 shows that the most common transport mode for commuting is motorcycles which accounts for 31.8%, followed by using Taipei Metro of 22.6%, private car of 19% and bus of 13.5% respectively. Note that the use of public transport systems including bus, the Taipei Metro, shuttle buses, trains, coaches and taxis account for 37.5%. Regarding cycling, only 2.5% of commuters would use bicycle for commuting.

Mass Rapid Transit (MRT) and bus systems have become two main transport modes in Taipei city. Taipei MRT is the first metro system in Taiwan, which is launched since 1996. Until now, there are 10 routes and 109 stations in operation with operation length 121.3 Km, and average daily usage has achieved to 1.64 million trips in 2012 (TRTC, 2013; DoT Taipei, 2014a). In terms of bus service, currently there are 14 operators which provides 295 lines served as the feedering mode of the Taipei metro with average daily ridership of 1.73 million trips in 2013 (DoT Taipei, 2014a). The market share of public transport which incorporates bus, metro, shuttle bus, taxi, and commuter train and bus has reached 37.5% in 2012, versus 23.8% in 1996 (DoT Taipei, 2013a). The most of which is done by Taipei MRT, accounting for 22.6% and followed by bus with 13.5% (DoT Taipei, 2013a).

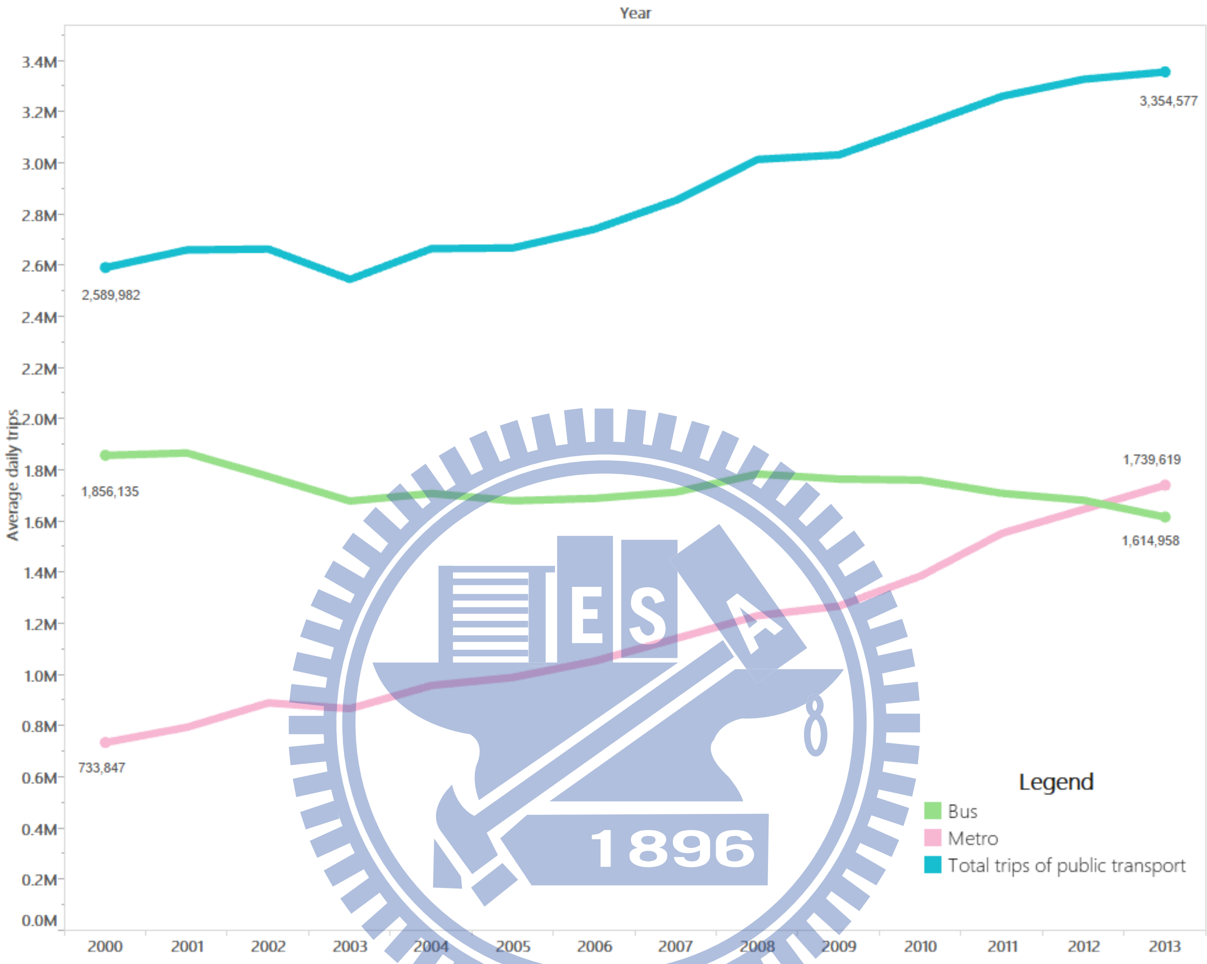


Figure 9 Public transport ridership in Taipei City in recent years

source: this study, data from DoT Taipei (2014f) and DoT Taipei (2014e)

Figure 9 above shows that Taipei public transport ridership from 2000 to 2013. Basically the mode share of public transport stably increases yearly in spite of sharp decrease in 2003 due to the threat of severe acute respiratory syndrome (SARS). Note that the growing trend of public transport is mainly contributed from increased mode share of metro. In contrast, the trend of bus mode share actually decreases during the period from 2000 to 2013, which may be resulted from the opening of new metro lines, attracting bus users to use metro. Figure 9 also illustrates that the daily average ridership of Taipei Metro has reached more than 1.64 million by 2012 (TRTC, 2013). It seems that the ridership would grow at a stable speed as other routes would be launched in following years such as Xinzhuang line will be launched in early 2012, Xinyi line in late 2013, Songshan line in late 2014, and Taoyuan International Airport MRT in late 2015. Regarding to bus, by 2012 the average number of passengers per day is up to 1.68 million persons (DoT Taipei, 2014a). Although the opening of new Taipei Metro lines (Xinzhuang line and Xinyi line in 2012 and 2013 respectively) has made modal shift from bus to metro, the evidence of increasing number of total public transport users every year clearly shows that public transport came out to be indispensable part of transport modes in Taipei metropolitan area. As public transport network and services are approaching more comprehensive, and in the situation of expected higher tendency of fuel price and more people becoming environmentally conscious, more and more people are expected to use green transport modes.

In terms of active transport (walking and cycling), modal split of active transport also increased to 19.7% in 2013, compared to the level of 4.6% in 2006 (DoT Taipei, 2007; MOTC, 2014). Specifically, by 2013, walking increases the most from 2.7% to 14.5% while cycling improves to 5.2% in comparison with only 1.9% in 2006 (DoT Taipei, 2007; MOTC, 2014). In addition, Taipei City has a great potential for cycling, with more than 320 Km of cycle paths which includes bicycle exclusive lanes and shared-used footpath have been established around the city (DoT Taipei, 2014d). And many of cycling paths follow three rivers pass through the Taipei (accounting for 111 Km in 2011), providing the astonishing view of the city (劉嘉祐, 2014).

The provision of PBS would have a great potential for enlarging the cycling population, encouraging cycling and using multimodal transport options through combination with public transport. Martens (2007) Indicates that combination of public transport and public transport-bicycle (‘’OV-fiets”) which is flexible bicycle rental at the activity-end of a train trip has resulted in to a substantial increase in bicycle use for egress trips. In addition, it also led to a slight increase in train ridership for 15% PT-bicycle users claimed that the combination of train and bike has replaced trips previously made by car (Martens, 2007). It implies that the combination of public transport and bike would contribute to increase public transport ridership and decrease in car usage.

3.3 Characteristics of Taipei YouBike

3.3.1 Design and planning concept

PBS is generally designed for short distance trips with the average intended trip length between 15 - 25 minutes or about 5 Km and having the advantages of lower travel cost compared to other modes (see Figure 10 below). Moreover, it is generally designed to fill a gap in the urban transport network between walking and transit/automobile travel, where the distance is too far to walk but at the same time too close to justify waiting for transit or incurring the cost of a car trip (Daddio, 2012). It is likely that 300 meters station spacing has become the general standard and such distance is equivalent to approximately 5-minute walk from anywhere within the surrounding area (Quay Communication 2008).

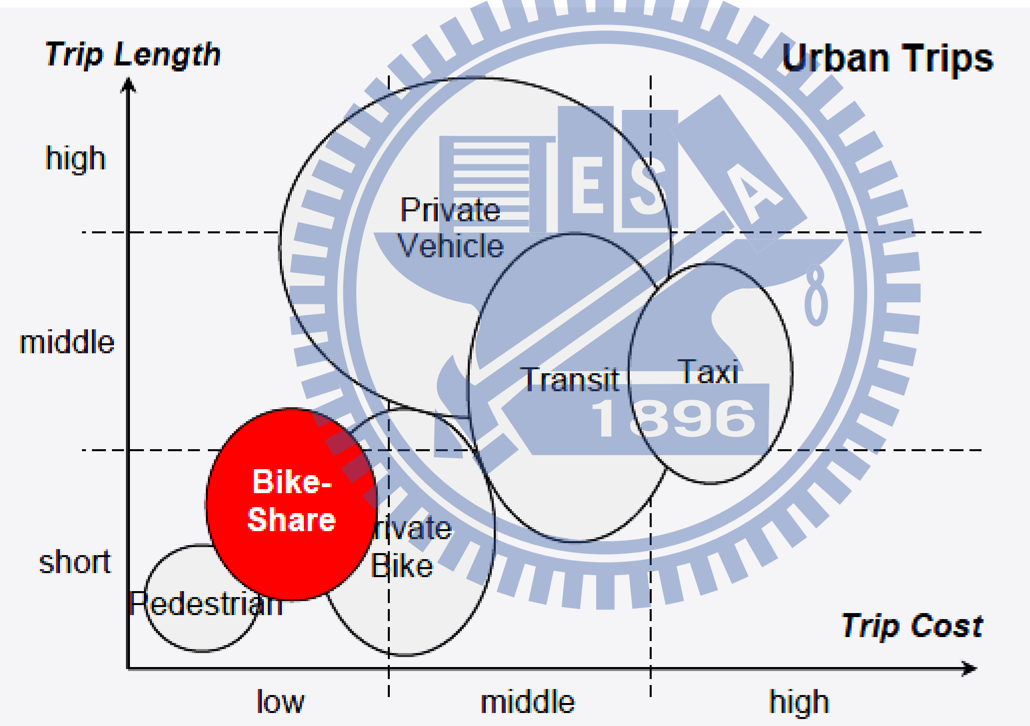


Figure 10 The niche of bikesharing system in urban transport systems

Source: Quay Communications Inc. (2008)

Bicycle network planning handbook is published which is suggested by Institute of Transportation in 2009 and Taipei City Government released Bicycle Lane Design Handbook in 2007 where the design of bicycle exclusive lane and shared-used footpath is standardised. However, there is no official bikesharing system designing handbook has not been published until now. The general guideline for the location planning of YouBike stations of have been disclosed as following shown (DoT Taipei, 2014c):

- In order to accommodate bicycle parking space and redistribution, the proposed bike station should have the capacity of at least 30 bicycles (15 docks) which are equivalent to an area of $26m \times 2m$ $(length \times width)$;
- Sufficient walking area or shared-space for pedestrians and bicycles; thus, the width of pavement is suggested to be 4 meters width;
- The proximity to power supply;
- The land of proposed station location should be owned by Taipei City Government or the privately owned however is committed by the land owner to use without compensation;
- The proximity to road in order to facilitate the maintenance work; and
- The proximity to metro stations or public transport terminal/stops; in addition, the implemented location of proximity to residential area, market, library or other public spaces should be evaluated by potential demand to prioritise the bike station implementation for accommodate the most citizens' need.

It is actually very general planning criteria and only covers the proposed station location planning in a vague manner without using dedicated method such as location models. Unlike other studies take both user's and the investor's point of view into account in addressing the design of public bikesharing system (Lin and Yang, 2011). Or using GIS approach to calculate the spatial distribution of the potential demand for trips to locate station location through allocation models, determining the capacity and defining the characteristics of the demand of stations (García-Palomares et al., 2012). Another study also uses GIS approach but integrated with multi-criteria analysis for evaluating bicycling facility location planning (Rybarczyk and Wu, 2010). The planning criteria of YouBike neglects the station sizing as it is forced to provide at least 30 bicycles without considering the underlying demand. Since the location of the bike station is one key to the success of bikesharing system, the relation with demand and the public transport system and the network distribution in the urban area should be discovered (García-Palomares et al., 2012). Therefore, various measures and design and planning handbook should be developed to optimise the bike station location properly.

3.3.2 The bloom of Taipei YouBike

YouBike, the PBS of Taipei City, (also known as Ubike), was undertaken in the spring of 2009 initially. It is established with 11 stations and 500 bikes in *XinYi* District initially for the pilot project, aiming at encouraging bicycling usage and providing for commuting use (YouBike, 2014d). Due to the free riding policy of the first three month since system opening in March 2009, the YouBikes users grows quickly, reaching around 23,000 trips by May. However, the ridership decreases sharply after the free using period for approximately 5,000 trips during the period from October 2010 to the August 2012 (DoT Taipei, 2014d). The reason of low usage of this pilot scheme could be blamed for insufficient bike station, complicated and inconvenient register process, and non-attractive price (劉嘉祐, 2014).

Taipei City Government tries to commit being green, embracing the philosophy of green transport. Therefore, a new generation of shared bicycle system was redeveloped and deployed quickly in the spring of 2012 and launched on 30 August. YouBikes are robust yet aesthetically pleasant and are convenient for users, with radio-frequency identification (RFID) embedded technology, low step-through design, adjustable seats, anti-theft and shirt-guard design, front and real lights as well as reflectors for enhancing safety and security (YouBike, 2014e). The new YouBike system was launched from August 2012, aiming at providing 162 stations and 5350 bikes in the following seven years, which is operated by *Giant*, recognised as the world's largest bicycle manufacturer. Besides, it was the first large-scale public bike sharing system to be implemented in Taiwan. At the beginning of YouBike was launched, about 41 stations and 1460 bikes were available (DoT Taipei, 2014g). The business model of YouBike is publicly owned and privately operated for a given time but operated by bicycle manufacturing company, which is somewhat different from the existing business model reviewed previously (see 2.1.5).

Unlike the failure of previous pilot scheme in Xinyi district, this re-development bikesharing scheme seems to be a success beyond city government and citizens' expectations. After the pre-opening session for three months, YouBike ridership has reached more than 1 million trips and 130 thousand of EasyCards (smartcard for payment on the public transport services in Taipei metropolitan area) have been registered (YouBike, 2014d). It is expected that it would have 190 bike stations across Taipei City by the end of 2014 (劉嘉祐, 2014). By the end of April 2014, there are about 1.75 million registered users and almost 19 million total rides since operation (YouBike, 2014d). Besides, YouBikes are proud of high turnover rate of YouBikes (up to 11 times per bicycle) and ultra-low rate of bike theft as well (蔡百蕙, 2014).

3.3.3 Descriptive analysis of YouBike stations

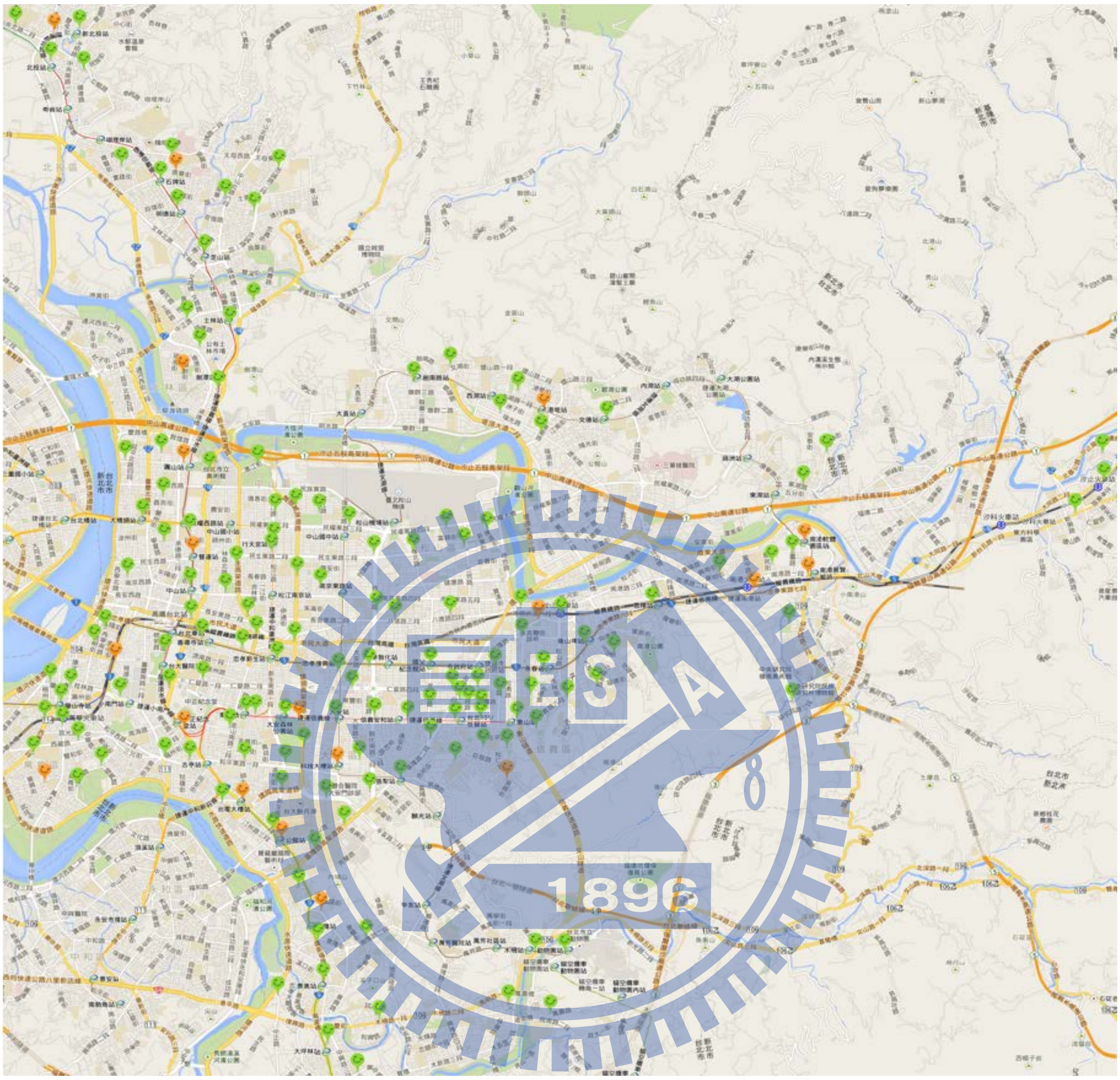


Figure 11 Taipei YouBike station map[13]

Source: Adapted from YouBike official site: http://www.youbike.com.tw/cht/index.php, and this study

According to YouBike (2014b), currently[14] there are 166 bike stations across Taipei metropolitan area are in operation including preoperational stations of the YouBike sharing system as spatially illustrated in Figure 11. The average distance of each bike stations ranges from 300 to 600 meters according to DoT Taipei (2012). Note that YouBike both servers whole Taipei city and part of New Taipei City for 12 and 2 administration districts respectively though

[13] The colour of station pin (smile icon) refers to the status of station for available bikes; however, it

[14] At the date of June 5, 2014

the numbers of stations in each administration district may not be even distributed. Additionally, it is expected that “the number of bike stations would increase to at least 190 station by the end of this year and would be likely to expand to 300 stations in the future” said by Mayor of Taipei City, Lung-pin Hau (蔡百蕙, 2014). Following Table 13 shows the number of bike stations by administration district. Daan and Xinyi District are the top 2 number of stations, followed by Zhongshan and Zhongzheng District. Note that for those bike stations in New Taipei City i.e., Xindian and Xizhi District currently have the least number of stations.

Table 13 Number of bike stations by administration district

Administration district	Number of bike stations
Beitou	10
Daan	25
Datong	10
Nangang	11
Neihu	8
Shilin	10
Songshan	11
Wanhua	12
Wenshan	10
Xindian (New Taipei City)	3
Xinyi	24
Xizhi (New Taipei City)	3
Zhongshan	15
Zhongzheng	14

Source: this study, data from YouBike (2014b)

Till 18th April 2014, the registered users of YouBike has reached 1.71 million and more than 18 million trips has been made since operation; recently, the ridership of YouBike has climbed up to more than 20 million trips in 19th May, 2014 (DoT Taipei, 2014b; YouBike, 2014d). Figure 12 below demonstrates the YouBike operation in terms of number of bikes and stations. During the period of pilot scheme from March 2009 to July 2012, the number of stations and bikes all stay at the same level for 11 stations and 500 bicycles respectively. Until this scheme is regenerated by *Giant* Manufacturing Co. Ltd. and Taipei City Government in the early spring of 2012 and launched by Giant for next 7 years, the number of stations and bikes start to accelerate from August. For establishment of each bike station associated with at least 30 bicycles provided, the relationship of station and bikes are ultimately related and it seems that they almost follow nearly the same growth rates during the expansion period as Table 9 previously demonstrated. It should be noted that the figure of number of stations may not be in line with the date we collected through using python script automatically. The reason may be that some stations are in pre-launch in a short given period before being formally launched; thus it is not recorded in database officially. For example, during the six weeks of data collection period, there are 165 stations recorded whilst it is recorded for only 159 stations from the Taipei Transport Statistics Database[15].

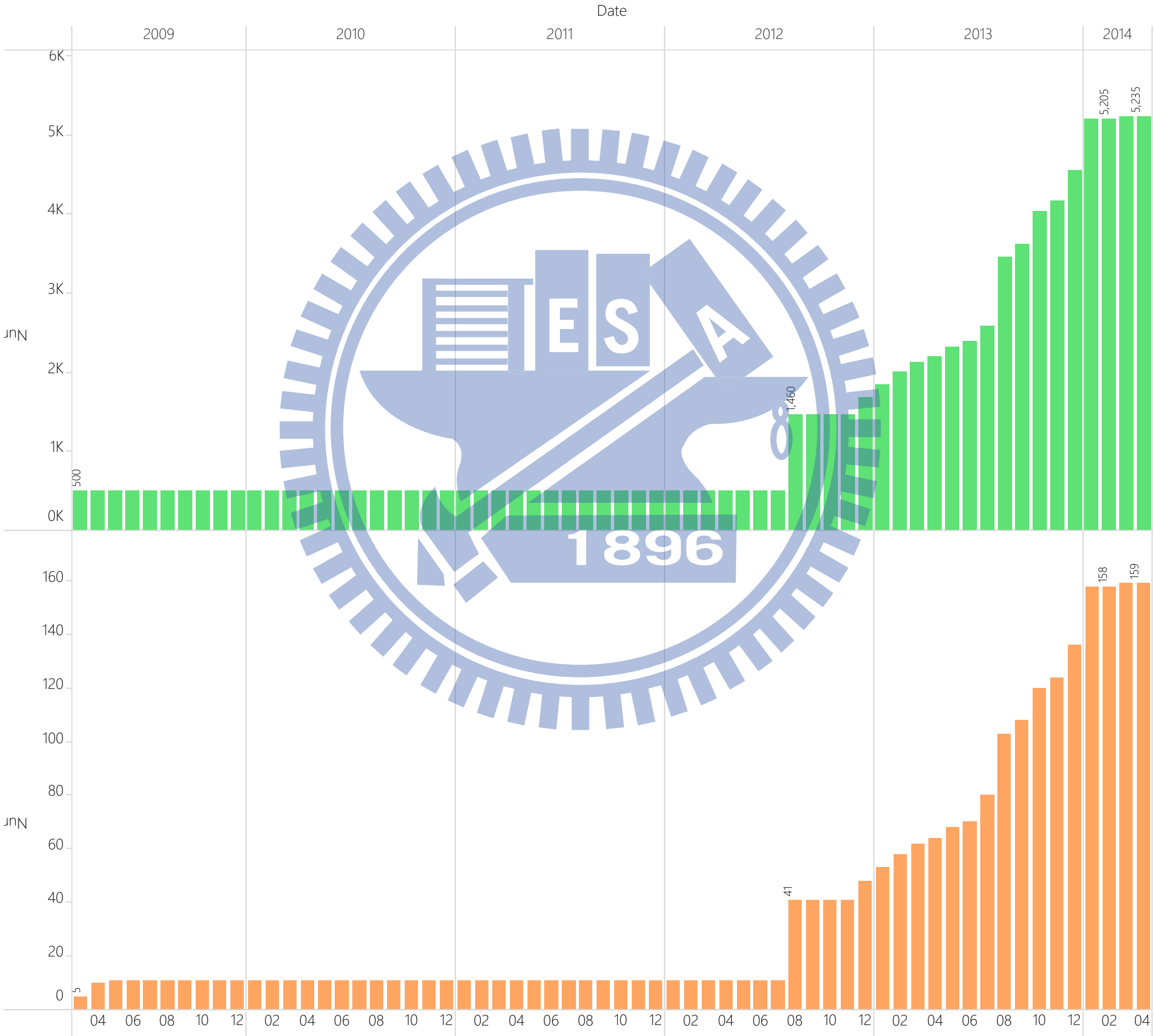


Figure 12 Evolution of the number of stations and bikes since operation

Source: this study; data from DoT Taipei (2014g)

[15] website: http://dotstat.taipei.gov.tw/pxweb2007P/Dialog/statfile9.asp

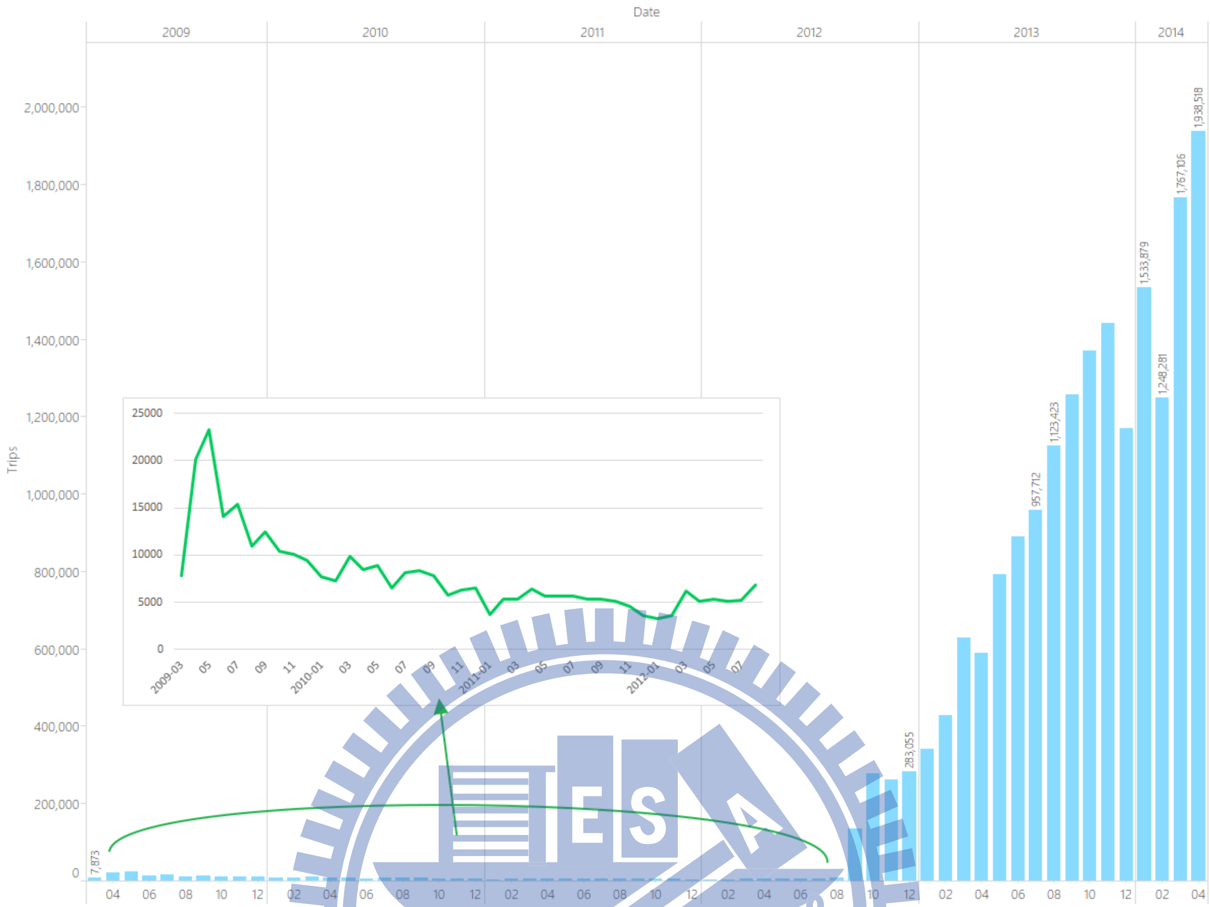


Figure 13 Number of trips of YouBike since operation

Source: this study; data from DoT Taipei (2014g)

The number of trips made by YouBike since operation is illustrated in Figure 13. In the period of pre-launch, while it increases at first then being declined and fluctuated. The acceleration of YouBike ridership is in line with the continuous expansion of stations and bikes as it is highly linear correlated ($r \cong 0.98$). However, the reasons are unclear that sudden sharp declines of ridership in December 2013 and February 2014. Overall, it concludes that the YouBike ridership is continuous growing.

Following Figure 14 illustrates the average usage of each bicycle per day i.e. turnover rate. The peak occurs in the June 2013 where is the average trips for each bicycle is 12.68 time. Since bicycle turnover rate is highly related to ridership, both sharp declines in ridership in Figure 13 are represented as “W-shaped” in Figure 14 as well. Looking at the past three months performance, bicycle turnover rate remains at more than 10 trips per day for each bicycle during this period.

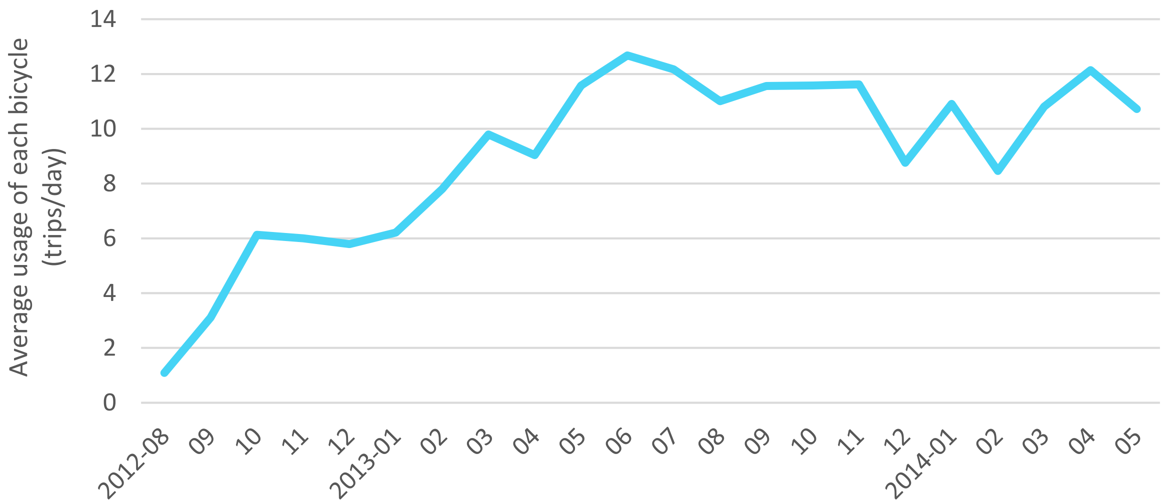


Figure 14 Average turnover rate of YouBike bicycles per day by months

Source: this study; data from YouBike (2014a)

3.3.4 Pricing and operation management

One of the main changes of the regeneration of YouBike system is that simplified rental process in terms of lower fare and simplified registration while using bikesharing system. Customers can be defined as two categories: short-term and long-term users. Both of these users can register at any KIOSK nearby each bike station; while the short-term users only can pay with credit card or CHT mobile phone bill, the long-terms users take advantages of their mobile phones and EasyCard[16] to register at KIOSK or other places and use EasyCard for payments. Details of usage fees and rates are presented in following Table 14.

Table 14 Usage fees and rates

	Single rent	Member
Customer type	short-term users	Long-term users
Payment option	Credit card or CHT mobile phone bill	EasyCard
Registration	Any KIOSK	Service centre, official website, official phone app, or any KIOSK
Charge rates	$10 NT per 30 min with the first 4 hours; $20 NT per 30 min between 4 to 8 hours; $40 NT per 30 min exceeding 8 hours	Free for the first 30 min; and ditto

Source: YouBike (2014c)

[16] EasyCard is a contactless integrated smartcard system for payment on public transport services and other retailers in Taiwan

Regarding to bicycle redistribution mechanism, there are some basic principles in order to address the issue of imbalanced bicycle distribution. For example, the bicycle redistribution is run by 24/7 work and usually done before the peak time of bicycle usage. Additionally, tablets are equipped in every rebalancing truck, monitoring the real time bicycle availability. Moreover, the maintenance work of bicycles are checked in a daily base regularly according to DoT Taipei (2013b).

3.3.5 Trip duration, trip distance and behaviours

It is interesting to discover the users' characteristics as a result of bringing about insights on operation improvements and marketing strategies. For example, the purpose of using bikesharing system, trips distance and duration, previous mode you take before using bikesharing system for measuring multimodal, trip origination and destination etc. are the common characteristics that operators, researchers and policy planners interest in. Such kind of data is often obtained from sensors which automatically record travellers' behaviours (see Borgnat et al., 2011; Vogel et al., 2011; Etienne and Latifa, 2012; Nair et al., 2013). Another data resource is the qualitative survey to bikesharing system users to obtain this kind of data (see Sener et al., 2009). However, the collected data in this study does not include the trip duration, trip origination and destination, pick up time and return time and this study also does not conduct a qualitative survey to explore YouBike users' characteristics. As a result, this kind of information is addressed by being obtained from second-hand data described as following.

白詩棨 (2013) conducts a survey to infer user behaviours of YouBike based on 577 respondents taken from January 15, 2013 to February 15, 2013. Results show that about 70% of YouBike users spend less than 30 min which may be associated with and people take advantage of free of charge for first 30 minutes policy (see Figure 15). Around 23.4% of users spend more than 30 min but less than 60 min whereas only 1.1% of users spend more than 2 hours. Regarding trip purpose of using YouBike (see Figure 16 below), daily activities which incorporate shopping and public transit take account of 39% whereas leisure use and commuting take account of about 28% and 30% respectively. Therefore, it indicates that bikesharing system seem to be capable for solving first/last problem and being part of multimodal transport. In terms of frequency of use, 40% of users use YouBikes for 1 to 5 times a month while 21% for about 1 time use and 19.5% for 5 to 10 times a month respectively, indicating the users of YouBike still does not consider bikesharing as a dominant mode for commuting or daily activities.

Regarding to desired walking time to nearby bike stations, 白詩棨 (2013) finds that most of users are likely to walk within 10 min to nearby bike station while about 12% of users are also feel comfortable for walking 10 to 15 min. It seems that the suitable walking distance to nearby stations would range from 420m to 840m if walking speed of 1.4m/s is preferred.

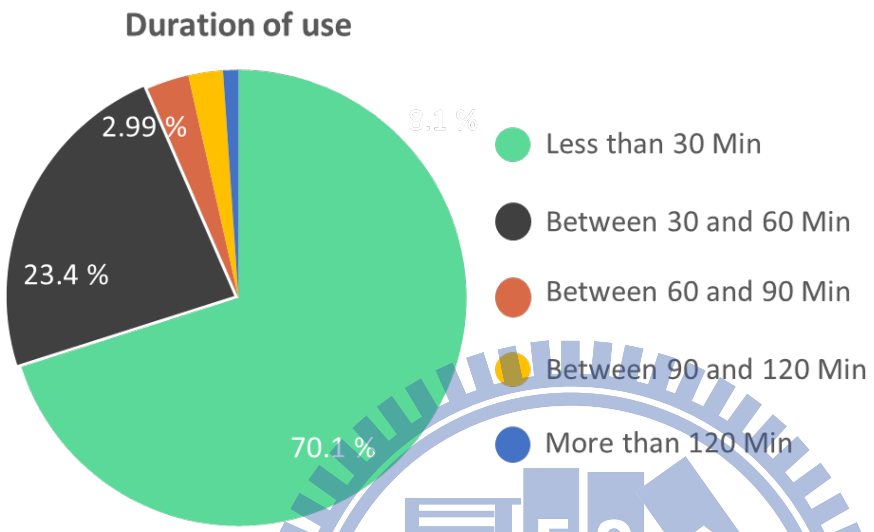


Figure 15 Trip duration of YouBike users

Source: adapted from 白詩棨 (2013)

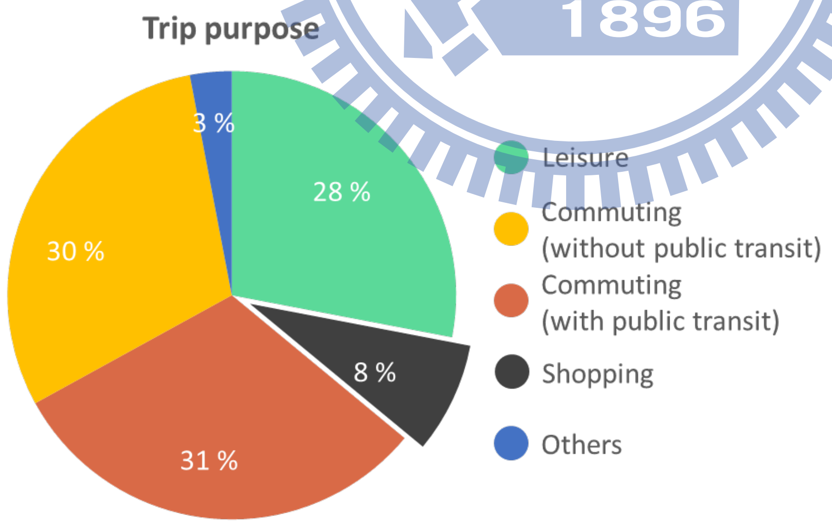


Figure 16 Trip purpose of YouBike users

Source: adapted from 白詩棨 (2013)

4. Data collection and processing

This section describes the details of how the data is collected and provides a basic description of the collected data and essential data pre-processing and cleansing process in order to make the data suitable for the analysis afterwards.

4.1 Data retrieval

The data is collected automatically from a dedicated web Application Programming Interface (API) in JSON (JavaScript Object Notation) format which is provided freely by Depart of Transportation, Taipei City Government. The easiness of data retrieval from online takes advantage of Open Data policy to public, facilitating obtaining data and further research. The official website also provides information service for users through the Google map API, illustrating a map of Taipei City overlaid with small smile markers to indicate YouBike station locations, the amount of available bicycles and free slots[17] at a given time for each station. JSON is designed to be a data exchange language and open standard format which is more human-readable and significantly faster for interchanging data compared to XML format (Nurseitov et al., 2009). Such data streams are often used for transmitting data between web servers and web applications as well as mobile phone applications or dashboard monitoring of the system concerned (O'Brien et al., 2014).

A Python (programming language) script which is developed by Shane Lynn[18] which underpins the main process for data retrieving and data storage is customised specifically for suitably retrieving data from the web API[19] on a regular basis (every 5 minutes) to access the YouBike docking station data online, excepting the web server error or the software and computer issue, parsing it and storing in a SQLite database. This Python script is run by PyCharm version 3.4 which is a Python IDE (Integrated Development Environment) developed by Czech company JetBrains and used for programming in Python. Demonstration of this Python script for retrieving date from YouBike open data API is shown in Figure 17 below.

[17] slots refer to parking space for one bicycle

[18] The original Python source code is contributed to Shane Lynn at http://shanelynn.ie/index.php/scraping-dublin-city-bikes-data-using-python/#more-222 and is adapted in order to meet the dissertation objective and the provided data structure

[19] Web API url: http://210.69.61.60:8080/you/gwjs_cityhall.json (before May 27th, 2014)

This JSON API contains several information including station name, latitude and longitude, station address, data update time, total slots etc.; however, there are only some information this study interests in as a result of specific data are selected for collection as shown in the following:

- Station ID number;
- Station name;
- Total slots;
- Available number of bicycles;
- Free slots;
- Update time; and
- Scrape time.

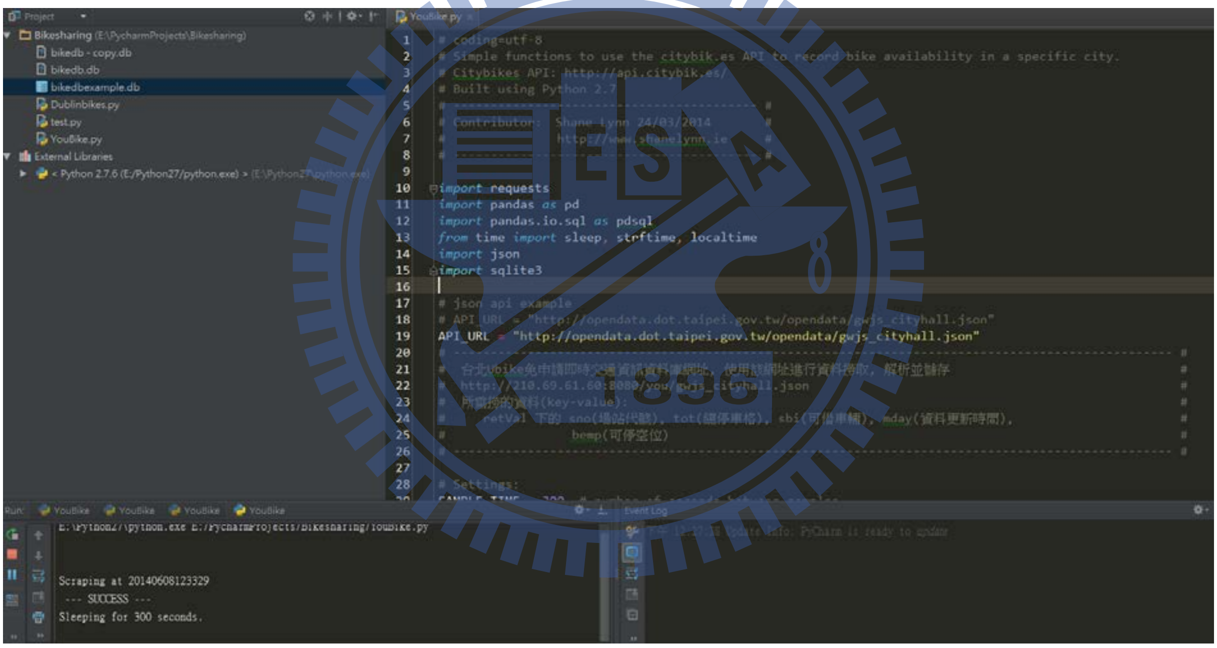


Figure 17 Demonstration of Python script run in PyCharm

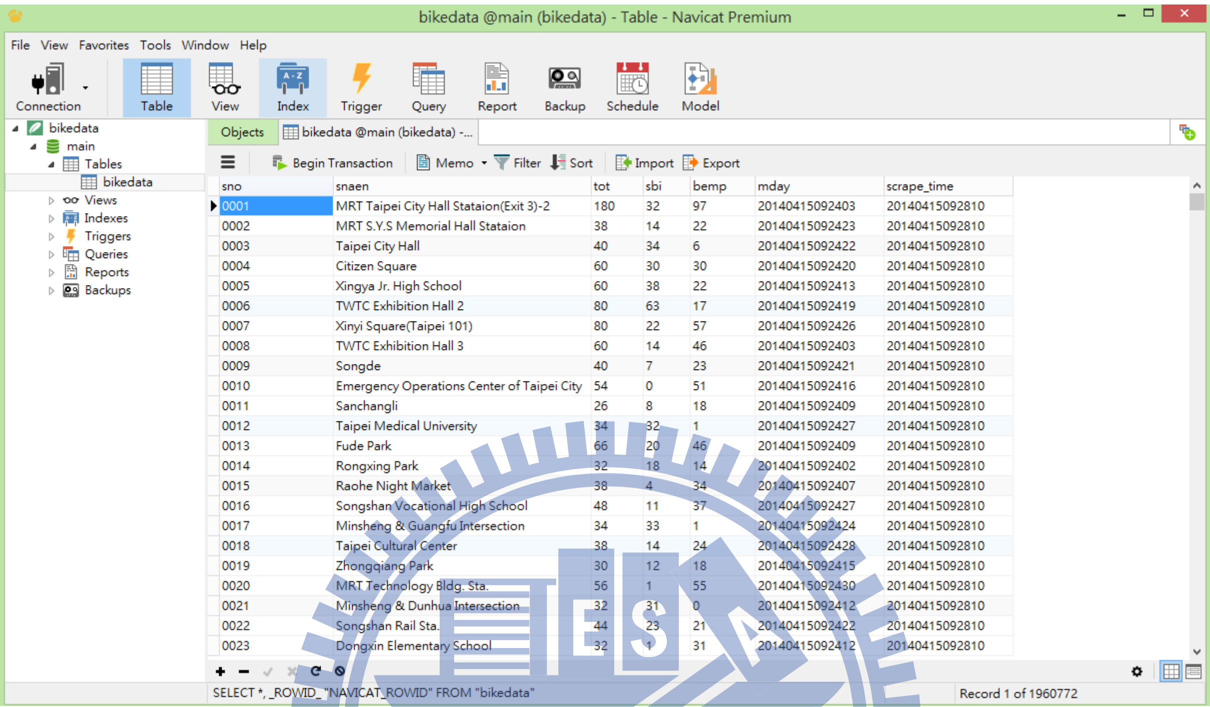
Source: image by author

Table 15 Structure of bikesharing ride data

Station ID	Station name	Total slots	Available bikes	Free slots	Update time	Scrape time
0007	Xinyi Square (Taipei 101)	80	22	57	20140415092426	20140415092810

Source: author

Above Table 15 illustrates the overall structure of bikesharing ride data which take Xinyi Square (Taipei 101) for example whereas following Figure 18 illustrates how the data is stored in a SQLite database which is managed by database administration tool, Navicat.



sno	snaen	tot	sbi	bemp	mday	scrape_time
0001	MRT Taipei City Hall Stataion(Exit 3)-2	180	32	97	20140415092403	20140415092810
0002	MRT S.Y.S Memorial Hall Stataion	38	14	22	20140415092423	20140415092810
0003	Taipei City Hall	40	34	6	20140415092422	20140415092810
0004	Citizen Square	60	30	30	20140415092420	20140415092810
0005	Xingya Jr. High School	60	38	22	20140415092413	20140415092810
0006	TWTC Exhibition Hall 2	80	63	17	20140415092419	20140415092810
0007	Xinyi Square(Taipei 101)	80	22	57	20140415092426	20140415092810
0008	TWTC Exhibition Hall 3	60	14	46	20140415092403	20140415092810
0009	Songde	40	7	23	20140415092421	20140415092810
0010	Emergency Operations Center of Taipei City	54	0	51	20140415092416	20140415092810
0011	Sanchangli	26	8	18	20140415092409	20140415092810
0012	Taipei Medical University	34	32	1	20140415092427	20140415092810
0013	Fude Park	66	20	46	20140415092409	20140415092810
0014	Rongxing Park	32	18	14	20140415092402	20140415092810
0015	Raohe Night Market	38	4	34	20140415092407	20140415092810
0016	Songshan Vocational High School	48	11	37	20140415092427	20140415092810
0017	Minsheng & Guangfu Intersection	34	33	1	20140415092424	20140415092810
0018	Taipei Cultural Center	38	14	24	20140415092428	20140415092810
0019	Zhongqiang Park	30	12	18	20140415092415	20140415092810
0020	MRT Technology Bldg. Sta.	56	1	55	20140415092430	20140415092810
0021	Minsheng & Dunhua Intersection	32	31	0	20140415092412	20140415092810
0022	Songshan Rail Sta.	44	23	21	20140415092422	20140415092810
0023	Dongxin Elementary School	32	1	31	20140415092412	20140415092810

Figure 18 Demonstration of part of data stored in the database

Source: image by author

In order to analyse the station activity patterns, we have been collecting data online since April 15th, 2014 to May 27th, 2014 every 5 minutes, parsing it and storing in a SQL database all the relevant information. Note that as the information changes over time, the data is added automatically to the database; for example, the data of new station are added automatically though this new station is not appeared firstly. Therefore, conducting a data cleansing process before analysing the data is needed. Note that the data continuously collects data for all stations at 5-minutes interval; however, the data may not be retrieved and returned to databased due to software errors or server downtime and maintenance or poor internet connection. Until the next data retrieved successfully, the data is logged in the database followed by previous recorded data.

4.1.1 Basic quantities of the data collected

Due to some problems occurred which demonstrated in the following Table 16 during the data collection period, some data are missing and may not be used for the study. For example, data of 24th May from 9:37 am. to 10:51 pm. was missing because of software idle. Notably on 27th May, the web API link is changed[20]. Therefore, the data collection results are based on the data before May 27th during the 6 weeks data we collected except those missing, not recorded data. Overall, the collected data in our study is from 166 stations with a total of 7,280 slots (165 stations with total 7,204 free slots since 15th April initially) provided. Total of 1,966,228 observations are collected. Note that the capacity for some stations would change during the data collection period. The station size per station ranges from 26 to 180 slots actually.

Table 16 Errors during data retrieval period

	Time	Duration	Types of error
4/16	11:24	141 min	Web server no response
4/18	9:30	2 min	Programme error
4/19	17:14	2 min	Programme error
4/20	00:32	2 min	Programme error
4/21	06:47	2 min	Programme error
	10:29	2 min	Programme error
4/22	17:57	14 min	Insufficient memory
4/27	18:06	120 min	Insufficient memory
5/9	16:54	7 hour 15 min	Programme error
5/15	23:58	1 min	Programme error
5/24	21:37	74 min	Programme error

Source: this study

According to Figure 16 most of error are unexpected programme error and the duration is up to more than 7 hours. The reason of various programme error duration is that while the error occurs, it is detected until checking the programme deliberately. Although the python script is run automatically, it still needs manpower involved to solve the unexpected error while running the programme. As the programme running for a while, the use of memory increases and they cannot release automatically. The error of insufficient memory occurs consequently as PyCharm is limited to use below the desired memory. The solution is to restart the programme

[20] The new web API url: http://opendata.dot.taipei.gov.tw/opendata/gwjs_cityhall.json since 27th May, 2014

or adjust the permitted amount of memory of PyCharm to use. However, the memory management is a delicate process; thus in this study we choose to restart the programme again instead. The error lead to inconsistent observations and diminish the quality of the collected data.

It is expected that the system expands over time; thus it is likely to build new stations or changes of station sizes. According to collected data, it is recorded that several station sizes are changed during the data collection period which is shown in Table 17 below. It shows that the sizes of MRT Dongmen Station (Exit 4) is diminished to 46 whereas the capacity of MRT S.Y.S Memorial Hall Station is increased to 48. There is a new station established, namely MRT Zhongshan Elementary School (Exit 4) with capacity of 70 bicycles.

Table 17 Changes of station size during data collection period

Station	Pre-size	post-size	When
MRT S.Y.S Memorial Hall Station	38	48	00:24 20th May, 2014
MRT Dongmen Station (Exit 4)	50	46	09:42 18th April, 2014
MRT Zhongshan Elementary School (Exit 4)	n.a.	70	00:08 17th May, 2014

Source: this study

4.1.2 Limitation

It may be argued that the data collection frequency (i.e., 5 min) may not be sufficient to demonstrate station activity patterns accurately throughout the day. Nevertheless, the study by Froehlich et al. (2009) address their data in terms of 5 min increments to use Bayesian network model for predicting available bicycles of specific station at a given time. As a result, it may be still acceptable that our data collection frequency would be appropriate. Note that the open data of YouBike provided by Taipei City Government can be retrieved in a more frequent base or even instantly though the application to Taipei City Government is needed. Moreover, it is designed to provide instant real-time information to mobile apps other applications for users to query the information at any time anywhere and everywhere; mobile apps developer also hand in the reports of application results and activity to the government annually. In addition, fixed-IP is also required to retrieve web API. Since this study only used for academic research, retrieving data in a 5 min base, allowing for retrieving data freely, is appropriate to use if consideration of the convenience of data collection. It is important to note that the collected data does not incorporate trips, i.e., trip originations and trip destinations. As a result, flows of bicycle between stations cannot be examined, indicating that this data cannot be used to count journeys. It only simply observes that the available bicycles and parking spaces at a given time, thus demonstrating the activity patterns of stations at a given time.

4.2 Data cleansing and pre-processing

The data that was collected from web API is not fully reliable representation of the activity of each station due to no response of web server, unexpected programme error, and insufficient memory as mentioned in Table 17 previously. Besides these technical errors, maintenance work of stations, broken bicycles or parking slots, data not as expected in 5-min based and etc. also result in noisy data. As a result, data cleansing process is required to pre-process the data through detecting, correcting and removing before analysis. Here is a multiple step cleansing process which is proposed by Froehlich et al. (2009) firstly and used by Lathia et al. (2012) as well is used to detect and eliminate the noise. Some definitions and notations are described following before conducing data cleansing process.

4.2.1 Definition and notations

It defines the terms, notations and intermediary process used in the analysis as suggested by Froehlich et al. (2009).

- Station Size: The specified station size of each station is obtained from the web API officially. However, due to bicycle lost or bicycle maintenance the actual station size varies which can be calculated as the sum of available bicycles (denoted as B_t) and parking slots (denoted as S_t) at time t at each station;

- Observation normalisation: Normalised available bicycles (NAB) is used to normalised stations' data by dividing each observation by the specified station size (see Equation 1), aiming to adjust different values to a common scale; thus it allows to be able to compare the usage of station activity in different size:

$$NAB_{i,t} = \frac{B_{i,t}}{S_{i,t}} \tag{1}$$

  where $S_{i,t}$ and $B_{i,t}$ are referred to the size of station i at a given time t obtained from web API and available bicycles of station i at given time t respectively. Note that NAB may be interpreted as the proportion of available bicycles occupied in parking slots for a given station. It can be seen as a key measure for each bike station and used by numbers of studies (also (Froehlich et al., 2008; Froehlich et al., 2009; Vogel et al., 2011; Lathia et al., 2012; O'Brien et al., 2014). NAB ranges from 0 (empty) to 1 (full);

- Station activity and event score: While the Activity Score (AS) is a measure of how activity a station is in a given time, the Event Score (ES) is a binary version of Activity Score, indicating whether the net flow of bicycles is greater than zero or not of a station at a given time. Activity Score is calculated by the absolute value of difference of available bicycles between current time t and the last time window $t-1$:

$$AS(t) = |B_t - B_{t-1}| \quad (2)$$

Where B_t is the number of available bicycles at time t.

4.2.2 Cleansing process and processing

The data cleansing process can be generally employed in three steps as discussed in the following:

1. Station size consistency: The sum of B_t and S_t should remain constant; however it may fluctuate over time due to temporarily broken bicycles or parking slots, station capacity expansion or contraction. Since the station size of each station is reported by YouBike official website, the observed values of $B_t + S_t$ is used to examine whether the observation is greater than the specified size for the given station or not. The observations are considered invalid and removed.

2. Day Data Threshold: If a specific station has a higher proportion of invalid or missing observations during a single day, it should be removed. More specifically, for those stations contain less than 70% of 288 possible observations (i.e., 202 samples) during a single day, the entire data of that day would be removed. Consequently, this accounts for abnormal station behaviour.

3. Station Data Threshold: If the station data is less than 45% of the possible weekday's data (i.e., 907 samples), the entire data of that station is removed.

In addition, for those stations have unexpected values obtained from web API with abnormal values such as $B_t + S_t \leq 0$ or specified station capacity ≤ 0 is seen as invalid data and being removed. This process is to ensure each station is in operation properly.

At the end of data cleansing process, it is not surprised that only very few data is removed (only 0.277% of all observations as shown in Table 19) which may be due to robust web server system and internet connectivity. More importantly, the errors are identified and addressed in a short time. Most of data is removed in terms of Day Data Threshold criteria and unexpected sum of $B_t + S_t$ as Y17 Youth Recreation Centre station accounts for 5,042 out of 5,456 (92.41% approximately) data missing which may result from maintenance work. In total, 1,960,772 of observations remained after data cleansing process. Nevertheless, it should be noted that while numbers of stations have almost the identical number of observations (11,897 samples) during the data collection period whereas the new station operated from 17th May only have 2,957 samples.

While Table 18 illustrates the detected errors through data cleaning process, the data continuity is important as well for the following temporal analysis and clustering. Therefore, data supplement is required to generate the reasonable value of data for analysing and plotting the figure in a more comfortable manner. Missing data is supplemented by adding the “null” value in the case of no additional information provided from neighbouring data whereas “linear interpolation” is used to fit the missing data given neighbouring data is known.

Table 18 Details of removed data

Station name or station ID	Removed criteria	Time[21]	Observation
Xizhi Dist. Office	$B_t + S_t$ is greater than station specified capacity	10:34 29th April	1
		10:39 29th April	1
Yulon Park		10:39 29th April	1
Renai & Yixian Intersection		23:52 8th May	1
Taipei Medical University		17:03 22th May	1
		17:08 22th May	1
		17:13 22th May	1
Y17 Youth Recreation Centre	$B_t + S_t$ is equal to 0 which may be due to maintenance work	01:19 28th April to 00:00 16th May	5,042
Taipei Medical University	$B_t + S_t$ is less than or equal to 0	12:47 20th April to 13:32 20th April	10
9904		13:13 24 April	1
9088		11:24 26th April to 16:39 26th April	42
Jianguo & Nongan Intersection		19:44 25th April	1
Dapeng Community		10:25 29th April	1
Xizhi Railway Station		10:29 29th April	1
Cathay General Hospital		10:37 29th April	1
Yulon Park		10:37 29th April	2
MRT DaPingLin Station		10:39 29th April	1
9921		13:26 6th May	1
MRT Gongguan Sta.(Exit 2)		19:37 13th May to 14:47 14th May	38
Y17 Youth Recreation Centre		00:00 to 00:10 16th May	2
MRT Zhongshan Elementary School(Exit.4)		00:08 to 03:35 17th May	42
Citizen Square		13:44 to 14:44 17th May	12
		06:30 to 08:25 27th May	24
7003, 7004, 7005		13:04 to 13:16 18th May	62
MRT Jingmei Sta.		11:27 to 13: 06 19th May	21
		21:11 20th May to 01:10 21TH May	49
MRT S.Y.S Memorial Hall Station		00:03 to 00:11 20th May	3
Taipei Medical University		07:24 to 09:09 20th May	22
Xinyi Square(Taipei 101)		21:10 20th May to 00:50 21th May	45
Xinsheng & Heping Intersection		01:02 21th May to 01:56 21th May	12
MRT Jiannan Rd. Sta.(Exit 2)		08:25 21th May	1
Taipei City Hakka Cultural Park		00:47 25th May	1
Donghu Junior High School		21:16 26th May	12
		Total	5,456

Source: this study

[21] refers to the last system update time of invalid data while scraping

4.2.3 Analysis tool

In this study, several tools are used in order to accomplish the presentation of analysis. Navicat Premium (version 11.0.18) which is a database administration tool is used to manage and process SQLite3 format (filename extension as .db). Additionally, query function is also used to filter the specific data efficiently and can be exported to common file formats such as txt, csv or excel format for analysis. IBM SPSS Statistics (version 22) is used as well for plotting usage patterns. R programming language is also used due to the abundant of packages provided to accommodate the common statistics needs. It is used to process the plotting of average temporal tendency of station activity, and generates the high quality and high resolution figures. More importantly, these figures may be contributed to the help of MATLAB in processing the original data since the data is stored in the database in terms of the order of station ID repeatedly every 5 minutes. Through a simple coding, MATLAB helps to reorganise the data in a time series order by each station automatically, thus decreasing the processing time if processed manually.

Orange which is an open source visual programming environment for data mining developed by Bioinformatics Laboratory in the University of Ljubljana. Not only Orange features a visual programming for data analysis and visualisation, but also being capable of developing advanced algorithms and executing complex data analysis procedure joyfully in terms of Python scripting (Orange, 2014). While this software is used to perform hierarchical clustering, partitional clustering (i.e., K-means algorithm) is done by R because of conducting Silhouette coefficient measure.

This study has shown that using multiple ways of pursuing the aims and objectives in the view of task-oriented.

5. Station activity patterns

This chapter commences with an analysis of the station activity patterns in terms of the amount of available bicycles. The analysis can be divided into three parts. Firstly, temporal activity patterns of some specific stations are illustrated in terms of weekday and weekend data. Then average system-wide temporal trends aggregated by all stations are illustrated as well in section 5.1. Secondly, clustering algorithm is used to analyse how station activity patterns are geographically distributed in the city based on their usage patterns and explore how these activity patterns relate to underlying cultural and spatial characteristics of Taipei City (section 5.2). Finally, the analysis results are discussed in section 5.3. Figure 19 provides an overview of the analysis process diagram of bikesharing usage data.

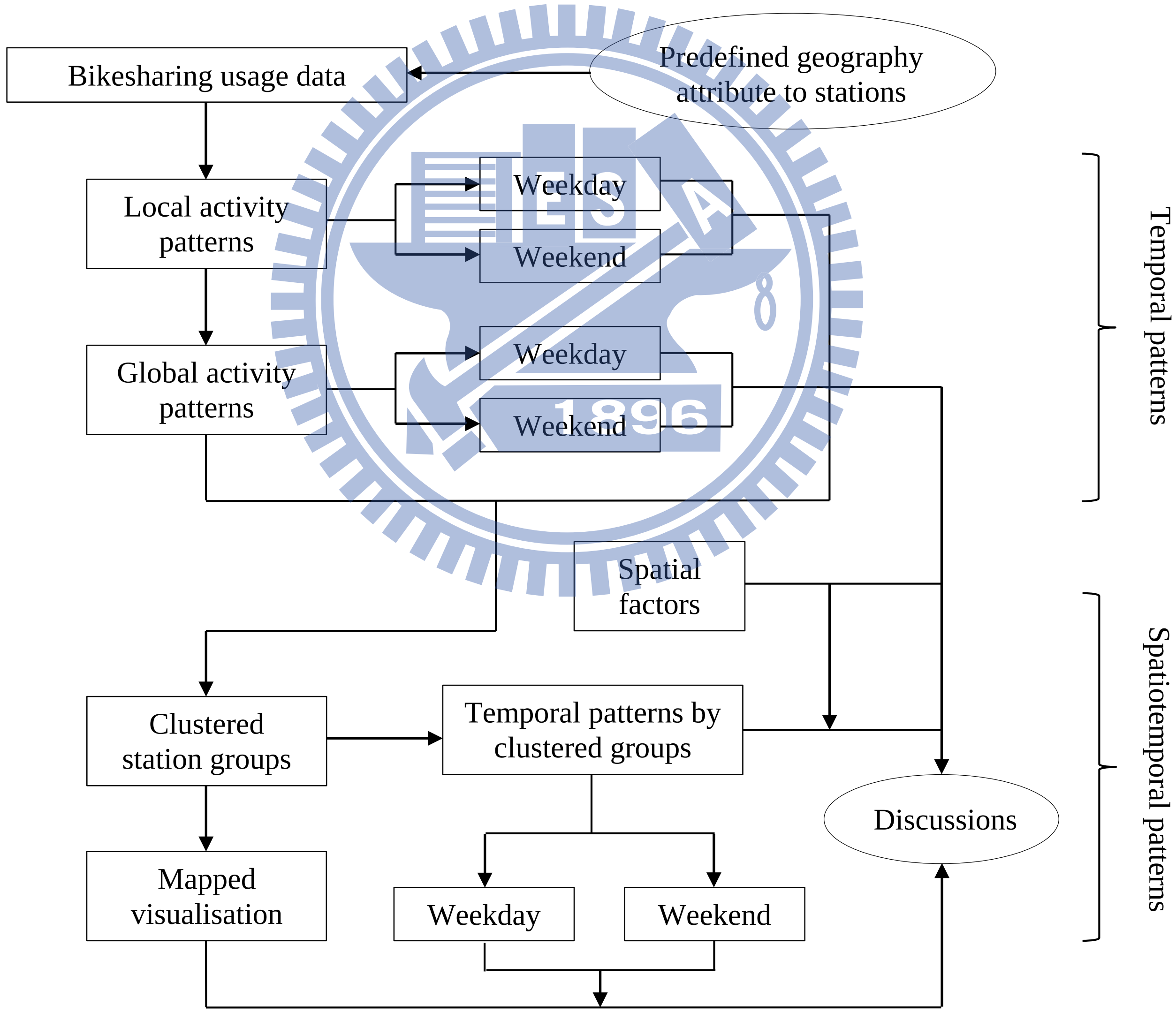


Figure 19 Bikesharing data analysis process diagram

Source: this study

Before exploring temporal patterns of bike stations individually or globally, each station is tagged with specific geography attributes where stations can be mostly represented by their neighbouring facilities. It is expected that it may help to examine how clustered stations group distributed geographically across the city, to identify their spatial characteristics such as proximity to stations or tourist attractions, and able to be compared among different clustered results. Therefore, the relationship between spatial characteristics and activity patterns can be further explored. Initially, there are six categories covering underlying daily activities and leisure activities as shown in following: *(1)* MRT or transit depot; *(2)* public facilities such as libraries, hospital and etc.; *(3)* working place and school; *(4)* shopping area; *(5)* tourist information; and *(6)* residence. Each station would only be tagged with unique geography attribute. However, note that it is possible certain stations are in close proximity to multiple places as illustrated above and hard to specify proper geography attribute to them. In this situation, the proper geographical tag would be based on their specific "station name" into account. For instance, since MRT Taipei City Hall Station (Exit 3) locates at the exit 3 of MRT Taipei City Hall Station with numbers of working place, shopping area nearby, it would be tagged with "*MRT or transit depot*" attribute. *Street View* provided by Google Maps is also used to identify. Lists of geography attribute for each station is illustrated in Appendix B: description of stations. Figure 20 illustrates the number of stations by geography attributes. It shows that the geography attribute of *MRT or transit depot* has the largest number of station (52 out of 166) whereas the tag of shopping area has the least number of stations, indicating the philosophy of bike station location planning.

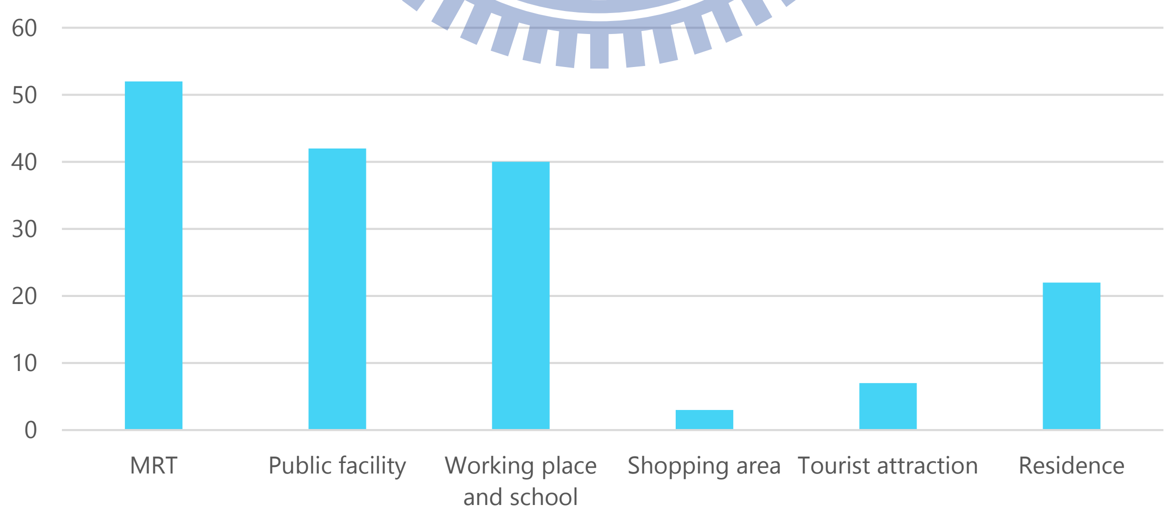


Figure 20 Numbers of stations by geography attributes

Source: this study

5.1 Temporal patterns

The temporal patterns are generated from collected data through using R mainly and IBM SPSS Statistics. Generally speaking, the result of temporal patterns of these bikesharing stations can be divided in terms of two parts: local activity patterns and global (aggregated) activity patterns.

5.1.1 Local activity patterns

We begin by considering station activity patterns of some specific stations with different embedded geographical attributes followed by the aggregated patterns of all stations. It is expected that the temporal patterns of each bike station reflects the actual bikesharing usage patterns which are underpinned by the daily routines of citizens in the city. Following will discuss several stations respectively based on their location attributes for example.

1. MRT and transit depot

Below Figure 21 shows an example of the time series activity pattern from a station close to MRT Zhongxiao Fuxing Station surrounded by number of shopping hotspots such as SOGO department stores and East metro shopping street, restaurants and some office. The time series pattern ranges from Tuesday, 15 April 2014 to Tuesday 27 May 2014 and ordered top-down according to their temporal sequence. Noted that the blue line indicate the number of available bicycles. Moreover, the fluctuation of total slots (red lines) which are calculated by the sum of available bikes and free slots is also illustrated to reflect the actual station capacity at a given time. Sometimes total slot does not correspond to the specified capacity of stations due to broken bicycles or defective slots. According to Figure 21, the overall temporal usage patterns during the 6 weeks of data collected are illustrated. The number of available bicycles basically fluctuates over time whereas the total slots mostly remain at the constant level (i.e., 54 slots) except for the missing data. It can be found that some sudden increases of available bicycles occur around 5 am which may be caused by rebalancing trucks moving bicycles from other full stations to empty or almost empty stations. It seems that bicycle redistribution plays a vital role of daily operation in this bike station as bicycle redistribution can be found in most of days during the 6 weeks period of data. Hence it is clearly that the amount of bicycles has a morning spike which is mainly to accommodate the morning commuting peak and starts to drop during the period of 5 am to 10 am. Similarly, it also has a spike which is normally in the evening then drops soon and stays at a low level of available bikes till the next day morning. Although the data we collected does not include the inbound and outbound journey of each bike, it can still imply that bicycles are rebalanced to 40 approximately because of other possible inbound bicycles.

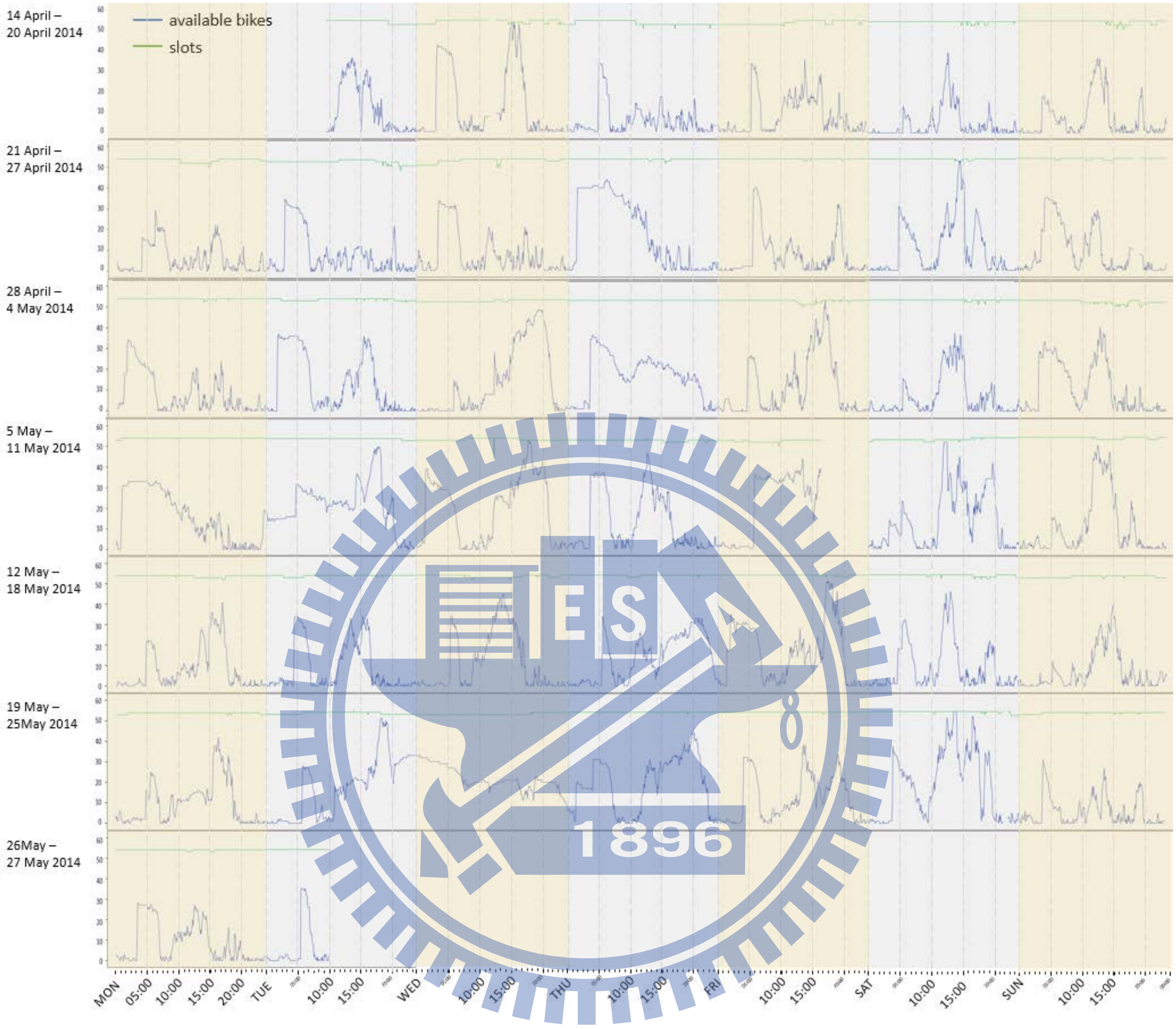


Figure 21 Time series of the number of available bicycles (blue line) and total slots (red line) at station No. 0111: MRT Zhongxiao Fuxing Station (Exit 2)

Source: this study

Average weekly activity pattern of this bike station is shown in following Figure 22, providing the more clear view in terms of the mean activity pattern of working days and weekends. Note that the golden shaded areas in Figure 22 plots the one standard deviation above and below the mean activity patterns within each bin (e.g., 288 bins/day) over time. Overall, the standard deviation of available bikes illustrates the observed patterns are quite fluctuating and tends to be larger during the working days rather than weekends. It may probably due to in weekends users are more likely to have similar trip purposes (i.e., shopping) thus riding bicycles to and from this station while in weekdays this station serves mixed groups of people including commuters and people going for shopping mainly. Note especially in the weekends (including Friday night) near zero deviation of available bikes is observed from 9 pm roughly to the next day 4 am in the morning.

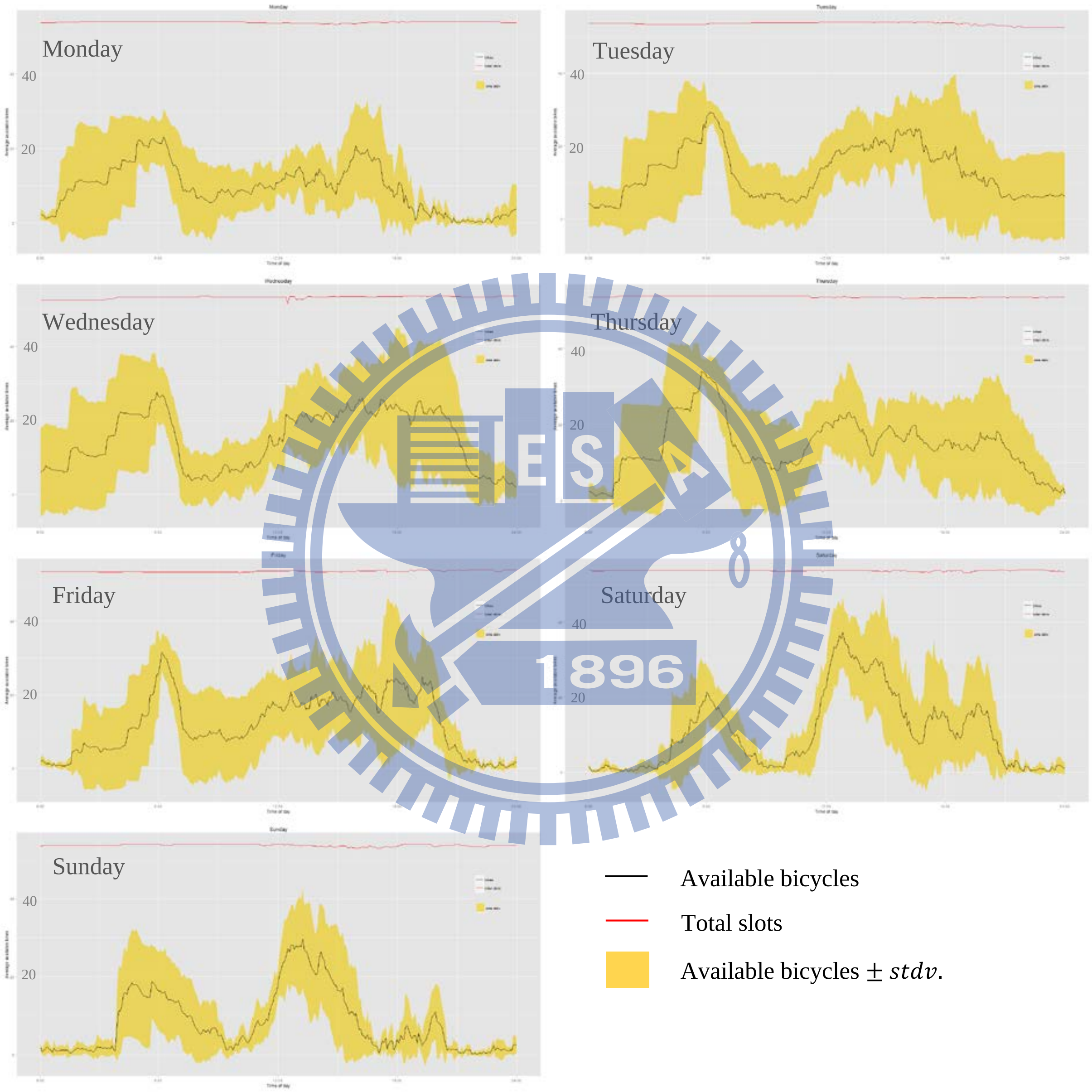


Figure 22 Average weekly station activity patterns of station No. 0111: MRT Zhongxiao Fuxing Station (Exit 2)

Source: this study

It can be observed from Figure 22 above that the activity pattern of working days differ from those in weekends. In terms of weekday patterns, it shows a quite narrow peak in the number of available bikes in the early morning between 6:00 to 8:00 approximately from Monday to Friday, which might be typical for commuting. The amount of bikes drops sharply between 6 am and 8 am and remains at the low level of bicycle to use. This corresponds to Figure 21 which mentions that bicycles seem to be refilled before the commuting hour. The figure also reveals that the number of bikes returns back to a higher level in noon and fluctuates until 9 pm where declines distinctly.

By contrast, weekend patterns reveal that five-pronged spike in station activity which corresponds to the morning, lunch, afternoon and evening (containing 2 spikes) respectively. It is interesting that the morning commute is still shown in weekend patterns. The apparent lunch spike which appears across both Saturday and Sunday occurs between 12:00 and 13:00, reflecting the number of bikes checked in is far greater than checked-out bikes. As one might expect, this station attracts people come to this station for launch and shopping later as many restaurants and SOGO department stores nearby. In addition, a small spike of availabla bikes in the afternoon may be caused by the other groups of people coming for shopping in this area. In regard to evening spikes, it suggests that people tend to use YouBike more between 5 pm and 9 pm in the Sunday evening than Saturday; and the level of available bikes both remains at near zero after 9 pm as shown in Figure 22.

Below Figure 23 illustrates the average weekday and weekend normalised available bicycles (NAB) at station No. 0111. It can be seen that fluctuations across the week are averaged out and smoothed, allowing the overall number of available bikes throughout the day more intuitively. Generally speaking, both activity patterns in weekdays and weekends follow the similar pattern in terms of their "M" shaped activity tendencies although they differ from the deviations of NAB and the changes of NAB at different timing. During the working days, it is more likely that people are hard to find a bicycle between 7 am and 11 am as average NAB is below 0.15 (less than 8 bicycles[22]) and the average standard deviation is around 0.12 during this period. The situation occurs in the weekends as well. After 12:00 in the working days, the average NAB is above 0.3 which lasts for a long time period and starts to fell after 7 pm roughly. In contrast to the loose

[22] The total slots of station No. 0111: MRT Zhongxiao Fuxing Station (Exit 2) are 54

M shaped average activity patterns in weekdays, the shape of activity pattern is tighter instead due to much earlier drop of available bikes from afternoon and near zero deviation of NAB during the period of 9 pm to 3 am. Note that this stations experiences a third peak starting at 6:30 pm and reaching its maximum at 8 pm in the evening.

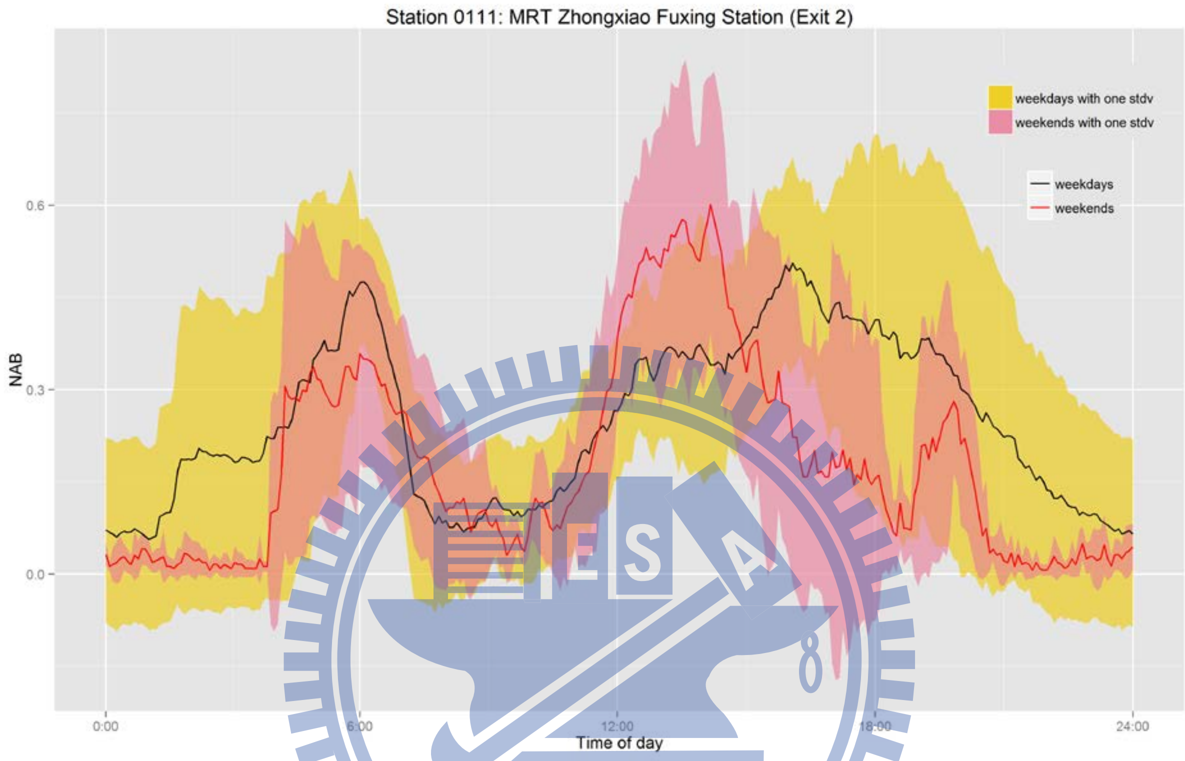


Figure 23 Average NAB during weekdays and weekends of station No. 0111

Source: this study

2. Public facility

Since it is found that there are several subgroups in the category of public facility, there are four different subsets chosen in the public facility group for being more comprehensive knowledge of overall temporal patterns for example.

a) Public park

Following Figure 24 illustrates the average weekday and weekend normalised available bicycles (NAB) at station No. 0014: Rongxing Park where is in the proximity to the residential area and two schools. Different activity pattern is observed. It shows a slight decreasing tendency of active patterns both on working days and weekends though the variation of NAB is larger than in working days and the spikes during the day are clearer. Generally speaking, before noon the NAB fluctuates at the level of 0.5 approximately, and starts to decline where the level of NAB ranges between 0.25 and 0.5 although a spike occurs around 6 pm on weekdays. It indicates that until around noon people leave the region which decreases NAB sharply; and people return the bikes in the afternoon but it fells again after the dinner time. The pattern occurs similarly during the weekend with larger variances instead. Note that normally the number of available bicycles in weekends tend to be much harder to rent a bike between afternoon and early evening compared to working days.

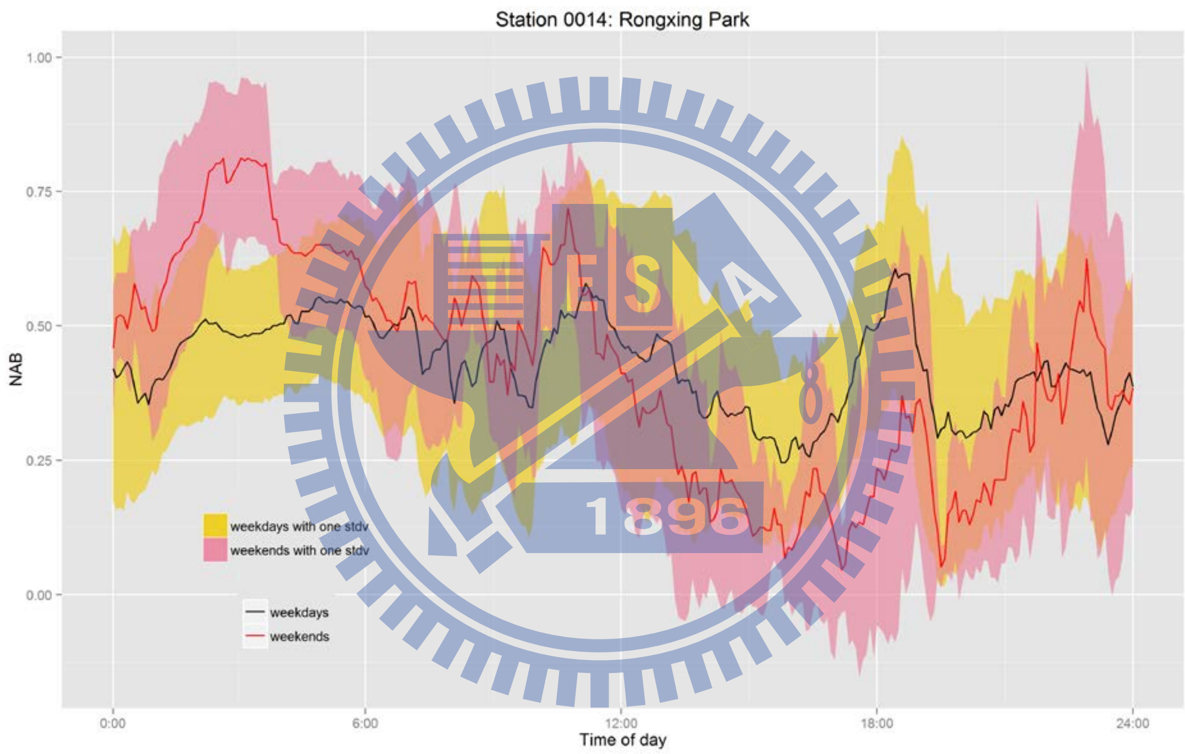


Figure 24 Average NAB during weekdays and weekends of station No. 0014

Source: this study

b) Sport centre

Figure 25 illustrates the average weekday and weekend NAB at station No. 0055: Taipei Stadium where is in the proximity to working places mainly, schools and Song Shan Sport Centre. It can be observed that initial rising of available bikes starting from the morning until around 9 am which may be largely brought by the commuters to working places nearby. Then the number of available bicycles fluctuate around at the level of 0.5 and decline in the afternoon. One might expect that it would have more inbound flow of bicycle in the evening as people come to here doing some exercise after work. Nevertheless, it rather shows a "flat" fluctuation of low level of bicycles occurs between 6 pm and 9 pm and likely to be nearly zero of bikes after 9 pm, indicating that closely balanced flows for commuting and sport. Regarding activity patterns during weekends, it is observed that the overall of available bicycles are below the level of those in the working days though share the similar patterns. Averagely, the NAB fluctuates at the level of 0.25 with larger variance than weekdays; and it turns almost zero while approaching 6 pm followed by a sudden rise of bikes, reaching the peak at 7 pm approximately. It implies that most people are likely to do some exercise during the evening weekends.

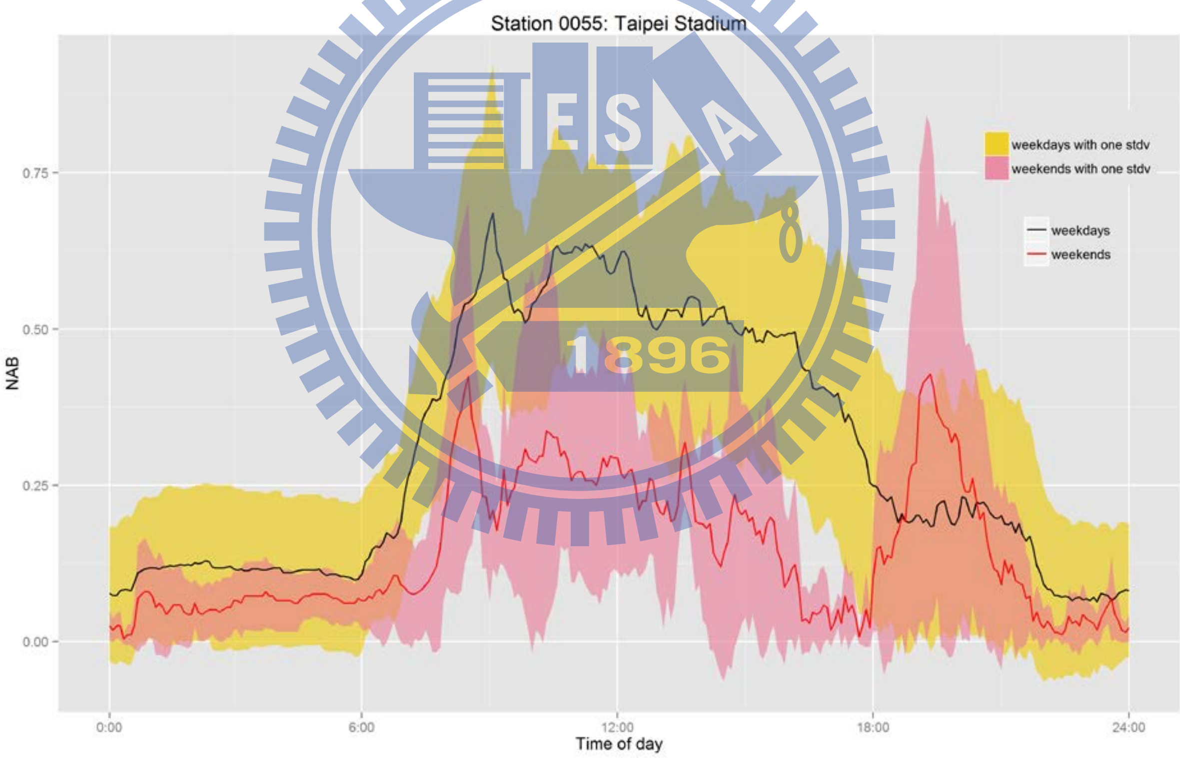


Figure 25 Average NAB during weekdays and weekends of station No. 0055

Source: this study

c) Hospital

Following Figure 26 illustrates the average weekday and weekend NAB at station No. 0063: Taipei City Hospital Renai Branch where is in the proximity to some working places mainly at North, some restaurants and residential area. It can be clearly observed that it has a spike roughly at 10 am with reaching 0.6 NAB averagely and shows a stable declining tendency of available bikes till midnight during weekdays and remains at near zero level of bikes till morning. Overall, the weekend also follow the similar patterns; nevertheless, the number of available bicycles are averagely lower than in the working days with smaller variability in the evening. Notably there is a small peak of available bicycles in the afternoon however they are declined and stayed at the ultra-low level of bikes then. Note that the activity patterns of Taipei Stadium and Hospital Renai branch seems to be similar for observed decreasing tendency starting before noon. Additionally, the location characteristics may be the reason that sudden rise of available bikes in the evening at station no. 0055 whereas it remains at the near zero of bikes at station no.0063 which probably caused by the residents mainly.

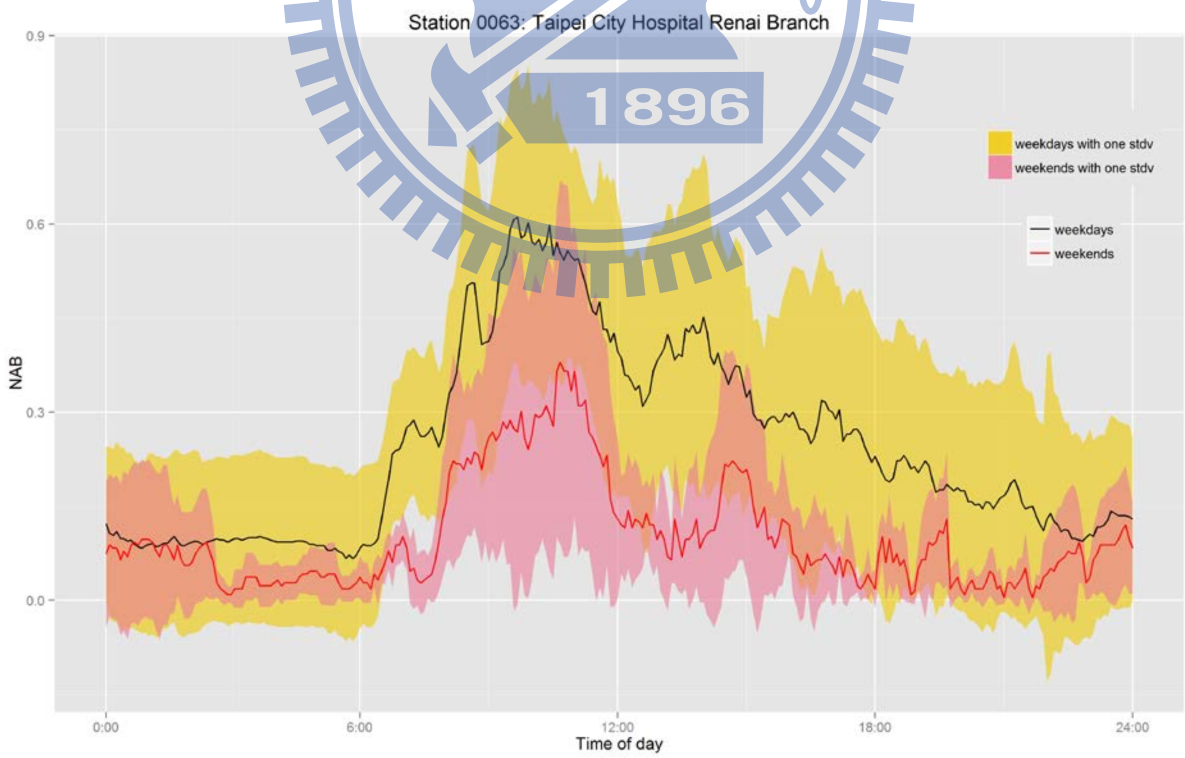


Figure 26 Average NAB during weekdays and weekends of station No. 0063

Source: this study

d) Library

Following Figure 27 illustrates the average weekday and weekend NAB at station No. 0064: National Central Library where is in the close proximity to the famous attraction: CKS Memorial Hall and MRT CKS Memorial Hall station. A clear narrow double peak in the number of available bikes between 6:00 and 18:00 with a valley around 12:00, followed by a small spike occurs again between 19:00 and 20:00. Overall, the weekend also follow the similar patterns; nevertheless, the number of available bicycles are averagely lower than in the working days with smaller variability in the evening. Specifically, starting from weekend afternoon (i.e., 3 pm) the available bicycles drops significantly to almost zero till the midnight, indicating the higher popularity of the station in the weekend afternoon and evening. Note that the variance of the bicycle quantities is quite low during this time period as well, indicating the type of flow may be mainly outbound or no significant inbound flow. It may be caused by the early closing time of library in Sunday evening (5 pm).

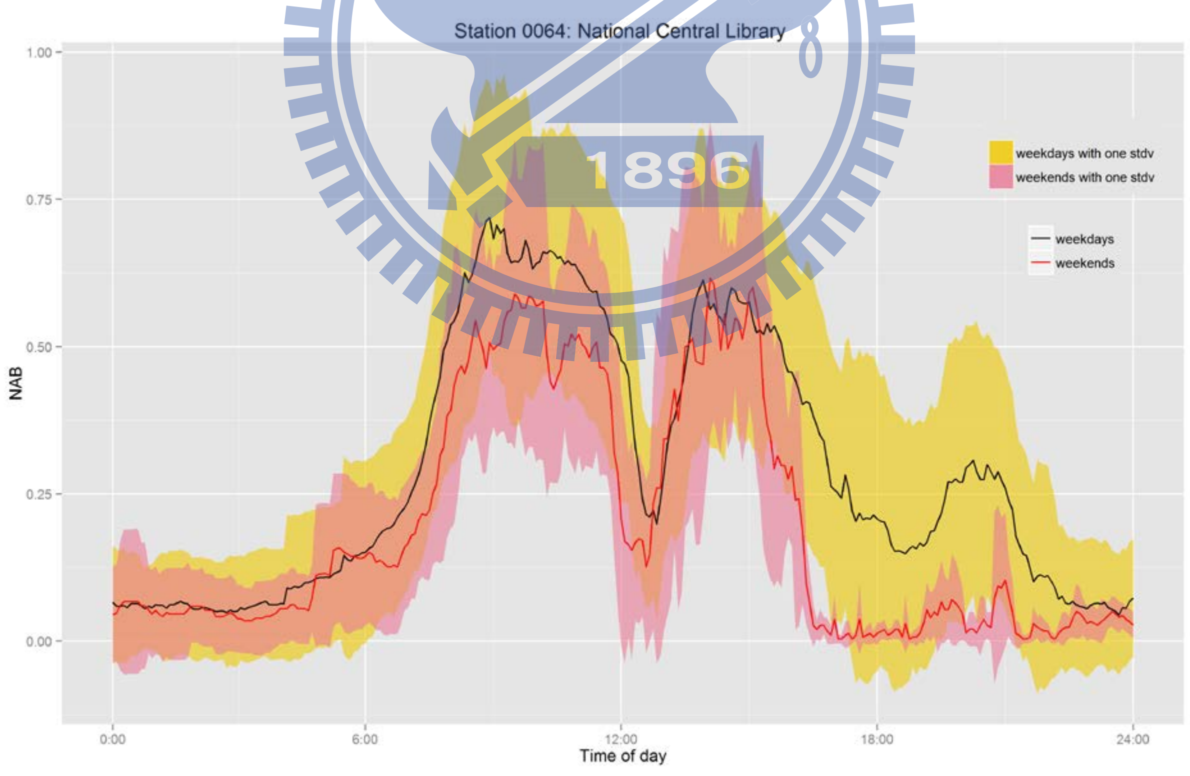


Figure 27 Average NAB during weekdays and weekends of station No. 0064

Source: this study

3. Working places and school

It is interesting that two different patterns of station activity are found and displayed respectively in the following. Following Figure 28 illustrates the average weekday and weekend NAB at station No. 0144: National Chengchi University where is close to the university and the commercial area surround by the university. One might expect that it would have the narrow peak in the number of bicycles in the morning which is probably typical for a university classes. However, it actually illustrates a small initial rise in the morning between 9:00 and 12:00, followed by the declines continuously till the evening. The may be caused by the far distance to the nearest bike station (about 1200 metres), enabling the higher possibility of inbound and outbound flow from the same station. It is also interesting that an opposite activity patterns compared to weekdays, showing a continuous decreasing of the number of bicycles before noon then remains fluctuations until around 9 pm where the number of bicycles starts to recover. Therefore, it can be observed that how difference of bike station close to a university without neighbouring station within 400 metres between weekdays and weekends pattern.

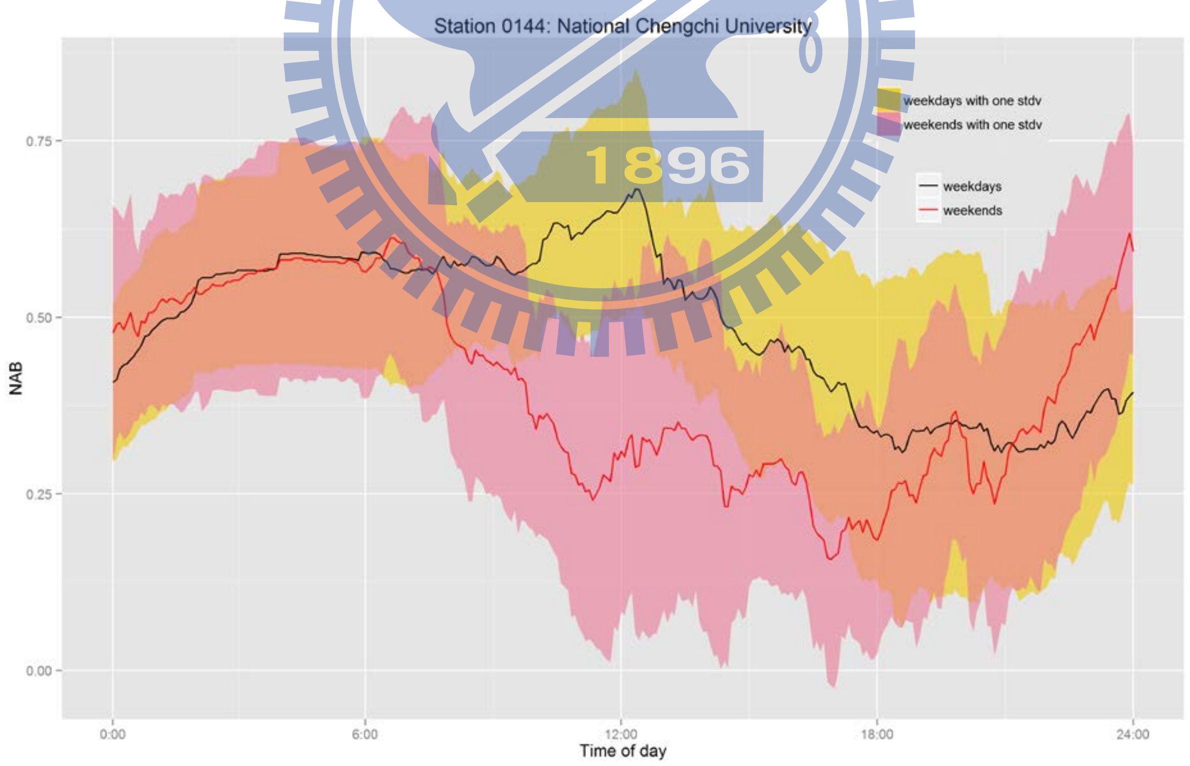


Figure 28 Average NAB during weekdays and weekends of station No. 0144

Source: this study

Figure 29 illustrates the average weekday and weekend NAB at station No. 0007: Xinyi Square (Taipei 101) where is in proximity to the Taipei 101 and number of working places nearby and residences mainly at the south side. Generally speaking, the level of available bicycles is below 0.3 averagely in working days whereas increases but less than 0.4 in weekends, indicating that the higher popularity of this station throughout the day. It shows that a double peak appears between 9:00 and 17:00, followed a small spike around 9 pm in working days, which seems to be typical for commuting workers. Regarding to activity patterns in weekends, it actually demonstrates the similar patterns with much narrower double peaks compared to those in working days. However, it remains at almost zero of bikes with much small variance since the weekend evening to the next day morning, indicating that this station mainly creates outbound flow during this time period or without significant inbound flows to the station. It should be further confirmed by the actual flow data of bicycle renting activity. One might expect that this station serves for workers and commuters primarily as higher income groups of people living in nearby residences which equipped with parking space privately.

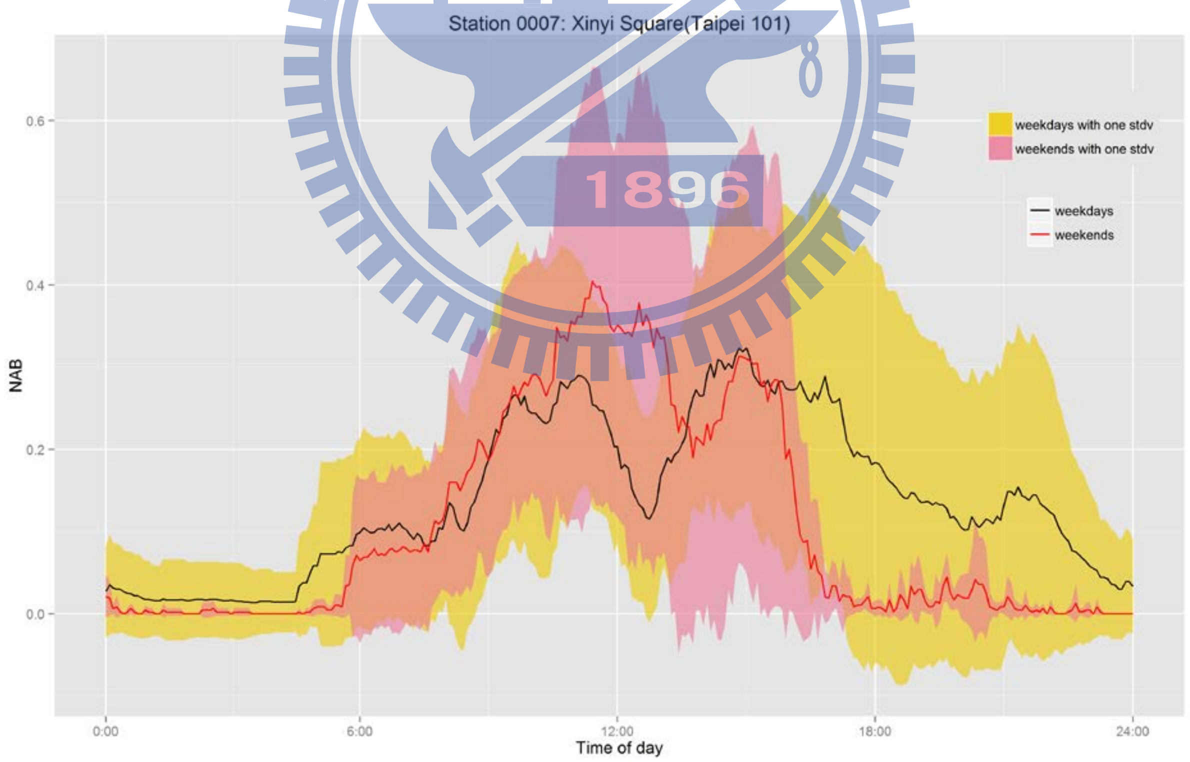


Figure 29 Average NAB during weekdays and weekends of station No. 0007

Source: this study

4. **Commercial and shopping area**

Following Figure 30 illustrates the average weekday and weekend NAB at station No. 0049: Longmen Square where it is surrounded by numbers of shopping hotspots such as SOGO department stores and East metro shopping street, restaurants and some office. Note that the location characteristics are very similar to the bike station: MRT Zhongxiao Fuxing Station (Exit. 2) which is 500 metres far; however, there activity patters are somewhat different. During weekdays, it is observed that the initial rising of available bicycles starting from 9 am which may correspond to the location of the bike station in proximity to the shopping area where starts to open in the late morning. Followed by the fluctuations of number of bikes until 18:00 then it begins to drop continuously till midnight. It indicates that inbound flows dominate in the daytime while in the nighttime outbound flows are outweighed by people leaving for home. In weekends, the peak of available bike appears at 1 pm which is probably caused by the people coming this place looking forward their lunches. Afterwards, it decreases though with a clear raise around 6pm until 8 pm followed by the nearly zero level of bikes then.

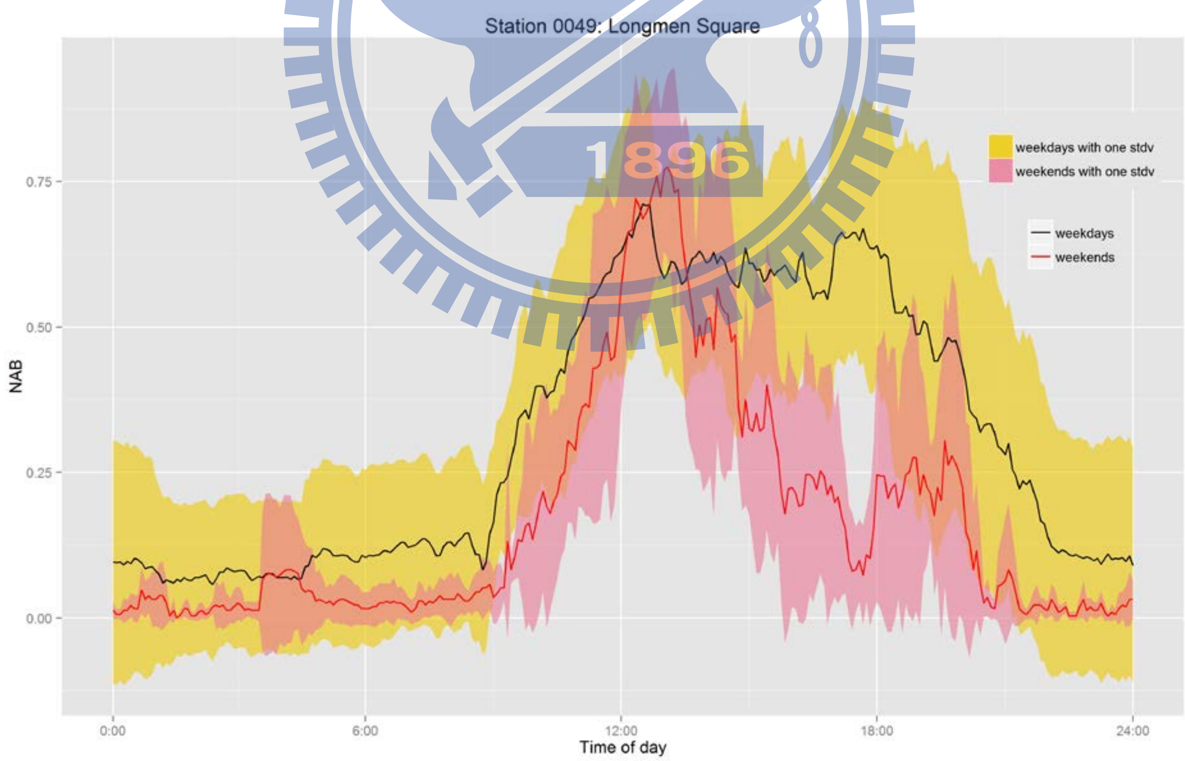


Figure 30 Average NAB during weekdays and weekends of station No. 0049

Source: this study

5. Tourist attraction

Following Figure 31 demonstrates the average weekday and weekend NAB at station No. 0109: Lin An-tai Historical House where is located in the Taipei Expo Park and is in proximity to the Dajia Riverside Park. Although during working days the overall level of NAB fluctuate around 0.5, it is interesting to observe that the raise of number of bikes occurs between 8:00 and 9:00 proceeded by staying at the NAB value of 0.5 and a little decrease from 16:00 approximately. It implies that people tend to use bike more from the station to other places since afternoon. During weekends, initial rise of number of bicycles begins at 8:00 roughly and lasts to 12:00, followed by the sudden drop of bicycles which may be caused by the people come to the place for leisure and leaving for launch afterwards. In addition, after lunch time the number of bike progressively decreases until it reaches a low level of available bikes at 6 pm; and it recovers considerably, peaking at 8 pm. It is probably caused by the location of the station provides a great opportunity for people renting bicycles to and from the station as going nearby leisure places such as Dajia Riverside Park for cycling.

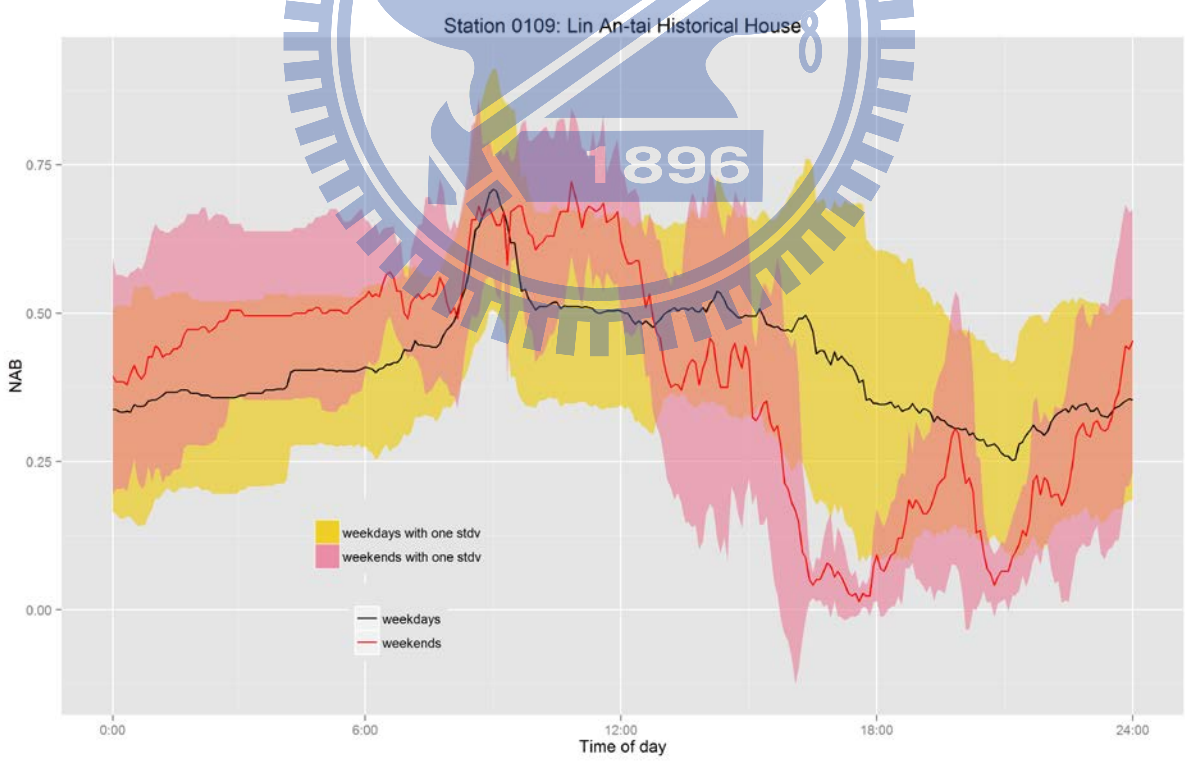


Figure 31 Average NAB during weekdays and weekends of station No. 0109

Source: this study

6. Residential area

Following Figure 32 demonstrates the average weekday and weekend NAB at station 0128: Chengong Public Housing where is in the proximity to the several financial offices and buildings as well as residential areas. It shows that people start to leave the region in the earning morning with a little spike at 9:00 approximately and people return the bikes later in the afternoon or late evening. The level of NAB value is averagely below 0.25 after 9 :00 and until 21:00 it finally recovers to higher available bikes, which indicates that the bike station is popular almost throughout the day. The weekend's pattern is generally similar to weekdays. The onsets of weekend activity patterns occurs earlier than during weekdays and has a spike at around 9 am and then fluctuates at the low level of available bikes afterwards. Until 6 pm it starts to recover, indicating that people are more likely to return to this region since weekend evening. Unlike other patterns have been shown previously, activity pattern of station located in residential area seems to have longer period of lower number of bicycles; in addition, it shows that YouBikes are popular at this region, and as a first/last mile of transport mode to and from the station to their desired destinations.

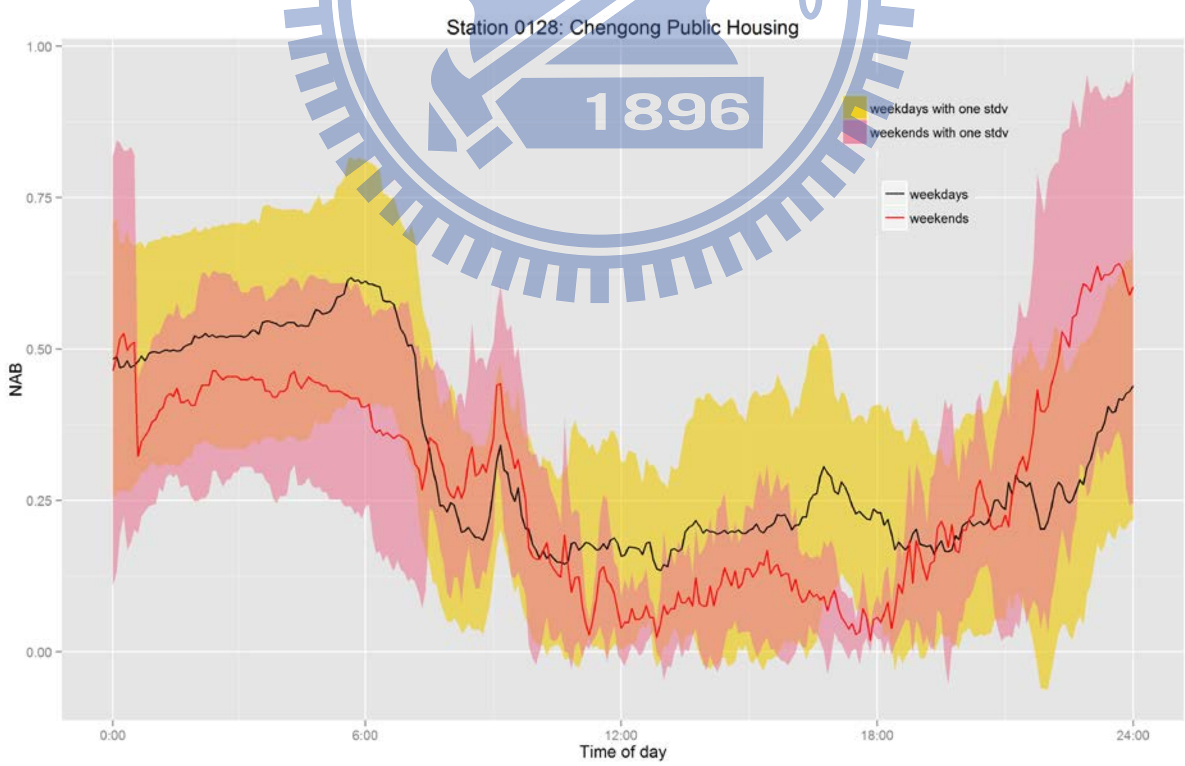


Figure 32 Average NAB during weekdays and weekends of station No. 0128

Source: this study

5.1.2 Global activity patterns

The global activity patterns of Taipei City throughout the day by means of using bikesharing system would be obtained as looking at the sum of available bicycles at all stations. Therefore, in Figure 33, the average activity patterns of NAB values across all stations split into the weekdays and weekends during a certain of the day are plotted. Regarding the traffic during working days (black lines with one standard deviation covered by golden area), generally speaking, a first minimum occurs at around 9:00 and second minimum at a little later than 12:00. These former minimum may correspond to the typical commuting hour which normally varies between 7:00 and 9:00 in Taipei City, which can be further confirmed by the fact that it reaches the first minimum during this period as shown in Figure 33. And a second minimum around noon might be caused by the lunch time; hence, the number of available bicycles increases after the lunch time. A third minimum is observed which varies between 17:00 and 19:00 with larger variations during this period; and followed by the available bicycles fluctuate as most of working schedules finished.

It can be observed that the weekend activity pattern is totally different from those in weekdays. While the maximum number of available bicycles reaches at around 6:00 for overall NAB of 0.45, the demand of using YouBikes steadily augments which contributes to the steady decreasing tendency until the number of bicycles in stations reaches the minimum a little earlier than 18:00 just before the dinner time. Afterwards the number of available bicycles steadily climbs up to the level of NAB at 0.3. Compare the station activity pattern based on the changes of NAB during the daytime and nighttime, it clearly shows the typical leisure patterns in weekends. Thus it might reveal that people leave for the leisure activities during the daytime and ended of the activities at around evening overall. Note that in general, the variance of available bicycles to rent is smaller and much stable than working days.

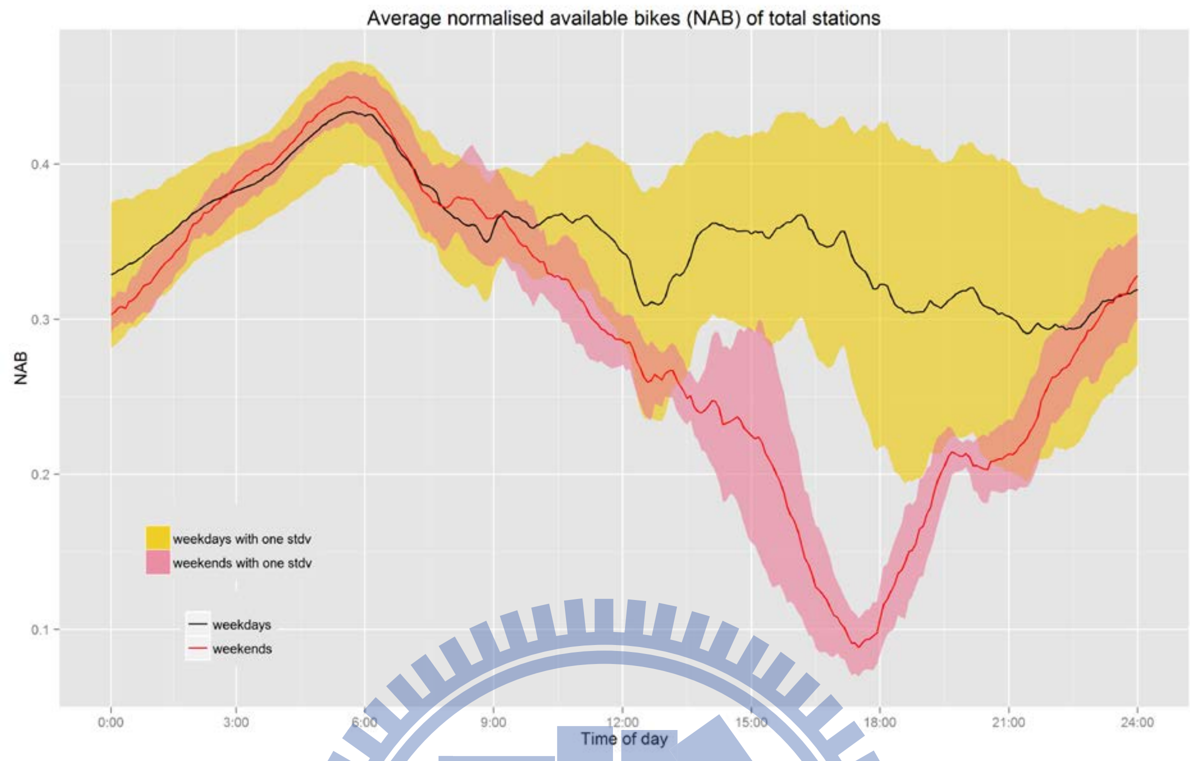


Figure 33 Daily average NAB of total stations

Source: this study

Figure 34 reveals that the average variations of the sum of available bicycles at total stations split into working days (Monday to Friday) and weekends (Saturday to Sunday). In regard to average Monday activity pattern, it reaches the first minimum between 8:00 and 9:00 and decreases to the second minimum of available bicycles around 12:00. Though it increases which might be caused by the finished launch break, and it decays again afterwards. It shows clearly that three-pronged spike in station activity from Monday to Friday with one of spike all occur around 6 am and the time of another spike varies. It can be observed that Tuesday and Wednesday seem to share the similar pattern in station activity though the number of available bicycles tend to have larger variance and lower than Wednesday in the nighttime. Activity patterns in Thursday are somewhat different than other working days; for example, with longer period of time at relative lower level of bicycles between 10:00 and 13:00m. In addition, the second spike of number of available bicycle occurs a little later (before 15:00 approximately) and the drop of available bicycles seems to occur lately as well. Regarding activity patterns in Friday, it is likely to tell another story than the other working days. It is observed that people are willing to use rental bikes in the Friday morning with surprising low variance of available bikes which acts like the morning patterns in weekends. It is also interesting that two close and narrow peak during the period from 12:00 to 18:00, followed by the sudden drops since then. With respect to the weekends' patterns which are totally distinctive compared to weekdays, both Saturday and Sunday pattern are closely identical in general. They both have the morning peak at 6 am followed by the steadily declines of available bicycles during the daytime until the evening it recovers instead. Note that the small standard deviations show that observed patterns are quite stable throughout the day in weekends, indicating that YouBike are more popular where people tend to use it for leisure purpose or go to other desired destinations.

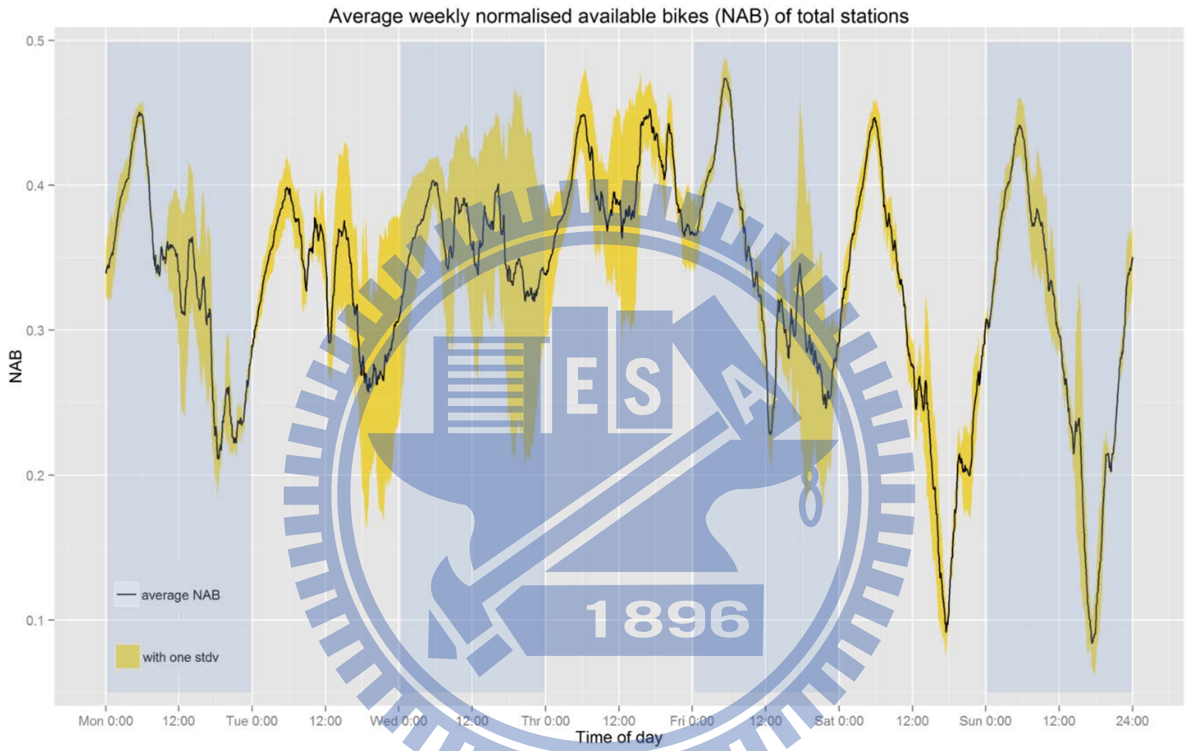


Figure 34 Weekly average NAB of total stations

Source: this study

5.1.3 Remarks

According to the above figures, it is clearly observed that different stations have different station activity patterns which may be affected by their locations and surroundings; in addition, weekend patterns are significantly distinctive from weekday's patterns. It is also found that station with different geographic characteristics and spatial layout would follow the similar patterns. Therefore, using clustering could help us to group the stations according to their temporal activities, examining the whether these activities depend on spatial factors or not.

5.2 Cluster analysis

In this section, clustering algorithm is used to analyse how station activity patterns are geographically distributed in the city based on their usage patterns and explore how these activity patterns relate to underlying cultural and spatial characteristics of Taipei City. It is expected that the outcome of clustering results of their average temporal patterns are visualised onto a map and spatially examined to explore geography characteristics for activity patterns.

Cluster analysis aims to divide data into groups which are meaningful and useful to discover the phenomenon hidden in the data. The goal of clustering is that the objects in the same group would be similar (or related) to another and different from (or unrelated to) the objects in other groups. In other words, an object in a certain cluster should be as similar as other objects in the same cluster, and be as distinct as possible from objects in the other different clusters (Mooi and Sarstedt, 2011). Generally speaking, the greater the dissimilarity between groups as well as the greater similarity within groups, the better of clustered groups. In essence, cluster analysis is the study of techniques to find the groups which are share common characteristics automatically (Tan et al., 2006). It also has been used in a wide variety of fields such as biology for creating a taxonomy of all living things, information retrieval for assisting users' query and query results, helping to find patterns in the atmosphere an ocean, detecting patterns in the temporal or spatial distribution of diseases, or segmenting customers for marketing and so on (Tan et al., 2006).

Basically, clustering techniques can be categorised into two groups: hierarchical and partitional which are most commonly used based on their clustering structure. Hierarchical clustering is characterised by the tree like structure called a *dendrogram*; and most hierarchical techniques belonged to agglomerative approach which starts with the points and individual clusters and merges with the closest pair of clusters sequentially according to their similarity at each step until only one cluster remains (Tan et al., 2006; Mooi and Sarstedt, 2011). By contrast, divisive hierarchical clustering is less used. Both agglomerative and divisive hierarchical clustering process are illustrated in Figure 35 blow. The drawback of hierarchical clustering is that once an object is assigned to a certain cluster, it is not possible to be reassigned the object to another cluster. Common measures of similarity and selection of suitable clustering algorithm for applying hierarchical clustering will be discussed in the later section.

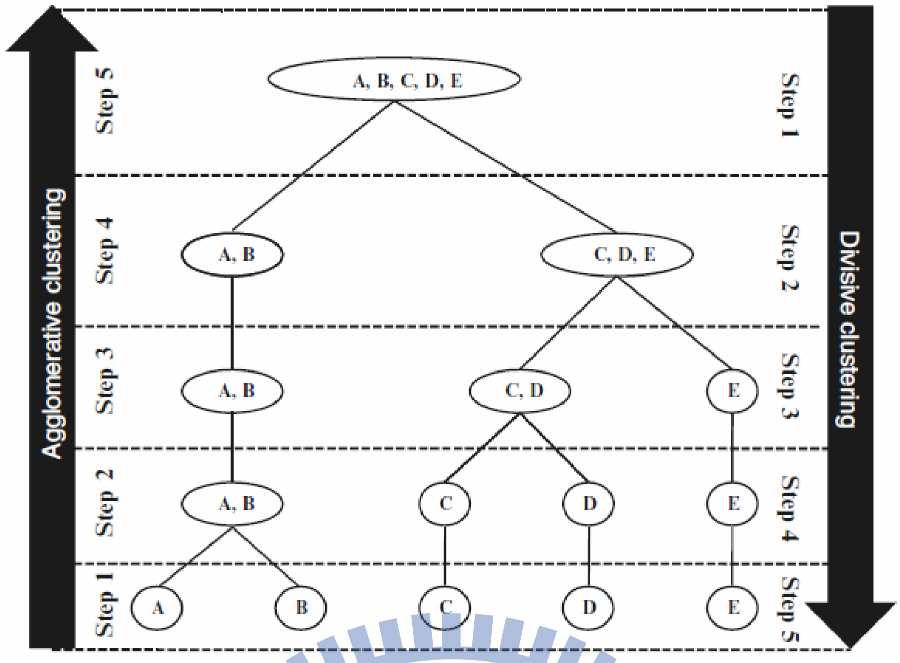


Figure 35 Agglomerative and divisive hierarchical clustering

Source: Mooi and Sarstedt (2011)

K-means clustering procedure is probably the most famous among various prototype-based, partitional clustering methods. It defines a prototype in terms of a centroid which can be represented for a certain cluster and attempted to find a specified number of cluster (*k*). This cluster process commences with assigning objects randomly to a specified number of clusters, hence generating k points as initial centroids. It aims at segmenting the data in terms of minimising the within-cluster variation, and successively reassigned each point in *k* clusters to its closet centroid (yielding new centroids of desired number of clusters) until centroids do not change. Note that unlike objects remain in the same clusters once specified, objects may be changed to the other cluster groups before reaching minimum within-cluster variance. However, the key issue is that what is the number of clusters should be desired at first while performing K-means clustering. As it can be assessed by various criteria such as Silhouette-Index (Rousseeuw, 1986) and Dunn-Index (Abonyi and Feil, 2007), it seems that applying two stage clustering which is introduced by Anderbeg (1973) is an alternative option. This method combines the concept and principals of hierarchical and partitioning methods and has gained increasingly attention in market research practice recently (Mooi and Sarstedt, 2011). For example, Borgnat et al. (2011) use Ward's method fist to group similar stations in communities at first, followed by applying K-means to cluster the bike flows between stations.

In this study, two stage clustering approach is used. First, the clustering process is illustrated and the chosen clustering algorithm and validation measures are also explained. Followed by the using two stage clustering approach in terms of NAB clusters and Activity Score clusters (combined with Ward's method and K-means clustering) is applied and evaluated with validation measures. Finally, visualisation of clustering results, activity pattern based on clustering outcomes, and interpretation of clusters with geography characteristics are examined.

5.2.1 Clustering process

Figure 36 shows the steps of two stage clustering approaches and discussed following.

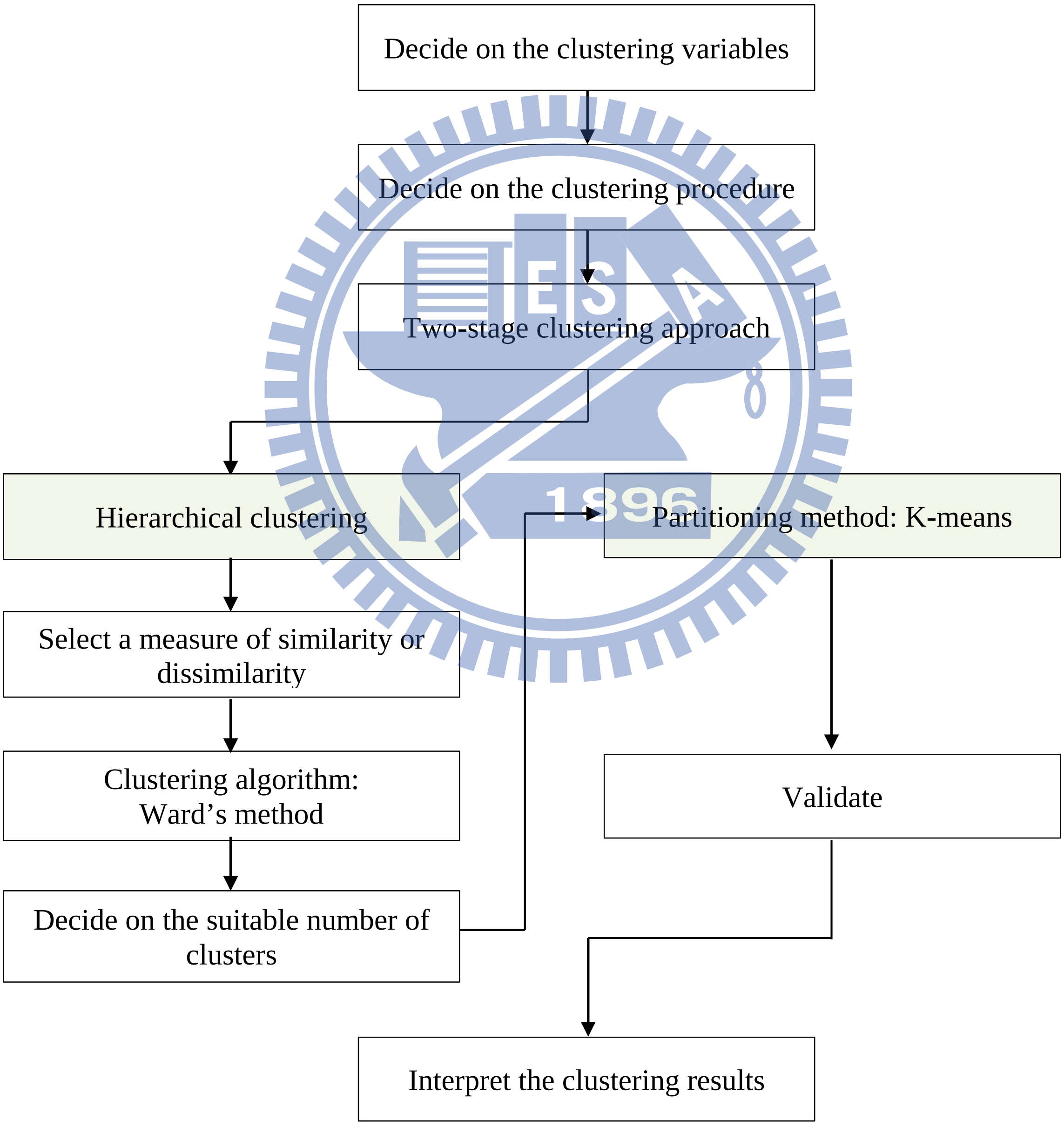


Figure 36 Cluster analysis steps

source: adapted from Mooi and Sarstedt (2011) Fig. 9.2

1) Choosing clustering variables

Using specific tools and techniques is essential for obtaining better understanding activity patterns of travellers and performance of a transport system (Etienne and Latifa, 2012). Using clustering method to group bike stations in order to realise which stations may have share common or similar activity patterns have been mentioned previously (see 2.3.1); moreover, O'Brien et al. (2014) investigate the each system characteristics in terms of load factors, geographical footprint and bicycle occupancy. The summary of those studies using clustering algorithm in terms of method, input attributes, and purpose is presented in following Table 19.

Table 19 Summary of studies using clustering

Study	Clustering method	Input attribute	Purpose
Froehlich et al. (2008)	Expectation Maximisation (EM)	Average number of available bicycles, the difference between the number of bicycles at the beginning and end of the bin's edge, and station activity[23]	To measure how the patterns of human movement via bicycles reflect culture and the overall spatial context of the city
Froehlich et al. (2009)	Ward's method as dendrogram clustering	Activity score DayViews[24], and available bicycles DayViews	To identify shared behaviours across stations and investigate the relationship to location, neighbourhood, and time of day in the city
Borgnat et al. (2011)	Ward's method	Newman's modularity *Q*	To group similar behaviours or interest (for people) with similar contents in communities
	K-means	The correlation between the temporal vectors of number of rentals	To cluster the flows between stations, highlighting the distribution in time along the week of the main spatial feature
Vogel et al. (2011)	Expectation Maximisation (EM)	The proportion of pickups or returns in a certain hour of day divided by total daily number of pickup or returns	To group stations according to their normalised bike pickup and return activity over time, and to discover location dependent reasons for activity patterns
Lathia et al. (2012)	Dendrogram clustering	Time series vector of NAB values for each station	To analyse how the weekday activity patterns are geographically distributed across the city
O'Brien et al. (2014)	Ward's method	number of docking stations; average docking station size; maximum simultaneous usage during September 2012; maximum load factor; system size; system area; mean nearest neighbour distance; Z-score; compactness ratio; number of usage peaks each weekday; number of weekend daily usage peaks; and large weekend usage indicator	To take a global view of 38 different sharing system characteristics in the world

[23] Station activity is defined as the percentage of change in the features with respect to the features observed previously
[24] DayViews is denoted as averaging station data into 5-min bin (i.e., 288 bins/day)

As seen from above Table 19, it summarises that the some similar variables are chosen in grouping station activity patterns. For example, the quantities of available bicycles are used as clustering variables by Froehlich et al. (2008), and Froehlich et al. (2009) or the time series vector of NAB used by Lathia et al. (2012).

Based on previous researches, this study selects two kinds of variables as clustering inputs for analysis:

- Normalised available bicycle (NAB): it is a time series vector of NAB values for each station; and
- Activity Score (AS): it is a time series vector of AS values for each station; note that this figure does not be normalised so that using the simple z-standardisation is required.

It should be noted that although there are two selected clustering variables, only either of them will be applied to conduct two stage clustering approach at one time. Therefore, it is expected that two clustering results based on these two variables will be presented. In addition, there is no geographic or positioning information tagged with these input variables.

2) First step of two-stage clustering procedure: Hierarchical clustering and Ward's method

Followings discuss the measures of proximity between objects (e.g., distance) and the measures of proximity between clusters respectively which typically defined with a particular type of hierarchical clustering algorithm. In this study, agglomerative hierarchical clustering technique is used which starts with individual points as clusters, successively merging the two closet clusters until only one cluster remains. It yields a hierarchy structure of clusters to be formed from the bottom up (see Figure 35 previously).

There are various proximity measures to express similarity or dissimilarity between two pairs of objects and discussed as following:

- Euclidean distance: which is the length of the line segment between two points in n-space;

$$d_{Euclidean}(P,Q) = \sqrt{\sum_{i=1}^{n}(Q_i - P_i)^2} \qquad (3)$$

Where $P = (P_1, P_2, \ldots, P_n)$ and $Q = (Q_1, Q_2, \ldots, Q_n)$ are two points in n-spaces

- City-block distance: also called Manhattan metric, which uses the sum of the variable's absolute differences;

$$d_{\text{City-block distance}}(P,Q) = \sum_{i=1}^{n}|P_i - Q_i| \qquad (4)$$

- Chebyshev distance: which are frequently used whereas working with metric (or ordinal) data, calculated as the maximum of the absolute difference in the clustering variables' values;

$$d_{\text{Chebyshev distance}}(P,Q) = \max(|P_i - Q_i|) \qquad (5)$$

Followed by the deciding the suitable clustering algorithm to apply which can be distinguished by the way they measure the proximity between clusters (i.e. the distance from a cluster to the others during the merging process). Most common agglomerative clustering procedures are shown as Figure 37 below and discussed following:

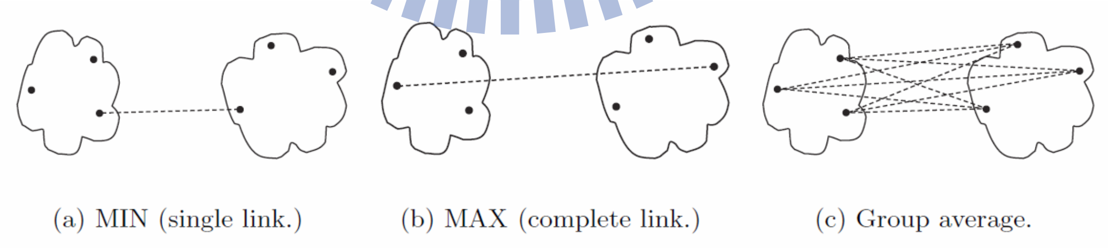


Figure 37 Popular agglomerative clustering approach of measuring proximity

Source: Tan et al. (2006), pp.517

- Single link: the distance between two clusters corresponds to the closet two points in different clusters;

- Complete link: the distance between two clusters is according to the farthest two points in different clusters;
- Group average link: the distance between two clusters is defined as the average pairwise distance of all pairs of nodes in the two clusters; and
- Centroid: the distance between two clusters corresponds to the distance between the two geometric centres (i.e., centroid) in each cluster.

Ward's minimum variance method which originally presented by Joe H. Ward, Jr. (1963) is an alternative option to measure the proximity between two clusters in terms of the increase in SSE[25] (see Equation 6) that results from the two clusters while it assumes that a cluster is represented by its centroid. It should be noted that each of these link algorithm as a base to merge closest clusters until ended of the process actually yields different results whereas applied to the same dataset (Mooi and Sarstedt, 2011). As using single link algorithm tends to yield one large cluster with other clusters containing only one or few objects, it is normally to be used as detecting outliers. By contrast, complete link method would be strongly affected by outliers and noises as a result of being compact and tightly clustered. In regard to average link method, it is an intermediate approach between single and complete link methods; hence it is likely to yield rather low variance within-clusters. It is suggested that using Ward's method is recommend to use as no outliers included in the dataset; hence generating equally sized clusters somewhat. Therefore, in this study, Ward's method with Euclidean distance is chosen for the first step of two-stage clustering approach.

$$SSE = \sum_{I=1}^{K} \sum_{x \in C_i} (C_i - x)^2 \qquad (6)$$

3) Determining the suitable number of clusters

According to Tan et al. (2006) , almost every clustering algorithm would yield clusters when given data; thus it is important to evaluate some of the clusters in the dataset have good quality at least and it is also suggested that using multiple clustering algorithm

[25] Error Sum of Squares

with evaluating the quality of generated clusters would ensure the clusters are good overall even tested with various clustering algorithms. However, due to the large costs on using multiple clustering algorithm to test the suitable number of clusters, this method will not be performed in this study. While the number of clusters suggested by a hierarchical clustering determines the desired number of clusters to be applied to K-means clustering later, we focus on evaluating the number of clusters generated by Ward's method. Since there are still various cluster validity measure for hierarchical clustering, with consideration to the author's knowledge in applying validity measures through using software such as SPSS, R (programming language) or Orange (open source data mining software).

Dendrogram is commonly used to help determine the number of clusters and it can be easily produced by the software mentioned above. Nevertheless, sometimes it does not work very well and often difficult to identify where the break actually occurs (Mooi and Sarstedt, 2011). No matter what the information provided by dendrogram, what is more importantly is that choosing the suitable number of clusters based on a priori knowledge, ensuring the results are meaningful and interpretable. In addition, the objects in each cluster group should be also large enough for warranting strategic attention. Mooi and Sarstedt (2011) also suggest that plotting the number of clusters on the x-axis against the distance where clusters are combined on the y-axis, i.e., the scree plot. The number of clusters can be indicated by the distinct break where an additional combination of two cluster would result in a greatly increased distance.

4) Second step of two stage clustering procedure: K-means

K-means aims at minimising the within-cluster variation. And the number of clusters has to be specified beforehand while observations are assigned to k clusters, which is resulted from the results suggested by Ward's method. Initially, k points would be assigned as initial centroids, thus forming k clusters by assigning each point to its closets centroid and consequently the centroid is updated. Repeatedly assigned points to the new centroids and updated; finally ended with no more changes of centroids occur. Note that Euclidean distance is used as proximity measure which calculates the error of each data point (i.e., the temporal vectors of NAB or AS values) to the closest centroid, and calculates the SSE for evaluating the quality of clustering.

5) Validation of number of clusters and quality

Silhouette coefficient is popular method to measure the quality of a clustering (i.e., cohesion and separation) through estimating how a pair of stations is similar to other pairs in its own clusters vs. pairs in other clusters (Borgnat et al., 2011). The value of the Silhouette coefficient varies between -1 and 1and the higher the value for silhouette coefficient the better the clustering. Silhouette coefficient is defined as:

$$S(i) = \frac{(b_i - a_i)}{\max(a_i, b_i)} \tag{7}$$

Where a_i is for the i^{th} object, calculate its average distance to all other objects in its own cluster, and b_i is the average distance from the i^{th} object to all the objects in another cluster. Comparing the clusters with independent t-tests or ANOVA can be used alternatively to examine whether the clusters differ significantly and distinguishable (Mooi and Sarstedt, 2011).

6) Interpretation

Interpreting clusters focuses on examining the cluster centroids, which are the average values of all objects in a given cluster. In addition, identify the suitable names or labels for each clusters and characterised each cluster by means of observations of input variables. The results of these clusters in terms of two clustering variables are discussed in the following section.

5.2.2 Normalised available bicycles (NAB) clusters

In this part, the cluster results would be discussed in terms of NAB of weekdays and NAB of weekends respectively because of the clear difference shown in previous discussions.

1. NAB clusters of weekdays

Firstly a hierarchical cluster analysis based on Euclidean distance, using the Ward's method is performed. While SPSS creating a dendrogram which rescales the distance to a range of 0-25 which may lead to a tight tree structure in some cases, resulting in difficulties deciding the number of clusters, this study uses Orange (open source data mining software developed by Bioinformatics Laboratory in the University of Ljubljana) instead. The criteria of choosing the suitable number of clusters would be based on the scree plot according to the agglomeration schedule produced by the programme and the dendrogram figure. Figure 38 illustrates the scree plot made by Excel spreadsheet and it only shows a distinct break while switching from two clusters to be merged into one cluster. However, it actually occurs in almost every situation of being merged to the last one cluster from two clusters. As a result, it is not a reliable indicator for determining the number of cluster. Instead, although there is no clear distinct break, one may argue that the number of clusters range from 3 to 6 clusters would be a solution according to their increasing incensement of distance. It would be further tested as being input to specified number of clusters perfumed in K-means clustering later. Following Figure 39 illustrates the example dendrogram in the case of 4 clusters. It can be seen that just slightly moving the distance line would yield different dendrogram in terms of different number of clusters. Consequently, the different number of clusters between 3 and 6 would be tested through using Silhouette coefficient to examine the quality of clusters to determine the suitable number of clusters and applied to K-means clustering later.

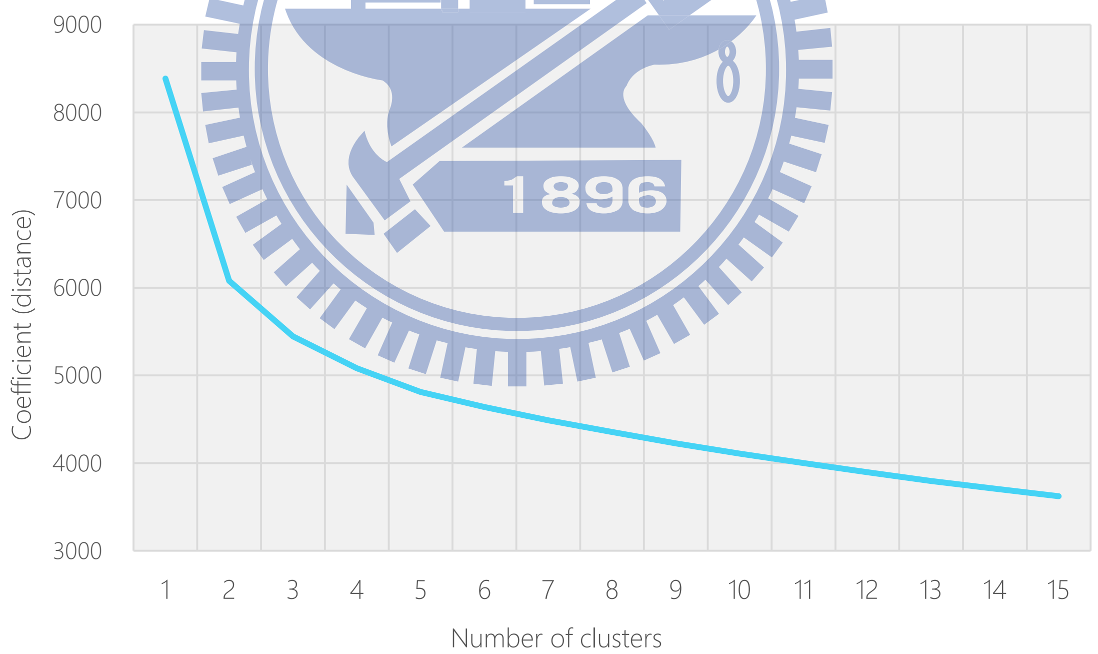


Figure 38 Scree plot of NAB clusters on weekdays

Source: this study

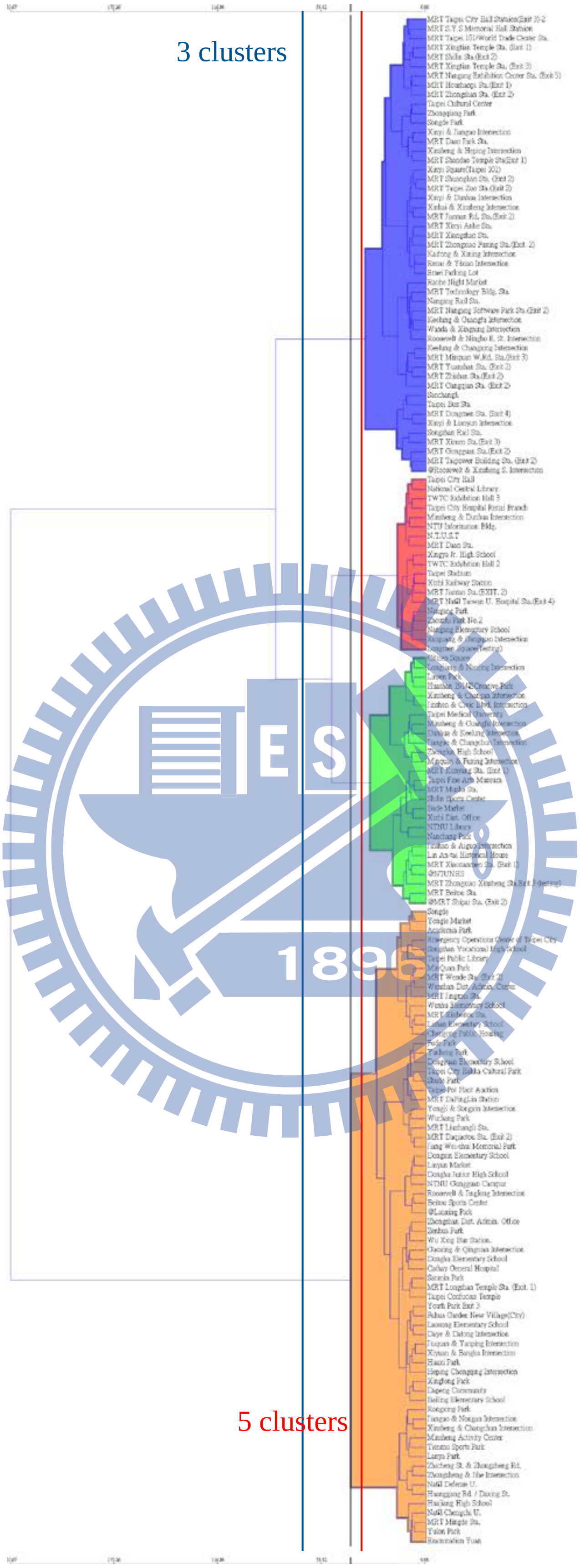


Figure 39 Dendrogram of four NAB clusters on weekdays by different ways of cutting level

Source: this study

R language is used to examine the cluster quality in terms of Silhouette coefficient. The code of R is presented in the Figure 40 and the test results are shown in Table 20. Additionally, the procedure finds 3 well-separated clusters where silhouette index are shown in Figure 41.

```
> km = kmeans(avg_NAB_total_weekdays[-1], 3, iter.max = 10000, nstart = 3)
> dissE = daisy(avg_NAB_total_weekdays[-1])
> dE2 = dissE^2
> sk2 = silhouette(km$cluster, dE2)
> plot(sk2)
```

Figure 40 The R code of K-means and Silhouette coefficient

Table 20 Summary of Silhouette coefficient in different number of clusters

# of clusters	Cluster	# of stations in the cluster	Silhouette index	Average Silhouette index
3	1	72	0.43	0.34
	2	44	0.25	
	3	47	0.28	
4	1	34	0.14	0.27
	2	46	0.24	
	3	27	0.38	
	4	56	0.33	
5	1	25	0.34	0.22
	2	42	0.21	
	3	41	0.23	
	4	28	0.18	
	5	27	0.17	
6	1	27	0.26	0.21
	2	22	0.10	
	3	28	0.17	
	4	25	0.18	
	5	20	0.35	
	6	41	0.21	

Source: this study

According to Figure 41, it is suggested by Silhouette coefficient that choosing 3 clusters for solution appears promising and validated. Note that the centroid of every cluster is used and represented as an average time series vector of temporal data points, i.e. the average NAB for every 5 minutes in a week of all stations belonging to the same cluster.

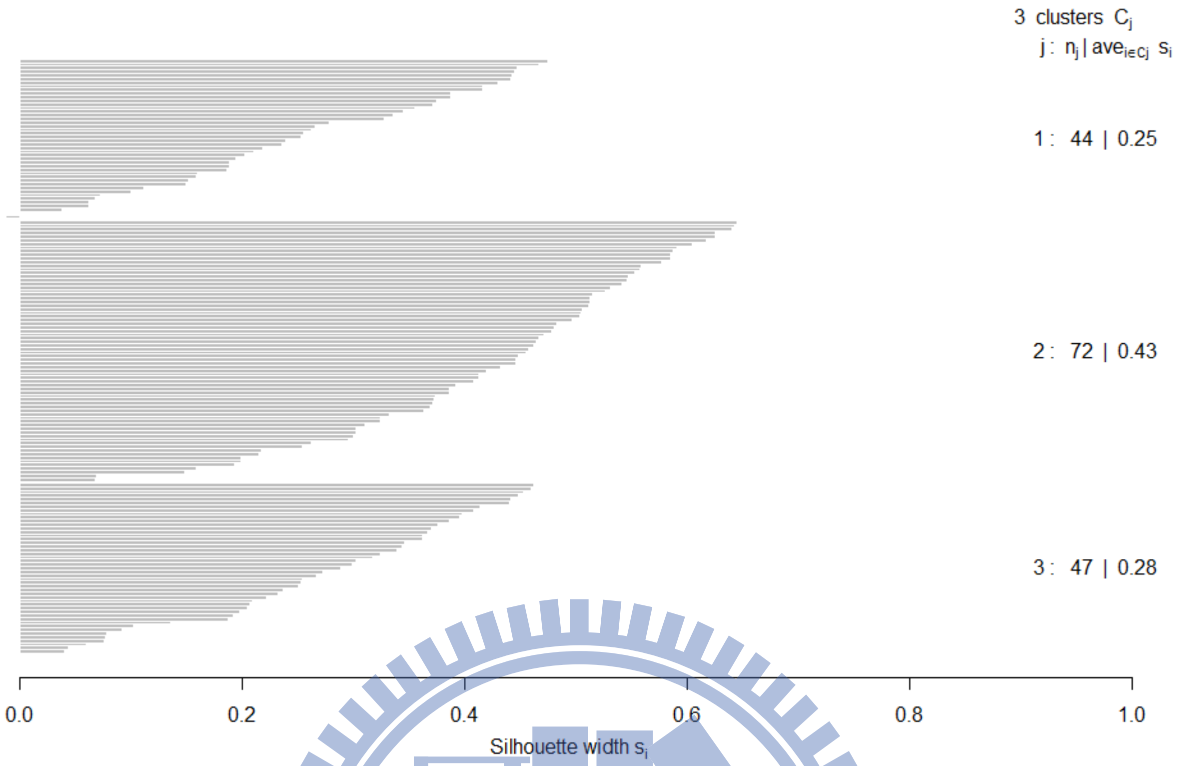


Figure 41 K-means Silhouette coefficient of the clustering results

Source: this study

Following Figure 42 shows the results of clustering NAB activity patterns in weekdays, illustrating the centroids of activity patterns of each cluster respectively. And the results of these three clusters are believed to represent the typical behaviour of various stations as shown and labelled in the followings:

- Daytime *origins* nighttime *destinations*: Cluster 1, on the top of Figure 40, is the group of locations where users rent bicycles from in the morning and flow to in the evenings. It shows a precipitous drop in the number of available bicycles between 6 am and 9 am as people leave for work and still declines thus reaching the minimum around noon. Followed by the fluctuations around 30% of available bicycles across all the station in the cluster 1 during the period from noon to 6 pm. And the available bicycles recover to the early morning levels by midnight.

- Daytime *destinations* nighttime *origins*: Cluster 2 refers to the morning destinations and the average station activity pattern shows the early inverse of that in daytime origins. People begin arriving in the morning between 7 am to 10 am approximately

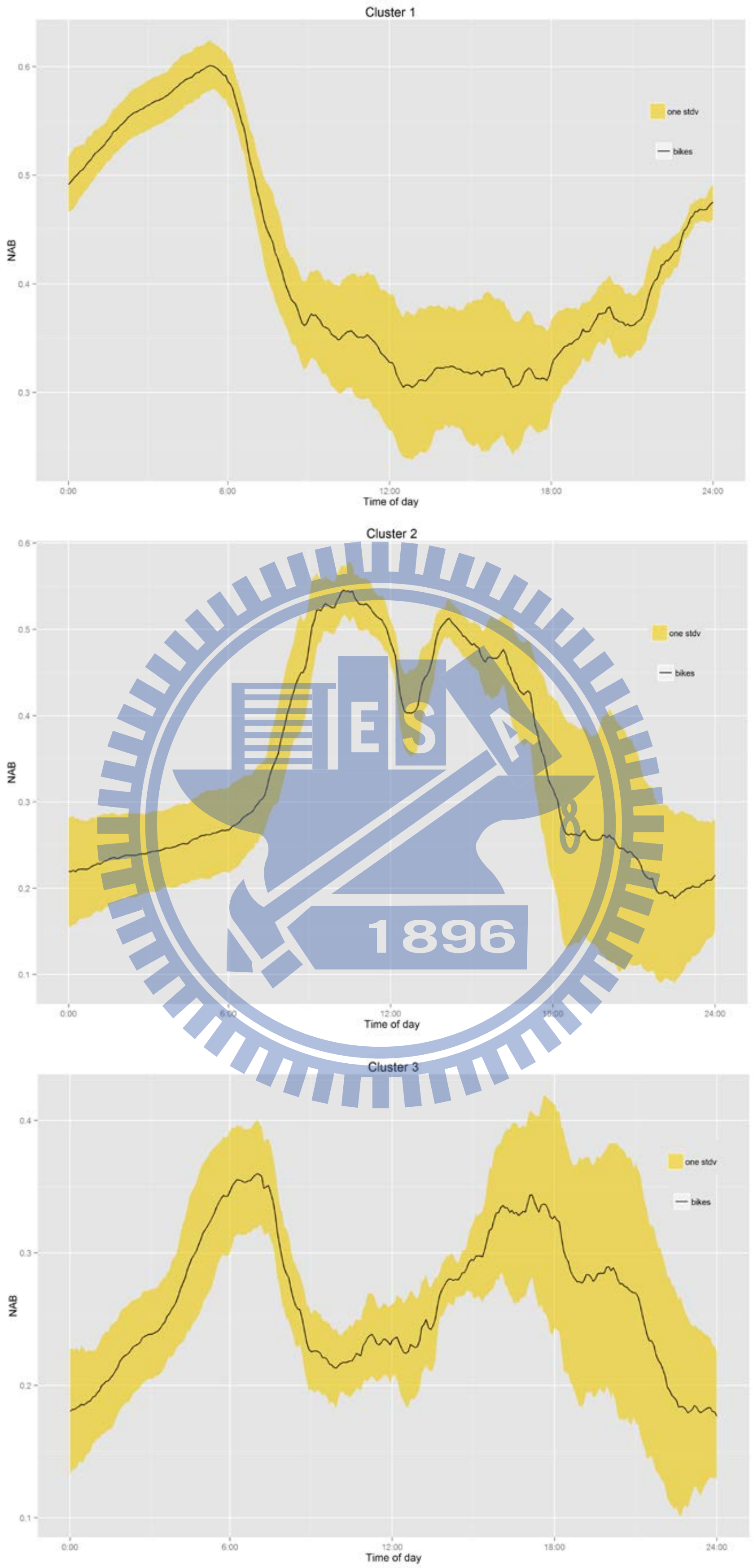


Figure 42 Usage patterns for average NAB of 3 clusters in weekdays

Source: this study

and slight decreases of available bikes during lunch and return just after the launch break at around 2 pm. People begin leaving from 4 pm in the evening and with a sharp decreases of available bicycles while approaching the typical commuting time in the evening. Moreover, decreasing lasts until 9 pm.

- Combined *Originations/Destinations*: Cluster 3 represents stations that display the combination of behaviours: both morning and evening leavings. With a delayed morning leaving in comparison to cluster 1, thus it reaches the first minimum around 10 am. Followed by the fluctuations of available bicycles at around of 0.23 NAB across all the station in the cluster, and begins climbing up till the time before 6 pm and declines again till midnight.

Overall, with the help of clustering algorithms stations are grouped according to their temporal activity patterns. The clustering results obtained while setting the clustering algorithm to produce three clusters are reported. This number is chosen due to the highest Silhouette coefficient compared to other number of clusters. However, according to temporal patterns of these three clusters illustrated previously, it may indicate the possibility of more numbers of cluster can be performed to be more appropriate and achieve a better explanation of temporal activity patterns. Note that all of these three clusters seem to have different scale of available bicycles during the certain period of time in a day; for example, cluster 1 has a larger variance of available bicycles during the period from 9:00 to 18:00. Therefore, it might be explained by introducing more clusters to cover the variances, thus achieving better explanation and more intuitive of the actual activity patterns.

The geographical distribution of NAB clustering results which are based on temporal weekday patterns without any geographical knowledge is visualised in the following Figure 43. Exploratory analysis of the cluster results and their surroundings brings about the following findings. It is observed that stations with the same clusters are likely to be located in neighbouring; in other words, neighbouring stations tend to share similar usage patterns. We also note that the clustering algorithm has separated stations spread around the edges of downtown and outer area of Taipei City, which mostly fall in cluster 1 (green), from those in the city centre which tends to be cluster 2 and 3 (orange and dark red). *Incoming* stations (i.e., daytime destinations) are primarily located in high density commercial areas and working places such as stations proximity to Taipei stations and stations proximity to Taipei City Hall for example, which is according to Taipei urban planning and land use zoning map[26]. This supports the objective of YouBike that serves for commuters. Stations within clusters 3 (dark red) are most likely to be spread around the MRT stations and rail station with working places and schools nearby. Therefore, it supports the vision of YouBike as a fist/last mile connection to public transport.

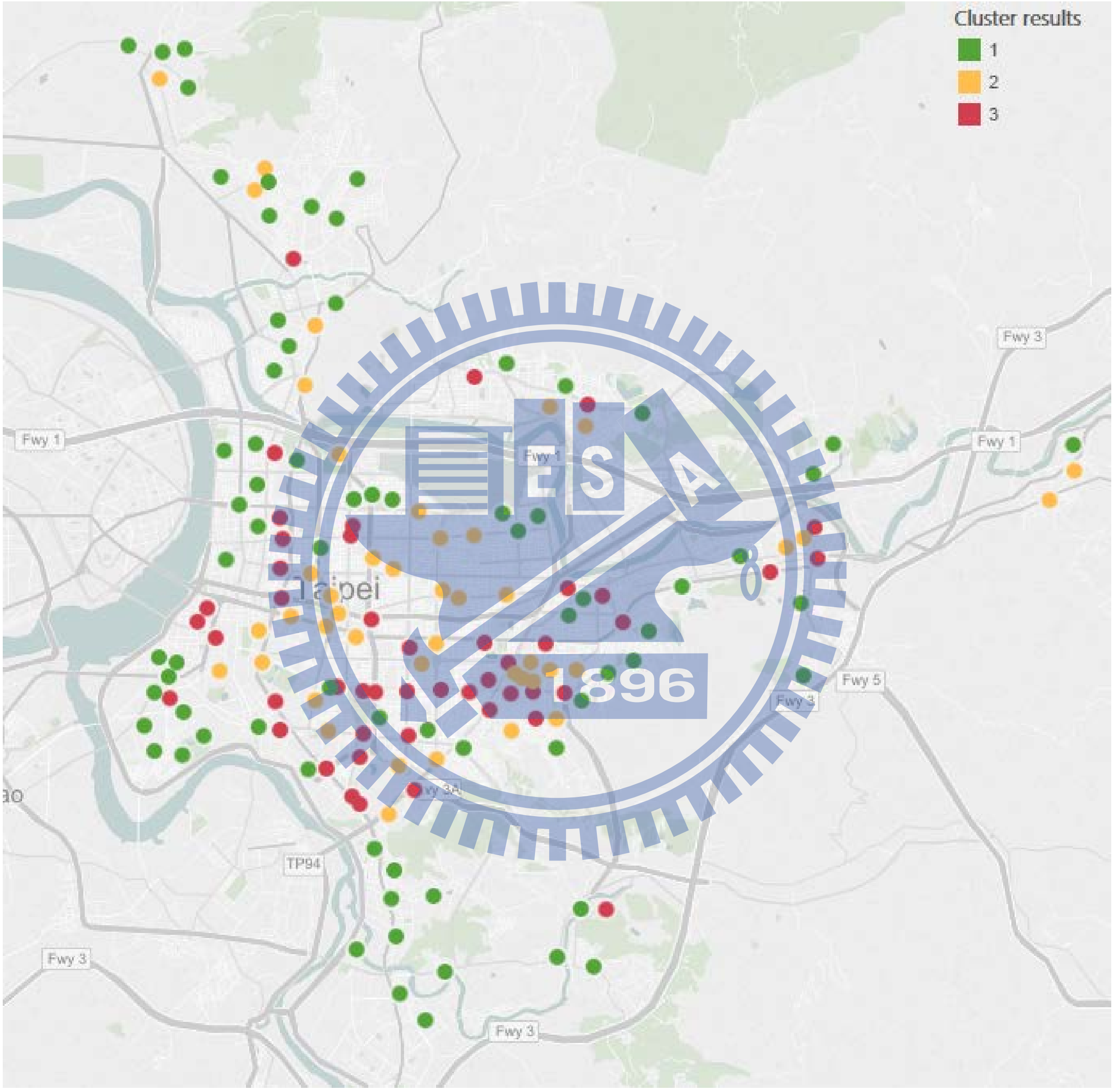


Figure 43 Map visualisation of NAB clustering results on weekdays

Source: this study

[26] http://gemvg.com/www/tpz.html

2. NAB clusters on weekends

We now repeat the same clustering procedures which have been shown previously to look at NAB clusters on weekends. Consequently, it is suggested by Silhouette coefficient that 4 clusters may represent the typical behaviour of various stations as average Silhouette width of 0.35 although it is only slightly greater than 3 clusters (Silhouette coefficient of 0.34). The results of usage patterns of these four clusters are shown in the following Figure 44, illustrating the centroids of usage patterns of each cluster respectively.

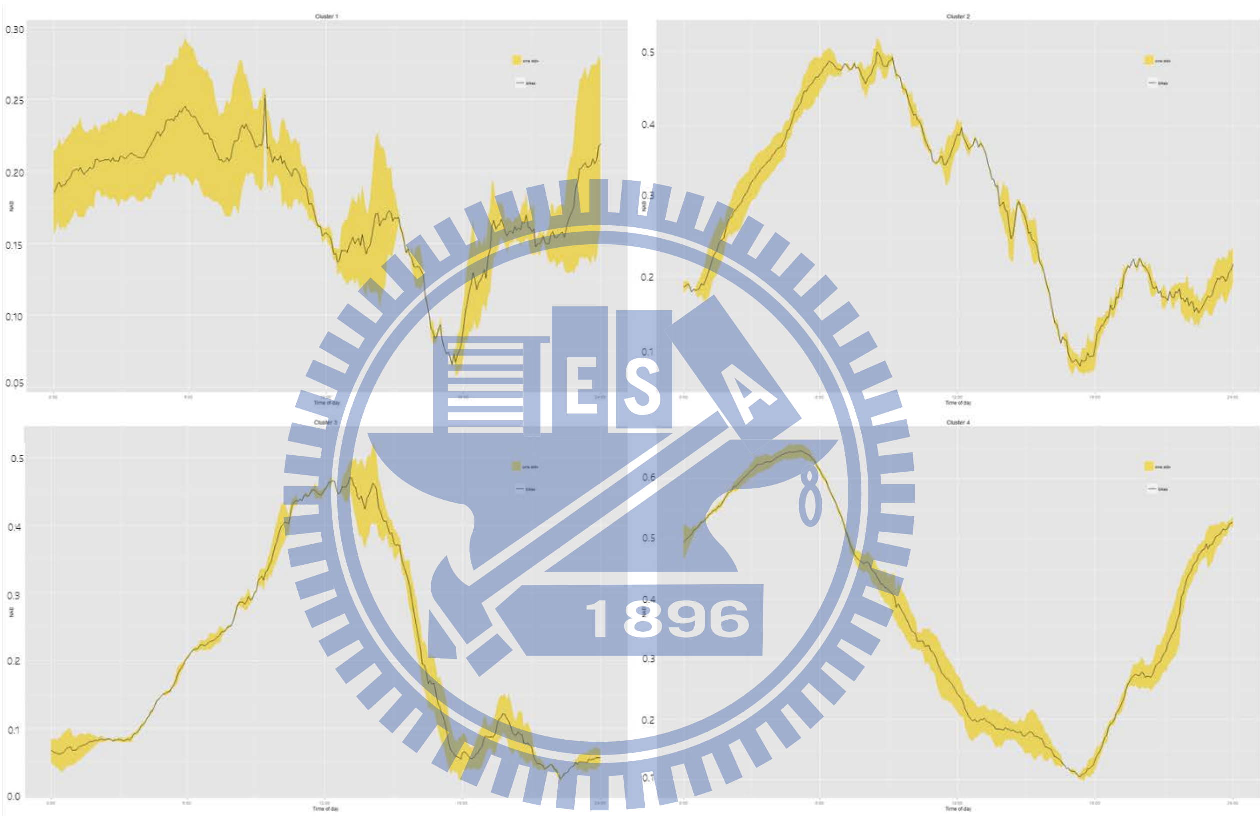


Figure 44 Usage patterns for average NAB of 4 clusters in weekends

Source: this study

Generally speaking, these four clusters seem to be categorised in two groups:

- Daytime *origins* nighttime *destinations*: Cluster1, 2 and 4 are belonged to this groups according to Figure 44. They share the similar patterns where bicycles are flowing out in the morning and returned in the evening. They basically illustrate that the overall number of available bicycles reach the minimum just before the evening. Though these cluster groups illustrates the pattern of morning leaving, it should be note that their leaving time differ. Both cluster 1 and cluster 2 show late morning leaving (clear precipitous drop from 11am and 9am respectively) whereas cluster 4 follows the overall weekend pattern which is shown in Figure 33 previously. Note that in both cluster 1 and cluster 2, it seems that they both have some significant incoming bicycles during the daytime. More specifically, it is found that significant incoming bicycle s between noon and 3pm in cluster 1 and before noon as well as around 3 pm in cluster 2 respectively.

- Combined daytime *origins/destinations:* Cluster 3 represents this pattern, illustrating morning incoming, afternoon leaving and evening incoming of available number of bicycles. According to Figure 44, it illustrates a very early morning incoming flows of bicycles, continually climbing up before noon and then fluctuating. Until approximately 2 pm, the available bicycles start to decrease instead till evening. Followed by significant increase of bicycle incoming flows.

By following the clustering process, the number of clusters is determined by the Silhouette index; and 4 clusters are chosen for the highest Silhouette index. Generally speaking, most of stations (82.2%) belong to the groups of daytime origins nighttime destinations which is the overall weekend patterns as shown in Figure 33 though cluster 1 and cluster 2 have some significant bicycle incomings during the daytime. Following Figure 45 illustrates the clustering results in a geo-visualisation of Taipei and it is observed that neighbouring stations generally share similar activity patterns. It is interesting to found that most of stations in cluster 3 (combined daytime origins and destinations) are located in Xinyi CBD and Taipei station surrounded area. Stations in cluster 4 typically reveal the overall weekend patterns as shown previously; stations tend to be located on the edge of city centre, outer area of Taipei City and in proximity to riverfront parks and public facilities. Regarding stations cluster 1, they seem to be located in proximity to MRT red lines and in Songshan district. 63% of stations in cluster 2 are proximity to MRT and rail station.

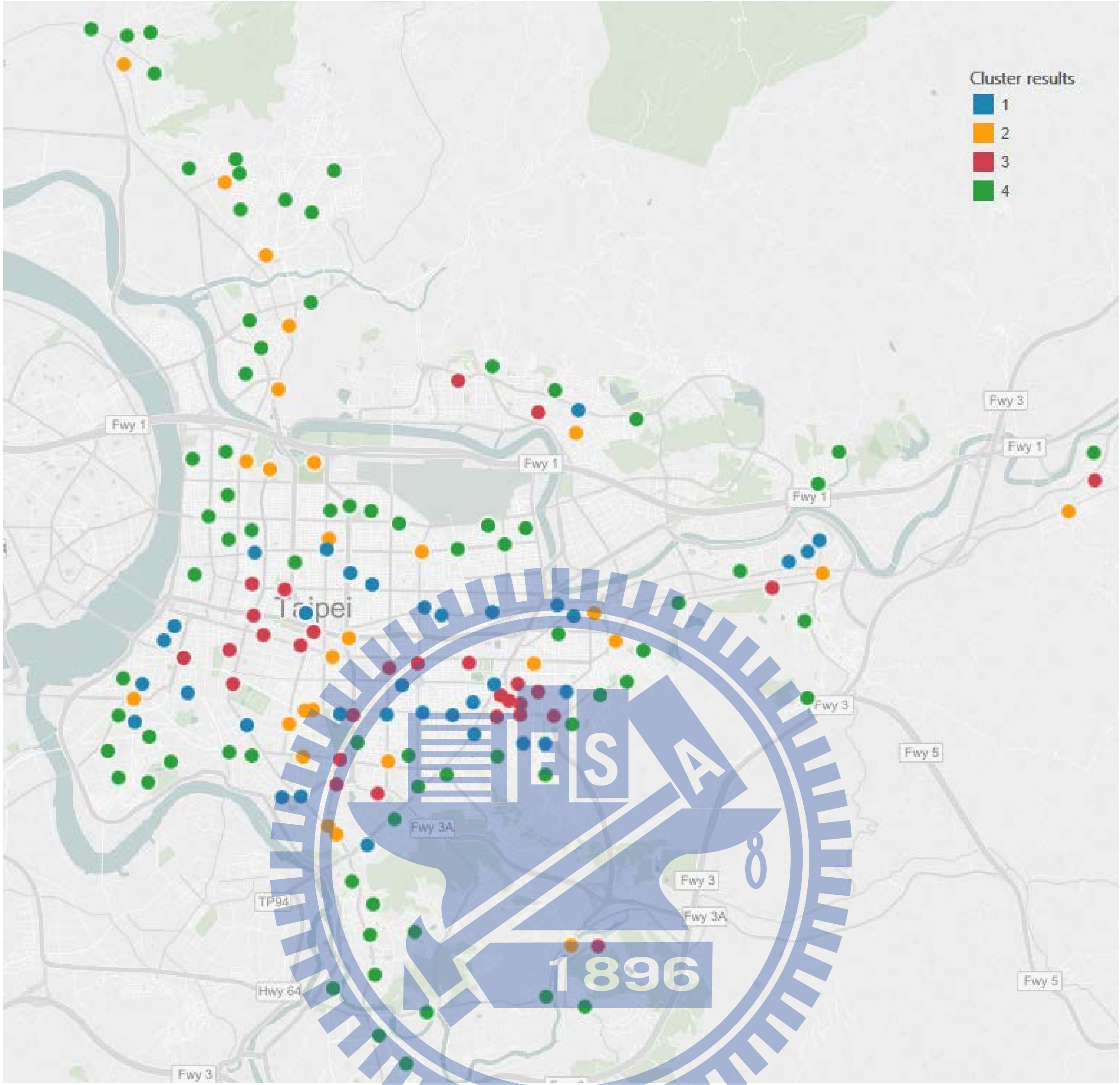


Figure 45 Map visualisation of NAB clustering results on weekdays

Source: this study

In regard to activity score (AS) clusters, it has been tested through using Silhouette index and found that neither AS cluster on weekdays or AS cluster on weekends has negative Silhouette index. Negative Silhouette means the point in more similar to the neighbouring points than to other points of its own cluster. As a result, it indicates that AS is not suitable for deploying clustering algorithm and it would not be discussed afterwards. The reason will be discussed in the following section.

5.3 Discussions

This section explains why AS is not suitable for clustering analysis and the role of NAB in the clustering results, and discusses the clustering results and implications, which are shown as following.

Activity score (AS) has been tested through using Silhouette index and found that using AS for clustering input variable is not appropriate as it yielding negative Silhouette value. The reason may be explained in terms of data retrieving interval and the meaning of this variable. Firstly, as the data retrieving collection interval is limited to the service provider, it is hard to process data in more frequent base (less than 5-min interval) or may be processed and combined data in a longer interval. Although the empirical results shows that using AS is not suitable for clustering analysis based on 5-min data retrieving interval, it is still possible to obtain different results and able to yield meaningful clustered groups. One might expect that using longer data retrieving data interval would yield more significant activity score since AS is the difference of absolute value between current state of number of available bicycles and the last state of available bicycles. Therefore, it may have more distinctive AS values among stations, leading to identify similar patterns of stations more easily. Using longer data retrieving interval allows us to investigate the bicycle pickup and return activity of certain station more comprehensively. Secondly, AS aims to explain the bicycle pickup and return activity of certain station at a given time period. However, it is still not able to describe the actual number of bicycle pickups and returns precisely. More importantly, it may neglect the full/empty station during the peak hour, perhaps remaining the same situation for a long time, thus returning the low or even zero AS value. However, in fact, it does not in line with the actual bicycle rental behaviour; in other words, longer time interval may also not be suitable for clustering analysis. It seems that selecting the suitable time interval of data is quite difficult and the demanding work is needed as well to process the original data structure to accommodate the analysis requirement.

The role of NAB only reflects the actual number of available bicycles of certain station at a given time period, neglecting the numbers of bicycle incoming and leaving flows and what are the origination or destinations this bicycle checked in/checked out. Since this kind of data is not provided, the flows of bicycles among stations may be reflected by visualising the mobility patterns of bicycles throughout the day in a longer time period such as one hour period. Therefore, to some extent, it distinguishes the bicycle flow in an alternative way without the bicycle data involved. It should be noted this method only can illustrate the available numbers of bicycles spatiotemporally and illustrate the overall trend of bicycle flow during the given time period. To obtain more delicate and actual flows of bicycles among station, the flow data of bicycles is still required.

It can be observed that there is a gap between the number of clustered groups on weekdays as well as weekends and the number of predefined geographical characteristics of stations. Since it is assumed that the station usage activity is largely depended on the station locations, the number of clustered groups should be the same or approximate to the six different geographical groups of stations predefined. However, empirical results show that neither weekday nor weekend clustered groups are not based on what we expect to see as there are 3 and 4 clustered groups on weekday and weekend station activity patterns respectively. According to previous visualisation results of clustering results, it seems that only certain clustered groups are sensitive to specific geographical characteristics. More specifically, cluster 3 (both morning and evening leaving) of weekday station activity patterns and cluster 2 (morning leaving and evening incoming) of weekend station activity patterns are tended to be located in proximity to MRT and public transit stations. It may be due to only NAB is used as clustering input variable without any additional information involved. Therefore, the stations in the same clustered groups follow the similar patterns rather their predefined geographical characteristics. Additionally, those clustered groups are also hard to reflect their actual geographical attributes.

The location of each stations based on their clustered groups on weekday and weekend station activity patterns have been visualised previously (see Figure 43 and Figure 45). However, there is no sufficient evidence to infer that the specific lifestyle or certain geographical characteristics of these clustered groups. It may be argued that such results are against the assumption that station usage activity is largely depended on the station locations. However, certain clustered groups illustrate most of stations in their groups are proximity to MRT and public transit stations. The key factor leads to such clustering results would be it is only based on NAB values. It might be have better clustering results if we incorporate the predefined geographical attribute of stations and other location factors such as the floor area of nearby residential and commercial buildings, administration area, etc.

Implications of local activity patterns and clustered results for operations and redistribution mechanism can be discussed in terms of their geographical locations and their average station activity patterns. Current mechanism work is a 24/7 shift work, monitoring the real time bicycle availability of each station. However, since the stations in different categories of geographical attributes typically illustrate their specific station activity patterns, their peaks or valleys of the number of available bicycles can be observed. Therefore, it gives an overview of overall status and the trends of bicycle availability throughout the day. It allows bicycle redistribution work where to put much effort at which certain stations at a specific time. Moreover, with the help of visualisation of clustered groups and based on their average station activity patterns, it not only helps to point out the similar patterns of stations but gives insights to bicycle redistribution routing issue. As similar patterns of stations tend to be located in proximity, the optimal routes can be obtained according to this phenomenon. It is expected that rebalancing trucks would redistribute bicycles at the least time consuming and the least operating cost.

6. Conclusions

This chapter concludes the dissertation in terms of reflecting the outcomes of the study corresponds to the stated aims and objectives. What have been done to meet the aims and objectives are summarised, followed by the key findings and results are then concluded. Finally, the chapter ends with the recommendations for future work.

6.1 Conclusions

As urban infrastructures are increasing digitalised through taking advantage of information and communication (ICT) technology, large-scale of human behaviour data will become ubiquitous and more easily accessible that can be used to measure the interrelationship between the policy, design, and usage of transport systems. The work presented in this dissertation has focused on what data analysis and data mining technique (e.g., clustering) can tell us the pulse of YouBike across Taipei City. It approves that data mining plays a vital role to help us discover the large amount of data regarding to real-world human behaviours.

This study shows that how public bikesharing usage data which refers to the changes of the number of available bicycles across all stations in this study not only reveals the bicycle usage patterns but also explores the underlying temporal and spatial dynamics of a city. Visualisation of the average daily variation in station activity allows us to observe the overall temporal tendency of activity patterns throughout the day. The clustering results indicate that station activity patterns during weekdays could be categorised into three groups: which are daytime origins nighttime destinations, daytime destinations nighttime origins, and combined origins and destinations. Each clustered groups reveal the different activity patterns throughout the day.

This study also illustrates a novel way to retrieve data independently thorough collecting the "Open Data" provided by the government freely though it would be better and more comprehensive if including more information for wider aspects of analysing. We believe that the visualisation of average temporal activity patterns and the clustered results could easily lead to better understanding the bicycle availability information. In addition, it is expected to improve the Taipei YouBike service itself, avoiding a future empty or full station through an improved redistribution of bicycles via trucks. As a result, it would help to improve user satisfaction with the service and it is possible to attract more people to use YouBike as an enhanced green transport system.

To sum up, as a growing number of PBSs is appearing around the world recently, and some of them also provide the API for retrieving bicycle availability freely, it is expected to yield increasing interest in this research topic.

6.2 Suggestions for future research

Based on the research process and results as shown previously, there are still some work can be performed to enable the research being better and provide some insights for further research. In addition, as a growing number of bikesharing stations and bicycles are appearing in the near future, some of the key research opportunities and recommendations for further research are discussed as following.

1. More robust data retrieval environment

   As mentioned in previous chapter, it can be observed that there are several errors regarding the insufficient computer ram run by Python IDE while collecting the data. It is expected to fix this issue by more ram provided or running the retrieving code in the original Python shell instead.

2. To have access to finer grained data as well as match it with other sources of information

   As the data is collected from retrieving the OpenData API provided the Taipei City Government, the collected data is limited to the information that has set by the government. Therefore, the collected data only obtains the present number of available bicycles where the data is retrieving and it could only be retrieved at 5 minutes interval as it is constrained to the free provided policy. It would be better to have access to transport authority's central database, allowing us to view the bikesharing system in the view of trip-basis. Consequently, the information of each bicycles user's origination and destination, as well as the journey duration time. It would not only allow us to perform above analysis better through being able to explicitly differentiate between registered user and casual users, but also investigate how bikesharing system is utilised from user's perspective. In addition, if we match the dataset with other daily information such as precipitation and temperature data, it is expected to explore the effect of weather on daily bikesharing ridership.

3. Longer period of collecting bikesharing usage data

To collect longer period of bikesharing usage data would allow us to explore station activity patterns more comprehensively through investigating the longer effect and the possible changes which might be brought by system expansion or minor changes of number of bicycles and slot in certain stations. In addition, it may be interesting to perform sensitive analysis to investigate the seasonal and designed changes affect the system.

4. Conducting questionnaire to investigate why people opt to bikesharing

It should be noted that the data we collected by passive sensors would only tell us how, when and what changes occur of the number of available bicycles; however, it fails to incorporate any information as to why people choose bikesharing at a certain station at a certain time. In other words, while we can investigate the variations of bikesharing activities through seeking hints by inspecting places such as transport depots, amenities, or residential area surrounded by the station, it still exist the gap between usage patterns and human behaviour. As a result, it may be useful to conduct a qualitative survey to help clarify and better understand why travellers use public shared-bikes. In addition, it may also decorate the results with these additional contextual information.

5. Incorporating location factors into clustering

The research could be further extended by incorporating location factors such as docking station size, docking station area, or maximum load factor of station during the day. Therefore, it is expected to examine the relationship between shared-bicycles' activity and station location and surrounded amenities.

6. Prediction of bicycles availability with the short time outlook into the future

The research also could be further extended by predicting the available bicycles or free slots at a given station at a given time. The prediction model is based on the current state of the station as well as aggregate statistics of the station's usage patterns. Hence time series analysis technique seems to be able to conduct the task. In addition, the predictions of bike availabilities would allow us to improve the current service of YouBike and enhance users' satisfaction, enabling the operator to predict shortage or overflow of bicycles in certain stations in advance. Hence, the redistribution plan could be meet the needs more precisely.

7. Comparative analysis to Kaohsiung City Bike

   It is also interesting that to compare the station activity patterns with Kaohsiung City. Not only specific station activity patterns of Kaohsiung City can be explored but also to examine the temporal trends of City Bike usage, reflecting the pulse of active transport users and their transport behaviours in Kaohsiung.

8. Redistribution mechanism and management

   As conducting average daily station activity patterns of each station and clustering results, it gives insights on the location of bicycle redistribution hubs and provide the robust information of bicycle availability throughout the day. Therefore, the optimal redistribution routes can be achieved and it allows us to know where and when to redistributing the bicycles to and from the full/empty station at acceptable cost basis.

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Appendix A: YouBike station list by administration region

Beitou District		Daan District		Xinyi District	
MRT Shipai Station (Exit 2	Huanggang Rd. / Daxing St.	Roosevelt & Xinsheng S. Intersection	Dunhua & Keelung Intersection	Citizen Square	Keelung & Guangfu Intersection
NTUNHS	MRT Beitou Station	Chengong Public Housing	Jinshan & Aiguo Intersection	Emergency Operations Centre of Taipei City	MRT Taipei 101/World Trade Centre Sta.
Beitou Sports Centre	MRT Mingde Station	Keelung & Changxing Intersection	MRT Taipower Building Sta. (Exit 2)	Fude Park	MRT S.Y.S Memorial Hall Station
Daye & Datong Intersection	MRT Xinbeitou Station	Longmen Square(Testing)	MRT Technology Bldg. Sta.	MRT Taipei City Hall Station (Exit 3)-2	MRT Xiangshan Sta.
National Defence University	Zenhua Park	MRT Daan Park Sta.	MRT Xinyi Anhe Sta.	MRT Yongchun Sta. (Exit 2)	Renai & Yixian Intersection
		MRT Daan Sta.	MRT Zhongxiao Fuxing Sta.(Exit. 2)	Sanchangli	Songde
		MRT Dongmen Sta. (Exit 4)	MRT Zhongxiao Xinsheng Sta.(Exit 3	Songde Park	Songshan Vocational High School
		MRT Gongguan Sta.(Exit 2)	N.T.U.S.T	Taipei City Hall	Taipei Medical University
		MRT Liuzhangli Sta.	NTNU Library	TWTC Exhibition Hall 2	TWTC Exhibition Hall 3
		NTU Information Bldg.	Taipei City Hospital Renai Branch	Wu Xing Bus Station	Wuchang Park
		Taipei Public Library	Xinhai & Xinsheng Intersection	Xingya Jr. High School	Xinyi Square(Taipei 101)
		Xinsheng & Heping Intersection	Xinyi & Dunhua Intersection	Yongji & Songxin Intersection	Zhongqiang Park
		Xinyi & Jianguo Intersection			

Zhongzheng District		Zhongshan District		Wanhua District	
Heping Chongqing Intersection	Huashan 1914 • Creative Park	Bade Market	Jianguo & Changchun Intersection	Dongyuan Elementary School	Emei Parking Lot
Roosevelt & Ningbo E. St. Intersection	MRT Nat'l Taiwan U. Hospital Sta.(Exit 4)	Jianguo & Nongan Intersection	Lin An-tai Historical House	Fuhua Garden New Village(City)	Guoxing & Qingnian Intersection
MRT Shandao Temple Sta(Exit 1)	MRT Ximen Sta.(Exit 3)	Linsen Park	Longjiang & Nanjing Intersection	Huajiang High School	Huaxi Park
MRT Xiaonanmen Sta. (Exit 1)	Y17 Youth Recreation Centre	MRT Jiannan Rd. Sta.(Exit 2)	MRT Xingtian Temple Sta. (Exit 1)	Kaifong & Xining Intersection	Laosong Elementary School
Nanchang Park	National Central Library	MRT Xingtian Temple Sta. (Exit 3)	Rongxing Park	MRT Longshan Temple Sta. (Exit. 1)	Wanda & Xingning Intersection
Taipei Bus Sta.	Jinshen & Civic Blvd. Intersection	Taipei Fine Arts Museum	Xinsheng & Changan Intersection	Xiyuan & Bangka Intersection	Youth Park Exit 3
Taipei City Hakka Cultural Park	Xinyi & Lianyun Intersection	Xinsheng & Changchun Intersection	Zhongshan Dist. Admin. Office		
		MRT Zhongshan Elementary School (Exit.4)			

Datong District		**Nangang District**		**Neihu District**	
Jiang Wei-shui Memorial Park	MRT Shuanglian Sta. (Exit 2)	MRT Nangang Software Park Sta. (Exit 2)	MRT Nangang Exhibition Centre Sta. (Exit 5)	Donghu Elementary School	Donghu Junior High School
Jiuquan & Yanping Intersection	MRT Yuanshan Sta. (Exit 2)	Dongxin Elementary School	Academia Park	Lishan Elementary School	MRT Gangqian Sta. (Exit 2)
MRT Daqiaotou Sta. (Exit 2)	MRT Zhongshan Sta. (Exit 2)	Linyun Market	Nangang Elementary School	MRT Wende Sta. (Exit 2)	Ruiguang & Gangqian Intersection
MRT Minquan W.Rd. Sta.(Exit 3)	Shude Park	MRT Houshanpi Sta.(Exit 1)	Nangang Park	Wenhu Elementary School	Zhouzhi Park No.2
Taipei Confucius Temple	Yongle Market	MRT Kunyang Sta. (Exit 1)	Nangang Rail Station		
		Yucheng Park			
Shilin District		**Songshan District**		**Wenshan District**	
Lanxing Park	Bailing Elementary School	Minquan & Fuxing Intersection	MinQuan Park	Examination Yuan	MRT Jingmei Sta.
Lanya Park	MRT Jiantan Sta.(EXIT. 2)	Minsheng & Dunhua Intersection	Minsheng & Guangfu Intersection	MRT Muzha Sta.	MRT Taipei Zoo Sta.(Exit 2)
MRT Shilin Sta.(Exit 2)	MRT Zhishan Sta.(Exit 2)	Minsheng Activity Centre	Raohe Night Market	National Chengchi University	NTNU Gongguan Campus
Shilin Sports Centre	Tienmu Sports Park	Sanmin Park	Songshan Rail Station	Roosevelt & Jinglong Intersection	Taipei Pot Plant Auction
Zhicheng St. & Zhongzheng Rd.	Zhongzheng & Jihe Intersection	Taipei Cultural Centre	Taipei Stadium	Wenshan Dist. Admin. Centre	Xingfong Park
		Zhonglun High School			
Xindian District		**Xizhi District**			
Dapeng Community	MRT DaPingLin Station	Cathay General Hospital	Xizhi Dist. Office		
Yulon Park		Xizhi Railway Station			

Source: this study; data from YouBike (2014d)

Appendix B: description of stations

Sta. ID	Station name (Chinese)	Station name (English)	Latitude	Longitude	Station area	Launch date	Spatial attribute	Sta. capacity
0001	捷運市政府站(3 號出口)	MRT Taipei City Hall Station(Exit 3)-2	25.04085789	121.5679044	信義區	20000101000000	MRT or transit depot	180
0002	捷運國父紀念館站(2 號出口)	MRT S.Y.S Memorial Hall Station (Exit 2.)	25.041	121.556945	大安區	20000101000000	MRT or transit depot	48
0003	台北市政府	Taipei City Hall	25.03779722	121.5651694	信義區	20000101000000	Working place and school	40
0004	市民廣場	Citizen Square	25.03603611	121.562325	信義區	20000101000000	Public space	60
0005	興雅國中	Xingya Jr. High School	25.03656389	121.5686639	信義區	20000101000000	Working place and school	60
0006	世貿二館	TWTC Exhibition Hall 2	25.03473611	121.5656583	信義區	20000101000000	Public space	80
0007	信義廣場(台北 101)	Xinyi Square(Taipei 101)	25.03303889	121.5656194	信義區	20000101000000	Working place and school	80
0008	世貿三館	TWTC Exhibition Hall 3	25.03521389	121.5636889	信義區	20000101000000	Public space	60
0009	松德站	Songde	25.03159	121.574353	信義區	20000101000000	MRT or transit depot	40
0010	台北市災害應變中心	Emergency Operations Centre of Taipei City	25.02866111	121.5661167	信義區	20000101000000	Public space	54
0011	三張犁	Sanchangli	25.034937	121.55762	信義區	20000101000000	Residence	26
0012	臺北醫學大學	Taipei Medical University	25.026679	121.561747	信義區	20120725000000	Public space	34
0013	福德公園	Fude Park	25.03809	121.58367	信義區	20120725000000	Public space	66
0014	榮星花園	Rongxing Park	25.06424	121.54037	中山區	20120725000000	Public space	32
0015	饒河夜市	Raohe Night Market	25.049845	121.571885	松山區	20120725000000	Tourist attraction	38
0016	松山家商	Songshan Vocational High School	25.036084	121.579135	信義區	20120725000000	Working place and school	48
0017	民生光復路口	Minsheng & Guangfu Intersection	25.0584	121.55504	松山區	20120725000000	Residence	34
0018	社教館	Taipei Cultural Centre	25.048268	121.552278	松山區	20120725000000	Public space	38
0019	中強公園	Zhongqiang Park	25.02863	121.56981	信義區	20120725000000	Public space	30
0020	捷運科技大樓站	MRT Technology Bldg. Sta.	25.025896	121.543293	大安區	20120725000000	MRT or transit depot	56
0021	民生敦化路口	Minsheng & Dunhua Intersection	25.057985	121.548982	松山區	20120725000000	Working place and school	32
0022	松山車站	Songshan Rail Sta.	25.048616	121.578095	松山區	20120725000000	MRT or transit depot	44
0023	東新國小	Dongxin Elementary School	25.055074	121.602798	南港區	20120725000000	Working place and school	32
0024	信義建國路口	Xinyi & Jianguo Intersection	25.032981	121.537328	大安區	20120725000000	Public space	46
0025	永吉松信路口	Yongji & Songxin Intersection	25.04543	121.57205	信義區	20120725000000	Residence	30

0026	捷運昆陽站(1 號出口)	MRT Kunyang Sta. (Exit 1)	25.050142	121.592375	南港區	20120725000000	MRT or transit depot	42
0027	捷運南港展覽館站(5 號出口)	MRT Nangang Exhibition Centre Sta. (Exit 5)	25.05469	121.61669	南港區	20120725000000	MRT or transit depot	26
0028	五常公園	Wuchang Park	25.04814	121.57467	信義區	20120725000000	Public space	36
0029	金山愛國路口	Jinshan & Aiguo Intersection	25.03164	121.52655	大安區	20120725000000	Working place and school	54
0030	基隆長興路口	Keelung & Changxing Intersection	25.017054	121.544352	大安區	20120725000000	Working place and school	40
0031	辛亥新生路口	Xinhai & Xinsheng Intersection	25.022413	121.53456	大安區	20120725000000	Working place and school	30
0032	捷運六張犁站	MRT Liuzhangli Sta.	25.023884	121.553161	大安區	20120725000000	MRT or transit depot	30
0033	中崙高中	Zhonglun High School	25.04878	121.56087	松山區	20120725000000	Working place and school	46
0034	捷運行天宮站(1 號出口)	MRT Xingtian Temple Sta. (Exit 1)	25.058369	121.532934	中山區	20120725000000	MRT or transit depot	32
0035	捷運行天宮站(3 號出口)	MRT Xingtian Temple Sta. (Exit 3)	25.059978	121.533302	中山區	20120725000000	MRT or transit depot	30
0036	臺大資訊大樓	NTU Information Bldg.	25.02101	121.54153	大安區	20120725000000	Working place and school	32
0037	捷運東門站(4 號出口)	MRT Dongmen Sta. (Exit 4)	25.0337	121.529166	大安區	20120725000000	MRT or transit depot	46
0038	臺灣師範大學(圖書館)	NTNU Library	25.02665	121.52889	大安區	20120725000000	Working place and school	34
0039	南港世貿公園	Nangang Park	25.058	121.61422	南港區	20120725000000	Public space	26
0040	玉成公園	Yucheng Park	25.04287	121.5864	南港區	20120725000000	Public space	34
0041	中研公園	Academia Park	25.047425	121.613706	南港區	20120725000000	Public space	30
0042	捷運後山埤站(1 號出口)	MRT Houshanpi Sta.(Exit 1)	25.04431	121.58174	南港區	20121128125356	MRT or transit depot	38
0043	凌雲市場	Linyun Market	25.035639	121.614154	南港區	20121128130528	Shopping area	36
0044	捷運南港軟體園區站(2 號出口)	MRT Nangang Software Park Sta.(Exit 2)	25.05973	121.616187	南港區	20121128131023	MRT or transit depot	36
0045	捷運公館站(2 號出口)	MRT Gongguan Sta.(Exit 2)	25.01476	121.534538	大安區	20121128131220	MRT or transit depot	30
0046	南港國小	Nangang Elementary School	25.05646	121.611027	南港區	20121128131552	Working place and school	44
0047	捷運忠孝新生(3 號出口)	MRT Zhongxiao Xinsheng Sta.Exit 3 (testing)	25.041924	121.533862	大安區	20121219100534	MRT or transit depot	40
0048	南港車站	Nangang Rail Sta.	25.05247	121.608202	南港區	20121219100955	MRT or transit depot	38
0049	龍門廣場	Longmen Square(Testing)	25.040901	121.548252	大安區	20121219102000	Shopping area	52
0050	民權運動公園	MinQuan Park	25.062002	121.560186	松山區	20121219102311	Public space	52
0051	建國農安街口	Jianguo & Nongan Intersection	25.065031	121.536775	中山區	20121231090803	Residence	44
0052	建國長春路口	Jianguo & Changchun Intersection	25.054761	121.536925	中山區	20121231091320	Working place and school	30
0053	八德市場	Bade Market	25.044781	121.536609	中山區	20121231091535	Residence	26

0054	臺北市立圖書館(總館)	Taipei Public Library	25.028798	121.538073	大安區	20130111095018	Public space	30
0055	臺北田徑場	Taipei Stadium	25.049505	121.549408	松山區	20130111095239	Public space	46
0056	Y-17 青少年育樂中心	Y17 Youth Recreation Centre	25.038954	121.522334	中正區	20130111095451	Working place and school	42
0057	新生和平路口	Xinsheng & Heping Intersection	25.026217	121.53519	大安區	20130201085924	Residence	46
0058	捷運善導寺站(1 號出口)	MRT Shandao Temple Sta(Exit 1)	25.045267	121.5222	中正區	20130201090323	MRT or transit depot	48
0059	林森公園	Linsen Park	25.052227	121.525805	中山區	20130208103613	Public space	32
0060	中山行政中心	Zhongshan Dist. Admin. Office	25.064317	121.533487	中山區	20130208103812	Working place and school	30
0061	台灣科技大學	N.T.U.S.T	25.0131	121.539723	大安區	20130304200547	Working place and school	46
0062	南昌公園	Nanchang Park	25.026827	121.520258	中正區	20130304200723	Public space	34
0063	仁愛醫院	Taipei City Hospital Renai Branch	25.037569	121.545632	大安區	20130304201131	Public space	36
0064	國家圖書館	National Central Library	25.037773	121.517029	中正區	20130408163632	Public space	50
0065	青年公園 3 號出口	Youth Park Exit 3	25.022725	121.502708	萬華區	20130507090740	Public space	38
0066	師範大學公館校區	NTNU Gongguan Campus	25.007528	121.537188	文山區	20130507091052	Working place and school	42
0067	捷運臺大醫院(4 號出口)	MRT Nat'l Taiwan U. Hospital Sta.(Exit 4)	25.042973	121.516428	中正區	20130507091530	MRT or transit depot	48
0068	國興青年路口	Guoxing & Qingnian Intersection	25.025865	121.506536	萬華區	20130507092136	Residence	36
0069	興豐公園	Xingfong Park	24.999837	121.547778	文山區	20130509110341	Public space	34
0070	捷運台北 101/世貿站	MRT Taipei 101/World Trade Centre Sta.	25.032752	121.561645	信義區	20130510130141	MRT or transit depot	52
0071	捷運信義安和站	MRT Xinyi Anhe Sta.	25.032985	121.554204	大安區	20130516184739	MRT or transit depot	30
0072	新生長安路口	Xinsheng & Changan Intersection	25.048611	121.529346	中山區	20130516184920	Residence	42
0073	酒泉延平路口	Jiuquan & Yanping Intersection	25.072228	121.510195	大同區	20130516185058	Residence	32
0074	信義連雲街口	Xinyi & Lianyun Intersection	25.033817	121.530547	中正區	20130523181138	Working place and school	40
0075	基隆光復路口	Keelung & Guangfu Intersection	25.030055	121.557841	信義區	20130619203136	Tourist attraction	30
0076	新生長春路口	Xinsheng & Changchun Intersection	25.056387	121.527522	中山區	20130619203335	Residence	36
0077	民生活動中心	Minsheng Activity Centre	25.059147	121.56297	松山區	20130621144511	Public space	32
0078	捷運圓山站(2 號出口)	MRT Yuanshan Sta. (Exit 2)	25.071824	121.519287	大同區	20130704102459	MRT or transit depot	52
0079	捷運民權西路站(3 號出口)	MRT Minquan W.Rd. Sta.(Exit 3)	25.061285	121.520205	大同區	20130704102651	MRT or transit depot	50
0080	華江高中	Huajiang High School	25.02751	121.495869	萬華區	20130704180426	Working place and school	44
0081	捷運台電大樓站(2 號出口)	MRT Taipower Building Sta. (Exit 2)	25.020547	121.528552	大安區	20130704180142	MRT or transit depot	40

0082	捷運西門站(3 號出口)	MRT Ximen Sta.(Exit 3)	25.041778	121.508693	中正區	20130709212101	MRT or transit depot	60
0083	捷運大安森林公園站	MRT Daan Park Sta.	25.033156	121.535161	大安區	20130710094448	MRT or transit depot	74
0084	復華花園新城	Fuhua Garden New Village(City)	25.029705	121.502899	萬華區	20130710094639	Residence	38
0085	信義敦化路口	Xinyi & Dunhua Intersection	25.033362	121.54911	大安區	20130715183258	Working place and school	46
0086	民權復興路口	Minquan & Fuxing Intersection	25.062344	121.545138	松山區	20130716195638	Residence	46
0087	捷運大安站	MRT Daan Sta.	25.033078	121.543057	大安區	20130716195812	MRT or transit depot	58
0088	捷運象山站	MRT Xiangshan Sta.	25.032835	121.571274	信義區	20130717140002	MRT or transit depot	58
0089	和平重慶路口	Heping Chongqing Intersection	25.027323	121.516385	中正區	20130717162023	Residence	44
0090	老松國小	Laosong Elementary School	25.037783	121.501708	萬華區	20130717162303	Working place and school	44
0091	市立美術館	Taipei Fine Arts Museum	25.070629	121.523268	中山區	20130717162439	Tourist attraction	36
0092	開封西寧路口	Kaifong & Xining Intersection	25.046618	121.507169	萬華區	20130719110707	Residence	42
0093	吳興公車總站	Wu Xing Bus Station.	25.023877	121.569836	信義區	20130719110823	MRT or transit depot	36
0094	捷運景美站	MRT Jingmei Sta.	24.993254	121.541059	文山區	20130719191809	MRT or transit depot	52
0095	東園國小	Dongyuan Elementary School	25.023393	121.497679	萬華區	20130729155220	Working place and school	36
0096	三民公園	Sanmin Park	25.061567	121.566558	松山區	20130729155552	Public space	30
0097	捷運劍潭站(2 號出口)	MRT Jiantan Sta.(EXIT. 2)	25.082825	121.524721	士林區	20130729155956	MRT or transit depot	52
0098	羅斯福景隆街口	Roosevelt & Jinglong Intersection	24.999378	121.540197	文山區	20130729160122	Residence	48
0099	捷運雙連站(2 號出口)	MRT Shuanglian Sta. (Exit 2)	25.057866	121.520711	大同區	20130729160229	MRT or transit depot	42
0100	金山市民路口	Jinshen & Civic Blvd. Intersection	25.045753	121.530697	中正區	20130729160345	Public space	40
0101	華山文創園區	Huashan 1914・Creative Park	25.043668	121.528487	中正區	20130729160545	Tourist attraction	50
0102	臺北市客家文化主題公園	Taipei City Hakka Cultural Park	25.02043	121.525322	中正區	20130729160805	Tourist attraction	32
0103	萬大興寧街口	Wanda & Xingning Intersection	25.031974	121.500474	萬華區	20130729160906	Residence	52
0104	台北花木批發市場	Taipei Pot Plant Auction	25.004023	121.54074	文山區	20130729161023	Working place and school	38
0105	峨嵋停車場	Emei Parking Lot	25.044412	121.505409	萬華區	20130729161141	Public space	42
0106	西園艋舺路口	Xiyuan & Bangka Intersection	25.032932	121.497674	萬華區	20130729161238	Residence	44
0107	捷運小南門站(1 號出口)	MRT Xiaonanmen Sta. (Exit 1)	25.036402	121.509422	中正區	20130729161331	MRT or transit depot	54
0108	臺北孔廟	Taipei Confucius Temple	25.073306	121.515843	大同區	20130809093136	Tourist attraction	32
0109	林安泰古厝	Lin An-tai Historical House	25.071606	121.530805	中山區	20130809093709	Tourist attraction	36

0110	文湖國小	Wenhu Elementary School	25.086376	121.560888	內湖區	20130819094543	Working place and school	44
0111	捷運忠孝復興站(2 號出口)	MRT Zhongxiao Fuxing Sta.(Exit. 2)	25.040184	121.543497	大安區	20130822113711	MRT or transit depot	54
0112	捷運新北投站	MRT Xinbeitou Sta.	25.137456	121.503124	北投區	20131001183941	MRT or transit depot	48
0113	仁愛逸仙路口	Renai & Yixian Intersection	25.037724	121.561178	信義區	20000101000000	Residence	38
0114	蘭雅公園	Lanya Park	25.109908	121.530386	士林區	20131001184326	Public space	30
0115	臺北轉運站	Taipei Bus Sta.	25.048222	121.520526	中正區	20131003194227	MRT or transit depot	68
0116	福林公園	Zhicheng St. & Zhongzheng Rd.	25.096122	121.530215	士林區	20131003195156	Public space	44
0117	捷運北投站	MRT Beitou Sta.	25.132581	121.498618	北投區	20131007110204	MRT or transit depot	58
0118	大業大同街口	Daye & Datong Intersection	25.136929	121.499152	北投區	20131007110327	Residence	36
0119	捷運劍南路站(2 號出口)	MRT Jiannan Rd. Sta.(Exit 2)	25.08418	121.555116	中山區	20131007110507	MRT or transit depot	56
0120	捷運龍山寺站(1 號出口)	MRT Longshan Temple Sta. (Exit. 1)	25.035479	121.50026	萬華區	20131007190221	MRT or transit depot	46
0121	龍江南京路口	Longjiang & Nanjing Intersection	25.05298	121.540568	中山區	20131014205048	Working place and school	66
0122	捷運港墘站(2 號出口)	MRT Gangqian Sta. (Exit 2)	25.079681	121.575458	內湖區	20131016120358	MRT or transit depot	50
0123	天母運動公園	Tienmu Sports Park	25.116325	121.534136	士林區	20131016123650	Public space	44
0124	振華公園	Zenhua Park	25.115863	121.518163	北投區	20131023182911	Public space	36
0125	華西公園	Huaxi Park	25.038609	121.498495	萬華區	20131023183035	Public space	30
0126	敦化基隆路口	Dunhua & Keelung Intersection	25.022073	121.548336	大安區	20131023183949	Working place and school	30
0127	東湖國中	Donghu Junior High School	25.073277	121.619521	內湖區	20131108100906	Working place and school	40
0128	成功國宅	Chengong Public Housing	25.026808	121.546726	大安區	20131114093852	Residence	36
0129	捷運文德站(2 號出口)	MRT Wende Sta. (Exit 2)	25.078292	121.585264	內湖區	20131120191945	MRT or transit depot	50
0130	羅斯福寧波東街口	Roosevelt & Ningbo E. St. Intersection	25.031445	121.519411	中正區	20131120192101	Residence	26
0131	洲子二號公園	Zhouzhi Park No.2	25.079322	121.568688	內湖區	20131127115629	Public space	34
0132	羅斯福新生南路口	@Roosevelt & Xinsheng S. Intersection	25.01603085	121.5331757	大安區	20131211192233	Working place and school	88
0133	蘭興公園	@Lanxing Park	25.111839	121.525888	士林區	20131217085155	Public space	40
0134	捷運芝山站(2 號出口)	MRT Zhishan Sta.(Exit 2)	25.10336	121.522629	士林區	20131217085353	MRT or transit depot	64
0135	捷運石牌站(2 號出口)	@MRT Shipai Sta. (Exit 2)	25.114513	121.515677	北投區	20131217203111	MRT or transit depot	54
0136	國立臺北護理健康大學	@NTUNHS	25.118049	121.517512	北投區	20131217203556	Working place and school	30
0137	國防大學	Nat'l Defense U.	25.137976	121.493066	北投區	20131223134159	Working place and school	46

0138	捷運永春站(2號出口)	"MRT Yongchun Sta. (Exit 2)	25.040558	121.575372	信義區	20131226100026	MRT or transit depot	30
0139	永樂市場	Yongle Market	25.054501	121.510549	大同區	20131226100109	Shopping area	30
0140	捷運大橋頭站(2號出口)	MRT Daqiaotou Sta. (Exit 2)	25.063404	121.512909	大同區	20131226100222	MRT or transit depot	46
0141	文山行政中心	Wenshan Dist. Admin. Centre	24.989902	121.569984	文山區	20131226100427	Working place and school	36
0142	捷運木柵站	MRT Muzha Sta.	24.997747	121.574214	文山區	20131226100530	MRT or transit depot	52
0143	捷運動物園站(2號出口)	MRT Taipei Zoo Sta.(Exit 2)	24.997659	121.578752	文山區	20131226100624	MRT or transit depot	72
0144	國立政治大學	Nat'l Chengchi U.	24.988363	121.576536	文山區	20131231191442	Working place and school	70
0145	樹德公園	Shude Park	25.066688	121.516149	大同區	20140107090703	Public space	40
0146	捷運士林站(2號出口)	MRT Shilin Sta.(Exit 2)	25.092546	121.526556	士林區	20140113132745	MRT or transit depot	46
0147	士林運動中心	Shilin Sports Centre	25.089175	121.521814	士林區	20140113132930	Public space	32
0148	捷運明德站	MRT Mingde Sta.	25.110331	121.518316	北投區	20140113133113	MRT or transit depot	68
0149	北投運動中心	Beitou Sports Centre	25.116665	121.509621	北投區	20140116103056	Public space	62
0150	松德公園	Songde Park	25.036568	121.57343	信義區	20140116103213	Public space	38
0151	考試院	Examination Yuan	24.987507	121.549827	文山區	20140120085747	Working place and school	34
0152	百齡國小	Bailing Elementary School	25.08521	121.519175	士林區	20140120085812	Working place and school	40
0153	蔣渭水紀念公園	Jiang Wei-shui Memorial Park	25.059885	121.516299	大同區	20140120085913	Public space	40
0154	中正基河路口	Zhongzheng & Jihe Intersection	25.093396	121.519867	士林區	20140120085950	Working place and school	38
0155	瑞光港墘路口	Ruiguang & Gangqian Intersection	25.076193	121.57505	內湖區	20140120191805	Working place and school	30
0156	東湖國小	Donghu Elementary School	25.068409	121.615938	內湖區	20140120192640	Working place and school	38
0157	麗山國小	Lishan Elementary School	25.082703	121.571467	內湖區	20140120192800	Working place and school	42
0160	捷運中山站(2號出口)	MRT Zhongshan Sta. (Exit 2)	25.053082	121.52029	大同區	20140120193250	MRT or transit depot	30
0161	大豐公園	Huanggang Rd. / Daxing St.	25.131143	121.503768	北投區	20140124111726	Public space	56
0162	捷運中山國小站(4號出口)	MRT Zhongshan Elementary School(Exit.4)	25.062924	121.52772	中山區	20140506133414	MRT or transit depot	70
1001	大鵬華城	Dapeng Community	24.99116	121.53398	新店區	20140429102552	Residence	38
1002	汐止火車站	Xizhi Railway Station	25.068914	121.662748	汐止區	20140429102910	MRT or transit depot	56
1003	汐止區公所	Xizhi Dist. Office	25.064162	121.658301	汐止區	20140429103119	Working place and school	46
1004	國泰綜合醫院	Cathay General Hospital	25.07315	121.662555	汐止區	20140429103340	Public space	40
1005	裕隆公園	Yulon Park	24.979649	121.546319	新店區	20140429103621	Public space	40

1006	捷運大坪林站	MRT DaPingLin Station	24.983977	121.541721	新店區	20140429103905	MRT or transit depot	32

Source: this study, data from http://opendata.dot.taipei.gov.tw/opendata/gwjs_cityhall.jso

Appendix C: clustering results by stations

Station name	Weekday	Weekend	Station name	Weekday	Weekend
MRT Taipei City Hall Stataion(Exit 3)-2	3	2	Nangang Park	2	1
MRT S.Y.S Memorial Hall Stataion(Exit 2.)	3	3	Yucheng Park	1	4
Taipei City Hall	2	3	Academia Park	1	4
Citizen Square	2	3	MRT Houshanpi Sta.(Exit 1)	3	2
Xingya Jr. High School	2	3	Linyun Market	1	4
TWTC Exhibition Hall 2	2	3	MRT Nangang Software Park Sta.(Exit 2)	3	1
Xinyi Square(Taipei 101)	3	3	MRT Gongguan Sta.(Exit 2)	3	2
TWTC Exhibition Hall 3	2	3	Nangang Elementary School	2	1
Songde	1	4	MRT Zhongxiao Xinsheng Sta.Exit 3	2	2
Emergency Operations Center of Taipei City	3	1	Nangang Rail Sta.	3	3
Sanchangli	3	1	Longmen Square(Testing)	2	3
Taipei Medical University	2	4	MinQuan Park	1	4
Fude Park	1	4	Jianguo & Nongan Intersection	1	4
Rongxing Park	1	4	Jianguo & Changchun Intersection	2	1
Raohe Night Market	3	1	Bade Market	3	2
Songshan Vocational High School	1	4	Taipei Public Library	1	4
Minsheng & Guangfu Intersection	2	4	Taipei Stadium	2	1
Taipei Cultural Center	2	1	Xinsheng & Heping Intersection	3	3
Zhongqiang Park	2	1	MRT Shandao Temple Sta (Exit 1)	2	3
MRT Technology Bldg. Sta.	3	2	Linsen Park	2	3
Minsheng & Dunhua Intersection	2	2	Zhongshan Dist. Admin. Office	1	4
Songshan Rail Sta.	3	2	N.T.U.S.T	2	1
Dongxin Elementary School	1	4	Nanchang Park	3	4
Xinyi & Jianguo Intersection	3	3	Taipei City Hospital Renai Branch	2	1
Yongji & Songxin Intersection	1	4	National Central Library	2	3
MRT Kunyang Sta. (Exit 1)	1	4	Youth Park Exit 3	1	4
MRT Nangang Exhibition Center Sta. (Exit 5)	3	2	NTNU Gongguan Campus	1	4
Wuchang Park	1	1	MRT Nat'l Taiwan U. Hospital Sta. (Exit 4)	2	3
Jinshan & Aiguo Intersection	2	2	Guoxing & Qingnian Intersection	1	4
Keelung & Changxing Intersection	3	4	Xingfong Park	1	4
Xinhai & Xinsheng Intersection	3	3	MRT Taipei 101/World Trade Center Sta.	3	3
MRT Liuzhangli Sta.	1	4	MRT Xinyi Anhe Sta.	3	1
Zhonglun High School	2	1	Xinsheng & Changan Intersection	2	1
MRT Xingtian Temple Sta. (Exit 1)	3	1	Jiuquan & Yanping Intersection	1	4
MRT Xingtian Temple Sta. (Exit 3)	3	2	Xinyi & Lianyun Intersection	3	2
NTU Information Bldg.	2	3	Keelung & Guangfu Intersection	3	1
MRT Dongmen Sta. (Exit 4)	1	2	Xinsheng & Changchun Intersection	1	4

Station name	Weekday	Weekend	Station name	Weekday	Weekend
NTNU Library	2	2	Daye & Datong Intersection	1	4
Minsheng Activity Center	1	4	MRT Jiannan Rd. Sta.(Exit 2)	3	3
MRT Minquan W.Rd. Sta.(Exit 3)	3	4	MRT Longshan Temple Sta. (Exit. 1)	1	2
Huajiang High School	1	4	Longjiang & Nanjing Intersection	2	1
MRT Taipower Building Sta. (Exit 2)	3	1	MRT Gangqian Sta. (Exit 2)	3	1
MRT Ximen Sta.(Exit 3)	3	3	Tienmu Sports Park	1	4
MRT Daan Park Sta.	3	1	Zenhua Park	1	4
Fuhua Garden New Village(City)	1	4	Huaxi Park	1	4
Xinyi & Dunhua Intersection	3	1	Dunhua & Keelung Intersection	2	4
Minquan & Fuxing Intersection	2	4	Donghu Junior High School	1	4
MRT Daan Sta.	3	1	Chengong Public Housing	1	4
MRT Xiangshan Sta.	3	3	MRT Wende Sta. (Exit 2)	1	4
Heping Chongqing Intersection	1	4	Roosevelt & Ningbo E. St. Intersection	3	1
Laosong Elementary School	1	1	Zhouzhi Park No.2	2	3
Taipei Fine Arts Museum	1	2	@Roosevelt & Xinsheng S. Intersection	3	2
Kaifong & Xining Intersection	3	1	@Lanxing Park	1	4
Wu Xing Bus Station.	1	4	MRT Zhishan Sta.(Exit 2)	3	2
MRT Jingmei Sta.	1	4	@MRT Shipai Sta. (Exit 2)	2	2
Dongyuan Elementary School	1	4	@NTUNHS	2	4
Sanmin Park	1	4	Nat'l Defense U.	1	4
MRT Jiantan Sta.(EXIT. 2)	2	2	Yongle Market	1	4
Roosevelt & Jinglong Intersection	1	4	MRT Daqiaotou Sta. (Exit 2)	1	4
MRT Shuanglian Sta. (Exit 2)	3	1	Wenshan Dist. Admin. Center	1	4
Jinshen & Civic Blvd. Intersection	2	3	MRT Muzha Sta.	1	2
Huashan 1914・Creative Park	2	3	MRT Taipei Zoo Sta.(Exit 2)	3	3
Taipei City Hakka Cultural Park	1	1	Nat'l Chengchi U.	1	4
Wanda & Xingning Intersection	3	1	Shude Park	1	4
Taipei Pot Plant Auction	1	4	MRT Shilin Sta.(Exit 2)	2	2
Emei Parking Lot	3	1	Shilin Sports Center	1	4
Xiyuan & Bangka Intersection	1	4	MRT Mingde Sta.	1	4
MRT Xiaonanmen Sta. (Exit 1)	2	1	Beitou Sports Center	1	4
Taipei Confucius Temple	1	4	Songde Park	2	1
Lin An-tai Historical House	2	2	Examination Yuan	1	4
Wenhu Elementary School	1	4	Bailing Elementary School	1	4
MRT Zhongxiao Fuxing Sta.(Exit. 2)	3	3	Jiang Wei-shui Memorial Park	1	4
MRT Xinbeitou Sta.	1	4	Zhongzheng & Jihe Intersection	1	4
Renai & Yixian Intersection	3	1	Ruiguang & Gangqian Intersection	2	2
Lanya Park	1	4	Donghu Elementary School	1	4
Taipei Bus Sta.	3	3	Lishan Elementary School	1	4
Zhicheng St. & Zhongzheng Rd.	1	4	MRT Zhongshan Sta. (Exit 2)	3	3
MRT Beitou Sta.	2	2	Huanggang Rd. / Daxing St.	1	4

Station name	Weekday	Weekend	Station name	Weekday	Weekend
Dapeng Community	1	4			
Xizhi Railway Station	2	3			
Xizhi Dist. Office	2	2			
Cathay General Hospital	1	4			
Yulon Park	1	4			
MRT DaPingLin Station	1	4			

Source: this study