Journal of Transport Geography 108 (2023) 103569

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

How public shared bike can assist first and last mile accessibility: A case study of the MRT system in Taipei City, Taiwan

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ARTICLE INFO

Keywords:
Public shared bike
Bike sharing
First and last mile
Travel time saving
Smart card data
Big data
Accessibility
PTAL

ABSTRACT

In urban areas, public transport can improve sustainable transport by reducing vehicles and congestion, and improving accessibility. Mass rapid transit (MRT) is especially important for large cities, such as Taipei City, Taiwan. In particular, MRT aims to improve mobility and reliability, but has limitations in providing first and last mile accessibility to final destinations or origins. Taipei City, Taiwan has introduced a public bike sharing scheme to service this gap. However, few studies have addressed how a public bike sharing scheme assists first and last mile accessibility. This study uses Taipei City as a case study to investigate this issue by comparing the demand and supply of the public bike sharing scheme, YouBike, at a detailed spatial scale. The supply of YouBike is represented by the time saving compared to walking for each identified origin and destination pair in the study area (i.e., Point of Interests (POIs) and MRT stations). The demand for YouBike is total trips from each YouBike station to a MRT station using public transport smart card data. By comparing the demand and supply for over 400 zones or villages, service gaps and areas of unbalanced service can be identified. The results show that YouBike does provide first and last mile service for the MRT network with some evidence of service mismatch in the study area, i.e., high service for low demand and vice versa. The conclusions of the paper can help cities wanting to introduce a bike sharing schemes to improve first and last mile transport.

1. Introduction

While public transport offers mobility and frequency in urban areas, one of its major drawbacks is providing first and last mile accessibility. Hence, many transport planners and policy makers have emphasized door-to-door services, in the hope of increasing the network effect of public transport. In particular, transfer and interchange among modes play a key role in meeting travel needs. Yen et al. (2018) noted that transfer and interchange behaviour accounted for >30% of daily public transport trips in major cities such as London or even as high as 80% in New York. However, transfer tends to be an unwanted feature of using public transport for customers. How to provide a seamless transfer service is important and there are several ways to achieve this and thus improve connectivity. Active transport has been considered one of the most effective ways, with shared modes such as shared bike and shared scooter. Taipei City, Taiwan has introduced a public bike sharing scheme to service this gap. This scheme allow people to ride a bike before or after taking public transport, enhancing the accessibility between public transport stations and trip destinations. Bike sharing also plays a key role in promoting sustainable transport since it is a green transport mode.

There is no doubt that a public shared bike scheme can improve the accessibility of first and last mile trips but the question is how to measure the benefit. However the standard needed to provide a good public shared bike service is not clearly defined. Another issue of a public shared bike system is where to locate bike stations. Location selection then leads to another question of whether a shared bike scheme can satisfy users' needs. To answer these latter two questions of measuring benefit and choosing locations, this paper presents a case study of Taipei City, Taiwan, which introduced a public bike sharing system, YouBike, in 2012. Since then, YouBike has become popular and is believed to have increased the use of public transport. The role of YouBike is important because Taipei City plans to increase its sustainable transport mode share from 67% in 2020 to 80% in 2050 (Taipei City Government, 2020) and determining whether the current YouBike system has adequate scale to create a network effect is important. Currently there are around 400 stations in the whole city in 2020 although it is planned to increase to 1200 in a few years. Hence, a study of the YouBike system in Taipei City

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https://doi.org/10.1016/j.jtrangeo.2023.103569
Received 29 June 2022; Received in revised form 12 January 2023; Accepted 3 March 2023
Available online 14 March 2023

is urgently required, particularly in performance measurement and site selection. This study focuses on measuring accessibility of supply and demand for the YouBike service at a detailed spatial scale, and provides relevant policies on the operational strategy for YouBike as well as recommendations for the location of new YouBike stations.

From the demand perspective, the use of each YouBike station can be measured. In Taipei City, the public transport smart card system is integrated and YouBike is included as part of the wider public transport system. Therefore, demand for YouBike can be evaluated using trip records with the transfer behaviour between YouBike and other public transport modes (e.g., Taipei MRT) being used as a proxy for demand. For the supply analysis, as using a public shared bike is intended to save travel time compared to the most basic mode of walking, time savings are used to measure YouBike supply. For a particular origin (e.g., MRT station) and destination (e.g., POI) pair, the travel time saving is the time difference between the total travel time for the trip by riding a bike, and the trip with walking only (i.e., first and last mile leg only). The analysis of demand and supply is used to identify service gaps, and advance the discussion by advising on operational policy. The conclusions of the paper point out the weaknesses of the current YouBike system, and suggestions are proposed to enhance the effectiveness of the YouBike system.

This paper is structured as follows. Section 2 presents the literature review of accessibility measurement and first and last mile transport, followed by the introduction of the case study area in Section 3. The model used in this study is presented in Section 4. Data is described in Section 5. Section 6 reports the analysis of YouBike demand and supply. Finally, discussion and conclusions are presented.

2. Literature review

2.1. Public transport accessibility

Transport planning focuses on the two-way interaction between transport accessibility and the location of economic activity. This highlights the importance of transport accessibility measurement in the evaluation of transport policy and the understanding of the links between transport and daily activities.

Transport accessibility is important in understanding many aspects of transport planning, with much research effort devoted to how accessibility should be measured. The seminal paper of Hansen (1959) identified that accessibility is not simply a measurement of distance to actual activities undertaken by individuals (such as shopping or education) but to the range or potential opportunities that an individual can access. Hansen added the normal geographical maxim of closer locations carrying more weight than further locations to produce gravity based measurement of transport accessibility. Much of the early work on accessibility was US based with Clark et al. (1969) presenting one of the earliest non-US studies by looking at European evidence. A decade later Morris et al. (1979) provided empirical evidence from Australia and set this in a context which emphasizes the relationship between accessibility measurement and its use in transport planning. This was reinforced by the state of the art review and synthesis by Vickerman (1974) which identified significant statistical difficulties in relating accessibility to the attractiveness of opportunities because of the strong association between conventional measures of accessibility and measures of urban structure.

These complexities have led to the development of a diverse set of accessibility metrics. Developed measures fall into three main categories. First, person based measures, generated at the individual level, measure how an individual experiences accessibility linking the characteristics of the land use to that of the transport network and spatial and temporal constraints (Geurs and Van Wee, 2004; Miller, 2005). While person based measures are useful for analysis at the individual level they are difficult to aggregate to gain understanding at a wider spatial scale or to evaluate policy (Boisjoly and El-Geneidy, 2017). The second category of measures are utility based and capture economic benefits from changes in the transport network. While these measures can be constructed to cover many of the accessibility dimensions they are challenging to interpret and communicate, particularly to policy makers (Van Wee, 2016). The final set of accessibility measures are location based and often used by planners because they provide different ways of looking at accessibility (Boisjoly and El-Geneidy, 2017) including the way in which opportunities may be distributed over space and how easy (or difficult) it is to move from one place to another. Time or distance is used to measure the transport component, usually on a mode by mode basis. Location based metrics are typically either a measure of cumulative opportunities (counting all opportunities reachable for a given travel cost constraint) or a gravity based measure that gives more weight to near opportunities over those which are further away thus integrating the idea originating with Hansen (1959). While cumulative opportunities are more reflective of the definition of accessibility, the gravity based measures are easier to generate and often to interpret.

The public transport accessibility level (PTAL) has been identified as a useful tool that can provide objective measurement of accessibility (Wu and Hine, 2003). PTAL is a method of measuring accessibility to the public transport network (Mulley et al., 2017; Transport for London, 1992, 2015) and it is a location based metric which considers various POIs that are specific locations that people may find useful or interesting. It combines walk access time with service frequency at service access points (e.g., railway stations, bus stops) within a catchment. PTAL has been applied in many studies (e.g., Adhvaryu et al., 2019; Shah and Adhvaryu, 2016). This study adopts the concept of PTAL to measure accessibility for the supply of YouBike.

2.2. First and last mile transport

As well as measuring public transport accessibility, many studies aim to find the efficiency of first and last mile public transport service, which is regarded as a vital component of the whole quality of experience for public transport users (Venter, 2020). To improve first and last mile public transport service, a variety of shared mobility services have been launched to serve as connections to public transport, including public bike sharing systems and scooter sharing (Shaheen and Chan, 2016).

Among the sharing modes, bike sharing is the most widely adopted by cities. Many studies have shown that the combination of bikes and public transport can increase public transport accessibility (Zuo et al., 2020), and reduce car use and increase train trips and bike use (Martens, 2007). Zuo et al. (2020) and Boarnet et al. (2017) assessed equity issues, evaluating how to facilitate first and last mile accessibility to employment in low income neighborhoods by a bike sharing system.

Bike sharing is a well-developed public transport mode in many cities, while electric scooter sharing and automated bus are being trialled in several countries to improve first and last mile service. Baek et al. (2021) examined the value of electric scooter sharing as a first and last mile transport mode in Seoul, and designed a stated choice experiment to analyze people's preferences. Chee et al. (2020) investigated how the potential users of a first and last mile automated bus service evaluate the service, and evaluated the factors which determine the willingness to use automated bus in Stockholm, Sweden. Regardless of which shared mode is used in different case studies, the key concept is that shared modes are indeed critical for a public transport system. Studies on a new type of first and last mile public transport mode often focus on the willingness of potential users. Therefore, this study uses a comparison to evaluate both demand and supply of the shared mode (i.e., shared bike) to identify potential service gaps.

3. Case study area

The study area of this research is the MRT system in Taipei City, Taiwan. The following sections briefly introduce Taipei City and provide an overview of the public transport system. The study catchment area is defined in this section.

3.1. Public transport system in Taipei City

Taipei City is the capital of Taiwan. The population density is 9700/km^2, making Taipei City one of the highest density metropolitan areas in the world. There are two Central Business Districts (CBDs) in Taipei City, each with a MRT station (Fig. 1). As a result, the central areas of Taipei City have relatively good quality public transport services and public transport mode share is the highest (42%) in Taiwan (Department of Transportation, 2019). If active transport modes (i.e., walking and cycling) are also included, the market share of sustainable transport is >60%. The public transport network includes bus system, rail system, and the YouBike system, as shown in Fig. 1, with an obvious radial network from the two CBDs. The following sections provide brief introduction of these public transport modes.

There are five major MRT lines in Taipei with 79 MRT stations and approximately 97 km of operation as shown in Fig. 1. Most of the metro lines are designed in an "L" shape to maximize catchment areas. The case study area also has two rail systems, Taiwan Railway (TRA) and High Speed Rail (HSR) with multimodal stations to provide seamless transfer service between MRT and TRA/HSR and sometimes with city bus and intercity bus services.

YouBike is a public bike sharing system in Taipei City that is designed to facilitate first and last mile transport needs. YouBike stations are designed as dock stations with capacity varying at different stations. The YouBike service is a 24 h service, with a vehicle repositioning service based on real-time monitoring with many of the YouBike stations being located near MRT stations and trip attraction locations such as schools, district offices, department stores, and hospitals. In general, YouBike patronage has increased from 7650 trips in 2010 to over 2 m trips in 2018.

City buses can be categorized into several types: ordinary routes, trunk routes, recreational bus routes, community bus, and shuttle bus. Trunk routes serve the major corridors of the city (e.g., Xinyi Trunk Line, Zhongxiao Trunk Line) with higher demand. Community bus routes provide free first and last mile service for residents in communities that are usually located in remote or *peri* urban areas.

3.2. Catchment area definition

Most daily activities are located in the centre of Taipei City via MRT lines which is the focus of this study. The smart card analysis (see section 4.1) identifies the maximum distance of a YouBike trip is 1891 m and this is used to set a buffer of 2 km from the centre of each MRT station as the catchment area to capture potential demand. This represents ~7 min riding a bike or ~ 25 min walking (Bernardi and Rupi, 2015). Although a bus service might be another alternative mode for this travel distance, this mode is not included in the analysis as the data source of the smart card only includes a 'tap on' for bus trips given the flat fare system. This limitation is discussed in Section 4.1.

4. Modeling approach

This section introduces the modeling approach and data used in the study. The modeling approach has two parts: passenger demand model and YouBike supply model.

4.1. Passenger demand model: Smart card data

Smart card data for MRT and YouBike for April to November 2018 was provided by the Department of Transportation, Taipei City Government. Smart card data for MRT include card number, entry/exit location and time, fee for the trip, and transfer trip. Smart card data for YouBike contain card number, rent/return station and time, fee for the trip and the bike identification. In this study, we use card number to join two dataset. We assume a particular user will use the same smart card to ride the MRT and borrow a YouBike.

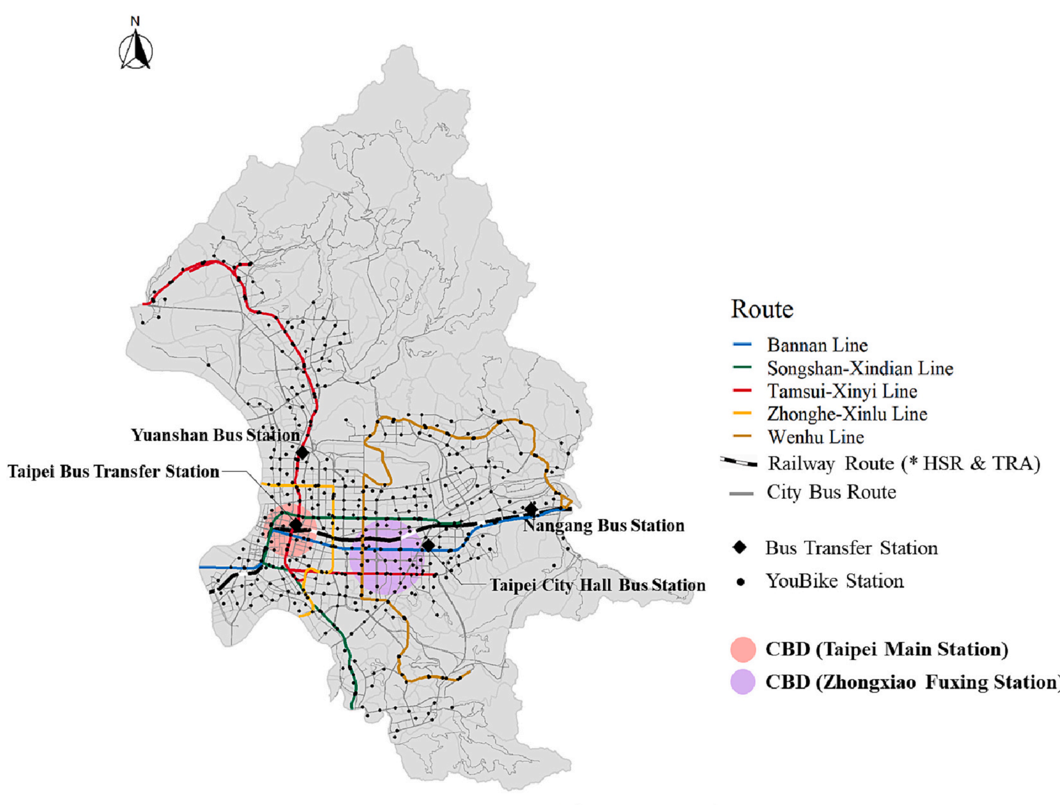


Fig. 1. Public Transport Network in Taipei City.

Taipei City has a series of transfer discount policies to encourage multimodal transport. One of the them is that if passengers transfer from MRT to YouBike within one hour, they can have a free ride for the first 30 min. As a result, we set the threshold as 1 h to define transfer trips. Transfer between MRT and YouBike is the key travel pattern that we investigate to understand how the bike sharing schemes can assist first and last mile travel. Transfer between YouBike and bus is not included in this study because in 2018 bus trips only have a single smart card record.

4.2. YouBike supply model: Time saving

The process to calculate the time saving is based on an adapted traditional PTAL with the output of accessibility index. Since the YouBike system does not have any service timetable and frequency, walkability is used to measure its accessibility.

To calculate the time saving, the following data is required: network topology, POIs, and stations (i.e., YouBike stations, MRT stations). Using Taiwan's Open Data platform (https://data.gov.tw/), 12 categories of POIs are selected for this study (2537 POIs in total): banks (28.3%), hotels (25.5%), schools (13.9%), hypermarkets (8.2%), post offices (6.2%), tourist attractions (5.8%), temples (4.3%), libraries (2.5%), department stores (2.1%), traditional markets (1.8%), hospitals (1.5%), and district office (0.5%). The distribution of POIs is shown in Fig. 2. Most POIs are located near the south-west which is one of the CBD areas (i.e., around Taipei Main Station).

This study finds the shortest distance to the nearest YouBike and MRT stations for each POI. The travel time of a walk-only trip (*time_walking*) is the shortest distance between the POI and stations divided by the walking speed, which is set as 4.8 km/h (Bohannon and Andrews, 2011; Fruin, 1971). The total travel time of a YouBike-involved trip (*time_YouBike*) can be split into three sections. The first section is the shortest distance from the POI to the nearest YouBike station, the second section is the shortest distance between the YouBike rent and return stations, and the third section is the shortest distance from the YouBike station to the MRT station. The speed of bike riding is set as 16.8 km/h (Bernardi and Rupi, 2015). Each section has a corresponding travel model, as shown in Fig. 3.

The travel time saving is defined as the difference in travel time between the walk-only trip and the YouBike-involved trip. However, this value alone is not enough to evaluate the accessibility. A POI which is extremely far from a MRT station often has a higher value on saving, that is, people can get substantial benefits in saving travel time, but the calculation cannot capture the "degree of improvement" in travel time. Hence, the "time saving percentage" is selected to represent the accessibility level from the supply side as follows:

$$savings = time_{walking} - time_{YouBike} \tag{1}$$

$$savings_{percentage(\%)} = \frac{savings}{time_{walking}} \tag{2}$$

This study uses travel time saving percentage to represent YouBike supply. Both walk and cycle trips are assumed to follow the shortest path but will nevertheless be subject to traffic influences (maybe different ones, such as road crossings for pedestrians and traffic lights for cyclists), a simplifying assumption is made that over the journey, the time impact of these on both modes is similar.

4.3. Zonal passenger YouBike demand and supply

The comparison analysis for Taipei City is conducted on the zonal unit of the village that is the second smallest residential zone. Each zone has around 150 people and no >450 people. The smallest residential zone, the Basic Statistical Area with <150 people, is too small for this analysis as some zones might not have any POIs and YouBike stations.

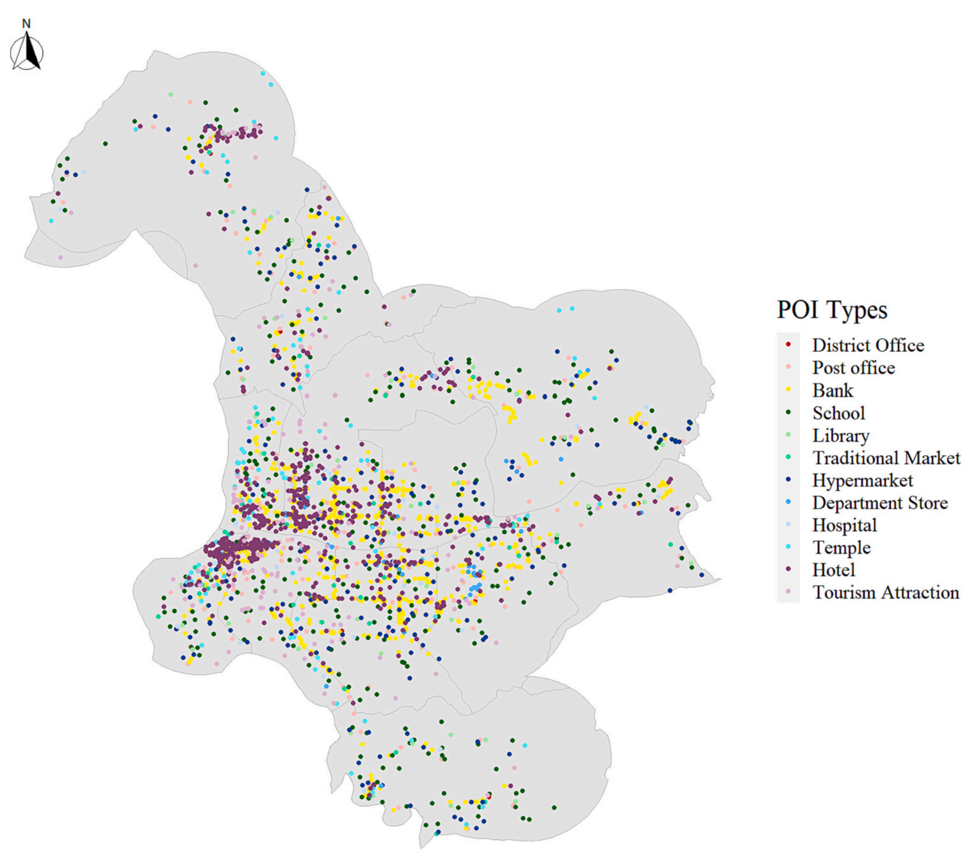


Fig. 2. POI Locations.

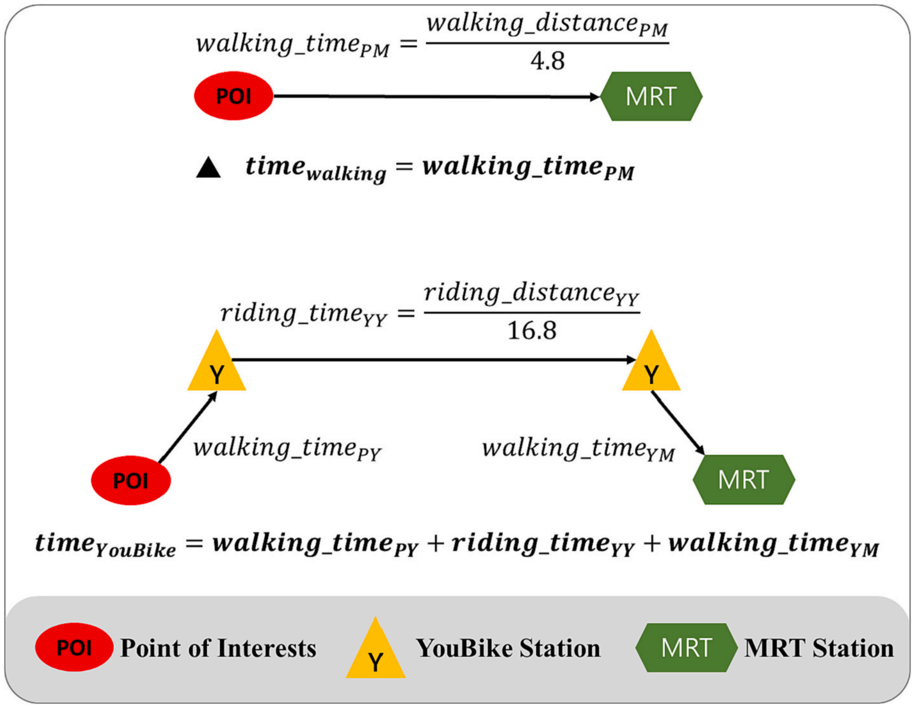


Fig. 3. Calculation of Walking and Bike Riding Time.

From the passenger demand analysis, we can directly identify passenger demand, proxied by YouBike transfer trips, from smart card data for each YouBike station. This is summed for all the YouBike stations within the same zone to represent zonal passenger demand. For YouBike supply, time savings for each POI are used. To aggregate to the zonal level, the average time saving percentage is calculated, and converted to an average time saving percentage for all POIs in the same zone.

$$Zonal\ passenger\ demand = \sum_{i=1}^{N} trips_i \tag{4-3}$$

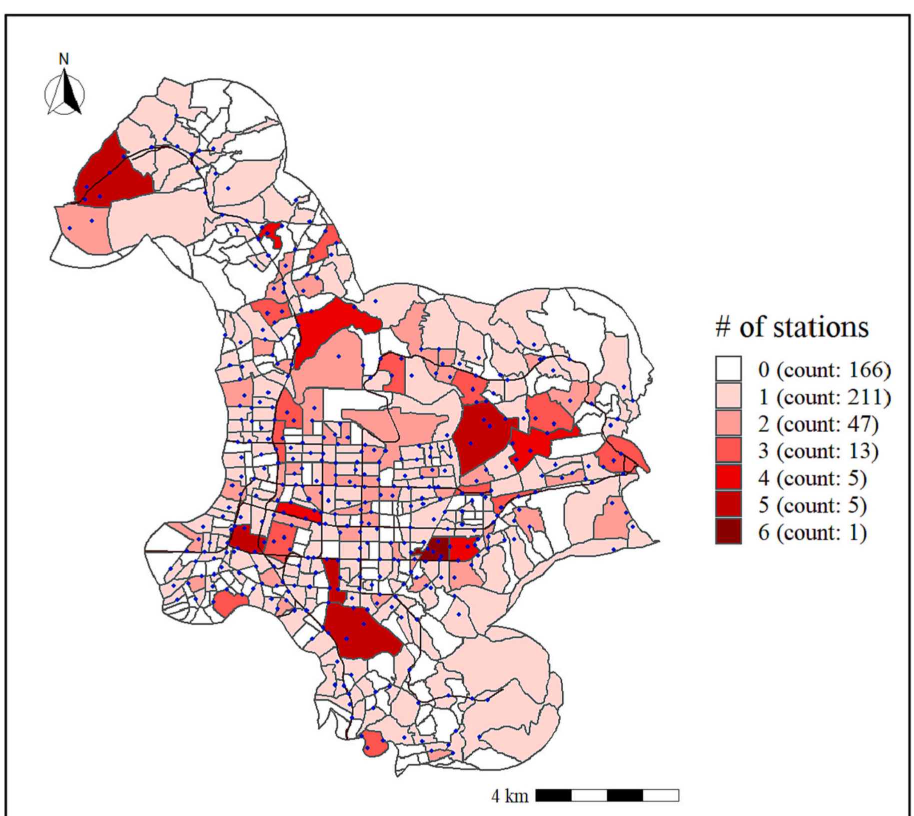


Fig. 4. Number of YouBike stations by village (448 zones).

$$Zonal\ YouBike\ supply\ (\%) = \frac{\sum_{i=1}^{N} savings_i}{\sum_{i=1}^{N} time_{walking_i}} \tag{4-4}$$

where N is the number of POIs in each village or zone.

5. Data acquisition

5.1. Demand from smart card data

To understand the distribution of YouBike infrastructure, counts of YouBike stations by zone are presented in Fig. 4, where a darker color means higher counts, with maximum count of 6 YouBike stations and a minimum of 0 by zone. In the study area of 448 villages, 282 (62.9%) have at least one YouBike station, while 166 (37.1%) have no YouBike stations. The area with most stations, 6 stations, is located near Taipei City Hall in Xinyi District, which is a major administration center and has multiple department stores. In addition, most of the villages with no YouBike station are located near the border of the study area, which is remote from the city center and some of the villages are in mountainous areas (e.g., north–east side of the study area) that are not suitable for cycling and thus have no YouBike stations. Villages without a YouBike station can use a YouBike station located in nearby villages.

Eight months (April to November 2018) of smart card data are available for Taipei City. This dataset only contains data for the three transport modes of MRT, bus and YouBike. The modal share of each public transport mode in the data is shown in Table 1 with the mode share in 2020 from the Department of Transportation is provided for comparison (last column in Table 1). Data from Department of Transportation is collected from all public transport fare collection systems, including the smart card system, paper tickets, credit cards and cash. Table 1 shows the smart card data is relatively representative. The data shows MRT is the major mode in Taipei City, while YouBike only accounts for <3%. The other major mode in Taipei City is bus, with 37.2% mode share. As mentioned earlier, the smart card data of bus only records information of either boarding or alighting. It is difficult to understand its relationship with YouBike and MRT data and so bus is excluded from this study, leaving the focus on the transfer between YouBike and MRT.

Of all YouBike trips, 26.8% are transfer trips between YouBike and MRT. Of these, 53.4% of the trips transfer from YouBike to MRT and 46.6% of the trips transfer from MRT to YouBike. The proportion of transfer trips for YouBike stations located within a 500-m buffer of each MRT station is illustrated in Fig. 5. The darker and larger the circle is, the higher the proportion of transfer trips. This conveys the importance of YouBike as the first and last mile transfer mode. It is interesting to note that higher demand for YouBike as a transfer mode is usually in the suburbs of Taipei City (e.g., Shilin District, Neihu District), with relative lower public transport supply compared to the city center.

5.2. Supply data of time saving percentage

For those areas where YouBike is not provided, the only mode that can be used for first and last mile transport is walking. Whilst driving private vehicles or riding personal bikes might be feasible as first and last mile modes, they are not commonly used. In Taipei City, driving a private vehicle generally encounters parking problems. Taipei City has only limited roadside parking spaces available and most of them are with extremely high parking fees (e.g., NT$ 150 per hour which is around USD 4.97 per hour). This parking fee should be compared with one zone bus fare of NT$15 (USD 0.5). In addition there is no park and ride infrastructure. Private bikes are rarely used as the YouBike system in Taiwan is provided by the well known manufacturer, Giant, and good quality bikes are part of the scheme and, as for the private bike, parking for private bike is also an issue in the city areas. For this reason, the only comparison made with the YouBike in this paper is walking.

To evaluate the importance of YouBike as a transfer mode, time savings are calculated for each origin and destination pair. If the time saving is positive, we assert that YouBike can assist first and last mile travel for this particular origin and destination pair. It should be pointed out that one of the origin or the destination must be a MRT station and the other end would be a POI. The time saving percentage can be derived for each village (Fig. 6). In Fig. 6, the red zones represent a positive time saving, while the greyscale zones represent a negative time saving. Most YouBike stations around the city center (e.g., Taipei Main Station) tend to have negative time saving, due to the very short travel distance between those stations and POIs (e.g., in some extreme cases, <10 m). A rational traveler would just walk for this kind of origin and destination pair, rather than using YouBike as a transfer mode. In contrast, if the distance between a particular MRT station and a POI is larger, the time saving tends to be positive and this confirms the importance of YouBike as a transfer mode.

The time saving percentage ranges from −556% to 68%. This is a very large range and the very large negative time saving percentage occurs only for specific trips when the YouBike is used for more than a simple first or last mile trip as defined by Fig. 3. It occurs, for example, when YouBike is used as a transfer mode to travel between POI and MRT stations. Those villages with less than −100% are viewed as outliers as this would indicate travel time is double when riding a YouBike as compared to walking. Besides, the median time saving percentage is 6.4%, meaning that more than half of the villages can save >6.4% travel time by using a YouBike to the nearest MRT station.

Table 1
Modal Share of Public Transport in Taipei City.

Mode	Smart card data		DoT
	Number of Transactions (April to November 2018)	Modal Share (April to November 2018)	Modal Share (2020)
Bus	283,570,684	35.7%	37.2%
MRT	491,726,680	62.0%	60.3%
YouBike	18,131,043	2.2%	2.5%

6. Analysis of YouBike demand and supply

6.1. Definition of analysis of YouBike demand and supply

Analysis is conducted to investigate the service gap between supply and demand of YouBike service by spatial area. As the YouBike supply (i.e., travel time saving percentage) for each village can be positive or negative, the analysis is separated for positive and negative time savings for clarity. Taking account of some villages without YouBike stations, defined as no YouBike (NY) gives three main groups for the analysis: positive time saving with YouBike Stations; positive time saving with no YouBike; and negative time saving. These are presented in Fig. 7. Of the 448 villages in the case study area, there are only 10 villages (2.2%) not included in the comparison analysis because they do not have any POIs.

6.1.1. Group 1: Positive time saving with YouBike stations

We first define the demand and supply at two levels (i.e., high and low) with the median value as the threshold. As a result, YouBike demand represented by transfer trips can be presented as high transfer or low transfer. The YouBike supply represented by travel time saving percentage can be presented as high saving or low saving. Thus, we can divide the villages with positive travel time saving into four groups:

1. High transfer trips (i.e., high demand) and high time saving percentage (i.e., high saving) (HTHS).
2. High transfer trips and low time saving percentage (HTLS).
3. Low transfer trips and low time saving percentage (LTLS).

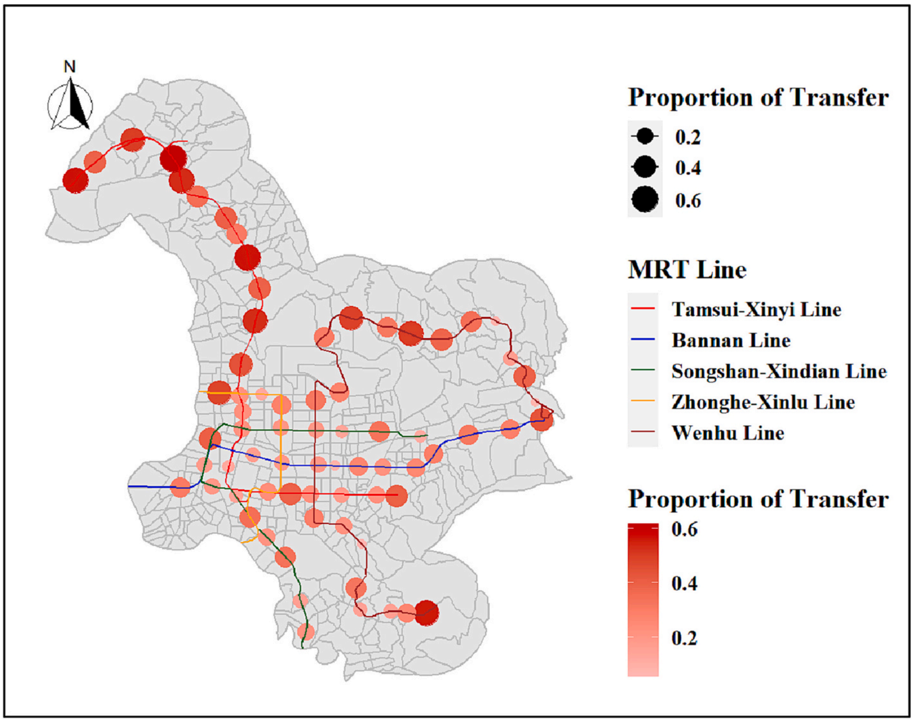


Fig. 5. Proportion of transfer trips.

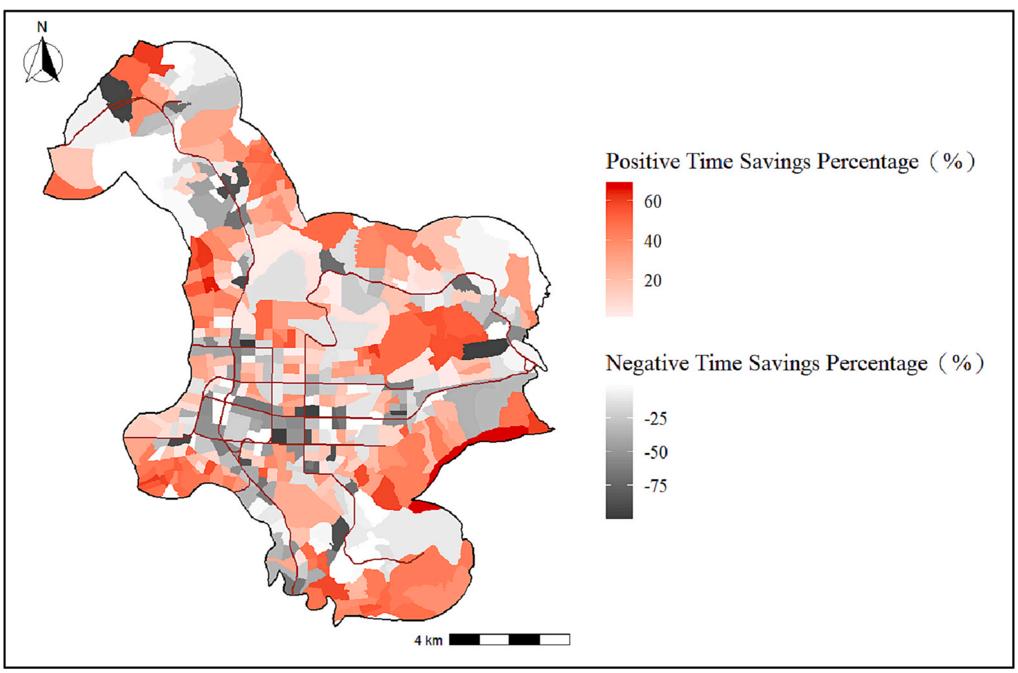


Fig. 6. Time savings (in percentage) of villages in Taipei City.

4. Low transfer trips and high time saving percentage (LTHS).

6.1.2. Group 2: Positive time saving with no YouBike stations

Several villages have no YouBike stations. Those villages still have POIs that can be serviced by the closest YouBike stations in other villages. Therefore, those village without YouBike can still have a time saving percentage that can be positive to be included in this group. We can then divide those villages into two groups:

1. No YouBike stations and high time saving percentage (NYHS).
2. No YouBike stations and low time saving percentage (NYLS).

6.1.3. Group 3: Negative time saving

Those villages with negative time saving (NS) are all categorized into this group.

In summary, all the villages in the study area are allocated to one of the three groups by the features of the transfer trip amount (demand model) and time saving percentage (supply model). Fig. 7 illustrates the

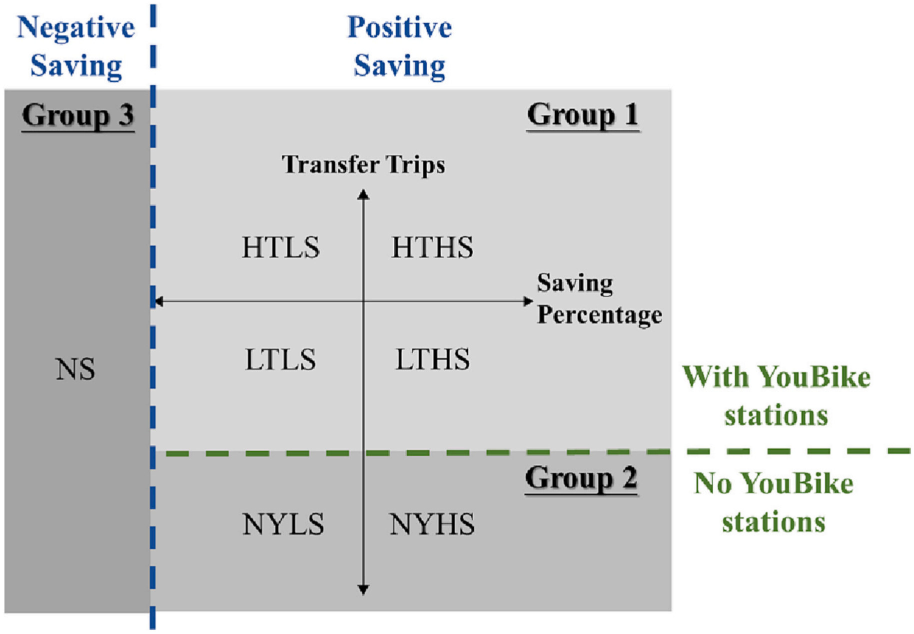


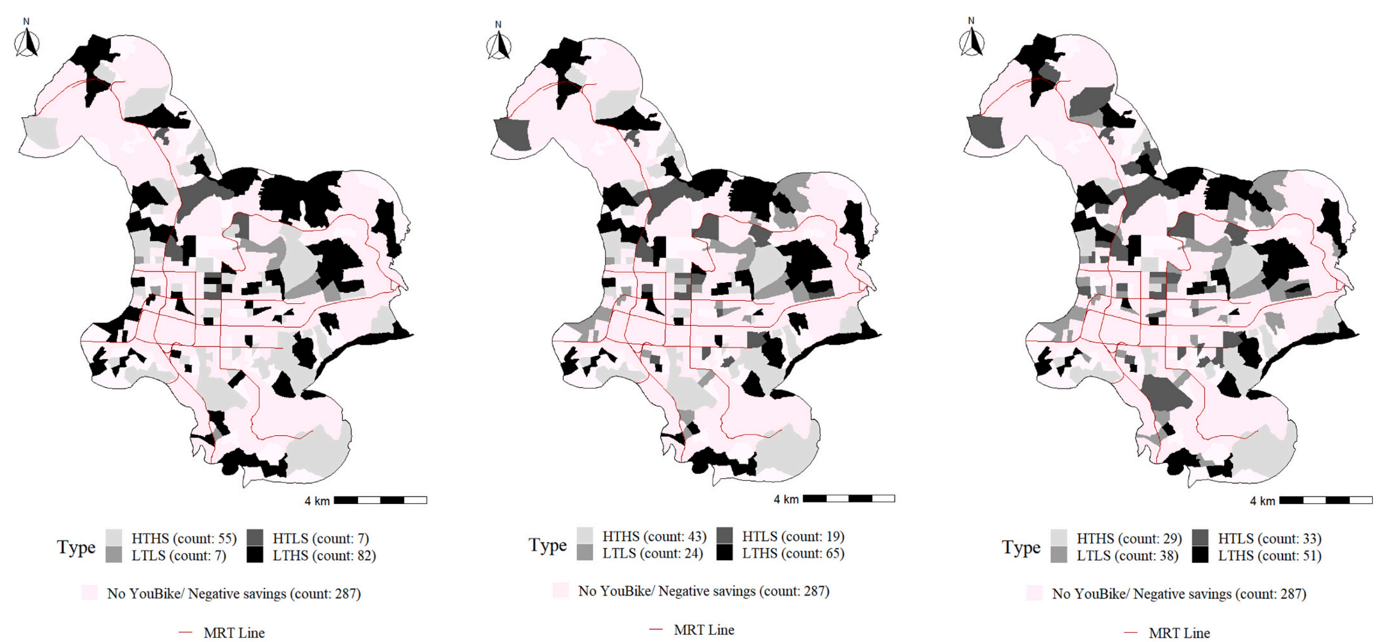
Fig. 7. Classification of villages by demand (total transfer trips) and supply (positive or negative time saving).

classification of the three groups.

6.2. Group 1: Areas with positive time saving with YouBike stations

For the villages in this group, we use median transfer trip, which is 66 trips daily, to classify YouBike demand. A particular village with transfer trips higher than the median value is defined as “High transfer”, and “Low transfer” for the rest. For Youbike supply, there is no standard service level in terms of time saving percentage. Therefore, three thresholds of time saving percentage are chosen, the 10th, 30th and 50th percentiles, which are 6.04%, 19.78% and 30.69%, respectively. For a particular village, if the time saving percentage is higher than the threshold, it is defined as “High time saving percentage”, and “Low time saving percentage” otherwise. With clear defined categories, we can compare YouBike demand and supply by zone. The comparison results are shown in Fig. 8. All villages in Group 2 (i.e., positive time saving with no YouBike Stations) and Group 3 (i.e., negative time saving) are marked in pink in Fig. 8. Further analysis for these two groups is shown in later sections. Fig. 8 has four categories: HTHS (pale gray); LTLS (gray); HTLS (mid gray); and LTHS (black). The darker areas are where there is a mismatch of supply and demand of YouBike service.

As expected, when the time saving percentage increases, the number of LTHS villages decreases, as well as for HTHS. In contrast, the number of LTLS and HTLS villages is increased. The policy implications of this are addressed in the next section where each of the different categories is examined in more detail (Section 7 Discussion).



(a) 10th percentile of time saving percentage (b) 30th percentile of time saving percentage (c) 50th percentile of time saving percentage

Fig. 8. Zones (villages) with YouBike stations with positive time saving.

6.3. Group 2: Areas with positive time saving with no YouBike stations

Some villages have no YouBike stations, but have a positive time saving. POIs in those villages without YouBike can be served by the closest YouBike stations in other villages. In the study area, some villages are very small, especially around the CBDs and users can easily access a YouBike service from other villages. The villages here can also be divided into two categories in terms of time saving percentages (i.e., high and low saving). As with Group 1, the 10th, 30th and 50th percentiles of time saving percentage are used for the comparison and the results are shown in Fig. 9 which only marks villages in Group 2, while others (i.e., villages in groups 1 and 3) are marked in white. Each map has two categories: NYHS (lighter color) and NYLS (darker color). As expected, when the time saving percentage increases, the number of villages of NYHS decreases, while the number of villages of NYLS increases. The darker-shaded villages have lower service from the existing YouBike network in terms of time saving percentages. Villages with high saving can receive relatively good service from the existing YouBike infrastructure, implying these villages might not have an urgent need to build YouBike infrastructure. The policy implications of this are addressed in the next section (Section 7 Discussion).

6.4. Group 3: Areas with negative time saving

Villages of positive time saving are all categorized in groups 1 and 2 (marked in white in Fig. 10), with the villages with negative time saving being shown in Fig. 10 (marked in red in Fig. 10). To understand the role of YouBike as the first and last mile travel mode, this study focuses on the positive time saving analysis. However, for the negative time saving villages, we report average walking time for each village where walking time is categorized into three groups: ≤5, 5– 10, >10 min. The result is shown in Fig. 10. If the walking time is large, the color of the village is darker. The darkest area represents the lowest service in terms of YouBike supply, implying people cannot save time by using YouBike and walking would be a better alternative in those areas.

7. Discussion

To explore transfer behaviour by YouBike, this paper categorized villages into three groups. Transfer behaviour has been used as a proxy for first and last mile accessibility. Thus, the focus of this section is on positive time saving (i.e., Group 1 and Group 2 villages) since negative time saving might not be rational behaviour. The policy implications are discussed for each group of villages as follows.

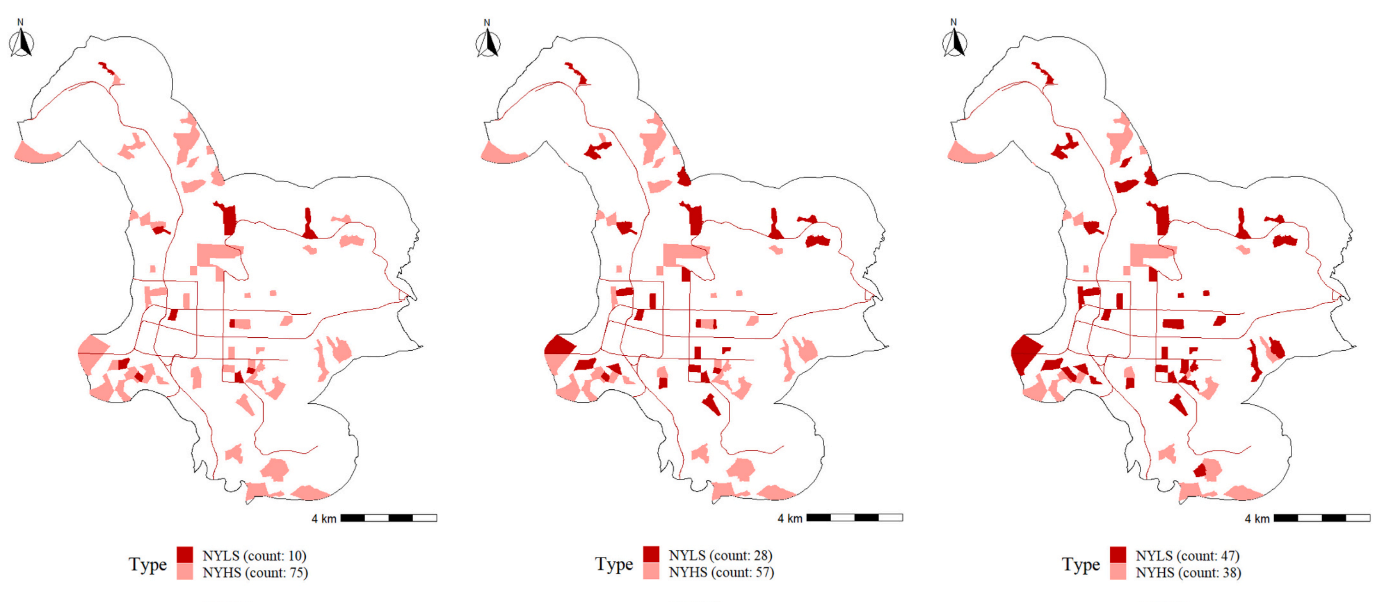
7.1. Group 1: Areas with positive time saving with YouBike stations

7.1.1. High transfer trips and high time saving percentage (HTHS)

HTHS indicates a perfect match between demand and supply for a village. Fig. 11 shows the distribution of HTHS villages (pale gray) under different time saving percentage thresholds. From the users' point of view (i.e., demand), they use YouBike to transfer from and/or to MRT stations to fulfill their first and last mile travel needs. Based on YouBike supply, most POIs in this area are not close to MRT stations with average walking time between POIs to MRT stations of 12 min. In general, for the 50th percentile of time saving percentage, users can save up 5 min on average compared with walking. As a result, HTHS villages meet the original policy goals of Taipei City Givernment in 2017 that set YouBike as a transfer mode to service first and last mile travel needs (Chung and Li, 2018). HTHS villages tend to be located further away from the CBD. As a result, the distance to the MRT stations is naturally longer. It is interesting to find that HTHS villages tend not to be commercial use areas, but most of them have residential, educational and mixed land use which might have larger regular demand (e.g., commuting or schooling). For those villages, sustainable transport planning should be implemented in the future to facilitate the integration of the public transport system, bike sharing schemes, and mixed land use to meet growing demand.

7.1.2. Low transfer trips and low time saving percentage (LTLS)

LTLS is the group with lower YouBike use, and this implies that the YouBike system has limited ability to improve the accessibility between MRT stations and POIs. Fig. 12 shows the distribution of LTLS villages (gray) under different time saving percentage thresholds. For example, the 50th percentile is equivalent to 2.7 min saving if using YouBike. Further, in the 50th percentile map, LTLS areas tend to be located along or near MRT stations. This implies that for POIs located close to MRT stations, walking tends to be a more convenient mode and a rational



(a) 10th percentile of time saving percentage (b) 30th percentile of time saving percentage (c) 50th percentile of time saving percentage

Fig. 9. Zones (villages) with no YouBike stations with positive time saving.

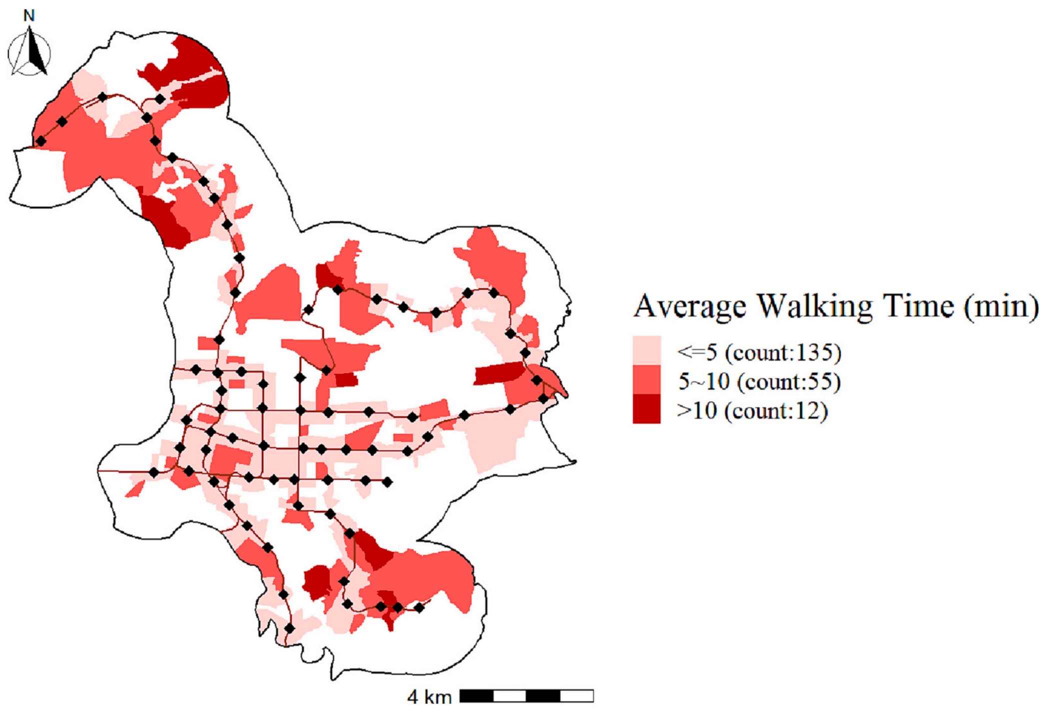


Fig. 10. Walking time for negative time saving villages.

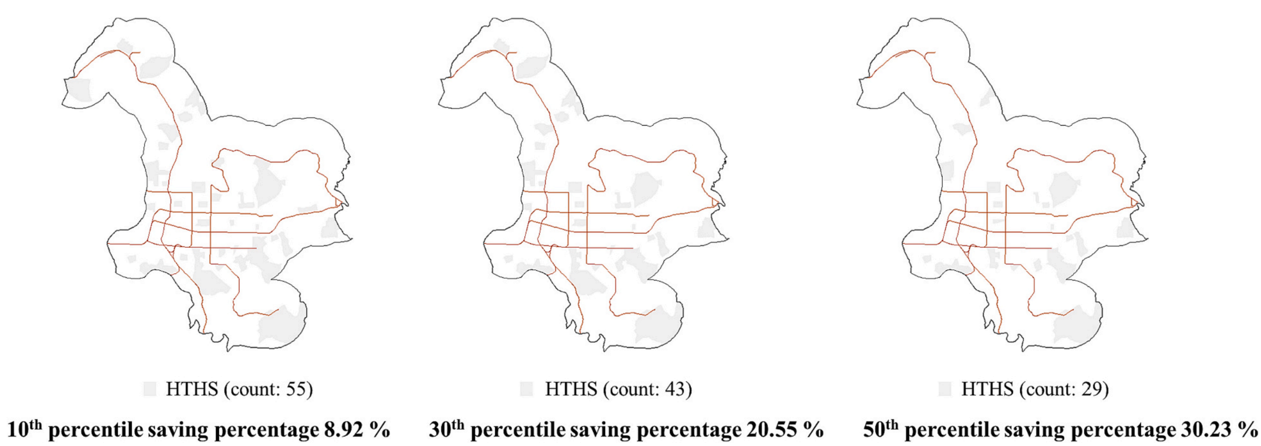


Fig. 11. HTHS areas under different time saving thresholds.

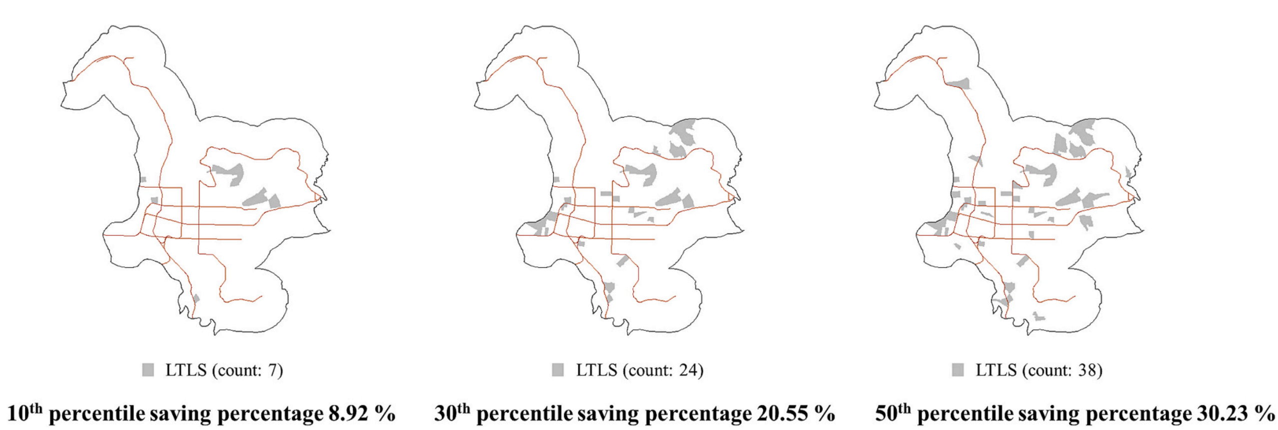


Fig. 12. LTLS areas under different time saving thresholds.

traveler would be unwilling to use YouBike. In those villages the YouBike facilities can be promoted as a sustainable transport mode for short distance travel rather than as a transfer mode for MRT. Further and more importantly, it is recommended pedestrian facilities in those villages are improved to provide high quality and safer service to pedestrians.

7.1.3. High transfer trips and low time saving percentage (HTLS)

HTLS is one of the types where there is mismatch between demand and supply (i.e., HTLS and LTHS). Fig. 13 shows the distribution of HTLS villages (mid gray) under different time saving percentage thresholds. The YouBike demand in those areas is very strong but using YouBike only saves a little bit more time compared to walking. This might be due to two reasons. First, users view YouBike as a faster mode without realizing that walking is actually similar in time. Second, users might be aware travel times are roughly the same for the two modes but still prefer YouBike because it can provide a more comfortable travel experience (e.g., transporting luggage). Taking the 50th percentile as an example, two villages (i.e., Wenhua Village and Xuefu Village; marked in Fig. 13) have a very large number of YouBike transfers. Those two villages happen to have several universities and famous shopping streets. Students tend to travel with heavy back packs and shoppers tend to have bags. During the time of the analysis there was a policy of a free ride within 30 min for the transfer trip and this policy might promote this transfer behaviour since users tend to use YouBike for a very short time. As a result, a large number of transfer trips are observed in those villages. It is interesting to see that users in those villages stick to YouBike. For a low time saving percentage threshold, excess travel behaviour can be observed.

HTLS occurs in the places where POIs and MRT stations are close to each other, and YouBike stations are located near most of the POIs. This distribution of facilities makes it convenient for users to use YouBike. For those areas, two potential improvements are recommended. First, provide better pedestrian facilities and perhaps separate the bike riding and walking zones. This might reduce excess travel behaviour by increasing the walking mode share. Second, implement more YouBike stations to provide better accessibility between POIs and YouBike stations to improve the time saving and to accommodate such high transfer demand.

7.1.4. Low transfer trips and high time saving percentage (LTHS)

Another service gap can be found for LTHS areas which are the most concern among the four positive time saving categories (i.e., HTHS, LTLS, HTLS, LTHS). Fig. 14 shows the distribution of LTHS villages (black) under different time saving percentage thresholds. LTHS areas do provide good YouBike service for first and last mile travel; but users are less likely to use this service. This could be explained by two reasons. First, there are a few mountains on the fringe of Taipei City (e.g., Jinmian mountain, Hu mountain, marked in Fig. 14) and many LTHS areas are located there. Using a YouBike around here would mean users need to make more effort and this may reduce the desire to use YouBike. As a result, even though using YouBike can save more time, users still prefer to walk or use other modes (e.g., bus) as the transfer mode. Second, there are not many economic and/or tourist attractions in LTHS areas, and hence, there are fewer POIs.

Therefore, LFHS areas can be classified as being oversupplied with YouBike services. There are two recommendations to remedy this situation. First, from the supply side, the YouBike system should be upgraded to electric bikes to improve users' experience and reduce physical exertion. Second, from the demand side, policy makers could create more local trip attractions (POIs), and thus increase the demand.

Fig. 14 shows the distribution of LTHS areas under different time saving percentage thresholds. As the threshold increases, many areas around the CBD are no longer categorized as LTHS, but areas near the border remain in this category suggesting peripheral areas have a significant over supply of YouBike.

7.1.5. Comparison among Group 1 (HTHS, LTLS, HTLS, LTHS)

The most desirable scenario is HTHS in which YouBike plays a key role to assist first and last mile service. With the 50th percentile time saving percentage, 31.1% of YouBike stations within villages with positive time savings are HTHS. Within Taipei City, those YouBike stations provide good first and last mail service and meet Taipei City's planning goal. However, there are two types of mismatched areas: HTLS areas, which are mainly due to mode choice stickiness, and LTHS areas, which are mainly due to topographic constraints. LTLS is the worst situation, implying that both demand and supply are very low. For LTLS areas, it is recommended planners review the regional plan to redefine the role of YouBike, for example, from providing transfer services to be another public transport mode to assist sustainable transport. As currently structured the YouBike may not be an ideal public transport mode in these LTLS villages.

7.2. Group 2: Areas with positive time saving with no YouBike stations

7.2.1. No YouBike stations and high time saving percentage (NYHS)

Villages with no YouBike service might be able to access YouBike located in other villages. NYHS areas are usually located around the CBD, and villages in those areas tend to be very small. This implies that NYHS areas can receive relative good quality of YouBike service with the current infrastructure and network. As a result, there is no urgent need to set up new stations in NYHS areas. Instead policy makers should focus on promoting existing facilities by, for example, setting up a clear way and wayfinding instructions for users.

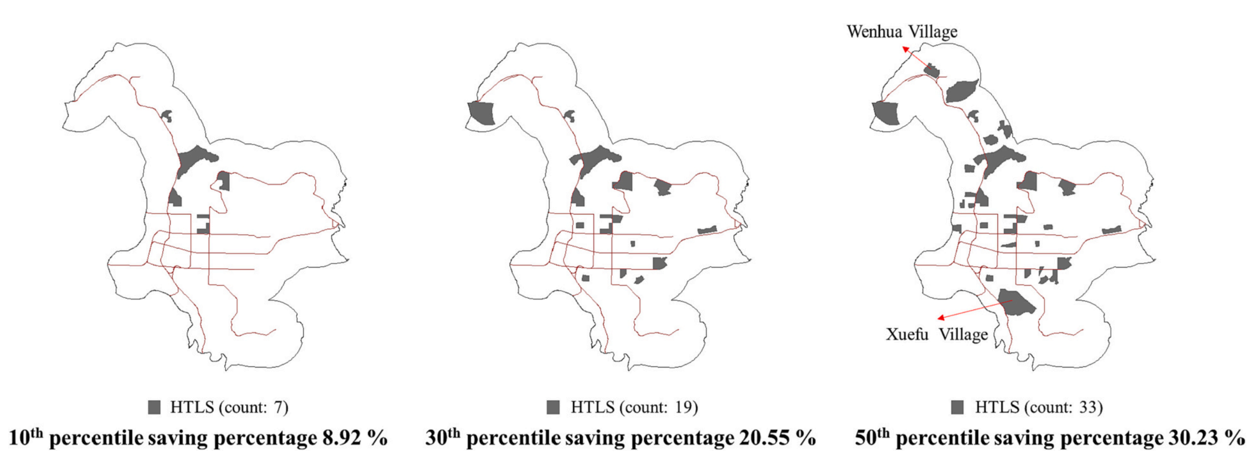


Fig. 13. HTLS areas under different time saving thresholds.

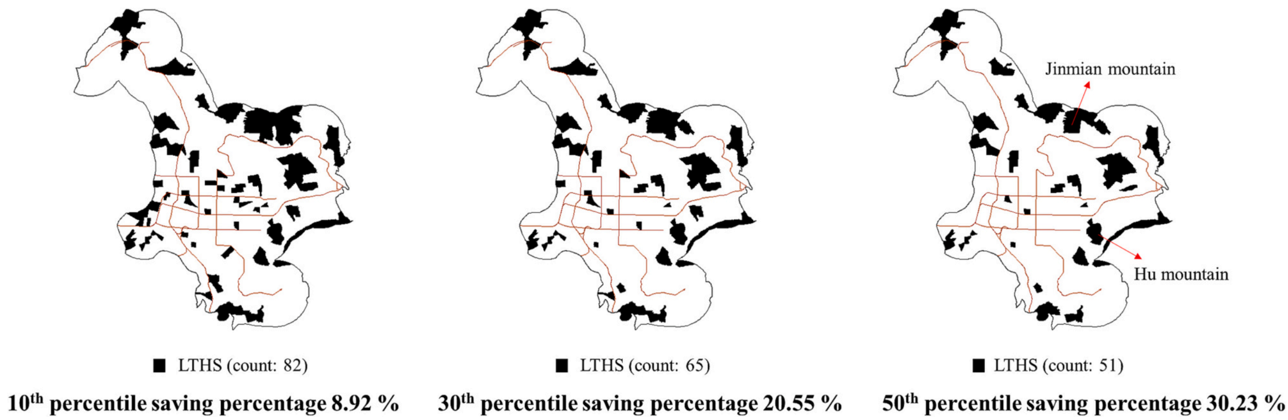


Fig. 14. LTHS areas under different time saving thresholds.

7.2.2. No YouBike stations and low time saving percentage (NYLS)

NYLS implies that those areas have no YouBike station, and they cannot easily access YouBike services from nearby villages to save time. "Walking" and "using YouBike in other villages" are competitive with each other, with approximately the same travel times. NYLS areas are usually located near MRT stations compared to NYHS areas, but are still a bit far away from MRT stations. In theory, setting up a YouBike station might be able to improve first and last mile service.

7.2.3. Comparison between Group 2 (NYHS and NYLS)

NYHS and NYLS areas both include villages which have no YouBike station. NYHS areas nevertheless receive a good quality service with the current infrastructure. This indicates that before implementing a new YouBike station, it is important to match the demand based on potential POIs to the current service network. For NYLS areas, this analysis suggests an urgent need to set up YouBike stations.

8. Conclusions

This paper investigates a public bike sharing service by an analysis of demand and supply at a detailed spatial scale of villages within Taipei City. Demand is proxied by the number of transfers between YouBike and MRT derived from smart card data, while supply is the time saving percentage derived by the difference between walking time and riding time of YouBike to/from a particular POI. On the supply side, villages can be classified as having positive time savings (riding time is shorter than walking time) or negative time savings (riding time is longer than walking time). Villages with positive time saving are classified into six categories: HTHS, LTLS, HTLS, LTHS, NYHS, and NYLS. For direct match villages (i.e., HTHS and LTLS), HTHS should not be an issue but LTLS villages should have some review process to investigate the reason for both low demand and low supply. Special attention should pay to those villages with mismatch of demand and supply (i.e., HTLS and LTHS). As to no YouBike villages, priority planning for YouBike could provide for NYLS villages to improve accessibility.

This paper must acknowledge some limitations which point to future research needs. The results of this study could be improved by considering the types and importance of POIs. For example, banks and hotels account over 50% of the defined POIs for the study area of Taipei City (Ministry of Digital Affairs, 2023) and this suggests possible over-representation. Besides, this study considers all POIs as equal. In future research it would be worth exploring the influence of POI types and use this to give appropriate weights to YouBike demand or supply. In addition, the paper discusses the issue of positive time savings and not the cases where most POIs are located very close to MRT stations (giving rise to negative time savings). The median walking time between MRT stations to POIs in positive time saving areas is 8.1 in contrast to 3.9 min in negative time saving areas. Rational users should not transfer by YouBike in negative time saving areas, where the median walking distance is approximately 300 m. There is a need to review the services for those areas and redefine the role of YouBike and to understand better the transfer characteristics of users in these areas. Related to this, the classification of the groups has been made first on whether or not the trip is a transfer to MRT trip or not and then on the basis of time savings. Future research could a more analytical approach to segmenting the sample, such as the use of cluster analysis. This paper uses public transport smart card data to represent YouBike demand without considering trip characteristics (e.g., smart card type is student card, elderly card or adult card) due to data limitations. If trip characteristics could be identified, more detailed analysis by socioeconomic group could be undertaken to target different segments (e.g., elderly people). This could allow, for example, hot spot areas for elderly people to be identified which would allow planners to plan barrier free facilities for those areas. Finally, as the analysis is conducted from a spatial perspective it has not taken account of temporal-spatial patterns for YouBike demand and supply which may provide useful insights in further analysis.

Declaration of Competing Interest

None.

Data availability

The data that has been used is confidential.

Acknowledgements

This study was partially sponsored by the National Science and Technology Council, ROC, under contract number 111-2223-*E*-A49 -002 -MY3 and 109-2221-E-009 -047 -MY3.

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