Spatial Patterns of First- and Last-Mile Accessibility: Identifying Bike-sharing Potential around Train Stations in Melbourne

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Abstract. Based on the Active Accessibility Framework proposed by Vale et al. (2016), this thesis proposes a novel framework that combines isochrone analysis, cluster analysis and fine-scale spatial identification to systematically examine active transport (walking and cycling) accessibility around train stations in Greater Melbourne, and further explores the potential role of bike-sharing in improving FLM connection. The research found that although cycling can expand the potential service area of the stations, this potential accessibility does not automatically translate into actual travel behavior. The findings provide new spatial insights and planning implications for integrating bike-sharing with public transport and planning strategies in place today to improve Greater Melbourne's accessibility.

Keywords: First/last mile accessibility, bike-sharing, micromobility, transit-oriented development, active transport, transport planning, Melbourne.

1. Introduction

The rapid expansion of cities and the continuous growth of their populations have led to increasing pressure on urban transportation systems, with traffic congestion and greenhouse gas emissions being particularly prominent issues [1]. In response to these challenges, people have begun to reflect on traditional planning approaches. Traditional transportation planning is usually based on two assumptions: people's travel demands arise from the need to participate in activities, and individuals always tend to minimize travel costs [2]. This has resulted in a focus on building faster roads and using speed to overcome longer distance [3]. However, this efficiency-oriented approach fails to fully consider the accessibility at the micro level. As a result, the appeal of local public transportation and active transportation has been weakened, while people's reliance on private cars has continued to increase [4, 5, 6]. For this reason, sustainable transportation has begun to emerge as an alternative path. It emphasizes the integration of land use and transport systems to reduce car dependence and enhance urban resilience [2]. Within this context, transit-oriented development (TOD) is widely regarded as a key strategy for promoting sustainable mobility and compact urban form, and has been implemented across cities in the United States, Europe, Asia, and Australia [7]. It aims to create a compact, walkable, and transit cantered urban spatial structure through the coordinated integration of land use, transport systems, and urban design [7, 8].

TOD focuses on the connection and integration among various modes of transportation. In principle, this should increase the share of green transport, including all public transport service and active transport modes (e.g. walking and cycling) [7]. However, its effectiveness remains contested, particularly in terms of whether it has actually shifted travel behavior toward these modes [9, 10]. Beyond network coverage and station connectivity, a key but often overlooked barrier is accessibility to and from stations [11, 12]. Many public transport passengers still rely on other means of transport to connect their origin/destination and stops - a process known as first/last mile (FLM) travel [11]. These approaches include shuttle services, private vehicles, and also the increasingly popular shared micro-mobility options such as shared bikes [11]. Existing research has pointed out that the compensation distance significantly affects people's travel choices. Most passengers will walk to the station, but once the walking distance exceeds 400-800 meters, the usage rate of public transportation will drop sharply [11]. This indicates that without effective non-motorized transportation connections (FLM), the TOD model will have difficulty fully achieving the goal of promoting green travel.

Among various non-motorized travel options, shared bikes are one of the most widely discussed solutions by both academics and practitioners, and are often used to bridge the aforementioned gap. As an active mode of transportation, cycling can expand the service radius of the station to 3-5 kilometers [13]. Compared with large-scale infrastructure construction, shared bikes have lower costs, greater flexibility, and a shorter implementation period, making them more feasible. International experience shows that shared bikes have significantly improved public transportation accessibility and reduced short-distance private car travel in many major cities, becoming an important strategy to address non-motorized transportation challenges [14]. Therefore, this study aims to analyze the FLM accessibility gap around transport stations and explore the role of bike-sharing in improving FLM connections.

1.1 Greater Melbourne Context

Greater Melbourne, the capital of Victoria, has a population of over 5 million [15]. Facing the pressure brought about by rapid urbanization, the Department of Transport and Planning [16] emphasized the principle of Transit-Oriented Development (TOD), particularly advocating for the formation of a multi-center structure along railway corridors and making railway stations key development nodes. The "20-minute community" policy proposed by this department [17] aims to concentrate development around railway corridors, so that most daily needs can be met within walking distance. However, most existing policies and studies mainly focus on the connectivity at the network level and land use integration, and do not pay enough attention to accessibility at the micro scale and non-motorized vehicle connections [16]. This deficiency is also reflected in residents' travel behaviors: from 2006 to 2021, the number of train passengers decreased by over 60,000, and the usage of buses and trams also declined; the proportion of walking and cycling in total travel trips was less than 5%, and it was on a downward trend [15]; private cars still accounted for over 46.5% of commuting trips [15]. These data illustrate a core contradiction: although Melbourne has designated over 120 station areas as activity centers and strengthened railway corridors as strategic growth areas [16], residents' daily travel still heavily relies on cars.

There are multiple structural factors behind this contradiction. Although active transportation facilities in Melbourne are gradually expanding, the routes leading to the railway station often involve detours and poor connections [18], and the intersections of main roads and railway lines thus frequently limit the potential of walking as the primary mode of transportation. At the same time, micro-mobility services such as shared bikes help expand the accessibility around the railway station. However, they are mainly concentrated in the city center and serve short trips, and are not well integrated into the TOD framework [19]. As a result, train stations as core TOD nodes still face significant FLM accessibility gaps. This weakens the attractiveness of public transport and limits TOD’s ability to reduce car dependence and support equitable mobility.

2. Problem Statement, Aim & Novelty

The disparity observed between planned goals and actual travel behavior in the Greater Melbourne indicates a major issue: the lack of a systematic understanding of the factors influencing FLM accessibility, and the limited research on the role of shared mobility in bridging these gaps in this context. Recent studies have proposed the Active Accessibility Framework developed by Vale et al. [20], which emphasizes the combined role of transport systems and activity opportunities in shaping accessibility (further details are in section 4.1.2). However, the existing research still lacks an analytical framework that can systematically integrate the accessibility gap of FLM and the mechanism of bike-sharing. Therefore, based on this framework, this study aims to develop a novel integrated framework to identify and assess the walking and cycling gaps in FLM accessibility around train stations, and further explore the role of bike-sharing in bridging these gaps, taking the Greater Melbourne as a case study.

The study novelty, therefore, lies in the development of an integrated analytical framework that combines spatial, infrastructural, and behavioral dimensions based on indicators identified in previous studies. This framework provides a new perspective for understanding the interaction between active and public transport and the purpose of using land-based planning for sustainable urban mobility in Melbourne.

3. Research Questions

How does a novel assessment framework for bike-sharing potential improve the FLM accessibility at Greater Melbourne's train stations?

To address this main question, two sub-questions are formulated:

(1) What are the spatial and infrastructural FLM accessibility gaps in walking and cycling at Greater Melbourne's train stations as TOD nodes?

(2) How is bike-sharing potential identified, considering the urban context and infrastructure conditions of the FLM accessibility at Greater Melbourne's train stations?

4. Literature Review

4.1 FLM Conceptualization

The "first and last mile" (Figure 1) refers to the initial and final links in a public transport journey — the trip from one's origin to the nearest station (first mile), and from the alighting station to the final destination (last mile) [21, 22]. Although it does not carry the main transport function, it acts as a critical interface linking homes, workplaces, and the public transport system. Its accessibility shapes perceptions of convenience and strongly influences the decision to use public transport [23]. Once the connection between the railway lines and stations fails, no matter how well the railway system is designed, its transportation capacity potential will still be difficult to fully utilize [24]. The goals such as reducing reliance on cars and promoting compact development, which are part of the TOD (Transit-Oriented Development) approach, will naturally be hard to truly implement [21, 24].

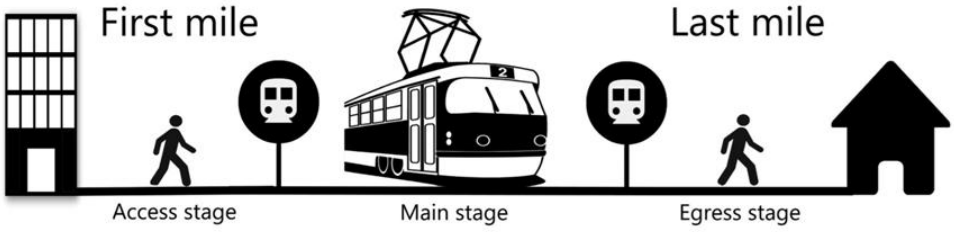


Figure 1. Access–Main–Egress Stages by Fahim & Minami, 2025, p.3.

4.1.1 Distance-based Accessibility

In the early studies of FLM (light rail system), this concept was mostly defined based on distance accessibility, viewing the FLM problem as an obstacle caused by stations not being within the public transportation service area [25, 26]. The longer the walking distance, the lower the possibility of using transportation [25]. A study of Calgary's light rail users showed that there were significant differences in walking distances across different urban areas. The average distance in the suburbs was approximately 649 meters, while in the city center it was 326 meters [26]. The station coverage range is not a fixed threshold and varies with the specific urban environment. El-Geneidy et al. [27] criticized the commonly used fixed buffer zone approach (400 meters for public transportation and 800 meters for rail transit), as most trips were within 300 to 800 meters, and many users still preferred to walk more than 1 kilometer [27]. These findings challenge the assumption that a unified standard is needed for station coverage. They indicate that using fixed distance thresholds may overlook variation in individual behavior, travel pattern and built environmental conditions [27].

4.1.2 Active Accessibility Framework

In fact, when analyzing the accessibility of transport stations, the primary consideration is to minimize the time and distance costs of walking journeys [26, 27]. However, the overall effective service area of station depends not only on its distance related to the origins and destinations, but also the characteristics of the surrounding built environment [20, 29]. Vale et al. [20] develop the active accessibility framework, which provides a theoretical basis for understanding how the built environment shapes individual travel behavior and, in turn, influences FLM accessibility to public transport.

This framework (Figure 2) shows that travel patterns have impact due to the socio-cultural factors along with the changes from the physical environmental characteristics [20, 30]. The built environment characteristic that influences commuters' travel behavior can be divided into explicit factors and implicit factors. The former includes travel distance [31, 20], street connectivity [32, 29], and network accessibility [29, 33] that can directly show that an individual can reach the station through active transport. The latter can have an influence by changing the travel demand and destination patterns, including the demographic pattern and land use structure [20, 34]. These two types are closely intertwined in actual travel behavior. Good network conditions can enhance the FLM connectivity of the site, but whether this effect can be achieved also depends on whether the travel demand is sufficient [20].

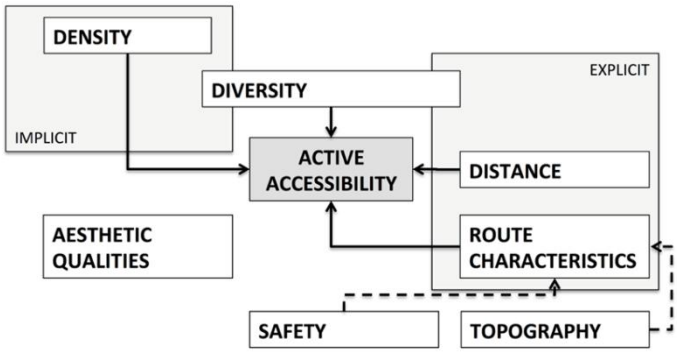


Figure 2. Active Accessibility Framework by Vale et al., 2016. p. 731.

4.1.3 Explicit Factors of FLM Accessibility

After the fixed buffer zone approach was criticized, network-based accessibility has gradually been regarded as a more interpretable indicator - it can incorporate spatial resistance and actual routes in the street network [34, 29, 35]. Commonly used ratios, namely the ratio of network distance to straight-line distance [36, 39]. The higher the ratio, the more circuitous the route, the commuting time and perceived distance are prolonged, and the FLM accessibility decreases accordingly [21]. Zhao et al.'s [36] study on Beijing's subway provides an example: for every increase of one unit in the detour rate, the possibility of walking significantly decreases, and commuters are particularly affected. In other words, an improvement in the geometric efficiency of the street network can expand the effective coverage area of the station without changing the straight-line distance [35, 36].

Route characteristics are also key in evaluating FLM accessibility, though standardized measures have not yet been established in the literature. A high connectivity of the street network will lead to more routes, shorter distances, and increased station accessibility [37, 38]. Therefore, most studies use intersection density to quantify street network connectivity [37, 39, 40]. Empirical results show that the density of intersections is significantly positively correlated with the proportion of active travel. Within a 500m or 1km buffer zone of a station, a higher intersection density is associated with a higher proportion of utilitarian walking [40, 41].

Furthermore, some studies incorporate path safety and continuity into the FLM analysis framework. Route interruptions, major road crossings, and discontinuous infrastructure increase perceived barriers, even over short distances [42]. Zhao et al. [36] further pointed out that in areas without bike lanes, the probability of arriving at the station within 1 kilometer by bike was

significantly lower than in areas with more complete facilities. This indicates that, in addition to spatial distance, people's perception of route safety, comfort, and continuity also play a role in determining whether they are willing to walk or cycle to the bus stop [36]. These qualitative factors are of great significance in active travel research, but have received relatively little attention in FLM studies.

4.1.4 Implicit Factors of FLM Accessibility

Density and diversity do not directly determine the accessibility of FLM (urban core area), but rather indirectly influence it through travel demand and destination distribution. The higher the population and employment density, the higher the potential travel concentration; the more diverse the land use, the more dispersed the travel purposes, and shorter-distance multimodal transportation trips between stations are more likely to occur [20, 34]. In the context of TOD, high-density areas have more convenient transfers and higher public transportation efficiency; while low-density suburban expansion weakens the competitiveness of public transportation [43, 20].

However, Sharifiasl et al. [44] propose another perspective to explore the relationship between FLM and density. Their research findings indicate that the connection pattern found between FLM and density can help in determining the spatial distribution of employment. Regions that rely on public transport connections can support higher population, while vehicle-based FLM connections allow more decentralized employment patterns [44]. This implies that in TOD that prioritizes compactness FLM should not be seen as a passive consequence of existing density patterns, but as a key mechanism to stimulate activity along the railway and alleviate dependence on private cars [44].

The diversity of land use is conducive to the mixed layout of residential, employment and consumption activities within the same area, thereby increasing the probability of using public transportation [45, 46]. The DMA framework argues that diversity is not just the presence of multiple functions, but their integration within an accessible range, enabling walking and transit use [47]. However, this impact varies depending on the specific circumstances. Railway accessibility is usually more conducive to the concentration of finance, real estate and service industries, especially when financial services (FLM) still rely on car travel; in contrast, bus accessibility has a more extensive and widespread impact on employment distribution [44].

Meanwhile, Kamruzzaman et al. [45] emphasize that the effect of land diversity can only be fully realized when there are effective connections among different connection patterns. For instance, integrating bike-sharing, walking and public transport can enhance the accessibility of opportunities brought about by land use diversity. In other words, land use diversity not only shapes potential demand but also depends on the matching and integration of multi-modal connections to reflect its impact on actual travel behavior [45, 48]. This suggests that diversity does not operate independently, but interacts with network conditions to shape actual travel behavior. Density, diversity, and network design are therefore interdependent components of accessibility [47].

4.2 Micro-Mobility Solutions for FLM

Density and land-use diversity shape FLM demand, but their effects depend on effective multimodal connections [45]. In this context, micromobility is gradually being regarded as an important means to improve short-distance connections. Compared with traditional connection methods, micromobility is more flexible, capable of supporting short-distance and multi-stage travel processes, and is more easily integrated with public transport [42,49]. Among them, bike-sharing is widely considered to be one of the most representative micromobility methods in the FLM scenario [50]. Cycling is flexible and adaptable and help the commuters to freely adjust their routes in the complex and ever-changing urban environment [51]. More importantly, due to its affordability, like no need to bear the costs of purchasing, maintaining, and parking bicycles, bike-sharing reduces barriers to access, thereby enhancing mobility equity across different socio-economic groups [49]. As a result, bike-sharing has expanded rapidly worldwide over the past two decades. It now operates in more than 1,590 cities and is widely used to reduce car dependence and support sustainable travel [42].

4.2.1 Bike-sharing Usage in Australia

Similar to global trends, Australian research increasingly highlights the potential of micromobility and bike-sharing for FLM travel. This potential mainly stems from the prevalence of short-distance travel in the urban travel structure. In Greater Melbourne, more than half of the daily travel distances are within 5 kilometers, and approximately one-third of the jobs are located within a 30-minute cycling distance from the residence [52]. It means that a considerable portion of commuting trips have the possibility of being connected to public transport systems through cycling [52]. In this context, compared to feeder modes that rely on fixed routes and stops (such as buses or shuttle services), bike-sharing, as a mode not constrained by predefined routes and capable of supporting short, segmented trips, could be more easily integrated into Melbourne's public transport travel chain [18, 53]. Its function could not only be to replace existing modes of transport, but also to make up for the lack of spatial continuity in the public transport system, thereby improving the overall travel efficiency [42]. This is also the reason why related studies in recent years have constantly emphasized its potential role in the urban transport system [53].

However, despite having the aforementioned potential, the development of bike-sharing in Australia today still faces multiple constraints. A qualitative study by Gerhard [54] indicates that users in Melbourne generally consider convenience to be the core factor influencing bike-sharing usage. However, this is highly dependent on its integration with the existing transport and infrastructure system. In cities like Melbourne, bike-sharing lacks effective integration at both the physical and institutional levels. It is not linked to ticketing systems or rail networks system [54]. Thus, bike-sharing is often used only as an independent mode of transport, rather than as a connection to public transportation. This means that travel still relies on long single-segment rides and is difficult to break down into short, rideable segments, thus reducing their applicability in actual travel [54].

In addition, the development of bike-sharing in Australia is confronted with significant institutional and governance constraints. In Sydney, early bike-sharing projects faced governance issues, including unclear regulation and poor coordination between government and operators [55]. As a result, restrictive measures such as vehicle bans and fines were implemented. Some of these plans were eventually abandoned after pilot phases [55, 53]. Although the governance model has shifted towards public-private partnerships, shared bikes are also regarded as a potential shared mobility solution. However, overall, the necessary stable and systematic institutional support is still lacking [55]. Despite the challenges, Australian cities, with their favorable climates, short distances, and increasing social acceptance, still have considerable potential for micromobility [53].

4.2.2 Bike-sharing Integration and Contextual Challenges

Shared bikes can increase the utilization rate of public transportation, but it depends on the matching of supply and demand as well as the operation mode (Figure 3) [56, 50]. Effective integration requires optimizing the location selection, coordinating passenger flow and rebalancing the vehicles [56, 50]. Yen et al. [56] compared the time savings for walking and bike-metro transfers in over 400 spatial units in Taipei, measuring the supply and demand. Shared bikes improved station accessibility, especially outside the regular walking range [56]. However, supply-demand mismatch is still widespread; when there are sufficient vehicles or parking points, the layout and commuting passenger flow are still inconsistent, which still limits the usage [56, 57]. Deployment must match actual demand.

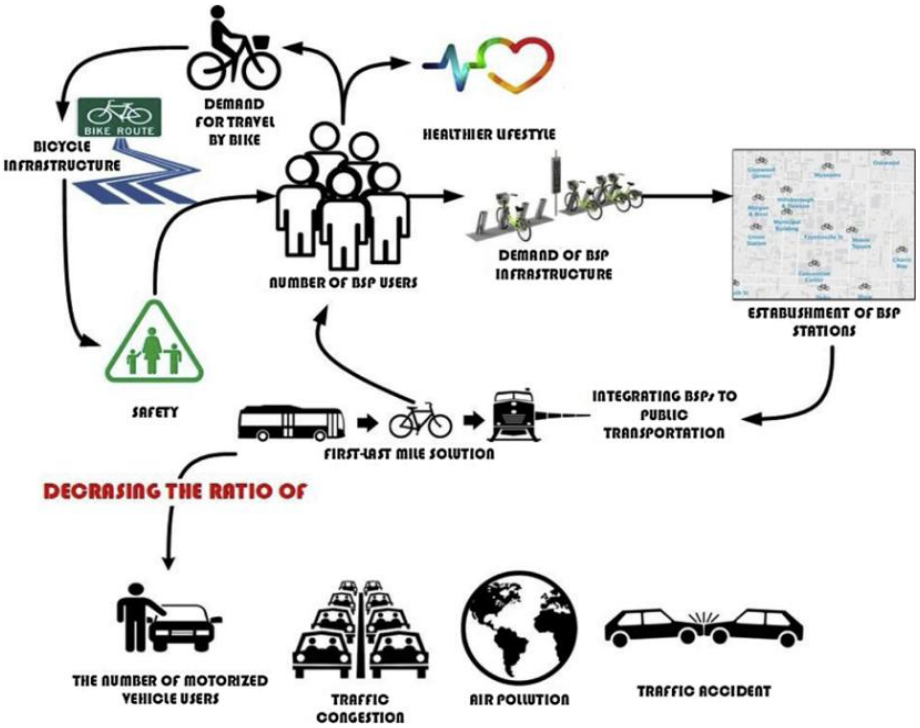


Figure 3. Integrating Bike-sharing to Public Transport by Eren & Uz, 2020. p. 6.

Based on this, scholars have further studied the interaction between the bike-sharing and the built environment around public transport stops (usually within a radius of 100 to 500 meters). These studies indicate that land use patterns and facility distribution significantly affect the efficiency of the integration of bike-sharing and public transport [58, 57]. For instance, Chiou and Wu [50], using origin-destination (OD) data of Taipei, found that the FLM effect of bike-sharing is particularly significant during commutes to mixed-use commercial areas, schools, and major corridors, but is relatively limited in low-density residential areas or suburban environments. This not only reveals the complementary role of bike-sharing in the accessibility of rail transit, but also highlights the two-way relationship between land use and bike-sharing. On the one hand, the mixed land use and functional layout encourage cycling adoption as FLM tools; on the other hand, the scale and presence of bike-sharing can influence people's perception of land use accessibility [59, 60].

Micro-scale travel conditions also affect the effectiveness of bike-sharing. Using GPS data from Hamilton, Yin and Scott (2026) show that factors such as intersection design, crossing facilities, and road safety strongly influence FLM integration. Barriers like major road crossings or two-stage turns increase travel time and reduce the competitiveness of cycling [61]. Weather conditions also matter. Low temperatures, rainfall, and high humidity reduce cycling frequency and duration, while extreme temperatures further discourage use [62]. In addition, bike–metro integration is most evident during peak hours, particularly for commuting and education-related trips [50].

4.3 Research Gap

Notable progress has been made in existing research on the FLM accessibility and its relationship with bike-sharing. Increasing literature has explored how the characteristics of the built environment, population density and the structure of the transport network affect active travel behavior. However, there are still some limitations. Firstly, most studies focus on single-dimensional factors (such as distance or density), lacking a comprehensive analytical framework. Also, methodologically, existing models usually measure accessibility through static indicators, lacking quantitative identification of the spatial differences in accessibility improvement potential among different regions, thereby limiting their application in spatial planning and decision-making.

For Greater Melbourne, these gaps are even more obvious. On the one hand, compared with major cities in Europe, North America and East Asia, station-level FLM evaluations using railway stations

as TOD nodes are still relatively scarce. On the other hand, there is a lack of systematic evidence on how to strategically deploy bike-sharing in Melbourne's multimodal transport system. As Curtis et al. [53] pointed out, the government's response to emerging travel modes mainly relies on regulation, focusing on the safety of cyclists' behavior, but lacks systematic policy tools and planning frameworks to support the construction of micro-travel infrastructure and its connection with public transport.

This thesis is based on the Active Accessibility Framework proposed by Vale et al. [20], and constructs a comprehensive analysis framework for analyzing the FLM accessibility around railway stations in Greater Melbourne. The study first identified walking and cycling accessibility characteristics of different stations by integrating spatial and built environment indicators, and used cluster analysis to reveal spatial differences among station types. Building on this, the study further examined the relationship between travel demand and spatial conditions at a finer scale by demand and spatial support dimensions to identify areas where bike-sharing is more likely to be effective. Finally, this study proposes potential deployment strategies for bike-sharing based on spatial suitability analysis, in order to explore their role in improving FLM connectivity and enhancing the overall accessibility of public transport.

5. Methodology

5.1 Study Area Definition

Greater Melbourne with its high urban population has a typical polycentric metropolitan structure [63]. This transportation system is based on railways as its backbone and is connected to extensive tram and bus networks. The area where it is located has the highest public transportation usage rate in Australia [63] (Figure 4).

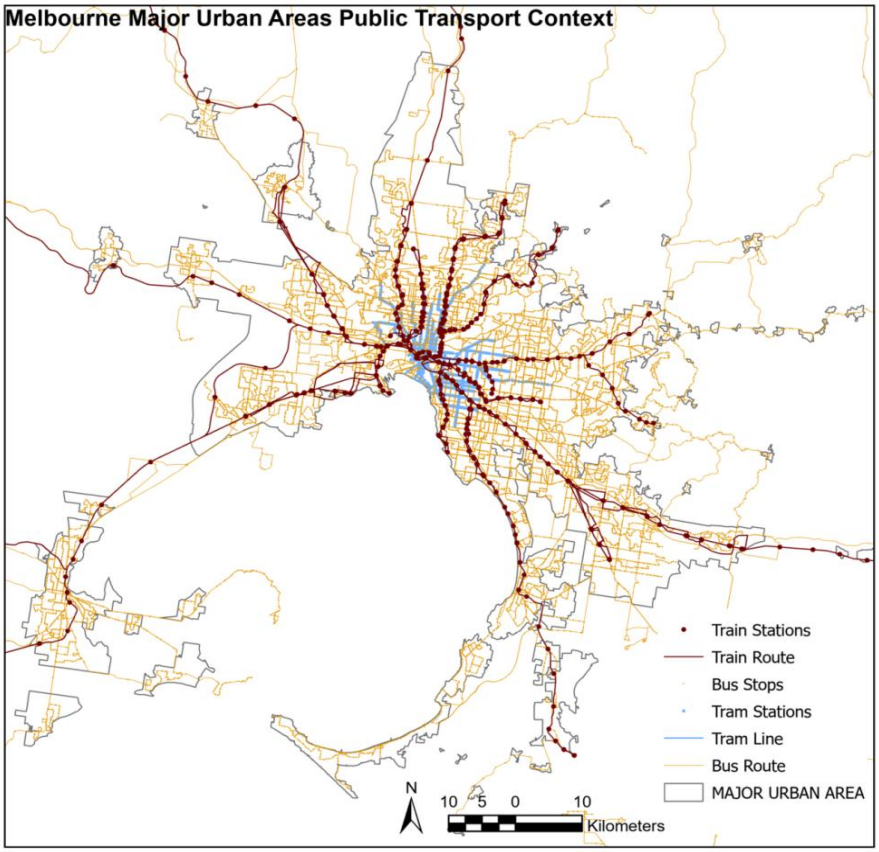


Figure 4. Melbourne Major Urban Areas Public Transport Context

This study is based on the Major Urban Area (MUA) of Melbourne that aligns with the Urban Growth Boundary (UGB). The MUA covers the continuous built-up area that serves a gathering place for a large population and employment locations, and transport infrastructure [63]. Thus, it reflects

the functional metropolitan core of Melbourne and the central role of railways in daily commuting. In addition, the spatial structure of MUA is established the TOD strategy of Melbourne. Plan Melbourne 2017–2050 emphasizes high-density, mixed-use development around railway corridors and key nodes to enhance public transport efficiency and reduce car dependence [63]. Therefore, taking MUAs as this thesis boundary not only ensures the consistency between the research objective and the empirical background, but also provides a policy-related framework for analyzing the integration of bike-sharing and TOD.

As railways are the backbone of Melbourne's public transport system and the areas around stations are key targets of TOD policies, they are highly suitable for studying how FLM connections affect commuting patterns. In contrast, the higher density of tram and bus networks can partially alleviate travel barriers, making FLM issue less prominent. However, they remain crucial for the integration of multimodal transport with railways. Therefore, this study takes the train station as the main analysis unit, while trams and buses will be included in the subsequent discussion on network integration.

5.2 Data Collection

This study is mainly based on spatial and demographic data from Department of Transport and Planning (DTP), Victoria State Government and the Australian Bureau of Statistics (ABS) (Table 1).

Table 1. Data Types and Sources

Data Category	Source	Description
Transit Infrastructure	Victorian Government Open Data Portal	Spatial dataset containing routes and stop locations for rail, tram, and bus networks
Road Network Characteristics	Vicmap Transport – Road Network dataset	Spatial dataset containing Victoria's road centerlines, attributes such as road hierarchy, and spatial topology
	Vicmap Transport – Road Infrastructure Point dataset	Spatial dataset capturing infrastructure features including intersections, pedestrian crossings, and signalized junctions
Cycling Infrastructure	Bicycle Infrastructure Network	Spatial dataset mapping Melbourne's cycling infrastructure
	Bike-share Dock Locations	Spatial dataset providing geocoded locations of public bike-share docking stations in Melbourne
Land use and urban form	Vicmap Planning – Planning Scheme Zone Polygon	Spatial dataset of statutory land-use zoning across Melbourne
Socio-economic indicators	ABS Census DataPacks	Census data at small-area geographies (e.g. SA1, SA2)

Using the above datasets, this study is divided into 2 phases: (1) the development of an accessibility evaluation framework of Greater Melbourne's train stations' FLM (detailed in Section 5.3, to answer Research Question 1) and (2) the development of an evaluation framework to enhance this accessibility through bike-sharing (detailed in Section 5.4, to answer Research Question 2).

5.3 Accessibility Evaluation Framework of FLM

The first phase of this study is based on the development of a novel and comprehensive system for evaluate FLM accessibility in the Greater Melbourne MUAs.

5.3.1 Base Framework and Indicators

To develop this first framework, this study builds on the Active Accessibility Framework proposed by Vale et al. [20], but the two frameworks differ in in terms of research focus and practical application. Vale et al.'s framework primarily explains how the built environment influences active mobility accessibility, focusing on establishing a conceptual analytical framework. This study is based on the FLM (Pedestrian and Cycling Linkage) at the railway station. It refines and expands the indicators based on existing research to accurately reflect the spatial characteristics and infrastructure conditions of the FLM connection area regarding walking and cycling.

The framework divides the mechanisms by which the built environment affects active travel into two categories:

(1) Clear indicators: These refer to the physical factors of the road network and transportation infrastructure that directly affect the travel conditions.

(2) Implicit indicators: These can be the social characteristics that show the travel demand and environmental insights.

This thesis retains the independent dimensions of each indicator to characterize the multidimensional structure of FLM accessibility. These indicators will be used to identify accessibility differences between stations and provide input variables for subsequent cluster analysis. The definitions and calculation formulas of each indicator are summarized in the following Table 2:

Table 2. The definitions and calculation formulas of Explicit and Implicit Indicators

Indicator Type	Dimension	Indicator Name	Description	Formular (if applicable)
Explicit Indicator	Route Characteristics	Detour Index (walking & cycling) [36]	Ratio between network and Euclidean distance, indicating street connectivity and efficiency.	$C = \frac{D_{network}}{D_{euclidean}}$
		Continuity of protected cycling facilities (cycling) [64]	Ratio of continuous protected cycling lane to total network length within the area.	$R_p = \frac{L_{protected}}{L_{total}}$
		Intersection Density (walking & cycling) [37, 40]	Number of intersections per unit area, reflecting permeability and street connectivity.	$I = \frac{N_{intersections}}{Area}$
	Integration with other modes	Coverage of public transport nodes (walking & cycling) [45]	Number or frequency of tram/bus stops within the 10-min walking buffer around the station.	$M_t = \frac{Stops_{PT}}{Area}$
		Existing bike-sharing dock density (walking & cycling) [45]	Density of public bike-sharing docks within the isochrone area.	$M_b = \frac{Docks}{Area}$
	Safety	Pedestrian Crossing Density (walking & cycling) [37]	Number of pedestrian crossings per unit area, reflecting walkability and safety.	$S_c = \frac{Crossings}{Area}$
Implicit Indicator	Density	Population Density (walking & cycling) [20, 44]	Population per unit area, indicating potential trip generation.	$D_p = \frac{Pop}{Area}$
		Employment Density (walking & cycling) [44]	Jobs per unit area, reflecting commuting attraction.	$D_e = \frac{Jobs}{Area}$
	Diversity	Land-use mix (walking & cycling) [46, 59]	Degree of balance among different land-use categories.	$H = -\frac{\sum_{i=1}^{n} p_i ln(p_i)}{ln(n)}$

5.3.2 Development of the novel Accessibility Evaluation Framework of FLM

To develop the new accessibility farmwork, the approach includes four main steps: (1) service area delineation, (2) indicator extraction, (3) standardization, and (4) clustering.

(1) Service area delineation

To capture residents' active travel behavior in the train stations' FLM stage, the first step is to define station accessibility catchments.

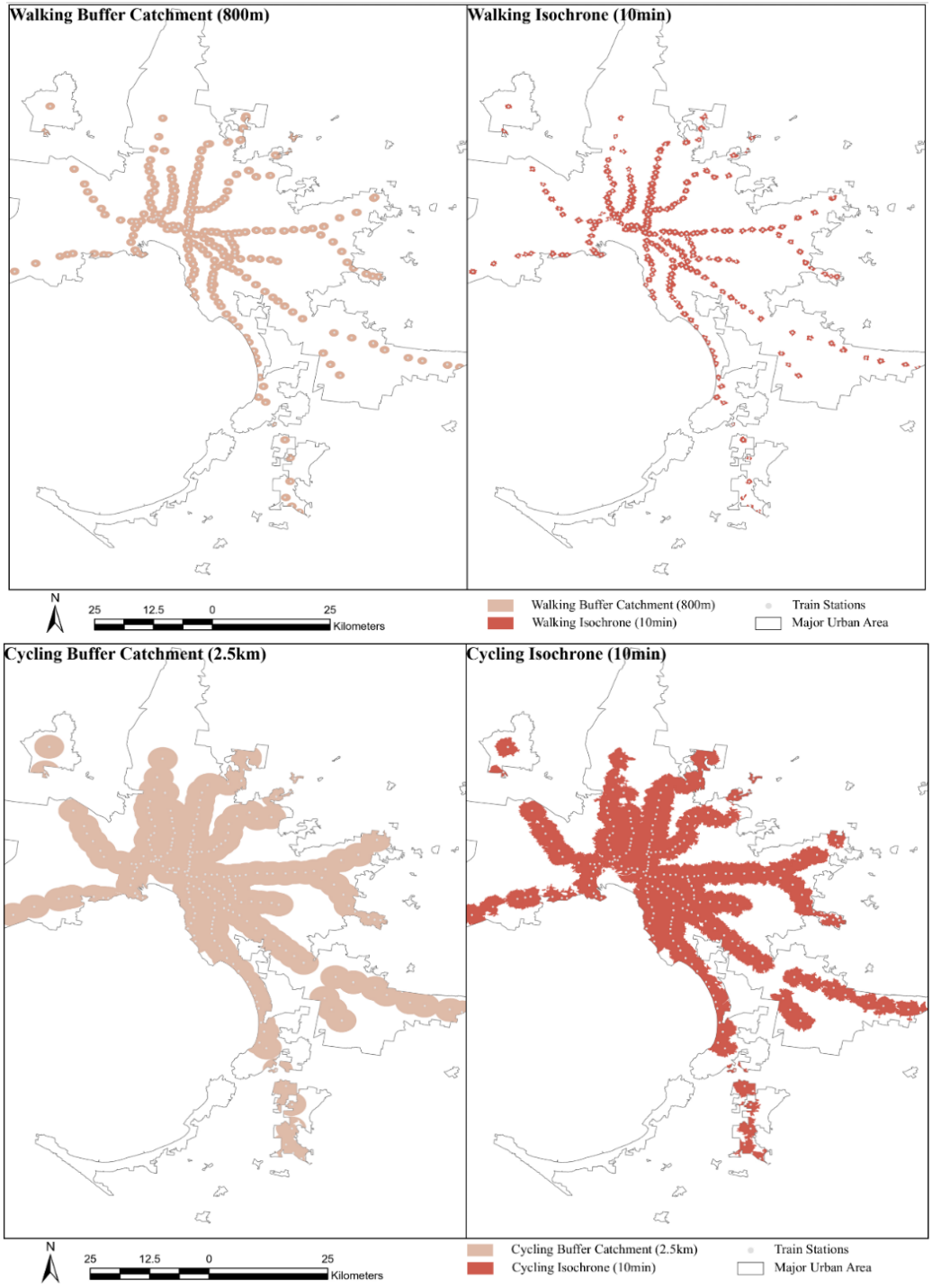


Figure 5. Comparison of Buffer Catchment and Isochrone

Previous studies commonly delineate station service areas using two methods: Euclidean distance–based buffers and network-based isochrones. The buffer method uses the GIS Buffer tool, applying a fixed radius to represent accessibility based on Euclidean distance [65. 66]. By contrast, isochrones are generated using the ArcGIS Travel Time tool. They are based on the road network and measure travel time or distance along actual routes, capturing network structure and travel constraints [66]. The definition of service areas varies depending on the method.

FLM travel mainly consists of walking and cycling. In this study, the service area of the stations is divided into a 10-minute walking distance (approximately 800 meters) and a 10-minute cycling distance (approximately 2.5 kilometers). The speed parameters are based on existing research (Joyce & Dunn, 2009; Larsen et al., 2010). Based on this, buffer zones and isochrone service areas are constructed and overlaid with land use data (Figure 5). The reachability and spatial characteristics of

the two methods are compared to provide a basis for subsequent index extraction and accessibility analysis.

The results show that the buffer zone coverage is too large, which may overestimate the reachability; isochrones better reflect the road network structure and actual travel paths. Therefore, this study adopts network-based isochrones to define the service areas of the stations.

(2) Indicator extraction

In each isochronous zone, the explicit and implicit indicators are extracted according to the definition in Section 3.2.

(3) Standardization

The indicators vary in terms of size, range and distribution, which may lead to deviations in direct comparisons or clustering [67]. Z-score normalization can preserve the data distribution and reduce the influence of extreme values, making it suitable for distance-based clustering. Its formula is as follows:

$$z = \frac{x - \mu}{\sigma}$$

x : the original value of the given spatial unit (or station);

μ : the mean value of each indicator;

σ : standard deviation

(4) Clustering

After standardization of the indicators, this study employed K-means clustering to classify the sites in order to identify the accessibility patterns. K-means is an unsupervised distance-based method that divides the data into K clusters by minimizing the within-cluster sum of squares (WCSS) [68, 69]. Within a cluster, the data points are similar, while there are significant differences between clusters. This method is commonly used in urban and transportation research to identify spatial types and structural differences [68].

Each station's isochrone is used as the unit of analysis, with accessibility indicators forming a feature vector. Clustering is conducted using Euclidean distance to group stations with similar characteristics. The number of clusters (K) is determined using the elbow method. This method examines the variation of the within-cluster sum of squares (WCSS) with the value of K [68]. The results show the curve flattens at K = 4, indicating diminishing returns (Figure 6).

The relative characteristics of each cluster can be interpreted by using their standardized means (Z-scores). These values are presented and discussed in the Section 6.1.4.

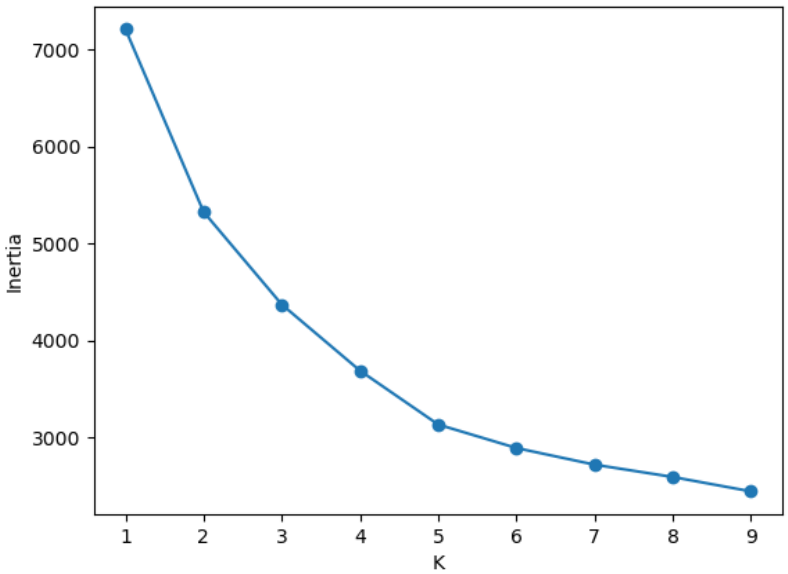


Figure 6. Elbow Method Result.

5.4 Accessibility Enhancement of FLM via Bike-sharing

The second phase of this study explores the spatial potential of bike-sharing in enhancing the accessibility of train stations within MUAs. Building upon the spatial gaps revealed in the previous analysis (Section 5.3), this phase focuses on integrating accessibility conditions, demand distribution, and built environment characteristics to support a location-allocation optimization process. The development of the framework is divided into (1) grid establishment, (2) indicator extraction, (3) normalization and calculation of suitability index and (4) bike-sharing station placement.

5.4.1 Grid establishment

To capture the potential accessibility gains from bike-sharing facilities across different areas, the entire MUAs are divided into a fishnet grid with cells of 500m × 500m, balancing spatial resolution and computational efficiency. This scale is derived from the research of Zhou et al. [70]. Through their spatio-temporal prediction experiments, they found that a 500-meter spatial window does not suffer from a loss in computational efficiency, and can also well preserve the spatio-temporal distribution characteristics of travel demands. Therefore, it is suitable for large-scale urban travel modeling. The grid is generated using the ArcGIS Create Fishnet tool, ensuring full coverage of the built-up area and consistency in projection and coordinate systems with the FLM gap analysis. Each grid cell served as the basic unit of analysis for calculating and aggregating bike-sharing suitability indicators.

5.4.2 Indicator extraction

In terms of indicator construction, existing studies generally hold that the core of selecting the locations for bike-sharing lies in identifying the spatial distribution of potential demand, especially key variables such as population, employment, and activity intensity, which jointly determine the generation and attraction process of travel [71, 72]. Based on this, this study adopts a demand-oriented indicator system and combines the accessibility gap analysis framework to divide the indicators into two dimensions: the demand and the spatial support.

Table 3 presents the core indicators used in this stage:

Table 3. Indicator for accessibility enhancement of FLM through bike-sharing

Category	Indicators	Description	Role in analysis
Demand dimension	Population	Residential population within each grid cell	Represents trip generation potential
	Employment	Number of jobs within each grid cell	Represents trip attraction potential
	Land-use generator / attractor	Functional role of land-use types (e.g., commercial, educational)	Captures directional characteristics and activity-based demand
Spatial support dimension	Land-use entropy	Degree of land-use mix within each grid cell	Reflects functional diversity and activity intensity
	Proximity to cycling lanes	Distance to nearest cycling infrastructure	Indicates cycling feasibility and infrastructure support
	Proximity to public transport	Distance to nearest public transport station	Reflects first- and last-mile integration potential

Note: This table summarizes the variables used in the position allocation analysis, and all these variables are calculated at the grid cell scale.

5.4.3 Normalization and calculation of suitability index

After the indicator system is determined, a comprehensive suitability index is constructed to evaluate the layout priority of shared bicycle stations in different spatial units. To facilitate comparison, all the indicators are first normalized from the minimum to the maximum [67] and unified to the range of [0, 1]. The formula is as follows:

$$\tilde{x_i} = \frac{x_i - min(x)}{max(x) - min(x)}$$

xi: the original value of the given spatial unit;

min(x): the minimum value of this indicator among all spatial units;

max(x): the maximum value of this indicator among all spatial units;

x̃i: normalized value.

The normalized values are first classified using the Jenks natural breaks method and assigned a score of 1 to 5 [70]. On this basis, the indicators are classified into two aspects: the demand dimension and spatial support. Each of these two dimensions calculates the average score in an unweighted manner; subsequently, they are combined with equal weights to form the suitability index.

5.4.4 Bike-sharing station placement

The location-allocation model is employed based on the results of demand distribution and suitability analysis for optimization of bike-sharing station allocation. The model takes into account the discrete demand points and the locations of candidate facilities. When the number of facilities is fixed, it minimizes the total transportation cost from each demand point to the nearest facility. Specifically, the "Minimize Impedance" model (P-median) in ArcGIS Network Analyst is used. The objective is to minimize the population-weighted distance from demand points to stations, and thus high-demand regions will have higher priority [71].

Actual travel does not occur uniformly. Therefore, the model incorporates spatial constraints. The demand points only fall within the high-demand areas within the cycling time intervals, which can be regarded as unmet service demands; the candidate stations are limited within the walking time intervals to ensure that users can reach them. Thus, the walking connections and cycling coverage are included in the same framework.

In terms of the number of stations, previous studies often estimate the scale of the shared bicycle system based on the total population of the city or the number of vehicles owned. This approach is more suitable for network planning at the city level [56, 50]. However, such approaches implicitly assume a uniform distribution of demand and fail to capture the significant spatial heterogeneity within cities. Their macro-scale decision logic also overlooks the local accessibility structure in FLM contexts, which is shaped by walking and cycling ranges [73, 71]. To avoid bias caused by scale mismatch, this study uses the number of facilities as a scenario variable in the analysis. With 20, 40, 60, 80, and 100 stations respectively, the impact of facility expansion on FLM service efficiency is assessed by comparing changes in service coverage under different supply levels, and the characteristics of its marginal benefit changes are identified [71]. Finally, the results are compared with the accessibility gaps identified in RQ1 to assess the extent to which the configured facilities are able to respond to these spatial gaps.

6. Results

6.1 Accessibility Evaluation of Melbourne Train Stations' FLM

This section addresses Research Question 1 by presenting the results of evaluating the accessibility of Melbourne's train stations' FLM using the novel framework proposed.

6.1.1 Isochrone Vs Buffer Method Comparison

In FLM analysis, isochrones and buffers show clear differences in service area extent. Buffer-based service areas are significantly larger than those defined by isochrones, meaning that the Euclidean distance assumption leads to an expansion of accessible areas. Further comparison of land-use structure shows that this expansion is not uniform (Table 4). In buffer-based areas, the share of residential land increases slightly. Industrial and other land uses show a more noticeable increase at the cycling scale. This suggests that the additional areas are mainly located in peripheral or low-

intensity zones. By contrast, isochrones have a higher share of commercial and mixed-use land, representing that network-based service areas are more concentrated in functionally active spaces. The buffer zone method often overestimates accessibility and includes more non-core land areas; while the isochrone method can better reflect the actual functional environment around the station.

Table 4. Comparison of land-use composition within buffer and isochrone service areas

Land-use type	Walking Isochrone	Walking Buffer	Cycling Isochrone	Cycling Buffer
Commercial-Employment	0.062	0.045	0.029	0.028
Green-Space	0.069	0.077	0.084	0.082
Mix-use	0.091	0.077	0.061	0.070
Residential	0.577	0.599	0.622	0.593
Public-Institution	0.033	0.039	0.040	0.040
Rura-Area	0.002	0.002	0.002	0.004
Industrial	0.034	0.046	0.059	0.067
Others	0.128	0.113	0.101	0.140

6.1.2 Spatial Patterns of Accessibility Indicators

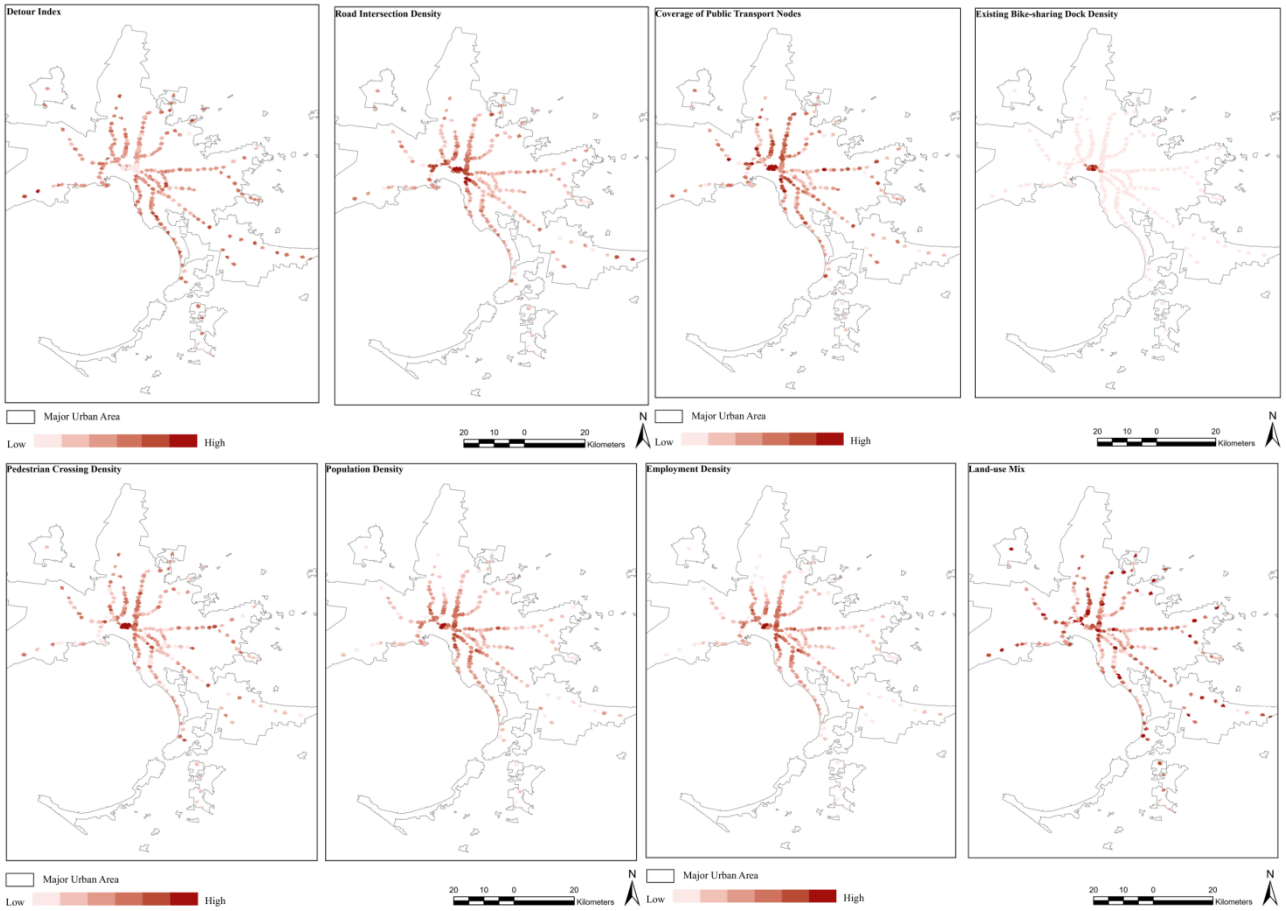


Figure 7. Spatial distribution of accessibility indicators within walking isochrones.

Note: Higher values indicate better accessibility, except for the detour index, where lower values indicate better conditions.

The spatial distribution of each accessibility index is generally consistent: high values are concentrated in the city center, extending along major transportation corridors, and are relatively low in the periphery. There is a clear gradient from the center to the periphery (Figure 7-8). However, this is not entirely the same for different travel modes. The service area of walking scale is limited, and the coverage areas of stations are relatively independent and scattered, with significant differences between adjacent stations. After the coverage of cycling expands, the surrounding areas of stations

often overlap, and the pattern becomes more continuous and consistent. The difference in scale also affects the spatial distribution of the indicators. The cycling coverage is wider, and it can capture more potential opportunities in indicators such as intersection density and coverage of public transportation nodes, resulting in relatively higher accessibility in the surrounding areas. Therefore, the conclusion for the walking scale should not be directly applied to the cycling scale, and they need to be interpreted separately.

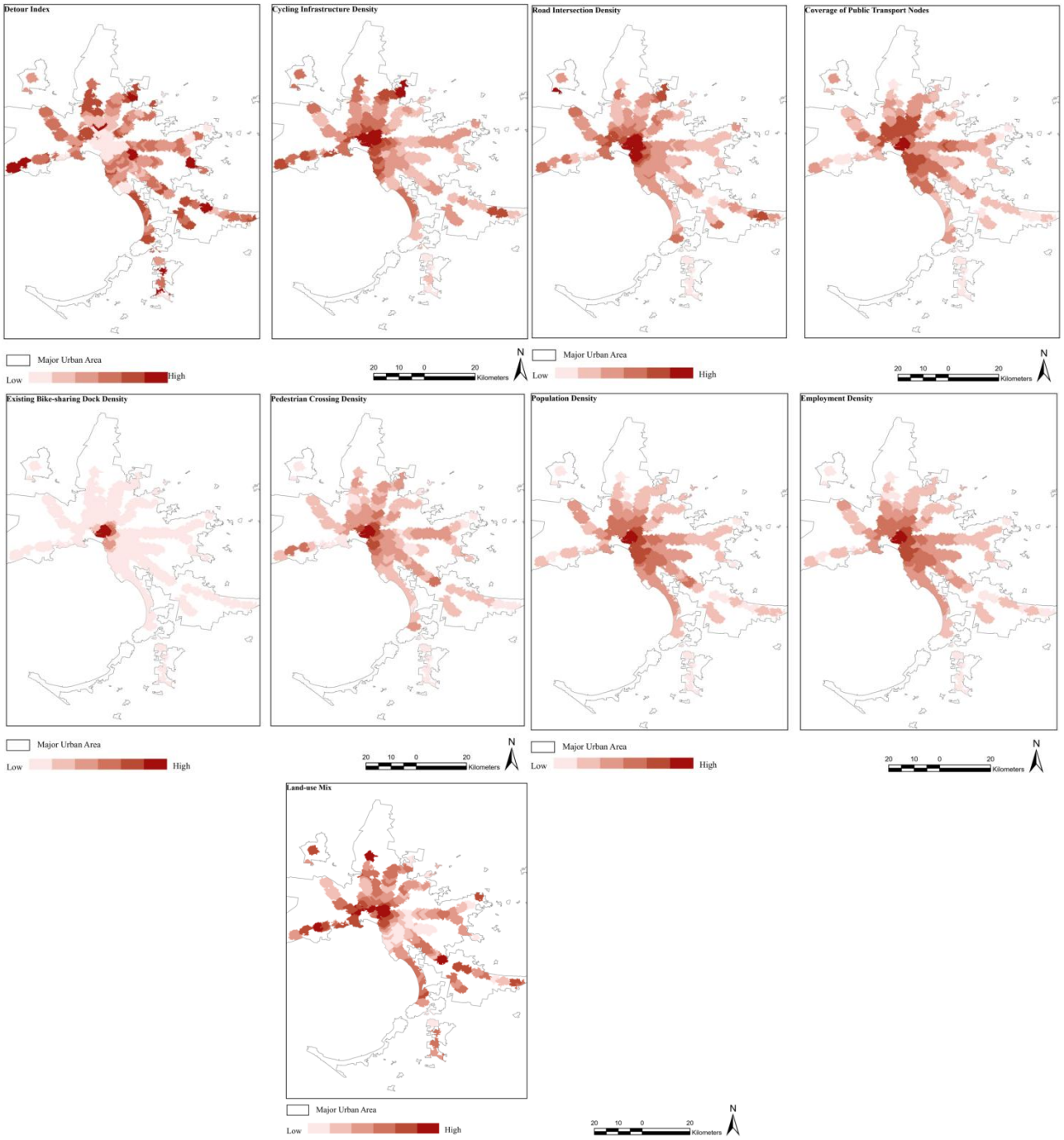


Figure 8. Spatial distribution of accessibility indicators within cycling isochrones.

Note: Higher values indicate better accessibility, except for the detour index, where lower values indicate better conditions.

6.1.3 Cluster-based Station Typology and FLM Spatial Distribution

The standardized mean values (Z-score) of accessibility indicators for each cluster are summarized in Table 5. Their spatial distribution is shown in Figure 9. Firstly, Cluster 4 represents highly concentrated stations and is mainly located in the Melbourne CBD. In the core area of the city and

along the southeastern corridor, there is a high-access zone between the central area and the suburbs. Both explicit and implicit indicators are generally higher than the average, and the traffic conditions and built environment are relatively well-matched. The intersection density (bicycles 1.969), bus coverage (bicycles 0.967), and land use mix (walking/bicycling 0.506/1.389) are all higher than those of other groups.

Most of the indicators in this area are relatively high, especially at the pedestrian scale: intersection density 2.891, bus coverage 3.04, population and employment density 4.583. The high values mainly come from the pedestrian scale: the range is small, the density effect is prone to be amplified, and after the elements are concentrated, the standardized values naturally tend to be higher. It is more like a relatively superior state of local high density and high concentration, rather than an overall spatial dominance. Population and employment densities are also relatively high. However, this cluster shows relatively low bike-sharing station density. This suggests that micromobility provision may still be insufficient, even in areas with otherwise high accessibility.

In contrast, Cluster 2 shows a more complex pattern, which is mainly located in areas surrounding the urban core. The table indicates clear variation across indicators. Explicit indicators, such as intersection density (-0.262 cycling) and public transport coverage (-0.006 walking/0.019 cycling), are at moderate or relatively low levels. In contrast, the implicit indicators such as population and employment density remain at a relatively high level; the indicators for bicycle infrastructure also perform well. Thus, the second cluster area is more like a transitional zone with great potential but lacking in facilities - the accessibility for walking and cycling is more constrained by infrastructure and network structure.

Table 5. Characteristics of station clusters (Z-score)

Variable	Active Transport	Cluster 1 High-accessibility urban core	Cluster 2 Moderate accessibility areas	Cluster 3 Low-accessibility peripheral areas	Cluster 4 Highly concentrated cluster
Explicit Indicators					
Detour Index	walking	0.255	-0.142	-0.814	0.79
	cycling	0.104	-0.129	-0.952	1.020
Cycling Infrastructure Density	cycling	1.294	0.824	-0.455	2.568
Intersection Density	walking	0.730	-0.151	-0.404	2.891
	cycling	1.969	-0.262	-0.250	0.351
Coverage of public transport nodes	walking	0.187	-0.006	-0.367	3.040
	cycling	0.967	0.019	-0.099	0.941
Existing bike-sharing dock density	walking	0.198	-0.163	-0.195	5.206
	cycling	-0.264	-0.283	-0.286	1.755
Pedestrian Crossing Density	walking	0.120	-0.175	-0.120	4.532
	cycling	0.154	-0.266	-0.359	1.866
Implicit Indicators					
Population Density	walking	0.333	0.120	-0.252	4.583
	cycling	0.412	0.148	-0.428	1.703
Employment Density	walking	0.402	0.095	-0.288	4.583
	cycling	0.456	0.155	-0.453	1.795
Land-use mix	walking	0.506	-0.057	-0.072	-0.678
	cycling	1.389	-0.255	-0.236	0.507

Note: Higher values indicate better accessibility across all indicators. To maintain consistency in the explanation, the detour index has been processed in reverse.

The indicators of the third cluster area are generally low, mostly located at the urban periphery. Both explicit and implicit indicators are low, and the traffic support and demand base are both weak. Its detour index is the lowest (walking - 0.814, cycling - 0.952), indicating a sparse road network and

poor connectivity, with limited path selection and travel efficiency. The stratified pattern shows that the accessibility of public transportation is uneven, and there are also differences in the matching degree of supply and demand.

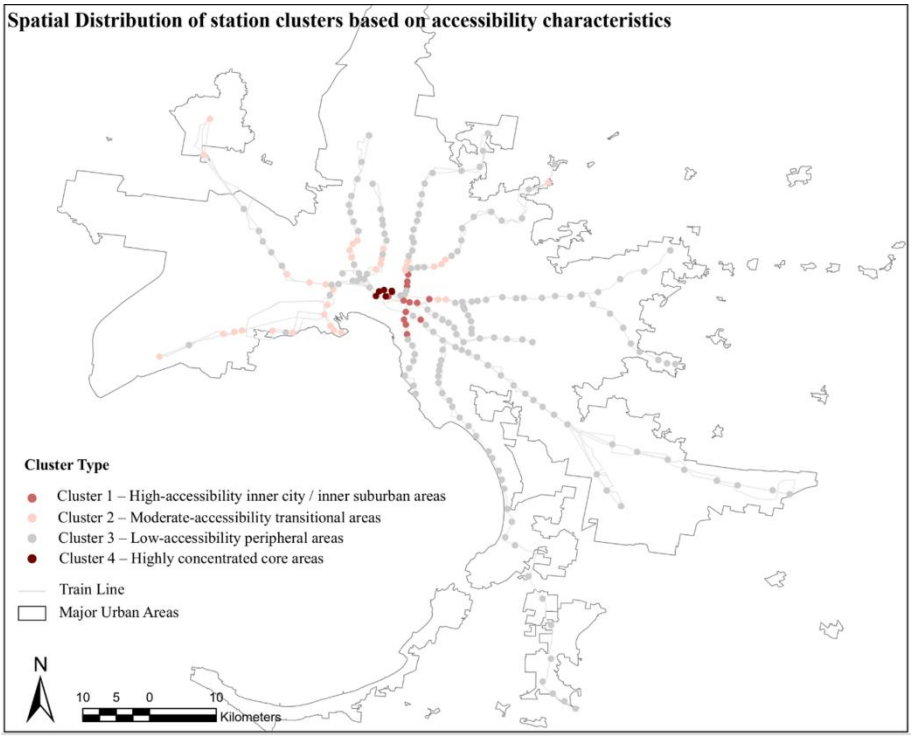


Figure 9. Spatial distribution of station clusters based on accessibility characteristics.

6.2 Accessibility Enhancement of Melbourne Train Stations' FLM through Bike-sharing

This section addresses Research Question 2 by presenting the results of the accessibility enhancement of Melbourne train stations' FLM through bike-sharing stations, based on the proposed framework for suitability assessment and the site selection-allocation.

6.2.1 Spatial Pattern of Suitability

The suitability of each indicator exhibits a clear but differentiated spatial distribution (Figure 10). Population and employment indicators show that highly suitable areas are concentrated in the urban core and extend outwards, with significantly lower suitability in peripheral areas. Land-use entropy exhibits strong spatial heterogeneity. High values are mainly concentrated in built-up areas with high functional mixing, while single-function areas have lower suitability. In contrast, high values for land use generator/attractor are more dispersed. Besides the core area, high-value clusters are formed in many local areas and major transportation corridors. This indicator, to some extent, complements the limitations of land-use entropy, identifying areas with relatively single functions but strong travel generation or attraction capabilities (such as residential and commercial land). The proximity to bicycle lanes and public transport indicators show a clear corridor characteristic, with high values continuously distributed along rail transit and major transport lines.

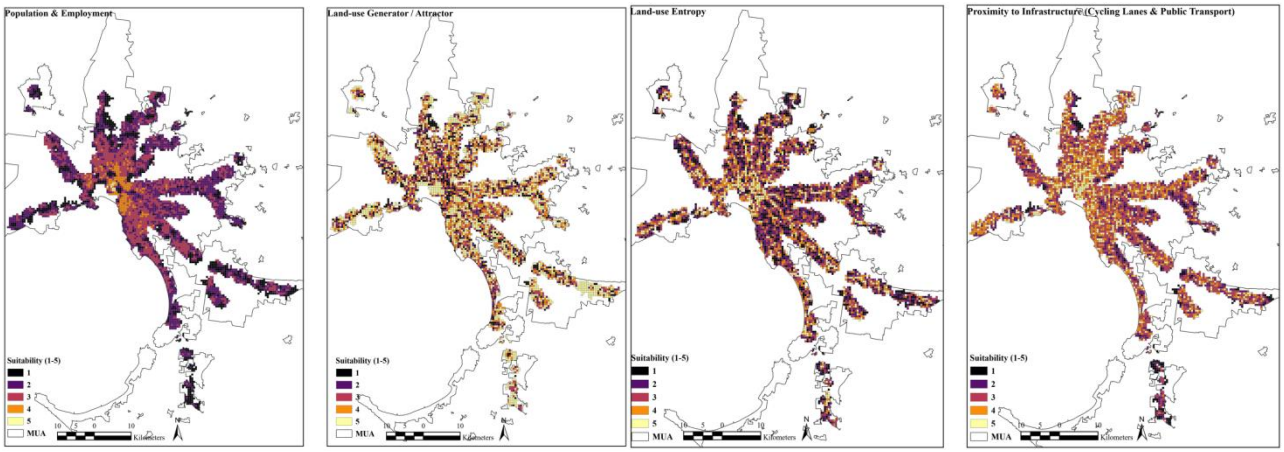


Figure 10. Spatial distribution of standardized suitability scores

Note: 1-Less Suitable; 5-Most Suitable. Proximity to Infrastructure has been reversed.

The final suitability distribution is obtained by integrating various indicators (Figure 11). High suitability areas (Class 4–5) are mainly concentrated in the urban core area and extend outward along the transport corridors. The peripheral areas are mainly of medium to low suitability, with only scattered high values. Compared with the results of a single indicator, the overall suitability is more spatially concentrated. Therefore, only areas with a suitability level of 4 or higher within cycling isochrone are defined as the priority demand areas for bike-sharing in this study. Subsequently, the site selection analysis is conducted within walking isochrone to determine the final site locations.

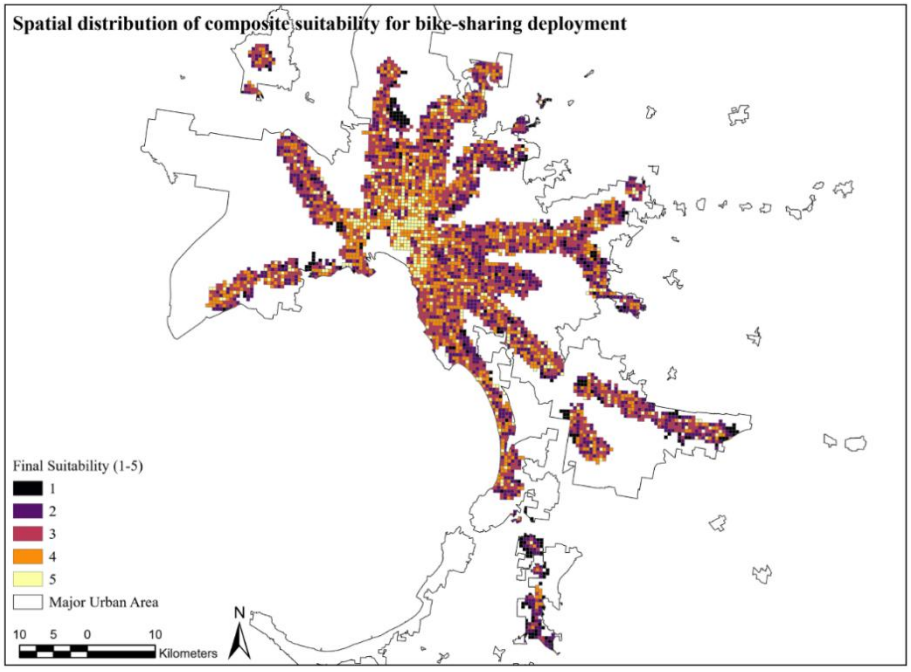


Figure 11. Spatial distribution of composite suitability for bike-sharing deployment.

6.2.2 Location-Allocation Results Under Different Scenarios

To evaluate the service capacity of bike-sharing systems under different facility scales, this study constructed five facility quantity scenarios (20, 40, 60, 80, and 100 sites) based on the location-allocation model. As shown in Figure 12, facility site selection exhibits distinct spatial characteristics under different scenarios. With 20 facilities, they are focused in the urban core, catering to high demand areas. As the number increases to 40–60, facilities expand to sub-centers. After the number of facilities exceeded 80, the layout expanded towards the surrounding areas, but became more scattered, and the coverage improvement slowed down.

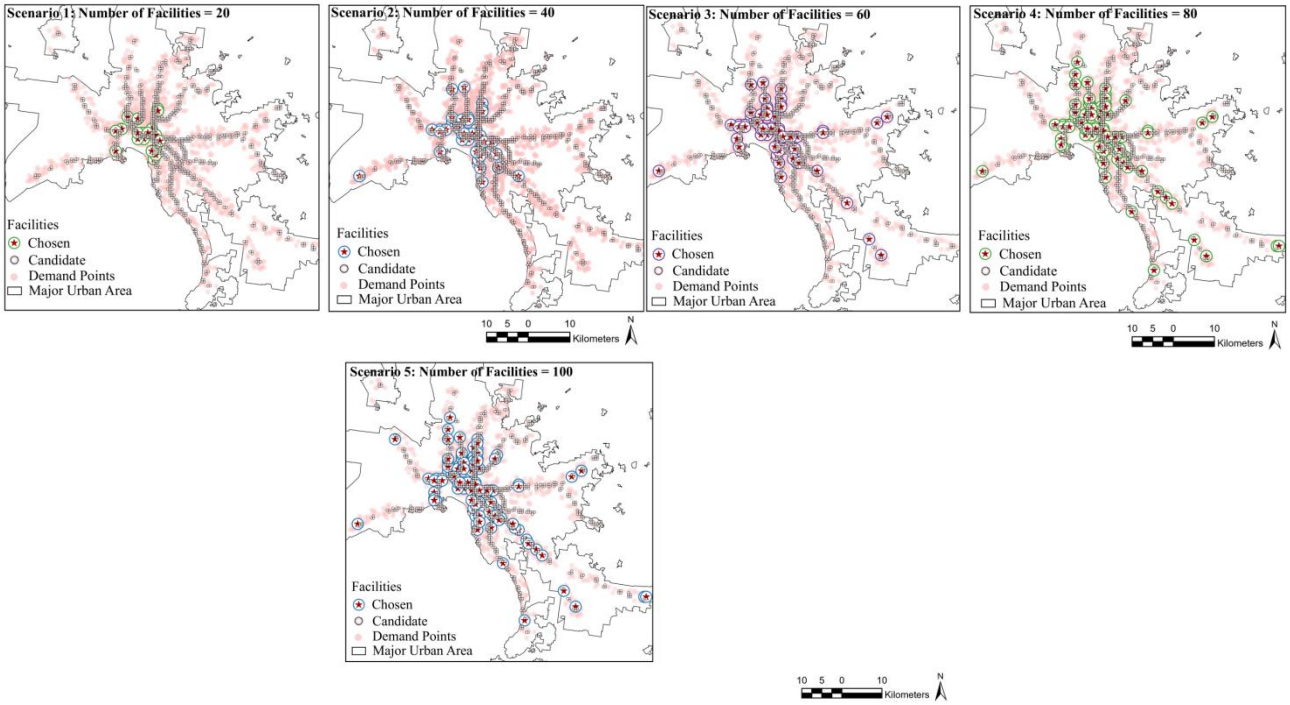


Figure 12. Spatial distribution of bike-sharing station locations under different facility scenarios

Table 6 shows that the number of service recipients increases with the expansion of facilities, but the growth is not linear. When the number of facilities increases from 20 to 40, approximately 64,000 more people are served; when it increases from 80 to 100, only about 22,000 more people are served. The diminishing returns in scale are obvious. Spatially, the 80 facilities have largely covered the main high-demand areas and provide a higher level of service. Further increasing the number of facilities brings limited benefits, and additional investment may not lead to corresponding improvements.

Table 6. Population served by selected facilities

Number of Facilities	Allocated Population (Persons)
20	98,508
40	162,651
60	207,170
80	244,793
100	267,321

6.2.3 Location-allocation Results in Relation To Station Clusters

The spatial distribution of the selected site locations was superimposed with the facility types determined when answering research question 1 (Figure 13). Approximately 61.25% and 21.25% of the facilities were located in the low to medium accessibility areas (the third and fourth categories); the proportions of the high accessibility core area (the first category) and the highly concentrated area (the fourth category) were relatively lower, at 11.25% and 6.25% respectively (Table 7).

Thus, the selected facilities are mainly concentrated in the low accessibility areas. Some areas that were considered difficult to reach in research question 1 actually have strong potential for bicycle travel, and therefore have higher spatial priority in the facility layout.

However, the results also show that not all low-accessibility areas are included in the facility deployment scope. Some areas with significant accessibility gaps were not selected, indicating that bike-sharing plays a role in alleviating the FLM problem, but its effectiveness varies significantly across spaces. Thus, the facility allocation responds to the spatial imbalance identified when answering Research Question 1. The results, therefore, lean more towards covering gap areas with demand support rather than providing homogeneous compensation for all inaccessible areas.

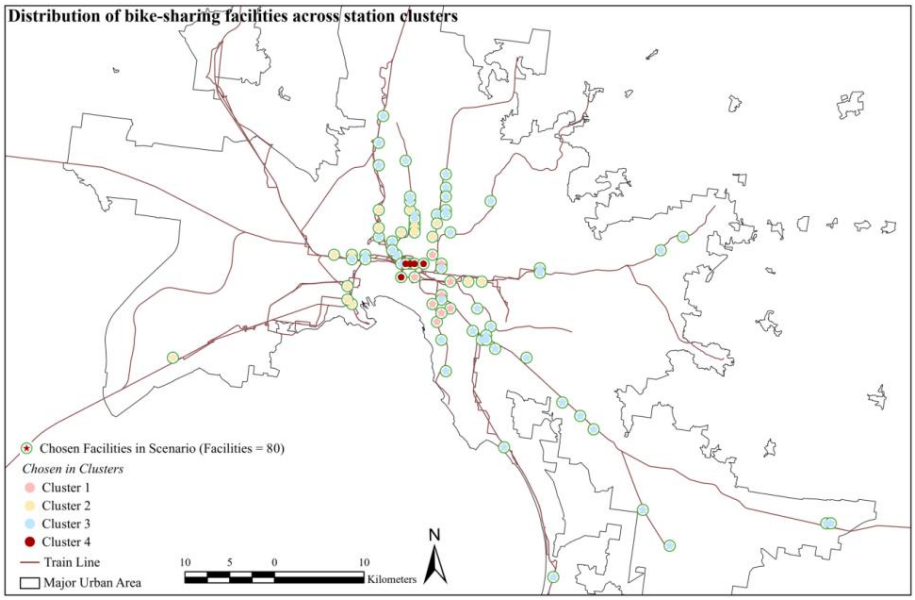


Figure 13. Distribution of bike-sharing facilities across station clusters

Table 7. Proportion of selected facilities by station cluster

Cluster	Cluster Meaning	Number of Bike-sharing Facilities	Percentage of Facilities in Each Cluster Area
1	High-accessibility urban core	9	11.25%
2	Moderate accessibility areas	17	21.25%
3	Low-accessibility peripheral areas	49	61.25%
4	Highly concentrated cluster	5	6.25%

7. Discussion

7.1 Reinterpreting First- and Last-Mile Accessibility Gaps

This thesis shows that the accessibility gap of public transport FLM around Greater Melbourne train stations cannot be simply attributed to the spatial distance, but should be seen as a structural problem formed by the combined effects of multiple spatial factors. Firstly, from the overall spatial layout, the accessibility evaluation shows a clear core-periphery differentiation. This phenomenon is not due to the shorter distance in the central area, but stems from the fact that the central area possesses more favorable conditions, including a higher road network density, stronger node connectivity, and a more complex land use structure [37, 74]. Relevant studies have shown that the street network connectivity and land use mix have a strong impact on accessibility of transport. This is because they directly determine the selectivity of travel routes and the spatial distribution of activity destinations [31, 74]. In contrast, even if the peripheral areas are geographically close to the station, their actual accessibility may be lower due to detours in the road network, lack of infrastructure, or the presence of a single function [31].

Furthermore, there is a diversity of FLM gaps among different types of regions. In some areas (Cluster 2), the population and employment density have reached a certain level, but the transport network and infrastructure supply are relatively lagging behind. The accessibility issues in these areas do not stem from a lack of demand, but rather from the absence of effective connection between supply and demand [75]. On the contrary, in the more peripheral and low-density areas (Cluster 3), the lack of accessibility is often accompanied by the overall absence of activity intensity and functional diversity, further reducing the attractiveness of public transport [75]. Lucas [76) suggests that the problem of transport accessibility often stems from the incompatibility between the transport system and the social spatial structure, rather than the deficiency of a single transport facility.

Therefore, the FLM accessibility gap should be refined as a spatial-functional mismatch. On one hand, the spatial accessibility is limited by road network structure and infrastructure conditions; on the other hand, the functional accessibility depends on the distribution of travel demand formed by population, employment and land-use. When these two dimensions fail to overlap effectively, the presence of transport infrastructure alone is insufficient to produce efficient FLM connectivity.

In this thesis, differences across travel scales further reflect this mismatch relationship. Some stations have limited-service coverage at the walking scale, but show greater accessibility potential at the cycling scale. Walking, as a low-speed and environmentally-sensitive mode of transport, its effectiveness not only depends on the distance, but also on whether the surrounding space can continuously provide sufficient support for travel purposes and routes [77]. Therefore, the spatial distribution of its accessibility shows a distinct core clustering feature. In contrast, cycling expanded the service coverage of the stations, incorporating some peripheral areas into the reachable range. However, this spatial expansion does not necessarily translate into actual travel choices in reality. This phenomenon can be explained by the difference between "potential accessibility" and "actual accessibility". When there is a lack of infrastructure continuity or an unsafe travel environment, even if cycling is feasible in terms of space, its actual appeal as a FLM travel mode remains limited [78]. The expansion of shared bikes has had limited impact, indicating that the transformation from potential accessibility to actual accessibility is still constrained by structural factors.

Mobility on wheels, especially shared bikes, was introduced precisely to bridge this gap: it connects accessible walking stations with longer cycling ranges, converting potential accessibility into available non-motorized transportation options (FLM).

7.2 Spatial Logic of Bike-Sharing Placement

The location selection for shared bikes is not limited to areas with the lowest or highest transportation convenience. Regions with relatively easy transportation accessibility, which can be easily translated into actual cycling areas, are also included in the layout. The convenience of walking, the coverage of cycling, the travel demands and the spatial support conditions jointly shape the suitability of the service. A single factor alone cannot determine it. The walkability and cycling accessibility provide the basic connection range, while the activity intensity, land use mix and infrastructure conditions affect whether the potential accessibility can truly be transformed into actual usage [56, 50, 71]. In other words, bike-sharing does not have the same effect in all areas. Their effectiveness is highly conditional and relational. Only when an area simultaneously possesses a certain level of travel demand, activity concentration, and a cycling-supportive spatial environment can bike-sharing transform existing but underutilized accessibility potential into actual FLM connection behavior [71].

The role of bike-sharing in shaping FLM accessibility varies significantly across different spatial contexts. In the areas with high accessibility (Cluster 1 and Cluster 4), the walking and public transport networks have achieved a high degree of integration, and the FLM connections mainly rely on short-distance walking to complete. In this context, the role of bike-sharing is more reflected in the supplementation of travel methods and the improvement of flexibility. Its functions mainly manifest as an alternative or supplementary travel mode, and acting as a long-term supporting tool for optimizing the transport system [79]. In contrast, the transitional area (Cluster 2) exhibits a more typical "supply-demand mismatch" characteristic. In such areas, bike-sharing plays the most direct and significant role. By lowering the barriers to cycling, it enables the conversion of existing but underutilized cycling potential into actual FLM connections, thereby effectively bridging connectivity gaps in the FLM stage [71, 14].

In the peripheral low-density area (Cluster 3), although it shows a relatively significant FLM accessibility gap, due to the generally weak population density, land use intensity, and transport support conditions, it is difficult to achieve systematic improvement merely by increasing micromobility supply. Previous studies have indicated that the demand for shared bikes is closely related to the characteristics of the built environment [80]. Regions with low activity levels and

limited transportation accessibility tend to have lower demand; low-density environments may also weaken the effectiveness of related interventions.

However, treating the third category of areas as a whole can easily mask their internal differences. Urban spatial processes exhibit significant spatial heterogeneity and do not behave consistently at different scales [81]. At smaller scales such as grid units, some areas that still fall into the third category may have conditions that support the use of shared bikes at the micro level, such as being close to transportation hubs, having activity concentration areas, or having basic cycling accessibility. The detailed analysis of this study confirms this and also indicates that the layout of shared bikes cannot only be based on macro structural conditions; local differences need to be identified to avoid homogeneous layout in low-demand areas.

Therefore, shared bikes are not a universal solution to the accessibility problem of FLM. Their effectiveness is conditional and is influenced by spatial factors. Facility supply is only one aspect; the more crucial point is whether the potential accessibility, urban functional structure, and spatial support conditions can effectively match. Only when the area has sufficient travel demand, activity concentration, and a space environment conducive to cycling, can shared bikes possibly transform the unused potential of accessibility into actual FLM connection behaviors.

7.3 Planning Implication

The research results indicate that there is no simple linear relationship between walkability and micro-mobility interventions, which is crucial for planning practice. Walkability cannot be merely regarded as a spatial coverage issue; it also involves the interaction between spatial structure, activity distribution, and traffic conditions, and is a transformation process [82]. Fixed walking thresholds for delineating station service areas may not accurately reflect the actual walkability. Therefore, planning practice needs to shift from assessing "walkability" to analyzing "availability" [27].

In the context of planning in Melbourne based on the "20-minute community" concept, the planning of shared bikes should not fill all the gaps in walkability, but should identify areas that can convert potential walkability into actual usage value. Such areas are usually neither the easiest nor the most difficult to reach, but rather lie between the two: they have a certain demand base and also have spatial support conditions. Micro-mobility can connect walking and cycling distances in these areas, converting underutilized walkability into actual non-motorized vehicle travel (FLM) connections [14]. Even in marginal areas with relatively weak overall conditions, spatial potential is not completely absent; it merely manifests in a local and fragmented manner. Therefore, planning should not be uniformly distributed based on macro-regional types, but should adopt more refined methods to identify local opportunity nodes. Transitioning from macro classification to micro identification helps avoid inefficient expansion in low-demand areas while retaining targeted local intervention potential [81].

These findings indicate that micro-transport planning needs to shift from a single supply-oriented approach to a comprehensive "demand-space-behavior" perspective. Relevant planning and policies should not only focus on facility expansion but also emphasize system integration, treating shared bikes as an extension of public transportation. For example, they can be coordinated with public transportation in terms of station layout, route design, and service coverage to enhance the overall connection efficiency of the urban transportation network.

7.4 Limitations

This study conducted an empirical analysis of the accessibility differences and spatial layout logic of urban shared bike services, but it still has limitations. At the behavioral level, the study mainly relied on potential accessibility and spatial conditions to infer travel choices, with the implicit assumption that providing cycling or shared bike options would lead individuals to use them. However, actual travel behaviors are also influenced by personal preferences, risk perception, socio-economic variables, and weather and other contextual factors [50], and these factors have not been fully incorporated. Therefore, the "potential accessibility" here is closer to theoretical possibility

rather than actual travel behavior; based on this, judging the potential for shared bike usage in certain areas may be overly optimistic.

In terms of data, this study relied on secondary data, and there is uncertainty regarding its spatial accuracy and classification method. Population and employment data are often allocated based on statistical units, making it difficult to accurately reflect the distribution of fine-grained activities; land use classification may also simplify functional structures, affecting the characterization of travel demands [83]. Moreover, the data are mostly static and difficult to reflect changes in travel demands at different times, which also limits the understanding of urban traffic accessibility and shared bike usage.

Finally, for methodology, this study made necessary simplifications in indicator selection and analytical framework. For example, in the suitability assessment, the weights and interactions between different variables were not fully modeled, which may underestimate or overestimate the actual impact of some factors. Furthermore, although this study revealed local spatial differences through fine-scale analysis, the overall analysis is still based on a specific indicator system and spatial division method. Therefore, the results are somewhat sensitive to parameter settings.

Despite these limitations, this study still constructed a multi-scale FLM analysis framework by integrating walking and cycling accessibility, spatial requirements, and the suitability of bike-sharing. Through the combination of cluster analysis and fine-scale spatial identification, the research not only revealed the overall spatial structure characteristics, but also further identified local spatial differences, thereby providing a more detailed analytical perspective for understanding FLM accessibility in different urban contexts.

8. Conclusion

This study focuses on areas surrounding railway stations in the Greater Melbourne as a case study. It adopts a FLM accessibility perspective to propose a novel framework to examine accessibility disparities across different spatial contexts and to explore the potential role of bike-sharing as a micromobility intervention. The results indicate that the accessibility issue of shared bikes is not simply reducible to spatial distance. It is more of a structural problem, formed by the interaction of the traffic network structure, land use characteristics, and activity distribution. The differences between different travel scales further expose the gap between potential accessibility and actual accessibility; this gap varies significantly in different spatial contexts.

Therefore, this study, at the mechanism level, is more inclined to view shared bikes as an "intermediary system". Instead of expanding spatial coverage, it is more about facilitating the transformation of potential accessibility into actual travel behavior under specific conditions. The study also found that the spatial suitability of shared bikes has strong conditional nature. Its distribution does not fall in the areas with the highest or lowest accessibility, but mainly depends on whether the travel demand, spatial structure, and traffic conditions can be matched.

These findings bring two insights. Theoretically, this study no longer regards accessibility merely as a distance issue, but emphasizes understanding FLM (urban traffic accessibility) as the relationship between potential accessibility and actual travel behavior. Methodologically, the study combines cluster analysis with fine spatial division to try to understand the connection between macroscopic structure and microscopic differences. This provides a more refined analytical framework for understanding the role of micromobility across different spatial contexts. At the empirical level, this study provides a basis for the spatial configuration of bike-sharing in the Greater Melbourne, and proposes a planning approach shifting from "filling gaps" to "identifying areas with demand bases and spatial support conditions".

Although the above findings have been provided by this study, future research can still be further deepened in multiple aspects. For instance, by combining actual travel data, the relationship between potential accessibility and actual behavior can be verified, and individual-level behavioral factors can be introduced to better understand the adoption mechanism of micromobility. In addition,

comparative studies across different urban or spatial contexts would help to assess the broader applicability of the findings. Further extensions could also explore other forms of micromobility, thereby broadening the understanding of FLM systems.

Overall, this study emphasizes that the relationship between FLM accessibility and micromobility interventions is not a simple correspondence, but rather a complex process that depends on multiple conditions. Future urban transport and planning practices need to shift from a single supply-oriented approach to a more comprehensive system perspective, by coordinating spatial structure, transport systems, and travel behaviors, to achieve a more efficient and sustainable connection system.

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