Bicycle train intermodality: Exploring mode choice decisions and mode shift potential

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B.Eng (Hons)

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Abstract

Population growth and urbanisation are placing substantial pressures on the transport network in many cities across the world. Consequently, demand for public transport, particularly metro rail travel, is expected to increase. To deal with such pressures, decision makers often primarily focus on network capacity increases. In this consideration, an important point that is often overlooked is the station access mode capacity issues that will inevitably rise as public transport usage increases.

Currently in Melbourne, Australia, car-based station access accounts for the second most common mode with over 136,000 daily entries. Demand for vehicular access to rail services is anticipated to grow requiring parking infrastructure. As most urban stations are landlocked with limited space for car parking infrastructure, increasing car parking supply requires expensive, multistorey solutions. Alternatively, promoting other station access modes make more economic, environmental and social sense.

One such option would to be to encourage mode shift behaviour from car-based access to the bicycle. While bicycle-rail integration offers a convenient mobility option, it accounts for less than one percent of the current access share. A better understanding of the factors influencing bicycle-rail integration is needed, particularly in the context of a re-emerging cycling nation such as Australia. Through the formulation of four studies this thesis aimed to further the understanding of bicycle-rail integration.

The associations between demographic, built/natural environment and station attributes on the rates of bicycle access to stations were assessed in Study 1. Multivariate modelling results indicate station patronage, frequency of departing trains during the morning peak period, availability of secure bicycle parking, topography, median age, presence of low speed local streets, bicycle crash count density and land use mix are correlated with the rates of bicycle access to stations.

Study 2 provided valuable insights into the disparity in satisfaction levels between cyclists using open-air facilities and caged facilities. Considerable levels of parking dissatisfaction were noted among open-air facility users. Efforts need to be made to improve bicycle parking to better meet the needs of current cyclists and to lower parking related barriers for those contemplating cycling to the station.

The Theory of Planned Behaviour (TPB) was used as a framework to examine the influence of latent factors on the Intention to cycle to the station in Study 3. Structural equation modelling was used to empirically test the relationships among the latent constructs of the TPB. Results indicate Attitudes and Perceived Behavioural Control are significant predictors of the Intention to ride to the station.

Study 4 explored the latent market share of the bicycle and its mode shift potential through a market segmentation approach. The findings indicate a substantial latent demand exists among rail commuters to use the bicycle as a station access mode.

Through the four studies, this research has made a significant contribution to knowledge. It has produced tangible outcomes that have scope to inform policy and practice. Ultimately there are substantial personal and societal benefits that are yet to be realised through increased cycling to access train stations.

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Refereed journal paper(s):

WELIWITIYA, H., ROSE, G. & JOHNSON, M. (2019). Bicycle train intermodality: Effects of demography, station characteristics and the built environment. *Journal of Transport Geography,* 74**,** 395-404. https://doi.org/10.1016/j.jtrangeo.2018.12.016

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WELIWITIYA, H., ROSE, G. & JOHNSON, M. (2018). Factors Affecting Where Commuters Park Their Bicycle at Railway Stations: A Case Study of Melbourne, Australia. *2017 Transportation Research Board Annual Meeting.*

WELIWITIYA, H., ROSE, G. & JOHNSON, M. (2017). Factors influencing commuters' bicycle parking choices at suburban railway stations. *Proceedings of the 39th Australasian Transport Research Forum, Auckland, New Zealand.*

ROSE, G., WELIWITIYA, H., TABLET, B., JOHNSON, M. & SUBASINGHE, A. (2016). Bicycle access to Melbourne metropolitan rail stations. *Proceedings of the 38th Australasian Transport Research Forum, Melbourne, Australia.*

Declaration

I hereby declare that this thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

This thesis includes one original paper published in a peer reviewed journal (Journal of Transport Geography). The core theme of the thesis is on bicycle train intermodality. The ideas, development and writing up of this paper in the thesis were the principal responsibility of myself, the student, working within the Department of Civil Engineering under the supervision of Professor Geoffrey Rose and Dr Marilyn Johnson. The inclusion of co-authors reflects the fact that the work came from active collaboration between researchers and acknowledges input into team-based research.

In the case of Chapter 4 my contribution to the work involved the following:

Thesis Chapter	**Publication Title**	**Status** *(published, in press, accepted or returned for revision)*	**Nature and % of student contribution**	**Co-author name(s) Nature and % of Co-author's contribution***	**Co-author(s), Monash student Y/N***
Chapter 4	*Bicycle train intermodality: effects of demography, station characteristics and the built environment.*	*Published*	*80%: Concept development, data collection, data analysis, and interpretation. manuscript writing*	*1) Geoff Rose, concept and design, data collection guidance and publication preparation: 10%* *2) Marilyn Johnson, concept and design, data collection guidance and publication preparation: 10%*	*No* *No*

I have not renumbered sections of the published paper in order to generate a consistent presentation within the thesis.

Student signature: Signed off **Date:** 28/02/2020

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the student's and co-authors' contributions to this work. In instances where I am not the responsible author I have consulted with the responsible author to agree on the respective contributions of the authors.

Main Supervisor signature: Signed off **Date:** 28/02/2020

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Chapter 1 Introduction

Access to commuter rail services, particularly the “first mile” link from home to the station, is an important dimension of the transport chain that is often overlooked in traditional transport planning (Semler & Hale, 2010; Brons et al., 2009; Rietveld, 2000; Replogle, 1993). This is potentially problematic, given commuters’ perception of the quality of the access link can influence their choice to travel by public transport (Givoni & Rietveld, 2007). Therefore, the promotion of convenient, efficient and cost-effective ways to get to and from railway stations is vital.

In Australia, most urban transit trips at the activity-end are dominated by walking or connections to other public transport services (Keijer & Rietveld, 2000), whereas at the home-end, access to public transport is primarily made on foot or by private motor vehicle (Public Transport Victoria, 2018b). As the population in major cities grow and transit patronage rises, demand to access railway stations by private vehicle is also forecast to increase. This will lead to localised station precinct congestion issues while requiring expensive parking facilities. Promoting the use of sustainable access modes for the “first mile” link of public transport trips is paramount. Encouraging mode shift from private vehicular access to cycling is one such possibility, providing social, health and economic benefits. However, lack of priority in planning and policy direction has resulted in the full potential of bicycle-train intermodality not being realised. This presents several key questions that need to be asked by policy makers, public transport authorities and operators:

1. How will rail commuters access the station?
2. What parking/storage facilities must be provided to deal with increasing rail patronage numbers?
3. What are the implications of accessing public transport on different access modes?
4. What is needed to encourage more cost-effective access modes such as cycling?

With the increasing popularity of cycling (Australian Bicycle Council, 2015; Garrard, 2009), research attention on cycling has also increased (Handy et al., 2014). However, to date there has been limited research into the integration of cycling and train use. It is important to address this knowledge gap to ensure an evidence-based approach is taken to maximise the benefits of bicycle-train intermodality. In response to this gap, the focus of this research was to explore the factors affecting commuters’ decision to cycle to the train station.

The remainder of this chapter presents an introduction to cycling as a station access mode in an Australian context, focusing primarily on Melbourne, the capital city of the south eastern state of Victoria. The rationale for promoting the use of the bicycle is also outlined. The chapter concludes with an overview of the broad research aims and a description of the thesis structure.

1.1 Research relevance

This section outlines the context and justification for the research conducted in this doctoral program.

1.1.1 Urbanisation and its impacts on transport

Urban densification is becoming an increasing challenge across the globe due to the concentration of the worlds' population around urban centres. With the continual growth of the global population coupled with population redistribution, the scale of urbanisation is at unprecedented levels. Globally, in 1950, 751 million people were concentrated in urban areas, this number rose to 4.2 billion in 2018 and is projected to rise to over 6 billion by 2050 (United Nations, 2018b).

Australia is not immune to this intense urban densification and meeting the transport needs of Melbourne's population is a cornerstone issue impacting liveability and accessibility of its residents. Primarily led by a net growth in population, rates of urban living are forecast to increase by over 90 percent by 2050 (United Nations, 2018a). This issue is particularly prevalent in Melbourne, with the current 4.4 million metropolitan population expected to exceed 7 million by 2040, surpassing Sydney to become the most populous city in Australia (Victorian Department of Environment Land Water and Planning, 2016). The sheer scale of the growth will increase the demand for services and put further pressures on existing and anticipated future infrastructure facilities (Victorian Department of Premier and Cabinet, 2017).

The need to maintain mobility options for a growing population, while paramount, is a challenging issue. Figure 1-1 shows the changes in travel mode patterns over time in Australia and highlights the importance and dependence on private motor vehicles.

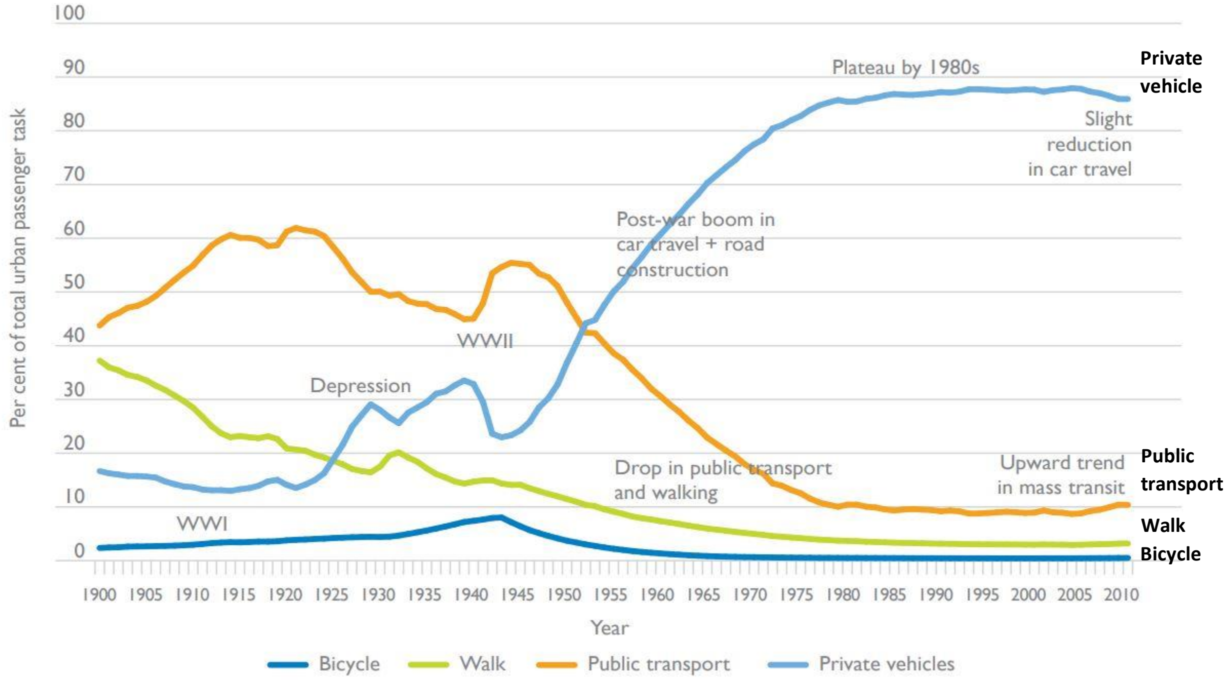

Figure 1-1: Travel mode patterns in Australia
Source: Cosgrove (2011)

Since the end of World War II, the use of private motor vehicles has risen with a concurrent decrease in walking, cycling and the use of public transport (Cosgrove, 2011). Nearly three quarters (70%) of the commuters who travel fewer than five kilometres to work or study do so by car, this increases to 83 percent for those travelling between five and ten kilometres (Australian Government Department of Infrastructure and Transport, 2013). It is projected that Melbourne's transport network will need to support an extra 10.6 million trips a day by 2050, up from the current 13.4 million (Transport for Victoria, 2017). If the current mode share trends continue into the future, congestion will be a major constraint on mobility and annual costs are projected to increase from $13 billion to $30 billion by 2030 (Bureau of Infrastructure Transport and Regional Economics (BITRE), 2007).

1.1.2 The role of public transport

Public transport services have a crucial role to play in addressing the above challenges through the efficient movement of people. In Melbourne, patterns of commuting highlight that there is a concentration of trips made from suburban areas to the inner-city area/central business district (CBD), which has an agglomeration of services and supports the highest density of jobs in the state (see Figure 1-2).

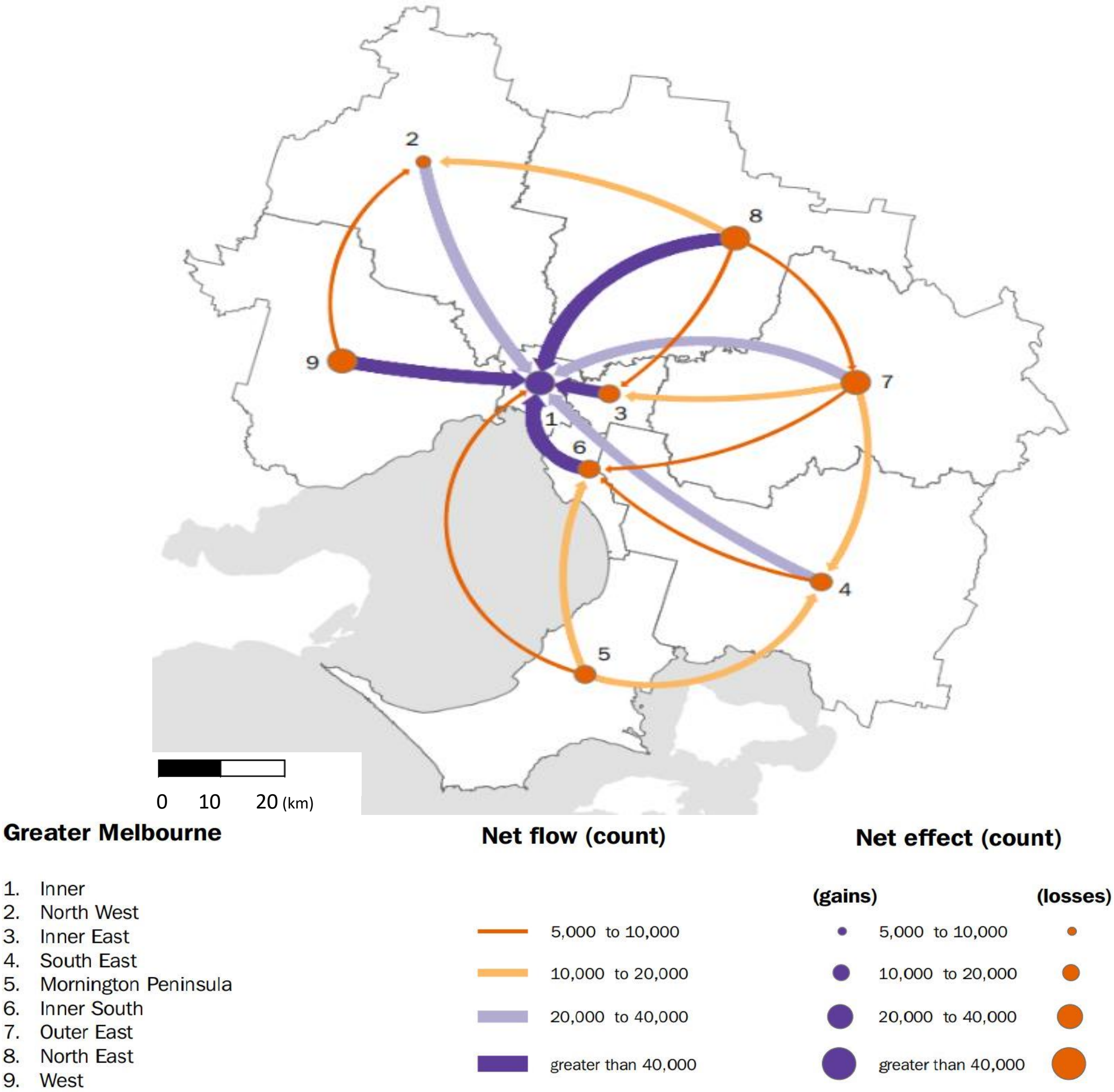

Figure 1-2: Net flow of trips into the Melbourne Central Business District (CBD)
Source: Australian Bureau of Statistics: Journey to Work, 2016

Commuter trips into the CBD can be serviced efficiently by the rail network. The metropolitan train network connects Melbourne's outer, mid and inner suburbs to the CBD with 405 kilometres of track length, 16 operational lines across 220 stations (see Figure 1-3). In 2016, it serviced 235.4 million passenger trips, accounting for higher patronage levels than the other metropolitan public transport services, tram and bus combined (Public Transport Victoria, 2018b). Overall, patronage levels have increased by 6.2 percent over the last five years (Public Transport Victoria, 2018a), with demand for public transport services expected to increase by 89 percent by 2031 (Infrastructure Australia, 2015).

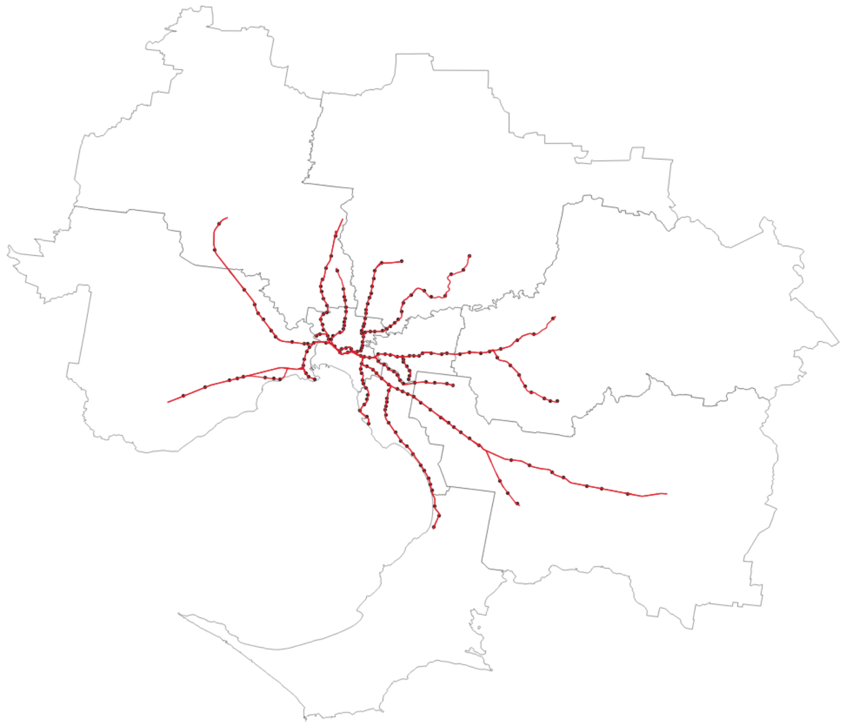

Figure 1-3: Melbourne's metropolitan rail network

To deal with such growth, the state government is investing in rail network capacity increases and improvements to enhance reliability and efficiency. Actions include major investments to increase or improve infrastructure: including the extension of inner Melbourne underground tunnel network, $11 billion; link to Melbourne Airport, $10 billion; Regional Rail Revival Program, $1.7 billion; purchasing 28 high capacity metro trains; enhancing rail system signalling; and, removal of 75 congested or dangerous level crossings (State of Victoria - Department of Premier and Cabinet, 2017). However, an important question that is often overlooked is: how will people access the railway stations?

1.1.3 The station access task

Currently in Melbourne, walking is by far the most common mode of getting to the station with over 400,000 weekday daily trips accounting for half of all commuters (56%) (Public Transport Victoria, 2018b). Car-based station access is the second most common mode with 136,000 daily weekday entries (18%). Other public transport that connects to the train station services account for approximately a quarter of commuters (train: 11%; bus: 8%; tram: 6%). The bicycle is the lowest access mode, accounting for less than one percent of commuters in Melbourne (Public Transport Victoria 2018). This is in stark comparison to the access mode share in the Netherlands (see Figure 1-4), where cycling has the largest share and accounts for almost half (43%) of all station access modes (Kennisinstituut voor Mobiliteitsbeleid, 2017).

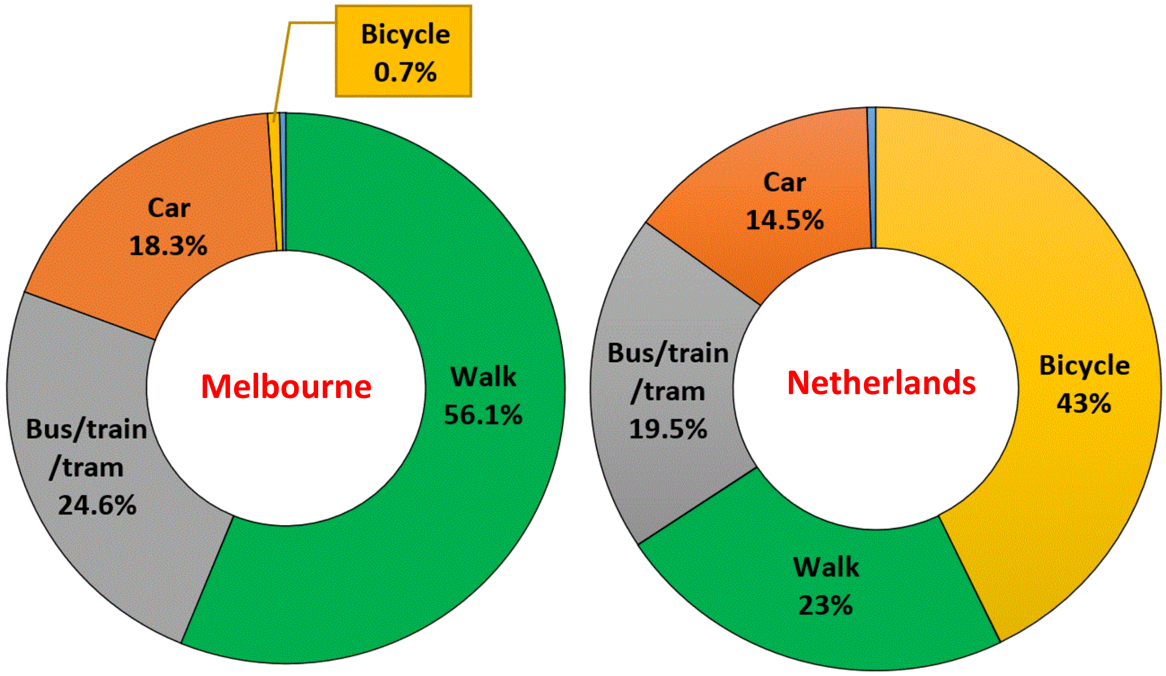

Figure 1-4: Station access mode share
The blue areas indicate 'other' marginal access modes such as by taxi

The demand for vehicular based station access will increase with the forecast rise in rail patronage levels, adding to the strain on existing car parking facilities. Currently, car parks at stations reach capacity well before the start of the AM peak period with overflow parking spreading into neighbouring streets and impacting local residents. The Government's response, to date, has been to build new station car parking facilities, which is a resource intensive endeavour. At almost $14,000 per additional car parking space, the current proposal by the Victorian Government to increase station car parking spaces from 38,000 to 49,000 will cost $150 million (Premier of Victoria 2018). As stations in metropolitan areas are landlocked with limited available space, provision of additional car parking often requires expensive, multistorey car parking solutions (Carey and Lucas 2015). Recently, a multistorey facility was built at a suburban station (Syndal) providing 250 new car parking spaces at a cost of $10.8 million. This equates to approximately $40,000 per car parking space.

Even with such increases in car parking capacity, the demand for dedicated station parking outstrips current supply leading to increased levels of car parking related congestion issues affecting areas in close proximity of the train stations (Mead et al., 2016). Alternative access modes need to be encouraged, both to meet public demand and as an economic and environmentally responsible priority.

Cycling can be part of the solution to manage future station access capacity issues as bicycle catchments between 3-5 km (Martens 2004), are comparable with most motor vehicle access trips to train stations. For example, in Perth in Western Australian, half the demand for park-and-ride was generated within a four kilometre radius of the station (Evans et al. 2004). Therefore, the bicycle provides a feasible mode shift alternative for station access trips. This is best exemplified in the Netherlands where cycling to the train station is encouraged as part of a multimodal mobility option providing a convenient door to door option, offering flexibility and reducing travel times (see Figure 1-5) (Martens, 2007). With half of households in Australia owning at least one bicycle (Australian Bicycle Council, 2017) and almost 1.4 million bicycles sold in Victoria in 2015 (Transport for Victoria, 2017), there is significant potential for the bicycle to have a greater share in the station access task.

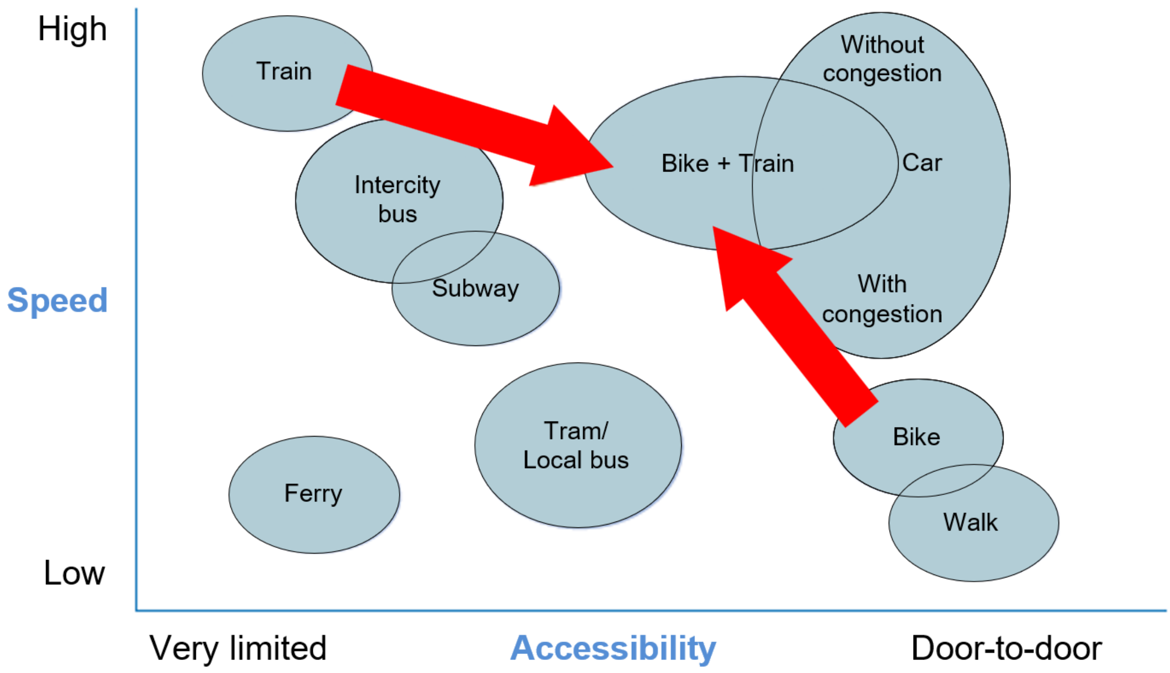

Figure 1-5: Speed and door-to-door accessibility of bicycle train intermodality
Source: Kager et al. (2016)

Often referred to as bike-and-ride, cycling to the station provides many secondary benefits. When commuters shift their mode from driving to cycling, incidental exercise improves individuals' physical fitness (Beavis & Moodie, 2014) and, reduces motor vehicle congestion and transport externalities such as air/noise pollution (Litman, 2013; Woodcock et al., 2007). There is also an economic basis for encouraging a greater bike-and-ride share compared to facilitating motor vehicle-based access. Cycling infrastructure is considerably less expensive and the footprint of land area needed to cater for cyclists' parking needs are much smaller (Martin 2009). In contrast to the unit costs associated with car parking facilities, the provision of bicycle parking facilities in Melbourne costs in the order of $250-1,000 for the installation of a single bicycle hoop and up to $4,000 per caged bicycle space (Martin and den Hollander 2009). Further, at stations where passengers are willing to lock their bicycles to existing poles or fences the cost of provision for bicycle parking facilities is effectively zero. However, for dedicated bicycle parking facilities at station to be economically feasible, they need to be utilised by attracting more bike-and-ride users and shifting people out of private cars.

Factors influencing the share of bike-and-ride users are closely linked with cycling for other trip purposes (Pucher & Buehler, 2009). In Australia, barriers to cycling include concerns about safety, lack of cycling infrastructure, sharing the roads with cars and, high speed zones inhibit a greater uptake of cycling for commuting purposes (Johnson et al., 2010; Bauman et al., 2008). Cyclists are one of the most physically vulnerable road user groups (Stevenson et al., 2016), with limited protection in the event of a collision and low physical tolerance to excessive forces. In addition to safety, other factors such as the built environment, presence/absence of cycling infrastructure, government policies, demographics and availability of storage facilities play a role in the levels of cycling (Barajas, 2012; Haworth, 2012; Pucher & Buehler, 2008).

Despite similarities shared between the factors affecting commuter cycling and bike-and-ride, a close examination of the participation rates indicates a dramatically difference exists. The 2017 Australian national cycling participation survey revealed about one percent of the sample (n = 9,984) had taken part in bicycle-train intermodal travel within the last month, consistent with the official station access mode share in Melbourne. In contrast, about ten percent had used a bicycle as the main mode of travel for commuting purposes at least once within the last month (see Figure 1-6). The research output for cycling as the main mode of travel, either for commuting or utilitarian travel, has increased (Handy et al., 2014). The level of research output related to the integration of cycling and train use is limited and presents a significant gap in knowledge.

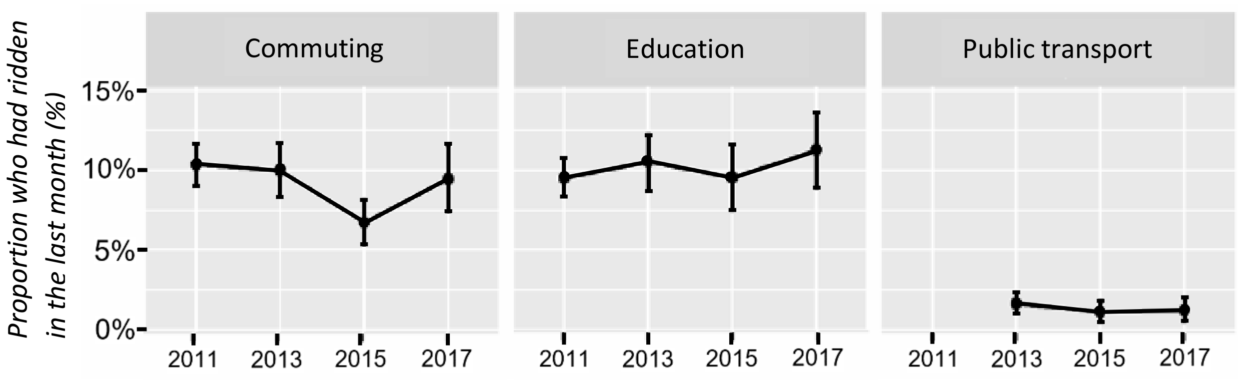

Figure 1-6: Cycling participation rates
Source: (Australian Bicycle Council, 2017)

Policy initiatives to encourage commuters to ride to the station are very much at their infancy in Australia and Melbourne (Semler & Hale, 2010). Caged bicycle parking facilities were first installed at railway stations in Victoria in 2008, mainly to offer a secured parking option and deter commuters from taking their bicycles on-board trains (Martin & den Hollander, 2009). Marketed as ‘Parkiteer’, 23 bicycle storage cages were installed across the rail network, each capable of storing 26 bicycles. Features of the Parkiteer include: a physical barrier between the bicycle and the general public and electronic swipe card access for registered users. Several other initiatives to encourage bike-train integration have specifically been outlined in the Victorian Cycling Strategy 2018-28 (Transport for Victoria, 2017):

1. Prioritise cycling networks to train stations and improving bicycle infrastructure at the station;
2. Amend the Victorian Planning Provisions to improve outcomes for cyclists in the planning phase;
3. Work with local governments to provide pathways and signs directing people to public transport services; and
4. Improvement end of trip facilities at stations and investigating more-flexible bicycle-parking options, especially in high-demand areas.

A focus on building safe environments for cyclists through appropriate infrastructure in conjunction with education, information and promotional activities have also been proposed (Australia Government Department of Infrastructure and Transport, 2012). Given the disparity in the rates of cycling to stations and cycling for other trips, further research is required to better understand the behaviour of bike-and-ride users and the potential for bicycle use among current rail commuters.

1.2 Broad research aims

There has been limited research output focusing on understanding bicycle-rail integration. The research to date has mainly focused on identifying objective factors that affect bike-and-ride rates in countries such as Netherlands which have a high cycling rate for other trip purposes. The context of these studies is substantially different to a re-emerging cycling nation such as Australia. To address this knowledge gap, this research program aimed to:

- Better understand the factors affecting commuters’ choice to use the bicycle as a station access mode; and
- Explore the potential market share for cycling and the likely mode shift to the bicycle as a station access mode.

1.3 Thesis structure

This chapter established the context for this research and provided an introduction to the issues and challenges related to bicycle-train integration. In Chapter 2, the focus is placed on the review of published scientific literature and key knowledge gaps were identified. Following this, Chapter 3 outlines the methodological approach taken in this research program to address the knowledge gaps, including rationale for utilising the Theory of Planned Behaviour as a theoretical framework and the identification of key research questions.

Four research studies were formulated, with each study focused on answering a key research question. The four studies are presented in separate chapters from Chapter 4 to 8. Chapter 4 (Study 1) explored the objective factors[1] (built/natural environment, demographic and station attribute) and their effects on the rates of bicycle access to stations within the metropolitan rail network. Three publications resulted from this study. Chapter 5 (Study 2) drew on primary data gathered from current bike-and-ride users to explore the bicycle parking needs at railway stations and factors affecting bicycle parking choice. Two publications resulted from this study.

A single data collection exercise was undertaken to inform Studies 3 and 4. This involved conducting a rail commuter intercept survey at 13 railway stations, targeting participants across different station access modes. Chapter 6 details the survey methodology. Chapter 7 (Study 3) explored the effects of latent factors[2] on the choice to cycle to the station using the Theory of Planned Behaviour and structural equations modelling was used to determine the relative importance of the latent measures on the intention to ride to the station. Chapter 8 (Study 4) provided a rich understanding of the behavioural dimension of the station access task by bicycle. It explored the latent market share and mode shift potential of the bicycle in replacing other station access modes. Chapter 9 presented a discussion of the research findings in relation to the broader scientific literature, key learnings to inform public policy or action and future topics for research into the area.

This thesis includes published work which meet the requirements of Monash University. All papers published during the PhD candidature have been peer-reviewed.

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[1] Objective factors are those which are measurable and observable. For example, this includes the number of cyclists observed riding to the station and elements of the built environment such as road network connectivity.

[2] Latent factors are theoretical constructs which cannot be directly observed such as attitudes and intention. Such latent constructs are abstract in nature and not able to be observed directly. Hence these variables are measured indirectly through observed actions or self-reporting.

Chapter 2 Literature review

Intermodal travel specifically the integration of cycling and rail use, relates to a variety of transportation research areas. In this chapter, the scope and focus will be on the two main strands which are the most relevant to this study. The first relates to commuter cycling when the bicycle is the main mode of travel and the second, more specifically aligned to this doctoral research program, is bicycle-rail integration.

This chapter continues with a description of the approach used for the literature review as there were two key stages. The first was an exploratory review of the literature focused on an overview of the factors affecting rates of commuter cycling as the main mode of travel. The exploratory review then informed a systematic literature search and a synthesis of literature relating to the factors influencing bicycle-rail integration. The synthesis of the literature is the primary focus of this chapter and provides a critical examination of the small but growing body of literature on bicycle-rail integration. Through the synthesis, the current gaps in knowledge were identified.

2.1 Literature review approach

The approach adopted for the literature review was to focus on two key aspects most relevant to cycling as a station access mode (Pan et al., 2010). These relate to:

- Commuter cycling, when the bicycle is used as the main mode of travel; and
- Bicycle-rail integration, when the bicycle is used for the station access link.

Key to identifying ways to encourage greater levels of bicycle access to stations is to understand the correlates associated with this task. The focus of this review was to explore the factors that contribute to the use of cycling as a station access mode. As general bicycle ridership rates are reported to influence the levels of bike-and-ride (Martens, 2004), factors which contribute to cycling as a mode of travel were also explored.

2.1.1 Exploratory review

In the exploratory search of the literature, key phrases such as ‘commuter cycling’, ‘cycling for transport’ and ‘bicycle use and active transport’ were used to search several indexed databases (Google Scholar, ScienceDirect and Scopus). Only peer reviewed articles were considered. The reference list from each article was scanned and other papers of interest were selected for further reading. This process continued until a sufficient knowledge base was developed with respect to commuter cycling. This understanding informed the development of the main descriptors of key concepts used for the systematic literature search.

2.1.2 Systematic search

The protocol used for the systematic literature search originated from the health sciences and is the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA Statement). The PRISMA statement outlines a structured search approach that is comprehensive and ensures repeatability. The PRISMA flow diagram (Figure 2-1), details how relevant articles related to bicycle-rail integration were selected for inclusion in the review.

The process was initiated by stating a clear and concise question related to the research program:

- What factors significantly influence the choice to access public transport services by bicycle?

The research question was used to guide the selection of key search concepts. *Bicycle* and *Public transport* were defined as the key search concepts, accounting for the intermodal nature of bike-and-ride behaviour. For each search term, variations and combinations of each word were identified and formed into a search phrase using Boolean operators:

- *(bicycl* OR bik* OR cyclist* OR cycling OR pedal* OR active transport*) AND (public transport* OR mass transit OR transit OR station OR train OR rail OR railway OR railroad* OR subway*)*

Using the search phrase, a systematic literature search was conducted in October 2016. The phrase was searched on eight online databases (see Table 2-1), with a separate Endnote library created for all the publications identified. Across all databases, a total of 6,633 citations were identified. Duplicates were then removed resulting in 5,024 citations. All titles and abstracts were then screened by two reviewers to identify publications which addressed the research question. Citations with disagreement between the reviewers were resolved by a third person who acted as an independent adjudicator.

From the screening process, 75 articles were identified for full review. Each of the articles were examined and an assessment on its eligibility was determined based on whether it addressed the research question. Of these, a total of 25 articles were excluded after the full text was read, reasons for exclusion were: lack of relevance to bicycle-public transport integration, focusing on the last mile link, studies grouping cycling and walking together as ‘active transport’, non-peer reviewed articles and articles not in English. Articles that were included following this stage (n = 50) were incorporated into the qualitative synthesis of the literature. This process is outlined in Figure 2-1.

Table 2-1: Databases incorporated in the systematic search (limited to peer-reviewed articles)

Database	**Returned**
Cochrane Library	24
EBSCOHost	1454
EMBASE	1076
Medline	764
ProQuest Research Library	732
PsycINFO	165
Scopus	726
Web of Science	1692
Total	***6633***

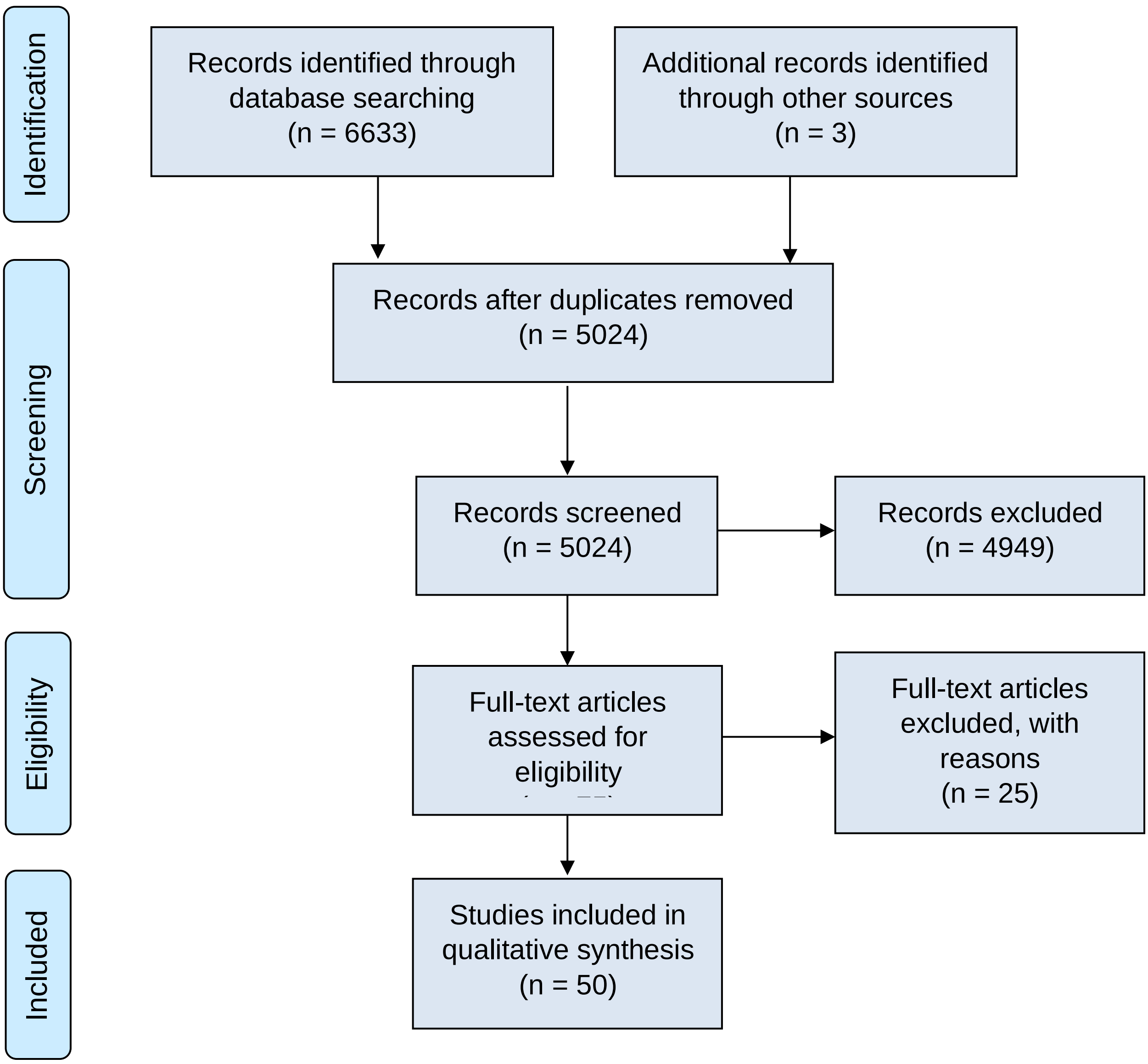

Figure 2-1: PRISMA flow chart

Having outlined the protocol used for the literature review, the following sections will focus on the evaluation of the content.

2.2 Commuter cycling: an exploratory review

Cycling participation is influenced by a diverse range of factors which contribute to the varying cycling rates observed across the world (see Figure 2-2). European countries have some of the highest rates of commuter cycling, with some cities reporting a quarter of all urban trips by bicycle (Pucher & Dijkstra, 2000). In Australia, rates of cycling are noted to be low, however, gauging reliable national participation rates is difficult as few comprehensive surveys are available to accurately measure such levels. Frequently cited is data from the Australian Household Census, specifically the data related to the Method of Travel to Work. Data from the 2016 Australian Census reported approximately 1.1 percent of work-related trips are made on a bicycle, marginally lower than the 1.2 percent noted in the 2011 Census (ABS, 2016; ABS, 2011). The use of journey to work data, however, has many limitations (Pucher et al., 2011). Particularly since the data is collected on a single day in winter when cycling participation rates are generally low. In contrast, the Australian Bicycle Council, which conducts a biennial telephone survey, has noted increased rates of participation between 2011 and 2015 (Australian Bicycle Council, 2015). The Cycling Participation Survey estimates four million Australians ride a bicycle in a typical week and a little over a third of the population ride a bicycle each year, either for recreation or transport.

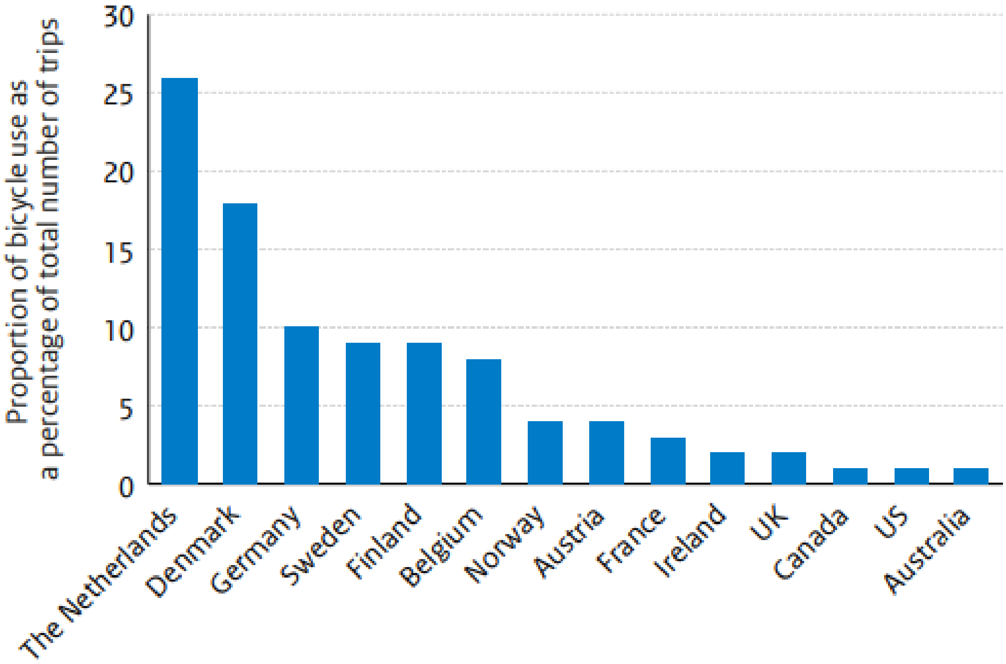

Figure 2-2: Commuter cycling rates

Source: (KiM, 2018) adapted from (Pucher & Buehler, 2012)

The literature, to date, has identified several significant factors which account for the varying rates of commuter cycling participation levels across nations: *government policies, safety/perceived safety, built environment,* and *culture and demographics*.

Government policies and planning practices are contributing factors which can help to explain the disparity in cycling rates across countries (Pucher et al., 2010). Precedents set by the Netherlands, Denmark and Germany demonstrate that an increase in bicycle ridership can occur in response to changes across government policy areas including transport, land use, urban development, taxation and parking. In the case of the Netherlands, an increase in cycling participation rates has, in part, been driven by significant and continued investment in cycling infrastructure. Per capita, the Netherlands spends approximately $25 on dedicated cycling infrastructure in contrast to $10 in Australia (Alan, 2013). Greater levels of investment for cycling infrastructure is coupled with policies and programs that discourage the use of private motorised transport modes, despite the concurrent growth in car ownership rates (Pucher & Buehler, 2008). These measures range from structuring the road network to prioritise cycling, restricting vehicular traffic on certain roads, supporting low posted speed environments and implementing traffic calming measures (Bicycle Dutch, 2018). In countries with a low share of cycling, such as Australia, historic land use and transport planning practices have prioritised private motorised travel by supporting high posted speeds, a lack of traffic calming measures as part of local area traffic management solutions and the low cost of owning and operating a motor vehicle (Pucher & Buehler, 2008; Pucher & Dijkstra, 2003; Pucher, 1988).

Safety and perceived safety play a crucial role in the uptake of cycling in urban environments. The actual and perceived risk of collisions are a major concern which may lower rates of commuter cycling (Haworth, 2012; Bauman et al., 2008). In re-emerging cycling nations such as Australia, safety concerns stem from the lack of connected cycling infrastructure, requiring cyclists to share roads with vehicles often on road environments with high posted speeds (Garrard et al., 2008). Further compounding this issue is a belief that roads are made to be used with motorised travel. A car-centric culture puts drivers of motor vehicles in the position of power on the road network, relegating other modes, including cyclists (Garrard et al., 2010). In such a context, an increase in trips to work by bicycle in Melbourne and Sydney have seen a rise in serious injury rates (Pucher et al., 2011). In contrast, cycling fatality rates in countries with high levels of cycling activity indicate that as kilometres travelled by bicycle increase the cycling fatality rates decrease contributing to a safety in numbers effect (Jacobsen, 2003). However, it is likely that cycling participation rates in Australia, a re-emerging cycling nation, has yet to reach the tipping point needed to achieve the safety in numbers outcome (Johnson et al., 2014).

Built environment and urban form can facilitate and promote the use of a bicycle for travel (Handy et al., 2002). In part, the high rates of cycling in Europe stem from an environment conducive to cycling. Such environments generally incorporate human scale travel distances through compact and mixed land use patterns and high density living (Nielsen et al., 2013; Fraser & Lock, 2011). Such measures have resulted in the average trip length being half that of comparable trips made in either Australian or North American cities (Pucher & Dijkstra, 2000). Cervero et al. (2009) further classified the different dimensions of the built environment which may influence the uptake of commuter cycling as the *5 D's*. In addition to the density and diversity (land use mix), the urban design, distance to transit and destination accessibility are important measures. The urban design and the influence of the transport network affects route directness, connectivity and travel time which impacts the choice to cycle (Fraser & Lock, 2011; Cervero et al., 2009). Measures to reduce vehicular travel speeds through traffic calming initiatives that prioritise pedestrian and cycling movements, particularly on local roads, may encourage cycling (Martens, 2007). Furthermore, historic built environment strategies in Australia have been to prioritise car-based travel, often at the expense of human scale movement such as cycling and walking. Retrofit solutions to provide cycling infrastructure to separate car and bicycle movements may encourage greater cycling levels.

The culture of cycling can in part explain for variation in cycling participation across populations (Handy & Xing, 2011; Wardman et al., 2007). In countries such as Australia and UK, where cycling is a marginal mode of transport, males are overrepresented in ridership rates and are more likely to be young to middle aged men. In contrast, countries where the cycling share is high, there are more comparable rates of men and women across all age groups (Pucher & Buehler, 2008). In Australia, 70 percent of trips under five kilometres are made using a private motorised vehicle, in comparison to 33 percent in the Netherlands (KiM, 2018; Australia Government Department of Infrastructure and Transport, 2012). As a result of bicycle friendly policies and infrastructure provisions, travelling by bicycle is often convenient, cheap and flexible which contributes to people forming a habit of using the bicycle (KiM, 2018).

2.3 Bicycle-rail integration: a review of the literature

A small but growing body of research was identified in the systematic search. Many of these studies explored cycling as a station access mode in countries that have a high general rate of cycling such as the Netherlands, Denmark and China. However, a sizeable number of studies were conducted in North America with a small number from Australia. Broadly, the researchers have used case study approaches with descriptive and univariate analysis. A small but increasing subset have employed multivariate statistical modelling techniques to identify factors associated with bike-and-ride levels.

In total, 50 articles were identified for inclusion in the synthesis. The articles are summarised and the main factors affecting cycling as a station access mode are presented in Table 2-2.

Table 2-2: Summary of selected bicycle rail integration

Author/Year	Country	Study design	Data analysis	Factors affecting bike-and-ride levels
Replogle (1984)	USA, Europe & Japan	Case study (national bicycle access rates and evolution of various policy and practice measures)	Descriptive analysis of trends	Provision of secure bicycle parking facilities
Replogle (1987)	USA, Europe & Japan	Case study (examination of policy and practice from across Europe, Japan and the USA)	Descriptive analysis of trends & policy analysis	Provision of secure bicycle parking facilities, bikes on-board, bicycle access routes to transit
Replogle (1993)	USA, Japan & Netherlands	Case study (lessons from overseas to increase bicycle-rail integration)	Descriptive analysis of trends & policy analysis	Marketing campaigns, traffic calming, compact land use, limited parking for cars, bicycle parking facilities and perception of cycling being acceptable
Keijer and Rietveld (2000)	Netherlands	Longitudinal case study - Dutch National Travel Survey (n = 5,405)	Descriptive analysis & modelling station access distance	Provision of bicycle parking and access distance to station (1.5-3.5 km)
Rietveld (2000)	Netherlands	Longitudinal case study – station access mode share trends	Descriptive analysis	Accessibility to stations, cycling infrastructure connecting commuters to the station, access distance to station (1.5-3.5 km), policy measures
Dieleman, Dijst and Burghouwt (2002)	Netherlands	Netherlands National Travel Survey (n=126,507)	Multinomial logit modelling	Integrating bicycles on-board public transport services
Rastogi and Krishna Rao (2003)	India	Transit access survey (n=1,449)	Classification and univariate analysis	Policy measures, access distance to station, vehicle ownership
Martens (2004)	Netherlands, Germany & UK	Case study (national commuter surveys focussing on trip characteristics, access mode share and distances travelled from (n = not specified)	Univariate and bivariate analysis	Work and education trip purposes dominate access to stations, faster transport services attract more bicycle access, access distance to station (4-5 km)
Givoni and Rietveld (2007)	Netherlands	Dutch railway customer satisfaction survey (n=2,542)	Linear regression modelling	Provision of bicycle parking, car availability is not a determining factor, distance to station has a negative correlation and the quality of the station
Martens (2007)	Netherlands	Case study (bicycle access rates, parking provision and various policy and practice measures implemented in the Netherlands)	Descriptive analysis of trends & policy analysis	Policy measures, marketing campaigns, investment in quality bicycle parking facilities (visible and close to entrance), bicycle paths within and in between urban areas
Debrezion, Pels and Rietveld (2009)	Netherlands	Dutch railway company satisfaction survey (aggregate data across 1,440 postcodes)	Nested logit modelling	Distance from station has a negative influence on choice to cycle, availability of bike parking has a positive influence on cycling choice and rail service quality has a positive influence on cycling choice

Table 2-2: Summary of selected bicycle rail integration

Author/Year	Country	Study design	Data analysis	Factors affecting bike-and-ride levels
Martin and den Hollander (2009)	Australia	Case study - (Parkiteer usage and catchment analysis at three stations using access swipe card data)	Univariate and Bivariate analysis	Provision of diverse bicycle parking facilities is important, and supply of secure bicycle parking has been noted to encourage mode shift
Pucher and Buehler (2009)	USA & Canada	Case study – (Policy measures and cycling provisions at stations in San Francisco, Portland, Minneapolis, Chicago, Washington, New York, Vancouver and Toronto)	Descriptive analysis of trends & policy analysis	Bicycle parking provisions Bicycle friendly policies such as allowing bicycles on-board public transport services
Burke and Bonham (2010)	Australia & USA	Case study (Cycling in suburbia in an Australian and USA context)	Trends in the share of cycling and a review of available literature	Posted speed environment, traffic calming, culture provision of end of trip facilities and accessibility to transit services
Krizek and Stonebraker (2010)	USA	Case study (Caltrains, Boulder County and Puget Sound) and identification of factors influencing bicycle-rail integration	A review of policy measures along wit factor analysis	Median household income, percentage population between 20 and 39, dwelling density, percent who commute by transit or bicycle at least 3 days per week and length of bicycle lanes
Montgomery (2010)	China	Origin destination survey (n=6,342) and intercept survey (n=1,171)	Travel distance and travel time analysis	Modifying existing conditions to make cycling and transit use complementary, safe and convenient bicycle parking facilities and improving accessibility to stations
Pan, Shen and Xue (2010)	China	Rail commuter survey (n=600) and cyclist station intercept survey (n=300)	Travel characteristics and multinomial logistic regression modelling	Constraints on bicycles on-board, provision of bicycle parking facilities and fear of theft. Low cost, speed, convenience of cycling and access distance to station. Negative attributes of competing access modes (increasing bus stop distances and longer headways) are associated with cycling to the station
Semler and Hale (2010)	Australia & USA	Case study (Reviewed the influence various station access facilities on the rates of cycling to the station)	Review of the literature	Topography, culture, weather, safe bicycle parking facilities with on-street and off-street cycling infrastructure
Amiton (2011)	USA	Case study (Boston)	Policy analysis	Promoting bike share schemes at stations
Bachand-Marleau, Larsen and El-Geneidy (2011)	Canada	Online transport survey (n=1,432)	Market segmentation through factor analysis	Occasional cyclists are more likely to choose cycling as an access mode, cycling infrastructure in suburban areas, provision of bicycle parking facilities at stations and permissibility for bicycles to be carried on-board
Krizek and Stonebraker (2011)	USA	Stated preference survey through focus groups (five communities, n = not specified)	Multi criterion decision making tool	Security concerns rank the highest amongst bike-and-ride users, distance to station

Table 2-2: Summary of selected bicycle rail integration

Author/Year	Country	Study design	Data analysis	Factors affecting bike-and-ride levels
Sherwin, Parkhurst, Robbins and Walker (2011)	UK	Survey of bike-and-ride users (n=135), Bike-and-rider movements observed at two stations in Bristol	Univariate and Bivariate data analysis	Trip purpose (employment), gender (male), habit, saving time and money, desire for exercise, social and cultural context, bicycles on-board, provision of safe and secure bicycle parking facility provision, actual and perceived safety for bike
Zhang (2011)	China	Estimation of the number of cyclists riding to the station based on demographic characteristics and public transport service levels	Linear regression	Attractiveness of public transport, distance from home to station (5-8 km), population density, employment and education related trip purposes as well as bike parking facilities
Andrade and Kagaya (2012)	Japan	Transit survey in a university setting (Hokkaido University, n=410)	Multinomial nested logit modelling	Car availability, distance from station plays a role
Cheng and Lui (2012)	Taiwan	Intercept survey (n=386)	Rasch model to evaluate inconvenience of intermodal travel	Females perceived greater inconvenience with bicycle train integration, commuters who are aware of bike lanes and paths to the station are less inconvenienced. Higher bicycle riding frequencies are less inconvenienced
Djurhuus, Aadahl and Hansen and Glmer (2012)	Denmark	2010 Danish national health survey (n=91,150)	Logistic regression modelling	Availability of public transport is associated with active commuting
L Chen, Pel, X Chen, Sparing and Hansen (2012)	China	Intercept survey at two metro stations (n=1,784)	Multiple linear regression	Distance affects choice to ride, parking facilities close to the station entrance
Monteiro and Campos (2012)	Brazil	Intercept travel survey (n=260)	Univariate analysis	Distance to station noted to be the most cited reason for not cycling. Lack of cycle way connections to the station
Tobias, Maia and Pinto (2012)	Brazil	Household survey in Belem (n= 101), Intercept survey in Recife (n= 1,152) and Salvador (n= 89)	Univariate and bivariate analysis	Age (young), trip purpose (work), income, gender (male), bicycle on-board transit, parking provision at stations, safety concerns, investment in cycling infrastructure
Cervero, Caldwell and Cuellar (2013)	USA	Longitudinal case study – (trends across two BART stations)	Segmentation of stations, descriptive analysis of trends & policy measures	Investment in quality bicycle infrastructure (bike paths and way finding signs), traffic calming (bicycle boulevards), station improvements to facilitate bicycle movement (ramps), provision of bicycle parking facilities and cost to park car at station
Flamm (2013)	USA	Examination of transit service levels, land use and ridership levels	Multivariate regression analysis	Temperature, precipitation, fuel price, miles serviced by transit

Table 2-2: Summary of selected bicycle rail integration

Author/Year	Country	Study design	Data analysis	Factors affecting bike-and-ride levels
Jingxu, Xuewu, Wei and Bao (2013)	China	Intercept survey (n=258)	Binary logit model	Distance to transit, increased barriers and user travel costs associated with non-cycle station access modes (encourage cycling)
W Chen and K Chen (2013)	China	Intercept survey at two stations (Zhonglou and Xiaozhai station)	Demand forecasting	Traffic levels in neighbouring areas and provision of bicycle parking at stations
Wang and Lui (2013)	USA	National household travel survey 2009, 2001, 1995,1990 & 1983	Time series analysis	Trip purpose (work), population density, gender (males) and ethnicity (white)
Chakour and Eluru (2014)	Canada	2010 on-board travel survey by rail authority (n = 3902)	Discrete choice modelling	Males are strongly likely to use active modes to access stations and being employed has a positive influence on active access modes to stations. As travel time to station decreases likelihood of active modes increase
Cui, Mishra and Welch (2014)	USA	2007/08 household travel survey in Baltimore (n = 14,365 households, 876 bicycle trips)	Spatial lag model to model bicycle ridership	Accessibility to stations and transport system surrounding station precinct (high traffic speeds, volumes and presence of freeways have a negative impact)
Djurhuus, Hansen, Aadahl and Glumer (2014)	Denmark	2010 Danish nation health survey (n=28,928)	Logistic multilevel regression analysis	Transport service levels (frequency, network connectivity), accessibility to stations, proximity to the station and density of public transport stops
Heinen and Bohte (2014)	Netherlands	Online survey (n=4299)	Descriptive analysis	Gender (male), education level (high) and positive attitude to cycling and transit
Mueller and Hunter-Zaworski (2014)	USA	Geographic and built environment data extraction in Salem, Oregon	Geographic Information System (GIS) manipulation and bivariate analysis	Accessibility is important in promoting the integration of cycling and transit. Low stress cycling facilities leading to the station
Park, Kang and Choi (2014)	USA	Rail user survey at single station (n=280)	Forward stepwise binary logit model	Distance from station, car availability, gender (males more likely to cycle) and ethnicity (white travellers more likely to cycle). Auto friendly streets (>35 mph) decrease rates of cycling to station
Rawal, Devadas and Kumar (2014)	India	Case study (Delhi)	Review of the existing literature and applying learnings in Delhi	Provision of secure bicycle parking facilities, integration of bicycles on-board, bike rental programs

Table 2-2: Summary of selected bicycle rail integration

Author/Year	Country	Study design	Data analysis	Factors affecting bike-and-ride levels
Hochmair (2015)	USA	On-board travel survey (n=323)	Ordinary least square regression modelling	Train service attributes (connectivity of transit station) are associated with an increase in bicycle access distance, street network intersection density affects access distance, morning peak trips and home-based work trips are associated with increased cycling distance
Lachapelle (2015)	USA	2009 United States National Household Travel Survey (n=25,550)	Negative binomial modelling	The more transit dependent a person is the less likely they had a car and the more likely the integration of cycling with transit
Puello and Geurs (2015)	Netherlands	Dutch railway company satisfaction survey (n=12000 across 35 stations)	Hybrid choice modelling	Trip purpose (education and work), car availability, assess distance greater than 3.6 km is a deterrent, population density and perception of rail network connectivity. Perceptions about the quality and availability of bike parking
Yang, Wang and Li (2015)	China	Commuter intercept survey (n=1310)	Multiple logistic regression	Transfer quality (shorten transfer distance, promote compatible smart card for bike share and transit), provision of bike lanes, trip purpose (touring more likely to cycle), trip distance (3 to 5 km) and perception of convenience and safety
Yang, Zhao, Wang, Lui and Li (2015)	China	Intercept survey at five stations(n=825)	Binary logit modelling	Not satisfied with insufficient bicycle parking facilities and a lack of security is a major concern
Arbis, Rashidi, Dixit and Vandebona (2016)	Australia	Bicycle parking inventory and observation survey at 146 stations	Data segmentation and regression analysis	Passenger entries positively correlated, motor vehicle per person within neighbourhood negatively correlated and security at parking facilities play a role. Income level has a positive relationship
Kager, Bertolini and Brömmelstroet (2016)	Netherlands	Case study of the Netherlands to understand the characteristics of bicycle-train integration	Review of bicycle-train characteristics including travel time, speed and catchment area	Train service attributes (frequency and speed), accessibility by bicycle, quality of cycling infrastructure and road congestions levels. Car parking availability
Mackenbach, Randal, Zhaoand Howden-Chapman (2016)	New Zealand	New Zealand household travel survey (n=482)	Mixed multilevel logistic regression	Low income was correlated with lower rates of cycling rail integration, housing density and land use mix. Transit service frequency and car parking price
Puello and Geurs (2016)	Netherlands	Dutch railway company customer satisfaction survey covering 35 railway stations	Hybrid discrete choice modelling	Perceptions of rail service (network capacity), perceptions of the station environment, quality of parking facilities, land use and the built environment

The comprehensive review identified several themes which were associated with bike-and-ride levels. These themes were organised into eight broad groups:

- Built environment;
- Station environment;
- Public transport service quality;
- Provision of facilities for competing modes;
- Latent factors;
- Trip and user characteristics;
- Weather and Safety; and
- Policy measures.

The following subsections outline a review of the literature specific to each theme. Individual factors, their influence on the rates of bicycle access to stations and the sources of literature are outlined in summary tables at the start of each subsection. For each factor, a positive association is note with a '+' sign, and a negative influence is marked with a '-' sign.

2.3.1 Built environment

Nine built environment factors were identified to influence rates of bicycle access to station. The factors and the related studies are included in Table 2-3.

Table 2-3: Contributing factors – built environment

Factor	Influence	Source
Vehicle volumes	-	(Cui et al., 2014); (Park et al., 2014)
Posted speed limit	-	(Burke & Bonham, 2010); (Park et al., 2014)
Cycling infrastructure	+	(Rietveld, 2000); (Martens, 2007); (Semler & Hale, 2010); (Bachand-Marleau et al., 2011); (Cheng & Liu, 2012); (Monteiro & Campos, 2012); (Tobias et al., 2012); (Cervero et al., 2013); (Mueller & Hunter-Zaworski, 2014)
Traffic calming	+	(Replogle, 1993); (Burke & Bonham, 2010); (Cervero et al., 2013)
Accessibility to stations	+	(Rietveld, 2000); (Burke & Bonham, 2010); (Montgomery, 2010); (Cui et al., 2014); (Djurhuus et al., 2014); (Mueller & Hunter-Zaworski, 2014); (Hochmair, 2015); (Kager et al., 2016)
Access distance to station	-	(Keijer & Rietveld, 2000); (Rastogi & Krishna Rao, 2003); (Martens, 2004); (Givoni & Rietveld, 2007); (Debrezion et al., 2009); (Pan et al., 2010); (Krizek & Stonebraker, 2011); (Ying, 2011); (Andrade & Kagaya, 2012); (Chen et al., 2012); (Monteiro & Campos, 2012); (Jingxu et al., 2013); (Djurhuus et al., 2014); (Park et al., 2014); (Yang et al., 2015a)
Land use mix	+	(Replogle, 1993); (Mackenbach et al., 2016); (Puello & Geurs, 2016)
Urban density	+	(Krizek & Stonebraker, 2010b); (Ying, 2011); (Wang & Liu, 2013); (Puello & Geurs, 2015); (Mackenbach et al., 2016)
Topography	-	(Semler & Hale, 2010)

Cyclists are one of the most physically vulnerable road user groups when sharing the road environment with motorised modes. Traffic volumes on road networks which surround station precincts can, therefore, influence the level of cycling activity to railway stations. The presence of roads which accommodate high flow traffic movements, such freeways and arterial roads, have been associated with lower rates of bicycle access to stations (Cui et al., 2014). This may be partially attributed to the increased risk and/or perceived risk of severe injury or death related to cycling on such infrastructure. However, past a tipping point, increased traffic will result in congestion and slower travel speeds. Such conditions may encourage greater levels of rail commuters to access the station by bicycle. Sherwin and Parkhurst (2010) noted traffic congestion was a primary motivator cited by bike-and-ride users, in the UK, as a reason for riding to the station. This suggests cyclists are willing to ride to the station along roads with high vehicular volumes during slow moving flows. Further research is needed to test this hypothesis and understand the volume and speed required to reach this tipping point.

Auto friendly streets that support high travel speeds are associated with lower rates of cycling to the station (Park et al., 2014). This indicates the posted speed environment is a factor which negatively affects rates of bicycle access. In the context of North America, Park et al. (2014) identified roads with a posted speed limit greater than 35 mph had a negative correlation with cycling as a station access mode. Burke and Bonham (2010), based on a review of the literature, hypothesised a similar mechanism would be present in the Australian context. Scope exists as part of this research study to explore the influence of road speed environments on the likelihood rail commuters would choose a bicycle as an access mode. Roadways which support high vehicular speeds may act as a severance point, deterring rail commuters from considering the bicycle to be a viable access option.

Closely related to vehicular speed, the literature suggests traffic calming measures are associated with increased levels of bicycle access to stations (Cervero et al., 2013; Burke & Bonham, 2010; Replogle, 1993). Implementing traffic calming strategies such as bicycle boulevards may promote cycling as a viable station access mode.

Where road environments are not conducive for cycling, either due to high traffic volumes or travel speeds, the provision of dedicated infrastructure is important to physically separate cyclist and motor vehicles. Provision of cycling infrastructure (on-road, off-road and shared paths) has been associated with increased cycling access rates to stations (Mueller & Hunter-Zaworski, 2014). In the context of the Netherlands and North America, provision of low-stress infrastructure facilities, en route to the station, are associated with greater levels of bike-and-ride behaviour (Cervero et al., 2013; Martens, 2007; Rietveld, 2000). These research studies have taken a case study, descriptive analysis approach ranging from the study of two BART stations (Cervero et al., 2013) to the wider network level implications of infrastructure policy on the rates of station bicycle access (Martens, 2007). An important research gap is to understand the influence of cycling infrastructure, those that are specifically found within a cycling catchment area of railway stations. Furthermore, given the increasing demands on already congested urban road networks, it is essential that robust analytical methods are applied to establish correlations between infrastructure provision and the rates of cycling to the station.

The quality and quantity of cycling infrastructure is also noted to play a role in attracting cyclists. Krizek and Stonebraker (2010a) recognised the provision of adequate cycling infrastructure to be consistently among the top three most influential factors affecting current bike-and-ride users' choice to ride to the station. The importance of quality infrastructure provisions is further reiterated by Cheng and Liu (2012). Analysis of transfer penalties revealed the perceived inconvenience of the intermodal nature of bike-and-ride trips were lower for cyclists aware of bicycle infrastructure facilities en route the station. Despite the importance of quality well connected cycling facilities, a gap in the literature exists related to objectively measuring the provision of such facilities and its resulting influence on station access rates.

Accessibility to stations is another component which positively influences the choice to ride to the station (Cui et al., 2014; Djurhuus et al., 2014; Montgomery, 2010; Rietveld, 2000). Accessibility is, in part, a measure of the directness to railway stations. Scheltema (2012) described directness to encompass linearity of the route from home to station, continuity of infrastructure to access the station and right of way for cyclists. Accessibility has also been evaluated using proxy measures, Hochmair (2015) explored the impact of street network intersection density in affecting the rates of bicycle access. However, few studies have utilised geographic information systems (GIS) to extract and study attributes of the built environment and its relationship with the station access rates by bicycle.

The distance of the "first mile" station access link is noted to influence the choice to cycle. Much of the literature conducted in a European context suggests access by bicycle is made within 1 to 5 kilometres from the transit service, with faster transit modes supporting a larger catchment area (Hochmair, 2015; Martens, 2004; Rietveld, 2000). Comparatively, in China, Ying (2011) identified greater access distances, typically 5 to 8 kilometres. Access distance is context dependent and can be affected by intrinsic properties of the road network and geographic features surrounding each station (Hochmair, 2015; Barajas, 2012; Rodríguez & Joo, 2004). However, given differences in auto-dependence and priority, it is unlikely that findings from Europe or China will be transferrable to the Australian context where cycling is still re-emerging. This research gap, to explore the catchment distances of bike-and-ride users in the Australia context will be addressed in this doctoral study.

Furthermore, few studies have explored the effects of land use on the rates of bicycle access to stations. In studies conducted in New Zealand and the Netherlands a diverse land use mix is associated with greater bicycle access rates to stations (Mackenbach et al., 2016; Puello & Geurs, 2016). In both studies, GIS was used to extract detailed land use attributes surrounding station catchment areas. Land use characteristics generally vary based on contextual settings and it is important to understand the influence of land use on cycling access rates in Melbourne.

Urban density is another aspect of the built environment noted to influence bicycle access rates (Ying, 2011; Krizek & Stonebraker, 2010a). Urban density has been measured using several metrics, Wang and Liu (2013) identified a positive relationship between population density and greater bicycle access trips whereas Mackenbach et al. (2016) noted a similar relationship with housing density.

Finally, Semler and Hale (2010) reviewed the general commuter cycling literature and hypothesised topography would have an influence on the station access rates by bicycle in Australia. The hypothesis of the correlation between urban density and topography and bike-and-ride use will also be explored in this doctoral research.

2.3.2 Station environment

Characteristics of the station environment have been associated with the choice to access transit by bicycle. Three key aspects of the station environment have been identified which positively influence the rates of cycling activity to stations (Table 2-4).

Table 2-4: Contributing factors – station environment

Factor	Influence	Source
Provision of bicycle parking facilities	+	(Replogle, 1993); (Keijer & Rietveld, 2000); (Givoni & Rietveld, 2007); (Martens, 2007); (Debrezion et al., 2009); (Martin & den Hollander, 2009); (Pucher & Buehler, 2009); (Burke & Bonham, 2010); (Montgomery, 2010); (Pan et al., 2010); (Bachand-Marleau et al., 2011); (Ying, 2011); (Tobias et al., 2012); (Cervero et al., 2013); (Chen & Chen, 2013); (Puello & Geurs, 2015); (Yang et al., 2015b); (Puello & Geurs, 2016)
Secure bicycle parking available	+	(Replogle, 1984); (Replogle, 1987); (Martin & den Hollander, 2009); (Krizek & Stonebraker, 2011); (Sherwin et al., 2011); (Rawal et al., 2014); (Arbis et al., 2016)
Quality of the station environment	+	(Givoni & Rietveld, 2007); (Chen et al., 2012); (Cervero et al., 2013); (Yang et al., 2015a); (Puello & Geurs, 2016)

Provision of bicycle parking facilities at railway stations was the single most cited factor associated with increased levels of bicycle-train integration (Cervero et al., 2013; Montgomery, 2010; Martin & den Hollander, 2009; Givoni & Rietveld, 2007; Keijer & Rietveld, 2000). Due to the nature of riding a bicycle to the station, the bicycle must either be parked at the station or carried on-board. Peak-period overcrowding issues often make it difficult for cyclists to take their bicycle along on the train journey and some jurisdictions have banned bicycles entirely from being carried on-board (Pucher & Buehler, 2009) although there are some exceptions for folding bicycles.

Studies have further elaborated the specific need for secure bicycle parking facilities to minimise the risk of theft and vandalism. This is a concern in re-emerging cycling nations such as North America where theft rates are much higher than those of more mature cycling nations such as the Netherlands or Japan (Replogle, 1987). Sherwin et al. (2011) noted both the actual and perceived safety for bicycles left at the station can influence the choice to ride to the station.

Availability of parking facilities is another component influencing the choice to ride, particularly when rates of cycling to the station are high such as in the Netherlands (Puello & Geurs, 2015). In the context of Melbourne, where limited bicycle parking facilities are provided at some stations, commuters may have to lock their bicycle onto railing or street furniture (Martin & den Hollander, 2009). Potentially, a key reason for the low share of cycling to stations.

The quality of facilities provided also plays a role in the choice to access the station by bicycle (Puello & Geurs, 2016), and is also closely related to the quality of the station environment (Chen et al., 2012). Quality of the station environment relates to features such as the visibility and proximity of bicycle parking to the station (Arbis et al., 2016). For commuters who are interested and able to take the bicycle on-board, facilities to integrate the transition such as ramps or lifts may encourage access to transit by bicycle (Cervero et al., 2013).

Provision of various bicycle parking facilities help to encourage cycling to stations. While satisfaction levels related to the station access trip are reported to be important (Givoni & Rietveld, 2007), there are limited insights from previous studies focusing on parking satisfaction levels. By understanding user satisfaction levels, provision of parking facilities can be provided which meet security and amenity needs. Further, there has been little focus on bicycle parking choice of cyclists at railway stations. Arbis et al. (2016) explored how active and passive forms of security, proximity of parking facility and patronage rates influence parking choice in Sydney, Australia. However, in Melbourne, bicycle parking facilities provided are substantially different, with secure caged parking, accessed by registered swipe card, provided in addition to traditional open-air bicycle hoops. Arbis et al. (2016) also did not consider access trip characteristics or cyclists' perceptions in modelling bicycle parking choice. These gaps in knowledge, presents an opportunity for further research focussing on bicycle parking user satisfaction levels and the factors influencing bicycle parking choice.

2.3.3 Public transport service quality

The service quality of the public transport system has been noted to affect the rates of bicycle access. Two aspects were positively associated with cycling to the station (see Table 2-5).

Table 2-5: Contributing factors – public transport service quality

Factor	Influence	Source
Transit service quality	+	(Debrezion et al., 2009); (Ying, 2011); (Djurhuus et al., 2012); (Flamm, 2013); (Djurhuus et al., 2014); (Hochmair, 2015); (Puello & Geurs, 2015); (Kager et al., 2016); (Mackenbach et al., 2016)
Passenger entries	+	(Arbis et al., 2016)

Several studies have identified that transit service quality plays a role in attracting cyclists. As the transit component of the trip is usually the main link, it should be well serviced to encourage multimodal connections by bicycle (Ying, 2011). In a Dutch study, Krygsman et al. (2004) identified on average 50 to 70 percent of the travel time for public transport trips are spent on transit services (excluding access and egress). Therefore, aspects such as frequency and connectivity of the public transport system play a role in access mode behaviour (Hochmair, 2015; Djurhuus et al., 2014). The perception of connectivity at public transport stops, to other services, has also been noted to affect rates of bicycle access (Puello & Geurs, 2015). Martens (2004) distinguished that faster public transport modes attracted greater levels of bicycle access from larger catchment areas. The total travel distance is required to be at least 10-15 kilometres to support multimodal journeys by bicycle and transit (Van der Loop, 1997), else an alternative single mode may be used.

As transit quality improves, particularly service frequency, passenger entries are likely to increase. Arbis et al. (2016) noted passenger entries at stations were correlated with the number of bicycles parked at the station. This may be due to an increase in competition for alternative access mode facilities such as car parking and may also relate to greater levels of passive security for bicycles left at those stations.

2.3.4 Provision of facilities for competing modes

The provision of facilities for competing access modes were identified to influence the rates of bike-and-ride users (see Table 2-6).

Table 2-6: Contributing factors – attributes of competing modes

Factor	Influence	Source
Station car parking	-	(Replogle, 1993); (Kager et al., 2016)
Car parking fee	+	(Cervero et al., 2013); (Jingxu et al., 2013); (Mackenbach et al., 2016)
Fuel Price	+	(Flamm, 2013)
Motor vehicle ownership	+/-	(Rastogi & Krishna Rao, 2003); (Andrade & Kagaya, 2012); (Lachapelle, 2015); (Puello & Geurs, 2015); (Arbis et al., 2016)
Increasing bus stop distance	+	(Pan et al., 2010)
Longer bus headway	+	(Pan et al., 2010)

Decreasing the utility of non-cycling station access modes can positively influence the choice of rail commuters to ride to the station. Station access by car is a dominant mode and therefore a key competing option to the bicycle in re-emerging cycling nations such as Australia. Evans et al. (2004) identified that in Perth, Western Australia, half of car related station access trips are generated within four kilometres of the station, well within a cycling catchment area. Availability of car parking facilities at stations can encourage greater levels of vehicular access (Kager et al., 2016). These results suggest that to promote cycling to stations, car parking availability should be reduced. As availability decreases, increased competition for parking bays may make finding a vacant parking facility difficult. In jurisdictions which support a station car parking fee, case studies have identified increased levels of bicycle access to stations (Cervero et al., 2013; Chen & Chen, 2013). Additionally, travel costs associated with motorised access can be a lever to encourage cycling. This is further emphasised with evidence from North America that fuel price can discourage car-based transit access (Flamm, 2013).

Car ownership and its effect on cycling rates is an aspect which is debated in the literature. Studies from several countries including Japan, India, North America and Australia have identified a negative association car ownership and cycling as an access mode (Arbis et al., 2016; Lachapelle, 2015; Puello & Geurs, 2015; Andrade & Kagaya, 2012; Rastogi & Krishna Rao, 2003). In contrast, research conducted in Canada demonstrated car ownership is not influential (Chakour & Eluru, 2014; Martens, 2004). As demand for rail travel increases, station access pressures by car will also grow. Therefore, competition with car-based station access has been investigated in this research program. Specifically, the effects of official car parking capacity at stations and motor vehicle ownership.

Furthermore, Pan et al. (2010) noted the competing effects of bus service provisions and bicycle access rates to stations. The value proposition of using a bus to access railway stations is reduced as the distance to the bus stop increases. In such conditions, the appeal of a bicycle to access rail services increases, particularly given the flexibility, convenience and travel time saving that the bicycle may provide compared to a bus (Van Mil et al., 2018). Also reduction of bus service quality, particularly an increase in bus headway, is noted to make cycling more competitive as an access mode (Pan et al., 2010; Brons et al., 2009). Evaluating the competition with bus services and other linking public transport services are beyond the scope of this research program.

2.3.5 Latent factors

Unobserved or latent factors are critical in motivating a person to undertake tasks involving physical activity including cycling (Titze et al., 2008). Three aspects have been noted to influence bike-and-ride levels (Table 2-7).

Table 2-7: Contributing factors – latent factors

Factor	Influence	Source
Perception of cycling being acceptable	+	(Replogle, 1993)
Positive attitude to cycling and transit	+	(Heinen & Bohte, 2014)
Culture	depends	(Burke & Bonham, 2010); (Semler & Hale, 2010); (Sherwin et al., 2011)

Replogle (1993) identified that perceptions about the acceptability of cycling affect people's choice to access transit services by bicycle. In Japan, community opinion in the early 1970s saw a rise in the use of bicycles to access transit services (Replogle, 1993). However, more recent research identified that middle- and upper-income workers had negative stereotypes of cyclists and were not likely to ride to the station. Cycling was seen to reflect poorly on their socio-economic status, whereas the use of a motorised vehicle was perceived as a status symbol (Tight et al., 2011).

The research conducted to date, has focused on specific attitudinal factors and their correlation with the choice to access the station by bicycle. Positive attitudes held in relation to cycling and transit use independently, was associated with greater levels of cycling to transit services (Heinen & Bohte, 2014). Whereas Puello and Geurs (2016) identified the influence of perceptions related to rail service quality and the station environment on bicycle-train integration. A limitation of identifying individual factors is that they may be context specific or confounded by other factors. To obtain a fundamental understanding of the influence of latent factors, Heinen et al. (2009) noted the importance of framing the research around established psychological theories. However, there has been limited use of such methodological approaches in the bike-and-ride literature and is a fundamental gap in knowledge. In this research program, a theoretical model was used to investigate the influence of latent factors including attitudes, perceived behavioural control, and subjective norms. This is described in detail in Chapter 3.

2.3.6 Trip and user characteristics

Common user characteristics and trip attributes were associated with bike-and-ride behaviour. Across the studies, there is variation as to whether these attributes have a positive or negative association with the rates of cycling to railway stations (Table 2-8).

Table 2-8: Associations – trip and user characteristics

Factor	Influence	Source
Trip purpose	depends	(Martens, 2004); (Sherwin et al., 2011); (Ying, 2011); (Tobias et al., 2012); (Wang & Liu, 2013); (Chakour & Eluru, 2014); (Hochmair, 2015); (Puello & Geurs, 2015); (Yang et al., 2015a)
Low cost of riding	+	(Pan et al., 2010); (Sherwin et al., 2011)
Perceived convenience	+	(Pan et al., 2010); (Cheng & Liu, 2012); (Yang et al., 2015a)
Low travel times and access speeds	+	(Pan et al., 2010); (Sherwin et al., 2011); (Chakour & Eluru, 2014)
Income	depends	(Tobias et al., 2012); (Arbis et al., 2016); (Mackenbach et al., 2016)
Gender	depends	(Sherwin et al., 2011); (Cheng & Liu, 2012); (Tobias et al., 2012); (Wang & Liu, 2013); (Chakour & Eluru, 2014); (Heinen & Bohte, 2014); (Park et al., 2014)
Education level	depends	(Heinen & Bohte, 2014)
Age	depends	(Krizek & Stonebraker, 2010a); (Tobias et al., 2012)

Trip attributes

Studies conducted in varying contexts from the Netherlands, Germany, UK, China to Canada show similar trip purposes amongst rail commuters who bike-and-ride. Access to employment make up a majority of bike-and-ride trips (Wang & Liu, 2013; Tobias et al., 2012; Sherwin et al., 2011; Ying, 2011; Martens, 2004), followed by trips to access educational services (Yang et al., 2015a; Ying, 2011; Martens, 2004). This may be because these trips are often made at peak travel times, where the demand for alternative station access mode provisions, such as car parking, is high. The choice to ride to the station may be related to the assurance of bicycle parking availability at the station, while car parking is unlikely in peak times. As noted in Section 2.3.4, the influence of competing access mode provisions at railway station will be examined on the choice for rail commuters to ride to the station.

The convenience of accessing transit services by bicycle is rated highly amongst current bike-and-ride users (Yang et al., 2015a; Pan et al., 2010). This could, in part, be related to the potential travel time savings resulting from commuting by bicycle to the station (Sherwin et al., 2011). Chakour and Eluru (2014) noted as travel time to stations decrease the likelihood of choosing an active access mode increases. Additionally, once a bicycle is purchased, cycling provides a flexible station access option at no daily cost to the user. The low-cost nature of bicycle station access trip has been identified as an influence in station access mode choice (Pan et al., 2010). These research findings have primarily resulted from a sole focus on bike-and-ride users, the perceptions of these trip characteristics have not been researched from other station access mode users. This presents a knowledge gap that needs further research.

User characteristics

People accessing transit services by bicycle in the Netherlands are reported to have high levels of educational attainment and income compared to the total population characteristics (Kager et al., 2016; Heinen & Bohte, 2014). However, again this is context dependent. In Brazil, income amongst bike-and-ride users is lower than the population average with the composition predominantly being young commuters (Tobias et al., 2012), while in North America, adults aged 20 to 39 years were more likely to ride to the station (Krizek & Stonebraker (2010a). Whereas in the Netherlands there was no correlation between age and the choice to access the station by bicycle (Heinen & Bohte, 2014).

Gender was observed to be associated with the choice to ride to the station. Studies conducted across the Netherlands, UK and China indicate males are more likely to use the bicycle to access transit services (Heinen & Bohte, 2014; Park et al., 2014; Cheng & Liu, 2012). This may potentially be due to females perceiving greater inconvenience with intermodal trips (Cheng & Liu, 2012). Bike-and-ride user characteristics vary across the globe, due to a lack of primary research, insights into the user characteristics in the context of Australia are not well understood. This presents an opportunity for further research to be undertaken focussing on the identification of user characteristics.

2.3.7 Weather and safety

Two other key factors were identified in the literature as having a direct impact on cycling rates to the station. These related to the weather conditions and safety (see Table 2-9).

Table 2-9: Contributing factors – weather and safety

Factor	Influence	Source
Poor weather	-	(Semler & Hale, 2010); Cheng & Liu (2012); (Flamm, 2013)
Safety	+	(Tobias et al., 2012); (Yang et al., 2015b)

As cyclists are exposed to the environment, it may be expected that there is a relationship between choice to ride and weather. Flynn et al. (2012) reported an increase in the likelihood of commuter cycling when there were increased temperatures and an absence of rain, snow or wind. Specifically related to bicycle-rail integration, adverse weather conditions such as rain affect the rates of cycling to the station (Flamm, 2013; Cheng & Liu, 2012; Semler & Hale, 2010). As the act of cycling to the station primarily tends to be for employment or education purposes, there may be a requirement to arrive well-dressed. Given a general lack of end of trip facilities at stations such as showers and change rooms, unlike at some workplaces, adverse weather conditions may have a substantial influence on the choice to cycle among rail commuters. As weather is context specific with different thresholds among people in different regions, the lack of primary research conducted in Australia presents a research gap.

Safety concerns associated with cycling can influence the choice to ride to the station (Tobias et al., 2012). As cyclists are often required to share the road environment with motorised vehicles, the provision of cycling facilities, especially on high trafficked high-speed roads, can promote a sense of safety. Studies have shown the rates of bike-and-ride are low where there is a lack of connected cycling infrastructure, particularly infrastructure which feed into the station precincts (Mueller & Hunter-Zaworski, 2014). Sharing the road environment with motor vehicles in high speed environments heightens the vulnerability of cyclists and increases the likelihood of fatal or serious injury outcomes in the event of a crash. While safety concerns are known to influence cycling behaviour, gaps in the bicycle-rail integration literature include examination of the influence of different road speed environments, associated likelihood of cycling in such environments to the station and the role safety concerns can play in the station access mode choice behaviour. These gaps will be addressed in this research.

2.3.8 Policy measures

Policy measures can affect bicycle access rates to railway stations. The literature specifies three policy measures, identified as having an influence on bicycle access rates (Table 2-10).

Table 2-10: Contributing factors – policy measures

Factor	Influence	Source
Bike share scheme	+	(Amiton, 2011); (Rawal et al., 2014)
Bicycles on-board	+	(Replogle, 1987); (Dieleman et al., 2002); (Montgomery, 2010); (Pan et al., 2010); (Bachand-Marleau et al., 2011); (Tobias et al., 2012); (Rawal et al., 2014)
Marketing campaigns	+	(Replogle, 1993); (Martens, 2007)

Station access mode choice behaviour is influenced by the policy measures implemented in different geographic contexts (Martens, 2007; Rastogi & Krishna Rao, 2003; Rietveld, 2000). In addition to the substantial investment in bicycle parking facilities at stations in the Netherlands, Dutch policies to incorporate flexible rental bicycles at stations has had a positive effect on bicycle-rail integration. Martens (2007) reported a greater proportion of access/egress links for non-recurring public transport trips are completed on bicycles, following the implementation of a bike share scheme. Yang et al. (2015a) postulated, to further promote the use of bike share schemes, smart transit cards should be integrated with bike share payment systems, enabling a seamless transition between transit and access/egress by bicycle. Such measures to incorporate bicycle share schemes at transit stations have been credited with increasing the rates of general cycling in cities that have had low rates of cycling (Amiton, 2011).

Permitting bicycles on-board transit services is a key policy approach that has had a strong positive influence on the choice to ride to the station (Dieleman et al., 2002; Replogle, 1987). Many jurisdictions in North America and Canada do not permit bicycles on-board or have specific time restrictions as to when they are permitted (Pucher & Buehler, 2009). Pan et al. (2010) identified that restricting bicycles on-board can impede the choice to ride to the station as bicycles must be left at the station where commuters may have concerns about theft or vandalism.

Also identified in the literature was an association between marketing campaigns focusing on bicycle transit integration and an uptake of intermodal travel (Replogle, 1993). Public awareness campaigns regarding new parking facilities at rural bus stops in the Dutch province of Brabant saw an absolute growth in the number of bike-and-ride users of approximately nine percent (Martens, 2007). Further, the availability of bicycle garages at stations, which provide parking and maintenance solutions, may also encourage cycling as an access mode (Replogle, 1987).

In order to promote cycling as a viable station access mode, a paradigm shift is needed with respect to policy actions implemented in Melbourne. The doctoral research study will focus on the implications of key findings on various policy measures guiding Victorian transport strategies and practice.

2.4 Summary of the knowledge gaps

Bicycle-rail intermodal travel is a relative new research area. The research to date has mainly focused on case study approaches in countries such as the Netherlands which have a high cycling rate. Comparatively, a lack of primary research has been conducted in re-emerging cycling countries such as Australia. Consequently, little is known about the factors influencing rail commuters' choice to access the station by bicycle. Specific knowledge gaps identified from this literature review are summarised below:

- In a re-emerging cycling nation like in Australia what objective factors affect the uptake of bike and ride? Are these factors substantially different from those countries which have a more mature bike and ride share and if so, what lessons can Melbourne adopt to increase the levels of bike and ride?
- Provision of secure bicycle parking facilities at stations is an important factor in encouraging commuters to cycle to the station. However, a gap in knowledge is understanding what factors affect the choice of bicycle parking facility used after arriving at the station. Ensuring the parking facilities provided are appropriate for cyclists riding to the station is paramount. This also raises a question regarding what are the parking needs of cyclists?

- Unobserved/latent factors are acknowledged to affect the choice to cycle to the railway station. However, the literature is limited and the role these factors play in the choice to bike-and-ride are not well understood.
- What is the potential for mode shift for the bicycle to replace other station access modes? To date, the literature has not explored this potential and insights will be valuable, particularly to policy makers and in relation to future investments to support station access by bicycle.

The following chapter outlines the methodological approach adopted in this research program. The formulation of the research method was crafted to address the above research gaps. Specific research objectives and questions were defined. Detail of the four studies undertaken as part of this doctoral program are also specified.

Chapter 3 Theoretical framework and methodological approach

As discussed in Chapter 2, several research gaps were identified in the literature and were the focus of this doctoral research. In this chapter the scope of the research program including the research aim, objectives and questions are defined. To address the research questions, four separate research studies were formulated, were relevant, drawing on established theoretical frameworks including the Theory of Planned Behaviour (TPB) and Market segmentation approaches. This chapter details each of the four studies conducted including an overview of the study design.

3.1 Research aims, objectives and research questions

The scope of work was guided by the articulation of an overarching research aim which helped to define specific research objectives and associated research questions.

3.1.1 Overarching research aim

As discussed in Chapter 1, there is a clear need for more diversity in the station access mode share. This presents an opportunity to encourage more sustainable station access modes such as cycling. Financial and social benefits to both the state and the individual (De Nazelle et al., 2011), in addition to environmental benefits (Hosking et al., 2012), are strong motivators to encouraging the use of a bicycle to access rail services. However, participation levels associated with cycling to public transport services are substantially lower than the general rates of cycling for commuting purposes (Australian Bicycle Council, 2017).

Current literature into bicycle rail integration is sparse and limited research has been conducted in re-emerging cycling nations such as Australia. The literature is explicit about the gaps in knowledge and the need for further research:

> *"Only a small number of studies provide more in-depth analysis of bicycle-transit integration behaviour" (Wang & Liu, 2013)*

> *"… relatively few studies have investigated the multimodal integration problems …"* (Cheng & Liu, 2012)

> *"Despite these potential benefits of bike-rail integration, little is known about existing behaviour or the use of facilities"* (Sherwin et al., 2011)

With the knowledge gaps in relation to the “first mile” access to the station, **the overarching aim was to identify the contributing factors that influence commuters’ choice to cycling to the station and to explore the potential market share and the likelihood of shifting modes to the bicycle.** Thus, two central themes exist in the research aim, one exploring the mode choice decisions and the other the potential market share/mode shift likelihood. The alignment between the overarching aim, themes, research questions and specific studies are illustrated in Figure 3-1.

3.1.2 Research objectives

In order to meet this broad research aim, four research objectives (RO) were developed:

- **RO1**: Identify how the built/natural environment, demographics and station characteristics affect the rates of bicycle ridership to railway stations;
- **RO2**: Identify and understand the parking needs of cyclists and the factors which influence bicycle parking choice at railway stations;
- **RO3**: Provide insights into the extent latent/unobserved factors affect the intention to access the station by bicycle; and
- **RO4**: Identify the potential market share and mode shift likelihood of the bicycle in replacing other station access modes.

3.1.3 Research questions

Based on the research objectives, the following key research questions (RQ) were developed:

- **RQ1**: What objective factors are correlated with the decision to access the station by bicycle?
- **RQ2**: What factors affect the choice of parking facility used at railway stations?
    - ***Sub RQ2***: What are the parking needs of bike-and-ride users?
- **RQ3**: What latent factors influence the intention to choose the bicycle as a station access mode?
- **RQ4**: What is the potential market share of the bicycle for station access trips?
    - ***Sub RQ4***: What is the likelihood of commuters shifting modes to the bicycle to access rail services?

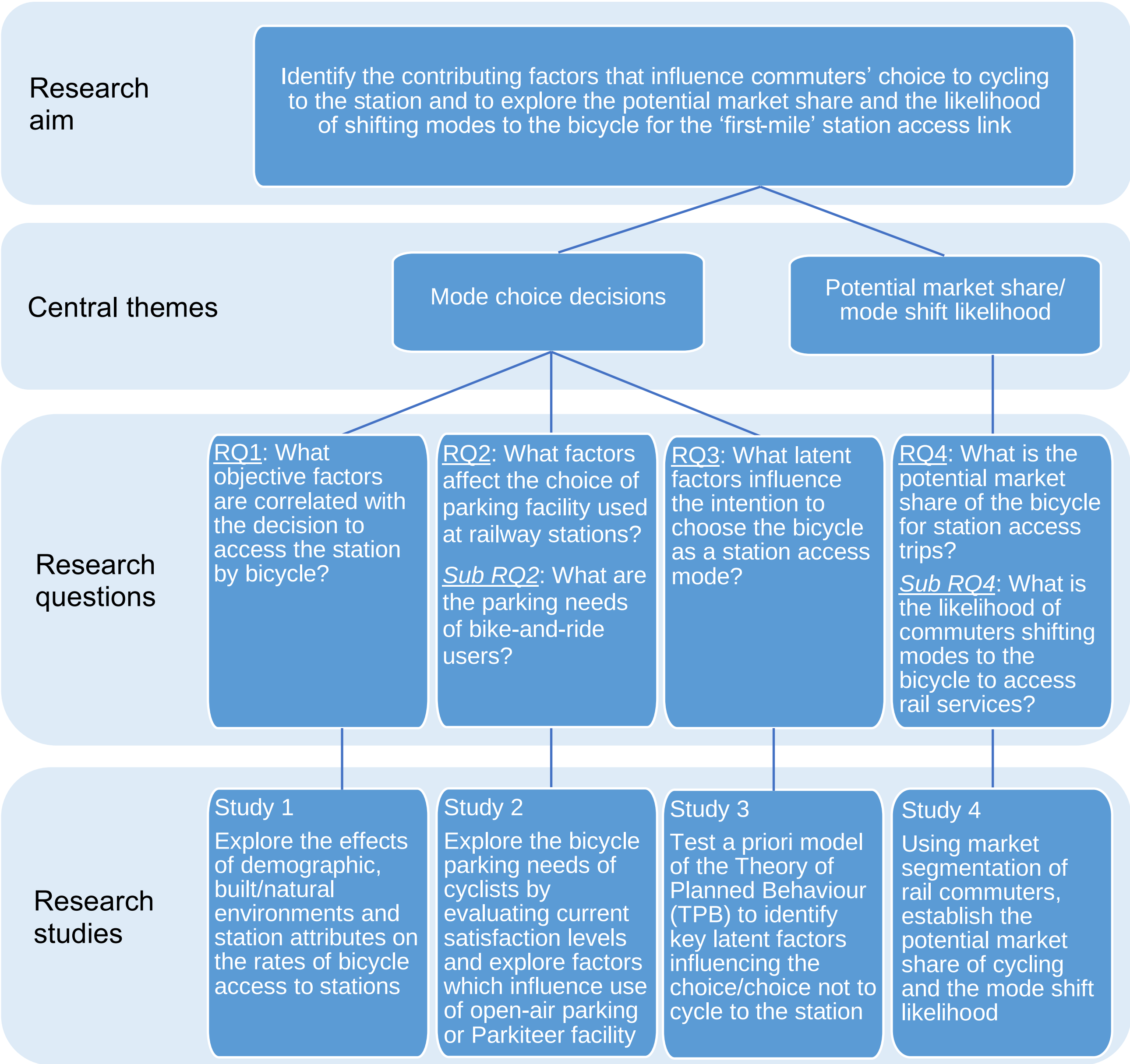

Figure 3-1: Overview of the doctoral research program

3.2 Theoretical approaches

To investigate the human behavioural choices component of this research program, two theoretical frameworks were used to underpin Study 3 and Study 4. These are outlined below.

3.2.1 Theory of planned behaviour

Theory of Planned Behaviour (TPB) is a validated model used to examine the link between belief and behaviour (Donald et al., 2014; Ajzen, 2011; Bamberg et al., 2003; Armitage & Conner, 2001). The TPB has been used extensively to predict and explain transport-related behaviours, ranging from personal car use (Anable, 2005; Aarts & Dijksterhuis, 2000), public transport use (Bamberg et al., 2007; Heath & Gifford, 2002) and the choice to commute by bicycle (Lois et al., 2015; de Bruijn et al., 2009). In Study 3, the TPB was used as a priori model to examine latent factors influencing rail commuters' choice to cycle to the station.

TPB posits that people's intention to participate in a given activity primarily influences and shapes whether the activity is performed (Ajzen, 2005). It contends that behaviour is directly influenced by a person's intention and that the intention is the closest determinant of behaviour (Walsh et al., 2007). Intention and behaviour are subsequently influenced by three latent factors:

- *Behavioural attitudes* towards the specific act or behaviour, these can be positive or negative;
- *Subjective norms* refer to an individual's perception of societal pressure to perform a given behaviour; and
- *Perceived behavioural control* which takes into consideration an individual's perception of the ease or difficulty in performing a particular behaviour. This has a direct influence on behaviour.

In this research program, the TPB provided the foundation to understand the role latent underlying psychosocial factors played in the choice to access the station by bicycle. This is particularly relevant as unobserved factors are highly influential in the decision to use a bicycle for both recreational and commuting purposes (Fernández-Heredia et al., 2016).

Study 3 builds on the current knowledge and provides an empirically grounded model to help understand the psychosocial factors influencing the intention to access the station by bicycle. The application of the TPB in the context of cycling as a station access mode choice is outlined in Figure 3-2. The central premise of this model is that the sequence leading from beliefs to behaviour is a rational process where individuals consider the available information systematically to form a behavioural decision.

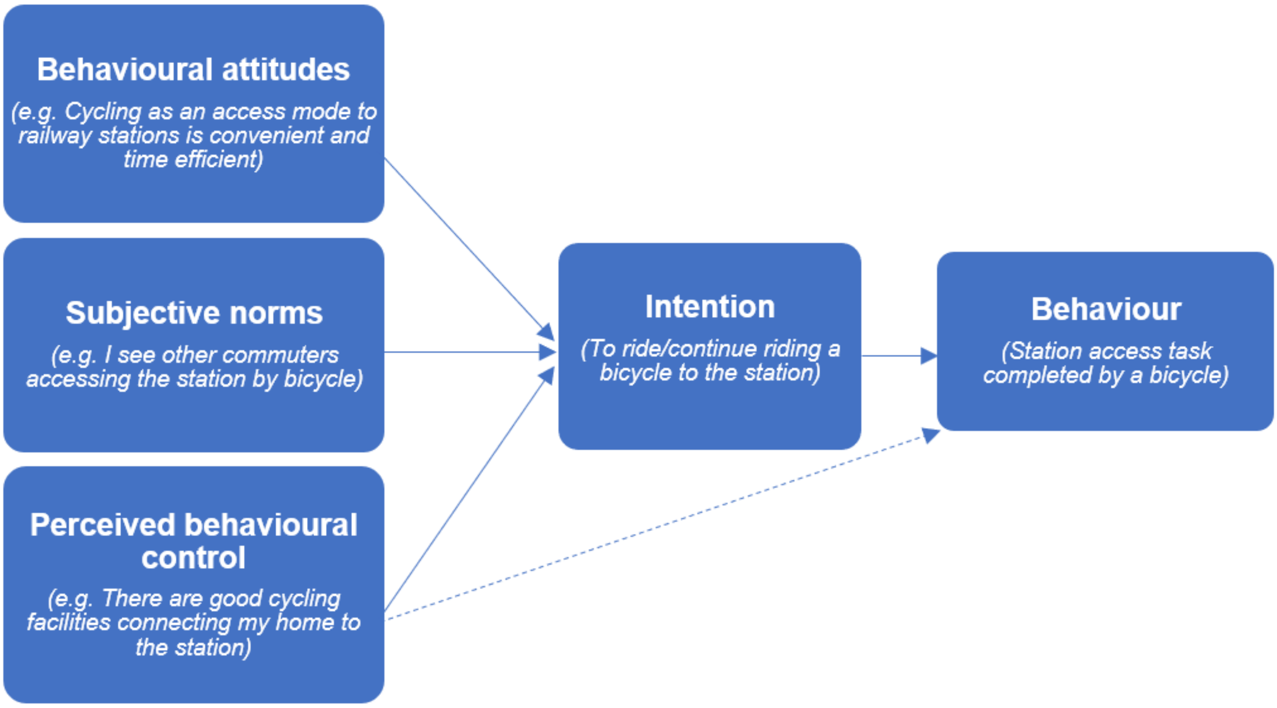

Figure 3-2: Elements of the Theory of Planned Behaviour

3.2.2 Market segmentation and the types of cyclists

To better understand the potential market share and commuters' likelihood to shift modes to the bicycle for the station access task, a market segmentation approach was adopted (Study 4). (Kotler et al., 2002). A modified version of the "Four Types of Cyclists", developed by Geller (2009), was used as the typological model (Table 3-1). This enabled for a rich understanding of current behaviour, specific wants, needs, barriers and facilitators of each segment.

Table 3-1: Types of cyclists

Typology	**Description**
Strong and Fearless	Very comfortable cycling on arterial roads without cycling infrastructure.
Enthused and Confident	Not comfortable on arterial roads without cycling infrastructure, but very comfortable on roads with cycling infrastructure.
Enthused but Not Confident	Not very comfortable cycling on arterial roads with or without infrastructure, but comfortable cycling on local residential roads.
Interested but Concerned	Interested in cycling, however, not very comfortable cycling on arterial roads with or without bike lanes and on local residential roads.
No Way No How	Very uncomfortable riding on a physically separated path from traffic or physically unable to ride a bicycle or not interested in cycling to the station.

Classification of commuters into a category was determined based on cycling ability, comfort levels on different cycling facilities and interest in cycling as a station access mode. This typology enabled all rail commuters to be categorised, regardless of current station access mode behaviour. By categorising rail passengers, into a *'type of cyclist'* based on the grouping criteria above, the following characteristics were explored:

- Potential for mode shift to the bicycle to replace other station access mode trips;
- Latent market share for cycling as a station access mode type; and
- Behavioural aspects, barriers and needs of rail commuters to encourage greater levels of bicycle access.

3.3 Research method and design

As identified in Figure 3-1, specific studies were developed to address each of the key research questions. In the following section, an overview of the four studies are provided.

3.3.1 Study design

The studies undertaken in this research program, examined several station access mode types. Figure 3-3 is used to sign-post the access mode(s) under investigation in each of the four studies. Chakour & Eluru (2014) noted the choice to commute by train broadly encompasses two key hierarchical choice sets: the access mode choice and the station choice. A possible hierarchy in the station access task is identified in Figure 3-3, with station choice assumed to precede mode choice (Chakour & Eluru, 2014). As the focus of this doctoral research program was on access mode choice, exploration of station choice was beyond the scope of this research project.

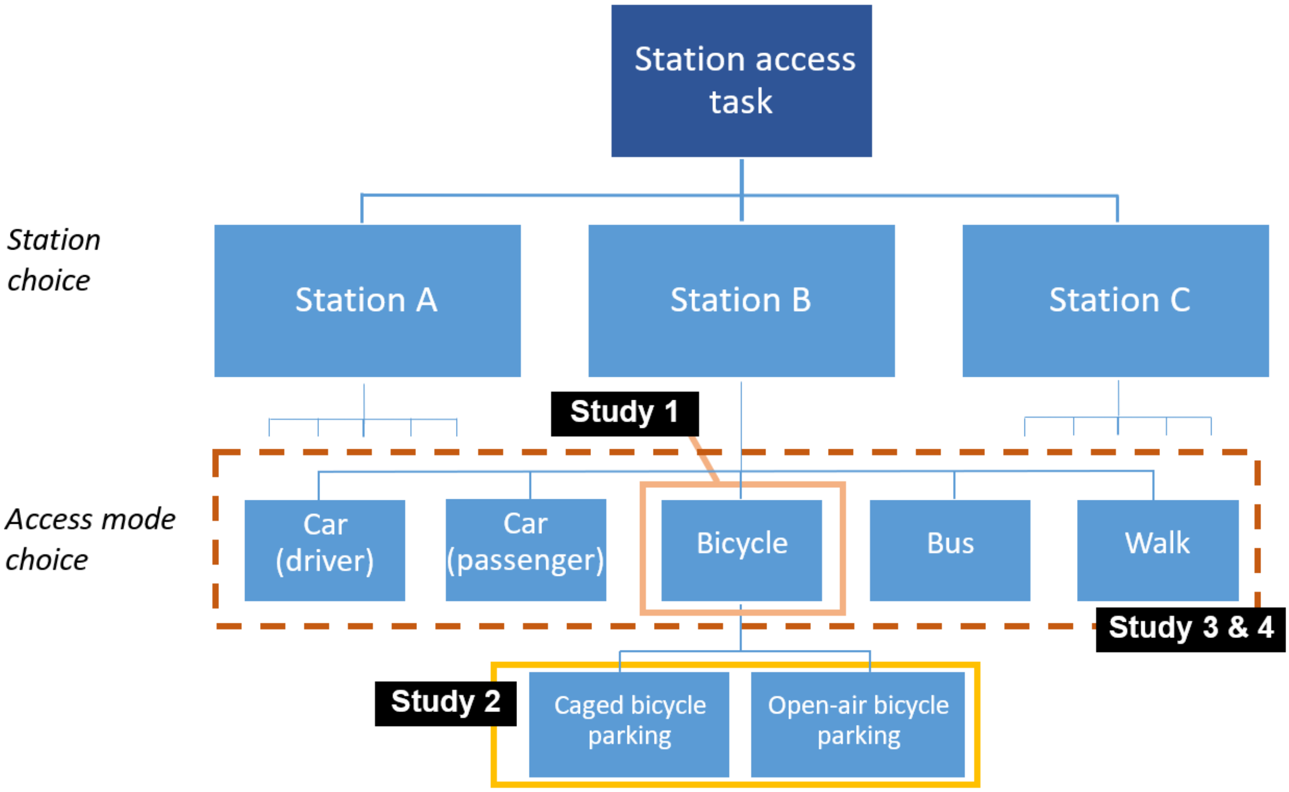

Figure 3-3: Access mode(s) under investigation

Table 3-2 provides an overview of each study, the method employed, the research question addressed, and underlying theoretical approaches.

Table 3-2: Linking studies, research questions, approaches and methodology

Study component	Research question addressed	Theoretical Approach	Method	
			Data source	Analysis technique
Study 1	RQ1		Bicycle access rates to stations, demographic and built environment data (secondary)	Multivariate regression modelling
Study 2	RQ2 Sub RQ2		Cyclist survey (primary)	Binary logistic modelling
Study 3	RQ3	Theory of Planned Behaviour	Rail commuter survey (primary)	Structural equations modelling
Study 4	RQ4 Sub RQ4	Market Segmentation	Rail commuter survey (primary)	Market segmentation

3.3.1.1 RQ1 – Study 1

A limited number of studies to date have examined the spatial dimension and its influence on bicycle access rates to train stations (Kager et al., 2016; Mueller & Hunter-Zaworski, 2014). In Study 1 the effects of demographic, built/natural environment characteristics and station attributes were examined on the rates of bicycle access to stations in Melbourne. Secondary sources of data were obtained from the 2011 Australian Household Census (census) (Australian Bureau of Statistics, 2011) and various statutory authorities and government departments. A geographic information system was utilised to extract and analyse demographic and environmental characteristics surrounding the station within a defined catchment area. Following which, statistical models were built to identify the correlates associated with the rates of bicycle access to stations.

In the statistical models, the dependent variable was the counts of rail commuters accessing each of the metropolitan stations by bicycle. This dataset was sourced from the Public Transport Victoria (PTV, Victoria's public transport authority) from a parent datafile titled: *Passenger activity by metropolitan station 2008 to 2014*. Bicycle access counts for 2014 were utilised in the modelling and was available for 207 of the current 220 metropolitan stations (94.1%).

The Australian Urban Research Infrastructure Network and the Victorian Government Data Directory (AURIN) was used as a central portal to gather independent variables related to the environmental characteristics from multiple authorities such as VicRoads (Victorian roads authority), PTV and the Victorian Department of Environment, Land, Water and Planning. At the time when this component of the research was undertaken, the 2016 census results had not been released, and so data from the 2011 census was used (Australian Bureau of Statistics, 2011) for the demographic attributes.

A novel approach was developed in ArcGIS 10.4 to compile, analyse and extract demographic and environmental data within cycling catchment areas around each of the 207 stations. Individual non-overlapping catchments were defined as the geographic extent to which data was extracted. Given the close proximity of many stations in the Melbourne rail network, overlapping catchments can be substantial and impact the reliability of the extracted data (see Mead et al., 2016). The use of non-overlapping catchment areas avoided this shortcoming.

Generalised linear models, in the form of Poisson and negative binomial regression models, were developed providing insights into key correlates of cycling rates at railway stations.

3.3.1.2 RQ2 – Study 2

Study 2 specifically focused on the use of bicycle parking facilities at railway stations. In Melbourne, often due to space limitations on rail carriages at peak periods, cyclists are often required to leave their bicycle at the train station. Consequently, they are exposed to the risk of theft and vandalism. To minimise the occurrence of such incidents, the provision of secure bicycle parking is important (La Paix Puello & Geurs, 2015; Pucher & Buehler, 2008). It is in this context, this study aimed to identify the parking needs of cyclists and the factors which affect bicycle parking choice.

As part of this study, primary data was collected through an intercept survey targeting current adult rail commuters (18 years and older), who accessed the station by bicycle between 7-9 AM[1]. Bike-and-ride users were intercepted at 36 metropolitan railway stations in Melbourne. Stations were selected based on the level of cycling activity expected at each station (using the PTV bicycle access counts as a guide) while avoiding locations experiencing disruptions and temporary station closures. As Melbourne is undergoing extensive capital works across the train network system (e.g. removal of 75 level crossings, new elevated track works) studies were carefully scheduled to avoid times of disruption.

Data collected from the survey was supplemented with police crime statistic data (counts of bicycle thefts from train stations). A forward stepwise logistic regression model was developed to identify the key variables influencing bicycle parking choice at stations.

[1] Ethics approval was granted by the Monash University Human Research Ethics Committee (MUHREC)

3.3.1.3 Rail commuter survey

From Study 2, the focus of the doctoral research broadened from the commuters already riding to the train station, to understanding more about people using key modes to access the train. Commuters across all access modes (car as driver or passenger; bus; walking; bicycle) were intercepted and recruited to participate in an online survey. The online survey was conducted in late 2017 and generated the data required for both Study 3 and Study 4[2]. The development of the questionnaire was informed by the TPB and contained questions addressing each theoretical element (i.e. attitudes, perceived behavioral control, subjective norms and intention). The survey also included questions which provided the basis for the market segmentation required for Study 4.

3.3.1.4 RQ3 – Study 3

A critical aspect motivating a person to undertake tasks involving physical activity, including cycling, are unobserved or latent factors (Titze et al., 2008). In the literature that explores bike-rail integration limited consideration is placed on the effects of latent factors in explaining the behaviour to access rail services by bicycle. This doctoral research addressed this gap in Study 3. The effects of attitudes, perceived behavioural control and subjective norms on the intention to use the bicycle as a station access mode were examined using the TPB as a priori model. Intention to access the station by bicycle was the fundamental measure as the TPB states that intention is the central determinant and direct antecedent of behaviour.

Structural equation modelling was utilised to make inferences of causal relationships between attitudes, subjective norms and perceived behavioural control on the intention to ride to the station. A measurement model was constructed, and Confirmatory Factor Analysis was utilised to ensure that the measures/survey items satisfied validity and reliability requirements. Establishing a measurement model was important in empirically validating measures/survey items exist in a distinct latent construct. Following this, the relationship between the latent constructs were tested using a structural model.

[2] Ethics approval was granted by MUHREC for the rail commuter intercept survey

3.3.1.5 RQ4 – Study 4

The focus of Study 4 was to examine the potential market share of the bicycle and its mode shift capability in replacing alternative station access modes. A market segmentation approach was adopted, whereby respondents to the commuter intercept survey were categorised into a *type of cyclist* based on a modified model of the *Four Types of Cyclists*, developed by Roger Geller (see Table 3-1). The classification of commuters into a type were determined based on cycling ability, comfort riding on different cycling facilities and interest in cycling as a station access mode. Through the process of separating rail commuters into groups of potential cyclists ranging from *'No way no how'* to *'Strong and fearless'* a rich behavioural understanding of cycling as a station access task was able to be made including exploring the associated barriers and facilitators. Through the process of market segmentation, insights into the mode shift potential of the bicycle for the station access task were able to be made.

3.4 Summary

In summary, Chapter 3 has described the theoretical and methodological approach that was applied in this doctoral research program. An overview of the research aim, objectives and key questions were provided. These have informed the methodological approach taken, specifically the use of four studies, each building new knowledge about bicycle-rail integration. As part of Study 3 and 4, theoretical approaches were adopted to ground the research, as human behaviour and choice were specifically under examination. This research program had utilised quantitative techniques to probe the factors influencing the use of a bicycle for the station access task and its mode shift potential. Both secondary data and primary sources of data, gathered from two intercept surveys, were relied upon during the course of this research program. In the next chapter, a detailed examination of Study 1 is made.

Chapter 4 Objective factors affecting the bicycle access rates at stations

This chapter presents a paper published in the Journal of Transport Geography. As part of Study 1, this paper seeks to examine the influence of demographic, built/natural environment and station attributes on the bicycle access rates at metropolitan stations. The analysis was conducted at a network-wide level, which focused on modelling 207 railway stations. Eight generalised linear models were developed. Highly correlated factors associated with the rates of bicycle access to stations were noted from each of the three broad categories (demographic, built/natural environment and station attributes). The scope for Study 1 is on existing cyclists as illustrated in Figure 4-1.

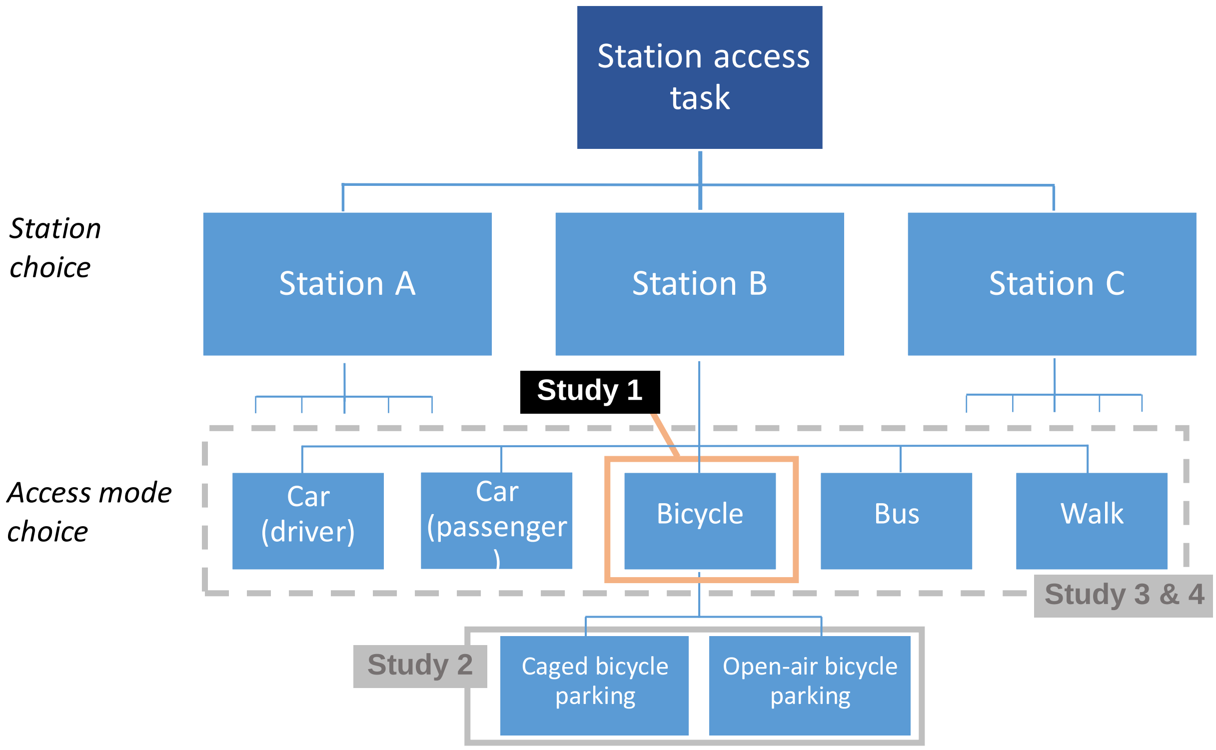

Figure 4-1: Access mode(s) under investigation

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Bicycle train intermodality: Effects of demography, station characteristics and the built environment

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ABSTRACT

As public transport patronage levels increase worldwide, an issue many cities face is providing adequate infrastructure capacity for station access modes. A cost effective solution is to encourage the use of the bicycle for the 'first mile' link, particularly for rail commuters who currently drive but are within a cycling distance of the station. However, to promote cycling as a station access mode, a better understanding of the associated correlates are needed. This study aims to address this knowledge gap by identifying factors associated with increased rates of bicycle access to stations in Melbourne, Australia. Bicycle access counts at 207 metropolitan rail stations were analysed and factors related to the rail station catchment areas (demographic data and built/natural environment) and rail station characteristics were considered. Visual representation of the demographic and built/natural environment characteristics and eight generalized linear models were developed to identify significant factors. A higher number of cyclists riding to the station were associated with a range of factors including *built/natural environments*: low sloping terrain; greater proportion of low speed local roads, diverse land use mix and increased bicycle crash count density. *Station attributes*: availability of secure bicycle parking facilities, increased train patronage, higher train frequency during the morning peak period and *demographic characteristics*: increasing median age were also correlated with a growth in bicycle access counts to stations.

1. Introduction

Urban densification is a global challenge with two thirds (68%) of the world's population expected to live in urban centres by 2050 (United Nations, 2015). The need to maintain mobility options and promote accessibility is paramount and will place increasing demands on existing transport networks. Public transport is one such service where use is expected to increase in the coming years. In Australia, demand for public transport is expected to increase by 89% by 2031 (Infrastructure Australia, 2015). To deal with such increases, emphasis is being placed on network capacity increases, in particular for heavy rail (high capacity trains, more frequent services and improved signalling systems). In this discussion, however, an important point that is often overlooked is the need to consider station access mode capacity issues that will inevitably rise as public transport usage increases.

Currently in Melbourne, Australia, more than half (56%) of the commuters access a train station by foot (about 400,000 daily entries) followed by the car (18% at about 136,000 daily entries) (Public Transport Victoria, 2018). In the Netherlands, bicycle access to stations account for up to 40% of trips, while in Melbourne it is < 1% (about 5000 daily entries) (Public Transport Victoria, 2018). The 2017 Australian national cycling participation survey produced similar findings: about 1% of the sample (n = 9984) had taken part in bicycle train intermodal travel within the last month. In contrast, 10% had used a bicycle as the main mode of travel for commuting purposes at least once within the last month. Given 50% of the demand for park and ride is typically generated within a 4 km radius of the station (Evans et al., 2004) the bicycle provides a feasible mode shift alternative for accessing railway stations, particularly as the typical cycling catchment to heavy rail is between 3 and 5 km (Martens, 2004).

With rail patronage levels forecast to rise, the demand for vehicular based station access will also likely increase, adding to the strain on existing car parking facilities. Currently, car parks at stations reach capacity well before the start of the AM peak period with overflow parking spreading into neighbouring streets impacting local residents. Government policy discussions, to date, have been on building new car parking facilities. An additional 11,000 additional car parking spaces are proposed costing $150 million (Premier of Victoria, 2018), an average of nearly $14,000 per space. As most urban stations are landlocked with limited land for car parking infrastructure, increasing car parking supply requires expensive, multistorey car parking solutions (Carey and Lucas, 2015).

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Table 1
Factors influencing cycling participation rates as the main mode of travel.

Author(s)	Context/Setting	Significant factors[a]
Mertens et al., 2017	Europe	bicycle infrastructure (+), speed limits below 30 km/h (+) traffic calming devices (−)Traffic calming devices (−)
Moudon et al., 2005	USA	land use mix (+) proximity to trails (+)
Vandenbulcke et al., 2010	Belgium	slope (−), traffic volume (−), accident risk (−), working men (+)
Heesch et al., 2015	Australia	distance to central business district (+)
Sallis et al., 2013	USA	land use mix (+) cycling facilities (+)
Saelens et al., 2003	USA	street connectivity (+), land use mix (+) population density (+)
Dill and Voros, 2007	USA	perception of bicycle infrastructure availability (+)

[a] + positive influence, − negative influence.

In contrast, parking facilities for bicycles are much more cost effective. A bicycle parking hoop can be installed for about $1000 and space in a secure bicycle parking enclosure is about $4000 per bicycle. Catering for cyclists accessing the station requires a significantly smaller parking footprint while also providing economic, environmental and health advantages.

At present there is a lack of understanding of the factors that are correlated with the levels of bicycle access to stations, particularly in re-emerging cycling nations like Australia. Research to date has primarily focused on the rates of bicycle participation as the main mode of travel for commuting. Given the disparity in the rates of cycling to stations and cycling for commuting as the main mode, this research aims to bridge this gap by identifying correlates associated with the levels of bicycle access to stations.

This research employs a different methodological approach compared with most previous studies on bicycle access to stations. Most have focused on the effects of policy measures (Martens, 2007) and longitudinal studies with before and after treatments (Cervero et al., 2013). This research builds on the work conducted by Mead et al. (2016) utilising not only socio-demographic variables but also station characteristic and built environment variables. The analysis is further extended with station access by bicycle modelled at a network level, across 207 stations, while also employing a more refined methodological approach in capturing demographic and built environment data.

The structure of the paper is as follows. Section 2 summarises insight from the literature review and that is followed by section 3 which outlines the study context and the research method employed. The results are presented in section 4. Section 5 contains the discussion and the final section highlights the conclusion and identifies directions for future research.

2. Literature review

Planning and policy measures have sought to increase cycling participation in cities worldwide (Haixiao, 2012; Hidalgo and Huizenga, 2013; United Kingdom Department for Transport, 2016; Transport for Victoria, 2017). This change of perspective in mobility has seen the bicycle being emphasised as an effective mode of urban transport. However, in countries including the United States of America (USA), United Kingdom (UK) and Australia, rates of utilitarian cycling remain low at a national level, partly due to historic planning practices of low density suburban sprawl (Pucher and Buehler, 2008; Pucher et al., 2011). Cycling in urban environments could be increased by combining cycling and rail, allowing longer journeys to be made. However, bike and rail integration remains largely an unrealised sustainable mobility option (Sherwin and Parkhurst, 2010, Public Transport Victoria, 2018).

In the context of bicycle and rail integration, few studies have explored the correlates associated with the levels of bicycle access to stations, particularly in countries where cycling is not a dominant mode of travel (Krizek and Stonebraker, 2010; De Souza et al., 2017). To facilitate bike and rail integration there needs to be a greater understanding of the factors influencing the choice to cycle to the station. Increased bike-and-ride levels have been correlated with accessibility (distance to railway stations) (Brons et al., 2009; Barajas, 2012), journey purpose, weather, car ownership (Givoni & Rietveld, 2007, Debrezion et al., 2009) and the availability of secure bicycle parking at stations (Barajas, 2012; Cervero et al., 2013). Mead et al. (2016) had examined the effects of demographic variables on the usage rates of secure bicycle parking at 37 metropolitan railway stations in Melbourne. Census data captured in overlapping station catchment areas by a Geographic Information System (GIS) was used to model and identify key variables affecting the usage of secure bicycle parking facilities at stations. Median age, population within cycling age and occupancy to dwelling ratio were identified to be correlates.

A range of barriers exist preventing more widespread use of the bicycle as the main mode for utilitarian travel (Pucher and Buehler, 2008). Of these, a central theme highlighted in the literature is safety. Traffic safety concerns are particularly pervasive in countries with low rates of cycling and discourages its uptake (Garrard et al., 2008; Johnson et al., 2010). Due to a lack of connected cycling infrastructure, cyclists are often required to share space with motor vehicles travelling at high speeds. The risk of collision, both actual and perceived, is therefore a major concern for many cyclists and potential cyclists (Bauman et al., 2008; Haworth, 2012; Bonham and Johnson, 2015). The built environment not only affects the perception of safety, several factors related to the built environment have been identified to affect rates of commuting by bicycle as the main mode of travel (Table 1).

A number of the factors found to significantly influence rates of cycling as the main mode of travel is outlined in Table 1. Several of these factors will be tested to see if they are correlated with the rates of bicycle access to stations. The following section outlines the study context and method adopted in this research.

3. Study context and method

A multivariate modelling approach was employed to examine the factors contributing to the rates of bicycle access to stations. This study focussed on Melbourne but employs an analysis approach that could be applied in other geographic contexts.

3.1. Study setting and analysis overview

The study was conducted in Melbourne, Australia. Melbourne is the state capital of Victoria and has a metropolitan population of 4.8 million. It is serviced by an extensive public transport network of heavy and light rail and buses. This study focused on the radial rail network, which is 400 km in length with a total of 219 metropolitan stations. At 73 stations there are dedicated secure bicycle parking facilities (a locked bicycle parking cage capable of holding 26 bikes). Some stations provide open-air bicycle parking hoops and cyclists are able to lock a bike at all stations (e.g. to a fence or post). Across the network there is substantial variation in the extent to which cycling is used as an access mode.

Secondary sources of data, classified as demographic, built/natural environment and station attribute data were compiled from multiple sources (identified in the subsection below). GIS was used to capture, manipulate and analyse spatial data relating to demographics and the built/natural environment at a station catchment level. The approach taken is outlined in Fig. 1 below. Following the GIS data extraction, a combination of univariate and multivariate analyses provided insight into significant relationships.

3.2. Geographic information system

GIS was used to compile, extract and analyse demographic and built/natural environment data around each metropolitan railway station in Melbourne. Previous research on cycling access to stations consider circular catchment areas of 3–5 km as zones to extract spatial data (Martens, 2004). However, in Melbourne, stations are spaced in close proximity resulting in substantial overlapping of the catchment areas, leading to the extraction of neighbouring station catchment characteristics.

To address the issue of overlapping catchments, non-uniform cycling catchment areas were created for each station by adopting a defined cycling radius of 4.5 km and overlaying this buffer with a Thiessen polygon (Fig. 2). These non-uniform cycling catchments around each metropolitan train station (n = 207), account for the interaction of neighbouring stations and defined the geographic extent to which the demographic and built/natural environment data were captured and associated with each station.

A cycling radius of 4.5 km was adopted, informed by the findings from previous research examining cyclists' access distance to stations in Melbourne (based on a cyclist intercept survey, n = 243).[1] Geocoded home origin data recorded at the resolution of the nearest cross-street were examined. A 4.5 km radius represents the 80th percentile of distance ridden to the station in Melbourne and covers the conditions of most commuters riding to the station. Prior to the extraction of spatial data, the non-uniform catchment areas were validated based on the home-end origins of the participants. Over two thirds (67%) of cyclists rode to the station which was associated with the catchment where their home cross-street was located. Of those who did not ride to their home catchment area station, the majority (73%) rode to a station in the immediately neighbouring station catchment area.

While the GIS catchment areas allow for a maximum possible radius of 4.5 km, the effect of the Thiessen buffer results in the average catchment area being 11.18 km^2, with an 'effective' radius of 1.89 km. This approach allows for the difference regions in Melbourne (inner city/suburbs, middle and outer suburbs) to be considered. Outer suburban areas, with lower densities, and stations spaced further apart, have larger catchment areas in comparison to inner city catchment areas.

Demographic and built/natural environment data were overlayed on top of the established station catchments. For demonstrative purposes, a visual representation of the median age and catchment elevation are identified below. At a catchment level, the median age of the population is lowest in Melbourne's central business district. A triangular irregular network elevation model was developed for the study area using spot heights in the GIS model. Areas in the east, north-east and parts of north-west have sloping terrain above a grade of 2° (Fig.3).

[1] Refer to Weliwitiya et al. (2017) for details of sampling and study method

3.3. Explanatory variables

To develop a model to identify the factors correlated with the number of people accessing the station by bicycle, a set of potential predictor variables were compiled, guided by a review of the literature. The explanatory variables were classified as: demographic factors, built/natural environment factors or station attribute factors (Table 2).

Demographics of the population living in each of the station catchment areas were obtained from the 2011 Australian census (Australian Bureau of Statistics, 2011) and included*: population density, occupancy to dwelling ratio*, *median age* and *population attending educational institutes*. Demographic data had a population resolution of 200 to 800 persons (Census data mesh blocks, Statistical Area Level 1). *Cyclist crash count density* was also included, however these were cases reported to police, therefore the data is likely to underrepresent the total number of cyclist crashes.

The built/natural environment is known to influence travel behaviour (Dill and Voros, 2007; Vandenbulcke et al., 2011; Mertens et al., 2017). Factors considered for this category include *municipal/principal bicycle network density* which compares the length of dedicated bicycle infrastructure provided in a given catchment area to the length of the road network in the same catchment area. The type of cycling infrastructure (on road, off road, shared paths etc.) within the catchment areas were also of interest. However, in the cycling infrastructure dataset over 80% had a missing or null classification of the infrastructure type and therefore this was not used as a variable. Also considered were *road network connectivity* and *bicycle network connectivity*, based on the connected node ratio metric (Dill, 2004; Tresidder, 2005). This metric measures connectivity by accounting for the proportion of cul-de-sacs within a network. Lower proportions of cul-de-sacs is presumed to provide a higher level of connectivity. *Traffic volumes along major arterial roads* and *land use mix* were included in the model. The *natural topography* and its effects on the rates of bicycle access to stations were also of interest as slopes > 3 to 5% have been reported to reduce general rates of cycling (Saelens et al., 2003; Heinen et al., 2010). As most cyclists are riding to the station to travel for employment and educational purposes (Martens, 2004; Rose et al., 2016) it was hypothesised that commuters would prefer a less physically taxing trip and a slope of 2° was selected to define an adverse grade. Furthermore, the *road network composition* within the catchment areas were also included in the model. This allowed for the proportion of local roads in a given catchment area to be measured and test the implications of these generally low speed/low traffic volume streets on rates of cycling to stations.

Aspects of the station such as the *number of car parking spaces, train patronage, train departure frequency during the morning peak period (6–9 AM)* and the *availability of secure bicycle parking facilities* were also of interest. Secure bicycle parking facilities, defined as enclosed parking facilities accessible only via a registered swipe card, were available at 73 rail stations.

Due to the non-uniformity of the catchment areas, a measuring metric was used to standardise each independent variable, enabling comparisons to be made across the different station catchments (Table 2).

Land use considered for this study include: residential, retail/commercial, industrial and public space (adapted from Frank et al., 2006)

3.4. Dependent variable

Public Transport Victoria (PTV), the state's public transport authority, provided counts of the number of cyclists riding to each of the metropolitan stations. Origin destination patronage data for 2012 across 207 stations was collected and used by PTV to model station access behaviour in 2008/09 and forecast access behaviour in 2013/14 (Public Transport Victoria, 2018). The 2012 data was collected from an intercept survey that took place at each station for a single day and

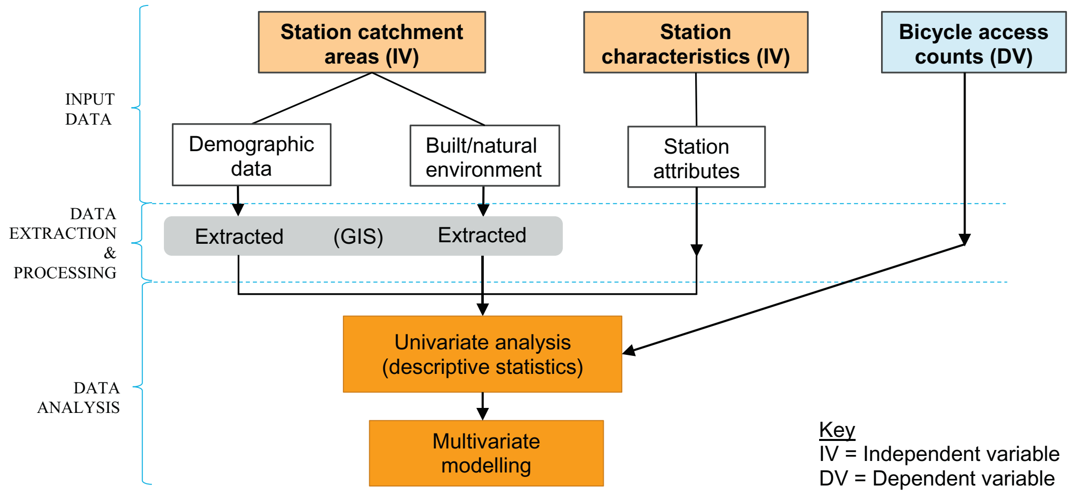

Fig. 1. Analysis overview.

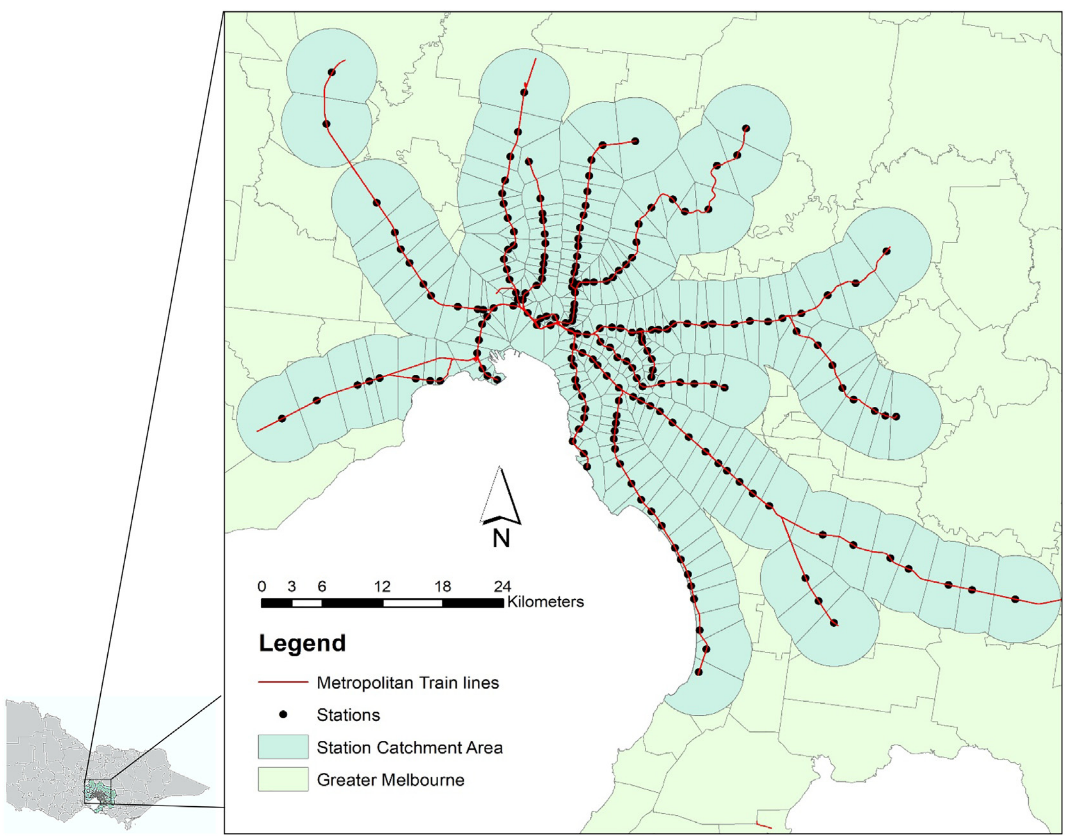

Fig. 2. Cycling catchment areas (around each metropolitan station).

involved a systematic sampling approach. This sampling approach involved instructing field staff to intercept every third person entering the station platform and was designed to minimise selection bias and produce a random sample (Richardson et al., 1995). The survey period went for most of the year, excluding school holidays, public holidays and weekends. As this was a sampling survey, responses were weighted by patronage and factored up to represent total patronage. The 2013/14 bicycle access numbers were used as the dependent variable in this research.

3.5. Data limitations

Data has been collected and aggregated from multiple sources across different time periods. Ideally, data would represent a particular cross section in time, however, this is not possible given the retrospective nature of the data from existing sources. Care was taken to ensure datasets were selected as close to the 2013/14 financial year, when the dependent variable was available. Furthermore, the validity, accuracy and integrity of the secondary sources of data is limited by the original planning and methods of data collection.

3.6. Model functional form and parameter estimation

The dependent variable is the count of bicycles accessing each metropolitan train station in Melbourne, therefore, generalized linear models in the form of 'overdispersed' Poisson and negative binomial

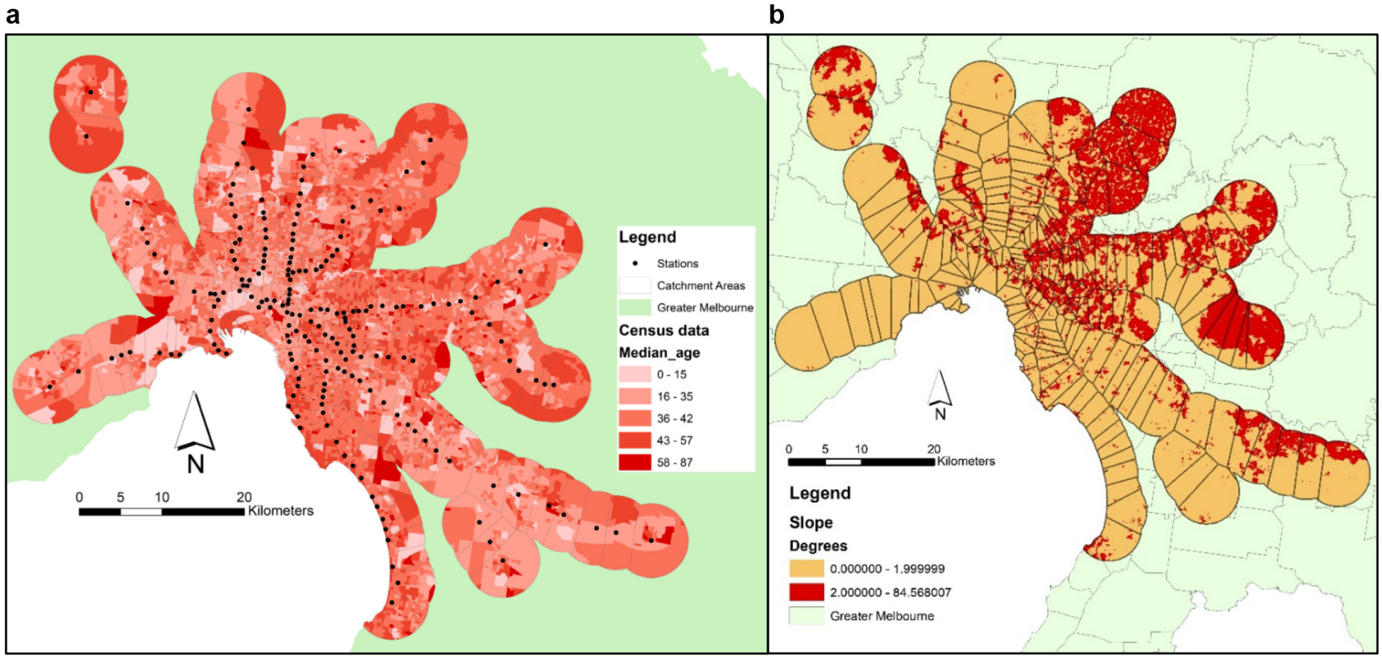

Fig. 3. (a) Median age (b) Catchment slope model.

Table 2
Variables of interest.

Input category	Variable	Measuring metric
Demographic	Population density[1]	Population in catchment/Catchment area[6]
	Occupancy to dwelling ratio[1]	Persons/dwelling[6]
	Median age[1]	Years[6]
	Population attending educational institute[1]	Percentage of population attending educational institution[6] (school, TAFE or university)
Built/natural environment	Municipal/Principal bicycle network density[2]	Bike network length/Road network length (within the same catchment area)
	Bike network connectivity[3]	Intersection count/(Cul de sacs + Intersection count)
	Road network connectivity[3]	Intersection count/(Cul de sacs + Intersection count)
	Arterial traffic volumes[2]	Average flow volume
	Land use mix[4]	Land use mix index score[7]
	Terrain slope[3]	Proportion of the station cycling catchment area with a slope $\geq 2^{\circ}$
	Cyclist crash count density[2]	Crash count/Catchment area
	Road network composition[2]	Percentage of local roads
Station attribute	Number of car parking spaces[5]	Count
	Availability of secure bicycle parking[5]	Categorical (Yes/No)
	Train patronage[5]	Count
	Train frequency[5]	Count

Data Sources:[1]2011 Australian Census, [2] VicRoads, [3] Department of Environment, Land, Water and Planning, [4] Department of Economic development, Jobs, Transport and Resources, [5] Public Transport Victoria.
Measuring metric:
[6]Area weighted method applied based on uniform distribution of population within the census mesh blocks, [7]Land use mix = A/ln(N).
$A = (b_1/a)*\ln(b_1/a) + (b_2/a)*\ln(b_2/a) + \ldots$
a = total area of land (catchment area).
b_1 = area of land dedicated to land use 1 (eg. Residential).
b_2 = area of land dedicated to land use 2 (eg. Commercial).
N = total number of land use types.

regression are used rather than a traditional linear regression.

Poisson models are widely used in regression analysis of count data (Frome, 1983; Karlaftis and Tarko, 1998; Ma et al., 2008). This technique assumes that the counts (y_i) of the bicycles accessing station *i*, has a Poisson distribution given by:

$$P(y_i) = \frac{\mu^{y_i} e^{-\mu_i}}{y_i!},\; y_i = 0, 1, 2, \ldots$$

Given a vector of demographic, built/natural environment and station attribute data, the expected number, μ_i, of bicycles accessing station *i* can be estimated by the equation:

$$In\ \mu_i = X_{ij}\beta$$

Where X_{ij} is a vector of *j* independent variables and β is a vector of regression parameters.

The mean and the variance are assumed to be equal. This assumption, however, does not hold for the bicycle access counts as the data is 'overdispersed' in nature. Poisson regression models violating this assumption can result in inconsistent parameter estimates (Shankar et al., 1995). To overcome this, the procedure outlined by McCullagh and Nelder (1989) was employed, in which the scale parameter equal to 1 is relaxed.

An alternative procedure to account for 'overdispersed' data is to rely on negative binomial regression models. Negative binomial distributions include a gamma-distributed error term, relaxing the Poisson's equal mean-variance constraint. Such a model is represented as follows:

$$In\ \mu_i = X_{ij}\beta + \varepsilon_{ij}$$

Where X_{ij} is a vector of j independent variables, β is a vector of regression parameters and $\exp(\varepsilon_{ij})$ is a gamma-distributed error term. The resulting mean-variance relationship is:

$$Var[y_i] = E[y_i][1 + \alpha E[y_i]]$$

If α is significantly different from zero, the data is overdispersed or underdispersed. In the case where α equals to zero, the negative binomial reduces to the Poisson distribution. As the bicycle access counts at stations is overdispersed the resulting probability distribution under the negative binomial assumption is:

$$P(y_i) = \frac{\Gamma(\theta + y_i)}{\Gamma(\theta)y_i!}\eta_i^{\theta}(1 - \eta_i)y_i,\ y_i = 0, 1, 2, \ldots$$

where $\eta_i = \theta(\theta + \mu_i)$, $\theta = 1/\alpha$ and $\Gamma(.)$ is a value of the gamma function. Maximum likelihood procedures can be used to estimate μ_i.

Both modelling techniques have been used as a robustness check given the number of stations in which bicycle counts were available ($n = 207$). For each regression technique, a full model including all explanatory variables was fitted. Additional models were created testing the influence of demographic characteristics, the built/natural environment and station attributes separately.

4. Results

The following section contains the results of the data analysis. Univariate data analysis is presented first followed by the multivariate regression modelling.

4.1. Univariate analysis results

On average, just under 25 cyclists access each of the 207 stations daily on a weekday. However, as seen from Fig. 4 below, at most stations the level of bicycle ridership is zero resulting in a positively skewed distribution.

Table 3 presents the descriptive statistics for the variables entered into the generalized linear models. The results show that the count data is overdispersed as the variance is greater than the mean. There is clear variation in key variables across the catchments. For example, on average, the population density is 2341 people/km^2 but varies from a low of 42 to a high of 7912. The average median age is 37 years and varies from a low of 25.5 to a high of 47.5. Across the catchment areas, on average 14.5% of the population attend an educational institute (school, technical and further education or university) but that varies from a low of 9.7% to a high of nearly 50%.

Across the catchment areas, on average, the bicycle network density is 0.19, indicating that for every 100 m of road infrastructure provided only 19 m of cycling infrastructure is available. The limited cycling infrastructure that is provided is not well connected indicated by an average bicycle connectivity index of 0.26 out of 1, this is in comparison to an average road network connectivity index of 0.93. The average land use mix index is 0.51 indicating relative mixed land uses exist within a given station catchment area. On average, 10.70 cyclist crashes are reported for each catchment square kilometre in the last 5 years. At each station, on average, 186 car parking spaces are provided with nearly three quarters (74.3%) of roads within each catchment area being local streets.

4.2. Multivariate modelling results

Goodness of fit statistics for each model are provided in Table 4. The full model and the sub models (station attribute and built/natural environment) for both the 'overdispersed' Poisson regression and negative binomial regression are statistically significant, indicated by the Omnibus test. While the Omnibus test is a comparison to the simplest model (the null model), the deviance can be examined to see how well the models fit the observed outcomes (a fully saturated model). As seen in Table 4, the negative binomial models have a better fit with the observed outcomes, indicated by smaller deviance values. For model comparison, the Akaike information criterion (AIC) can be used, smaller AIC values denote preferred models. The correlation coefficients between each of the variables were < 0.7.

Station, environmental and demographic categories were significantly correlated with the rates of cycling to railway stations (Table 5). In the full models, *train frequency, availability of secure bicycle parking* and *elevation* are significant at a 95% or higher confidence level (CL). *Patronage* is also significant at a 90% or higher CL in both full models. The demographic variable *median age* was significant in only the full negative binomial model at a 95% CL. Median age had a positive effect on the rates of cycling to stations, that is for every unit increase in median age, cycling rates to stations are expected to increase by a factor of 1.055. In addition, the percentage of local roads was significant in the full negative binomial model, at a 90% CL. A higher number of station bicycle access trips is correlated with an increase in

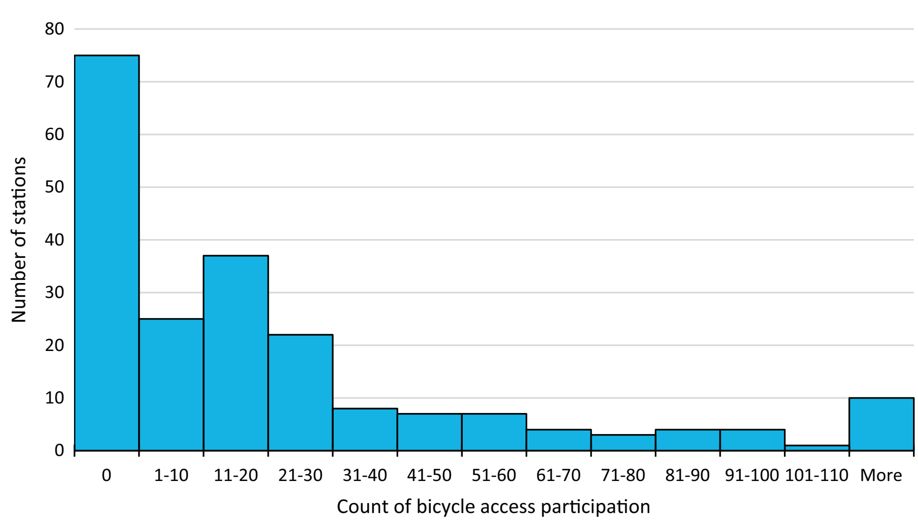

Fig. 4. Distribution of bicycle access counts.

Table 3
Descriptive statistics.

Variable	Mean	Standard deviation	Min	Quartile range			Max
				Q1	Q2	Q3	
Bicycle access counts	24.83	40.09	0	0	11.06	29.06	281
Population density	2341.02	1357.68	41.73	1316.16	2169.06	2962.88	7911.86
Occupancy to dwelling ratio	2.60	0.31	1.81	2.40	2.59	2.79	3.64
Median age	37.09	3.33	24.51	34.97	37.26	39.24	47.49
Population attending educational institute (%)	14.46	3.78	9.70	12.55	13.72	15.54	48.05
Municipal/Principal bicycle network density	0.19	0.07	0.01	0.15	0.18	0.23	0.44
Road network connectivity	0.93	0.04	0.83	0.90	0.94	0.96	0.99
Bicycle network connectivity	0.26	0.08	0.03	0.15	0.27	0.30	0.46
Traffic volumes	8345.28	1347.58	6121.63	7370.74	8149.56	8963.41	13,574.77
Land use mix	0.51	0.20	0.09	0.34	0.52	0.66	0.97
Terrain slope (%)	23.86	23.66	0.00	5.50	14.00	38.00	89.00
Bicycle crash count density	10.70	19.18	0.04	1.52	3.83	10.38	139.59
Road network composition - local roads (%)	74.28	13.97	23.51	66.04	75.71	84.66	99.74
Number of car parking spaces	185.91	200.88	0.00	17.00	119.00	292.50	947.00
Patronage (x10ˆ6)	1.04	2.65	0.02	0.31	0.52	0.82	27.96
Train frequency	19.44	8.62	0.00	15.00	18.00	23.00	62.00

Table 4
Model goodness of fit.

Statistics	'Overdispersed' Poisson regression				Negative Binomial regression			
	Station attributes only	Built/natural environment attributes only	Demo-graphic attributes only	Full model[a]	Station attributes only	Built/natural environment attributes only	Demo-graphic attributes only	Full model[1]
Deviance	5859.30	6571.48	7187.98	5133.86	511.99	526.57	612.83	464.29
df	189	185	189	172	189	185	198	172
Deviance/df	31.00	35.52	38.03	29.85	2.71	2.85	3.10	2.70
Log likelihood	−3242.17	−3598.27	−3906.51	−2875.36	−778.22	−785.51	−860.78	−747.79
AIC	6494.34	7214.53	7823.03	5784.72	1566.44	1589.99	1731.56	1529.58
Omnibus test	< 0.001	< 0.001	0.104	< 0.001	< 0.001	< 0.001	0.312	< 0.001

[a] Includes all station, built/natural environment and demographic attributes.

the percentage of local roads present within a station cycling catchment area. A single unit increase of this variable will increase the levels of bicycle ridership to stations by a factor of 4.5.

Across the full models the directionality of the shared significant variables were the same, therefore, in the following section, discussion of the results will focus on the full Negative Binomial model. In this model the variable with the largest positive effect on the rates of cycling to a station was the level of rail patronage (total passenger entries). As patronage levels increase by one unit change, levels of cycling to the station are expected to increase by 1.105. Frequency of departing trains during the morning peak period also has a positive relationship with the rates of cycling to the station. With a unit increase in the frequency of departing trains, rates of cycling are expected to increase by 1.027. Availability of secure caged bicycle parking facilities at stations is also correlated with a larger number of cyclists riding to the station. The model indicates that bicycle access rates to stations without secure caged parking facilities is 0.542 times that of those stations with such facilities. The terrain, in terms of the percentage of the catchment area with a slope of 2° or more, had the largest negative effect on the rates of cycling to the station. A single unit increase of this variable will see a decrease in the rates of cycling to stations by a factor of 0.287.

Land use mix is noted to have a positive influence on the rates of bicycle access to stations across both built/natural environment models at a 99% CL. As the land use mix index increases by one unit change, levels of cycling to the station are expected to increase by 3.642. Bicycle crash count density is also found to be significant at a 90% CL in the Poisson built/natural environment model. A greater level of bicycle access to stations is correlated with an increased bicycle crash count density. Both land use mix and bicycle crash count density are not noted to be significantly correlated with bicycle access rates in the full models.

The interplay between the rates of cycling to stations with the competition for available car parking space at stations were also examined in additional models. The level of competition for official car parking bays at stations, measured by number of car access trips divided by station car park capacity, were not found to be statistically significant and the models had reduced overall goodness of fit based on the AIC. Given 72% of patrons accessing the station by car, park in unofficial parking locations (neighbouring streets, parking garages etc.) such a metric may not be appropriate in accounting for the inherent competition present. These models were therefore omitted.

5. Discussion

This study provides new insights into the effects of observable attributes on the extent to which cycling is used as an access mode to public transport. Previous research has provided insights into bike-rail integration using case studies and qualitative studies (Rietveld, 2000; Martens, 2004; Martens, 2007; Barajas, 2012) or have been focused on recreational and commuter cycling without focusing on public transport access (Saelens et al., 2003; Mertens et al., 2017). This study adds to that knowledge base in a context where the costs of providing car parking at railway stations provides a strong incentive to promote lower cost access options.

Station attributes play a key role in encouraging greater levels of bicycle access to stations. Cyclists riding to the station are often required to leave the bicycle unsupervised for extended periods of time, making them easy targets for vandalism and theft. The availability of secure storage areas for bicycles can therefore encourage commuters to cycle to the station (Titze et al., 2008; Barajas, 2012; Fleming, 2012).

Table 5
Multivariate modelling.

	'Overdispersed' Poisson regression				Negative Binomial regression			
	Station attributes only	Built/natural environment attributes only	Demographic attributes only	Full model[a]	Station attributes only	Built/natural environment attributes only	Demographic attributes only	Full model[a]
	Exp (Coeff.)	Exp (Coeff.)	Exp (Coeff.)	Exp (Coeff.)	Exp (Coeff.)	Exp (Coeff.)	Exp (Coeff.)	Exp (Coeff.)
Patronage	1.118***			1.074**	1.140***			1.105*
Train frequency	1.034***			1.034***	1.032***			1.027***
Secure bicycle parking available								
No	0.581**			0.630**	0.560***			0.542**
Yes	Reference			Reference	Reference			Reference
Number of car parking spaces	1.000			1.001	1.000			1.000
Terrain - slope		0.180***		0.262**		0.197***		0.287***
Bike network connectivity		1.105		1.197		1.455		2.222
Road network composition -local roads		0.247		1.349		0.578		4.478*
Land use mix		3.807***		1.773		3.642***		1.541
Road network connectivity		36.294		70.643		16.168		7.964
Municipal/Principal bicycle network density		0.205		0.138		0.260		0.143
Bicycle crash count density		1.015*		1.009		1.008		0.998
Traffic volumes		1.000		1.000		1.000		1.000
Population density			1.000	1.000			1.000	1.000
Median age			1.070**	1.049			1.036	1.055**
Population attending educational institute			1.033	1.025			1.019	1.027
Occupancy to dwelling ratio			0.545	0.678			0.832	
Intercept	13.467***	2.664	4.814	0.136	15.564***	1.515	7.581	0.485

*** Significant at a 99% confidence level.
** Significant at a 95% confidence level.
* Significant at a 90% confidence level
[a] Includes all station, built/natural environment and demographic attributes.

The results presented here support this insight from the literature by highlighting stations with secure bicycle parking facilities are more likely to have a greater level of bicycle ridership than those stations without secure bike parking. Increasing patronage levels and frequencies of departing trains during the morning peak period have been found to have a positive effect on the rates of cycling to stations. Frequently used stations, as measured by the patronage levels, may encourage greater rates of cycling due to an increased level of competition in finding a station car parking space. As car parking, both official and unofficial, becomes harder to find, commuters may be encouraged to use alternative station access modes, such as the bicycle. Further research is however needed to confirm this hypothesis. Furthermore, at stations with high patronage levels, the levels of passive security are expected to be greater, this may also encourage commuters to ride to the station (Arbis et al., 2016). Rail service improvements and provision of secure bike parking facilities at stations have been correlated with higher levels of bike ridership to stations.

Several built/natural environment attributes significantly influence the levels of bicycle train intermodality. The terrain of the station cycling catchment area, as measured by the percentage of area above a 2° slope, negatively affects the rates of cycling to stations. This corroborates previous research findings which suggest that rates of cycling, as the main mode of travel, are reduced in areas with slopes > 3 to 5° (Saelens et al., 2003; Heinen et al., 2010). An adverse slope of 2° suggests commuters accessing the station by bicycle may prefer even lower physically exerting riding environments, as often there are no change room facilities at stations and cyclists tend to cycle in their work clothing (Weliwitiya et al., 2017). Encouraging mixed land use areas have been shown to promote general rates of cycling (Pucher and Buehler, 2008), this is also observed in the rates of bicycle access to stations. The percentage of local roads within a station catchment area has a positive influence on the rates of cycling to stations. Local roads generally have a restricted speed limit of 50 kph in Melbourne, where the cyclists share the space with motor vehicles. This may suggest cyclists riding to the station prefer low speed road infrastructure. Lower road speeds have been noted to encourage rates of cycling (Mertens et al., 2017) as cyclists perceive a greater level of safety. However, other risks exist when cycling on local roads, such as, dooring from parked vehicles or vehicles pulling out from the kerb (Bonham and Johnson, 2015). Related to safety, an increase in the rates of bicycle access to stations is correlated with an increase in the bicycle crash count density. Jacobsen (2003) outlined a 'safety in numbers' effect in more well established cycling nations, however, similar to the finding from Pucher et al. (2011), increasing participation in bicycle train intermodality has seen a rise in crashes in the Australia context.

Demographic variables were also noted to be correlated with the number of cyclists riding to the station. In this study an increasing median age has a positive correlation with the number of cyclists riding to the station. Similar findings have been highlighted by Mead et al. (2016). This factor, however, has a contrasting effect based on the findings of other studies that correlate median age increases with decreasing cycling rates (Australian Bicycle Council, 2013). This could potentially be because cycling to the station is specifically for utilitarian transport purposes, where a large portion of cyclists accessing the station are adults on their way to work (Weliwitiya et al., 2017). For older commuters health related concerns may encourage active transport options such as cycling to be considered. Further research is needed to identify the factors influencing individual behaviour.

In relation to bicycle train intermodality, compared to cycling as the main mode of travel, population density, road network connectivity and bicycle network density were found to be nonsignificant, indicating these do not impact rates of bicycle ridership to stations. Particularly relating to population density there is debate in the literature as to their effects on the rates of cycling. Some studies (Krygsman et al., 2004; Moudon et al., 2005) find that cycling rates increase with a greater population density while others (Sallis et al., 2013) find countering evidence. In the case of bicycle ridership levels to stations, areas with greater population densities often have improved localised public transport services (buses and trams), these may compete with the bicycle and offer an alternative station access mode option. Road network connectivity rates in Melbourne suggest stations have high levels of accessibility, however, due to a lack of on road cycling infrastructure, road network connectivity does not translate to an increased level of bicycle access to stations. Furthermore, bicycle network density, relating to cycling infrastructure provided across the network, does not influence levels of bicycle access to stations. This may be because there is a lack of connected cycling infrastructure that currently exists feeding commuters within a catchment area into the station precinct.

Much of the evidence suggests emulating the practices and policy changes currently present in Netherlands, Denmark and Germany can have a positive effect on the rates of cycling to stations in re-emerging cycling nations like Australia. In countries where cycling rates are low, transport planning efforts focusing on motorised modes of travel combined with low density suburban sprawl have made it difficult for cycling to be adopted for utilitarian travel. Focus should be placed on integrating cycling with public transport, particularly as an urban mobility option. Measures to encourage this should primarily focus on making cycling safe and convenient around station cycling catchment areas. Cycling master plans should specifically outline investment and planning details regarding the integration of cycling and public transport. Consideration should be given to lowering speed limits along roads that feed into station precincts, providing connected cycleways enhancing access to stations by bicycle and modifying intersections to protect cyclists from exposure to traffic dangers (Pucher and Buehler, 2008). This research suggests existing bicycle infrastructure is not well connected and does not provide adequate access to stations, as a result, cyclists are required to use routes that lead to the station using low speed local roads. Improving rail services and bicycle parking facilities should also be considered (Heesch and Sahlqvist, 2013).

6. Conclusion

Integrating the bicycle with public transport offers a convenient urban mobility option that has many benefits. This study examined the associations between demographic, built/natural environment and station attributes on the rates of bicycle access to stations. Multivariate modelling results indicate station patronage, frequency of departing trains during the morning peak period, availability of secure bicycle parking, cycling grade, median age, presence of low speed local streets, bicycle crash count density and land use mix are correlated with the rates of bicycle access to stations. Systematically lowering the barriers which prevent people from cycling to the station could help to unlock the potential of this access mode as demonstrated by its high use in many European countries. Contextual differences between countries with high levels of cycling overall, and emerging cycling nations such as Australia, highlights why deeper research on this topic is needed. Specifically in the context of bike and rail integration, future research should aim to unpack the effects of overflow car parking availability around the station precincts accounting for both official and unofficial parking bays. Also, consideration should be given to expand the socio-economic variables tested to include household composition (specifically the presence of children), education attainment and occupation. Finally, metrics from the built/natural environment and station attributes could be combined and simplified to form a station bikeability index.

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The paper presented insights into the objective factors affecting bicycle access rates at metropolitan railway stations. Tangible measures were discussed, which if employed, may have a positive impact on encouraging greater levels of bicycle-rail integration. The next chapter builds on the results of Study 1, to investigate the factors affecting bicycle parking choice.

Chapter 5 Bicycle parking choice at stations

Provision of secure bicycle parking facilities at railway stations plays an important role in promoting and sustaining bicycle access trips to the station. The previous study (Chapter 4), identified, in the context of Melbourne, stations with a Parkiteer caged facility have higher rates of bicycle access trips than stations with traditional open-air parking facilities. Examination of Parkiteer touch-on data, however, indicate high variability in usage across the different locations with many bike-and-ride users opting to instead use open-air facilities. Given the planned expansion of the Parkiteer program, this study aimed to identify the factors affecting bicycle parking choice. Furthermore, with a marked increase in reported bicycle thefts at railway stations, the focus was also placed on identifying the parking needs of bike-and-ride users.

Insight gained through this study, can inform the strategic direction of parking facility investment across the rail network. Figure 5-1 outlines how this study fits in with the other elements of the doctoral research program.

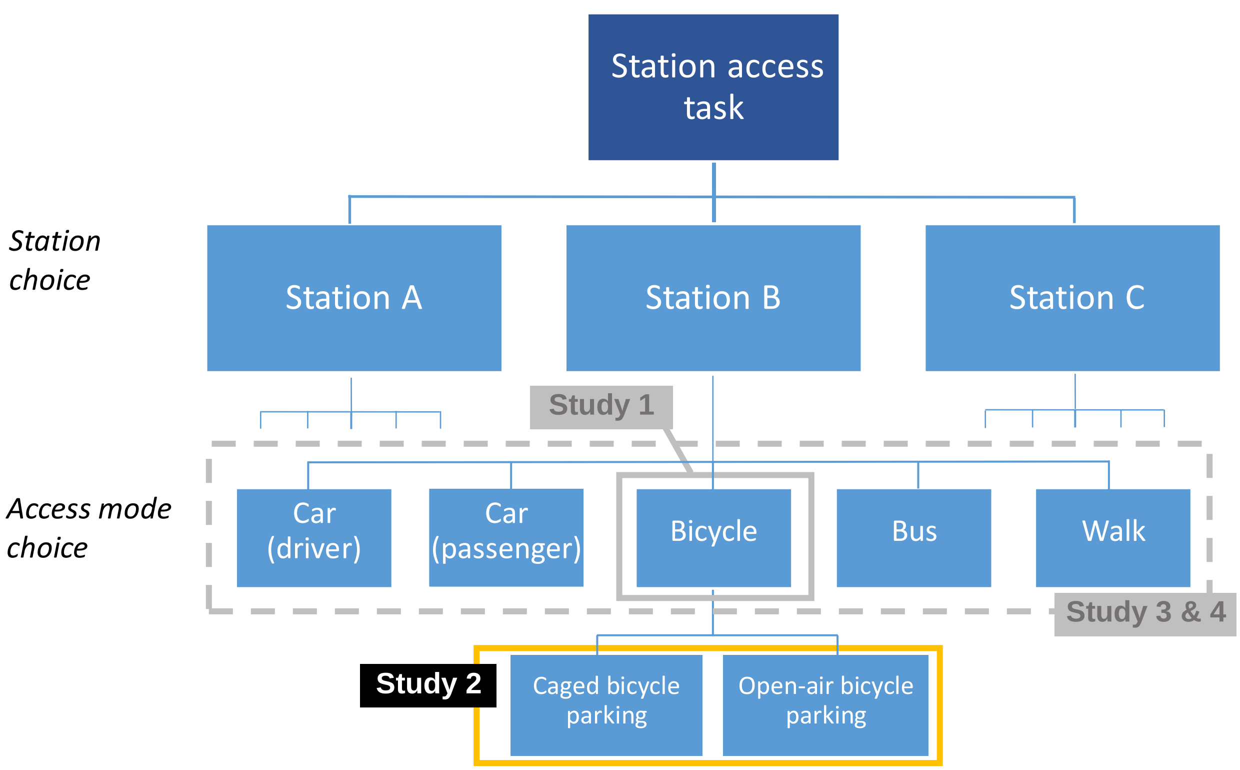


Figure 5-1: Access mode(s) under investigation

5.1 Introduction

Having ridden to the station, an issue many cyclists face is the inability to carry their bicycle on-board either due to regulatory requirements (Pucher & Buehler, 2009) or because of a lack of available space. In Melbourne, bicycles are permitted on trains, however, this is often impractical during peak periods where severe overcrowding issues are commonplace. Cyclists, therefore, often leave their bicycle unattended at railway stations for long periods of time where they are exposed to the risks of theft or vandalism (Weliwitiya et al., 2018). To minimise these risks and help to promote and support rail commuters to ride to the station the provision of secure bicycle parking facilities is needed (Cervero et al., 2013; Barajas, 2012a; Fleming, 2012).

In Melbourne, cyclists riding to the station are provided the option of locking their bicycles on to open-air facilities (bicycle hoops, fences or street furniture) (Figure 5-2, Left), or at some stations, in Parkiteer caged facilities (Figure 5-2, Right). Parkiteer caged facilities offer restricted access, via a swipe card, and have a capacity to store 26 bicycles. As of December 2019, Parkiteer cages had been installed in over 100 stations, with more planned across the 220 rail station network. At a unit cost of $120,000 ($4,615 per bike), Parkiteer facilities are considerably more expensive than alternative bicycle parking facilities such as bike hoops which cost in the order of $250 to $1,000 each ($125-$500 per bike).

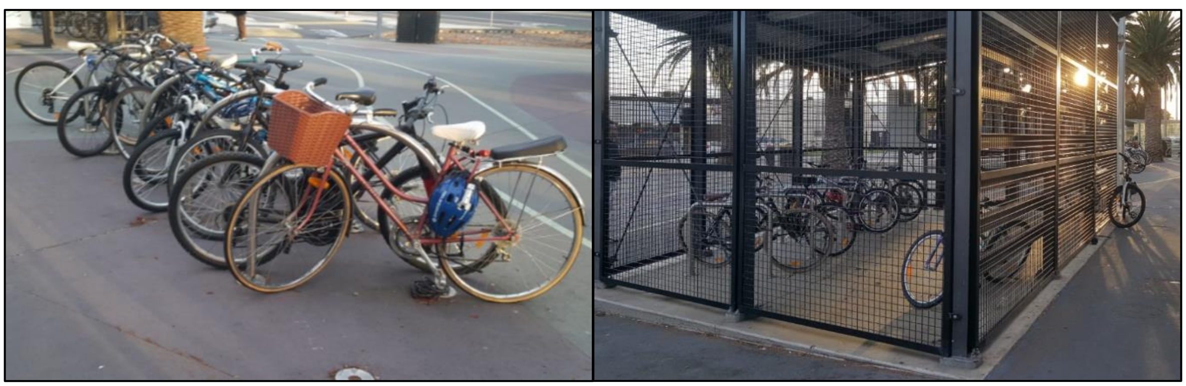


Figure 5-2: Bicycle parking facilities at Springvale station
Left: Open-air bicycle parking (hoop), Right: Parkiteer caged facility

Parkiteer usage, as measured by the swipe card access data, demonstrated a high variability across the network with some Parkiteer facilities at capacity and others with low usage rates (Mead et al., 2016b). For example, the Parkiteer cage in Laverton Station (21km west of CBD) had a wait list for registration and was frequently overcapacity with all bike racks inside the Parkiteer occupied on weekdays. In comparison, Parkiteers at stations northwest of the CBD (Roxburgh: 22km; Diggers Rest: 33km) operate at less than five percent capacity on most weekdays.

Variability in Parkiteer usage can be attributed to a multitude of factors such as the road environment, ease of cycling to the stations and demand for bicycle related access. This variability can also be influenced by the commuters' bicycle parking choice. Observational reports, conducted as part of this study, indicate almost half (48%) of bike-and-ride users parked at an open-air facility despite the availability of a Parkiteer. With the planned expansion of the Parkiteer program, there is a need to understand parking behaviour to better inform operational and investment decisions.

Research examining the factors that influence bicycle parking choice and usage is limited (Arbis et al., 2016; Van der Spek & Scheltema, 2015). With increasing rates of reported bicycle thefts at some stations and the planned expansion of the Parkiteer program, it is important to ensure parking facilities meet the needs of bike-and-ride users. To maximise the return on bicycle parking investment this study aimed to:

- Examine the parking needs of cyclists at railway stations (*Sub RQ2*); and
- Identify the factors which affect commuters' bicycle parking choice at railway stations (*RQ2*).

Insight gained through this study, can inform bicycle parking policy including siting, provision of auxiliary features (e.g. lighting, undercover parking and closed-circuit television (CCTV) monitoring) and the strategic direction of parking facility investment across the rail network.

5.1.1 Reported cases of bicycle theft at railway stations

Bicycle theft is a major issue at some railway stations. Over 96 percent of reported thefts in a public transport setting took place at a railway station (Crime Statistics Agency, 2019). Between October 2004 and September 2016, a total of 4,063 bicycles were reported to have been stolen within station precincts. Over this period, the rate of reported bicycle thefts had also grown, with a substantial increase in recent years (see Figure 5-3)

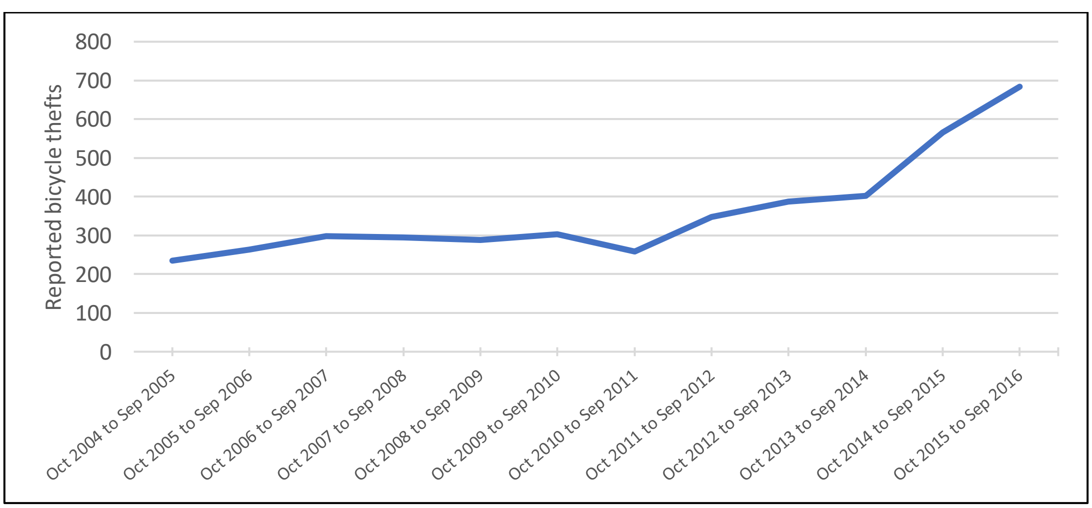


Figure 5-3: Reported cases of bicycle theft at stations over time

5.1.2 Trends and variability in Parkiteer use

Parkiteer swipe card data from 2010 to 2015 was analysed to identify the trends and variability in usage across the stations. On average, in 2010, the Parkiteer network (48 cages) served 157 cyclists daily with this number increasing to 479 cyclists daily in 2015 (82 cages).

Analysis of the Parkiteer usage patterns revealed high levels of variability at different railway stations and across lines (see Figure 5-4 and Figure 5-5). The annual growth rate of usage between 2010 and 2015 was plotted against the average daily ridership in 2015 (Figure 5-4). Parkiteers that were operational both in 2010 and 2015 (n=48) were used in this comparison. Across all 48 sites, the average daily ridership (both weekdays and weekends) was slightly below 6 bicycles parked in a Parkiteer, however, at individual sites the ridership counts ranged from almost zero to almost 16 bicycles parked daily. At all but four Parkiteer sites, the usage rates experienced a growth between 2010 and 2015. High rates of growth were observed at Parkiteers which had low average daily ridership, whereas low to modest rates of growth were noted at Parkiteers with an above average daily ridership.

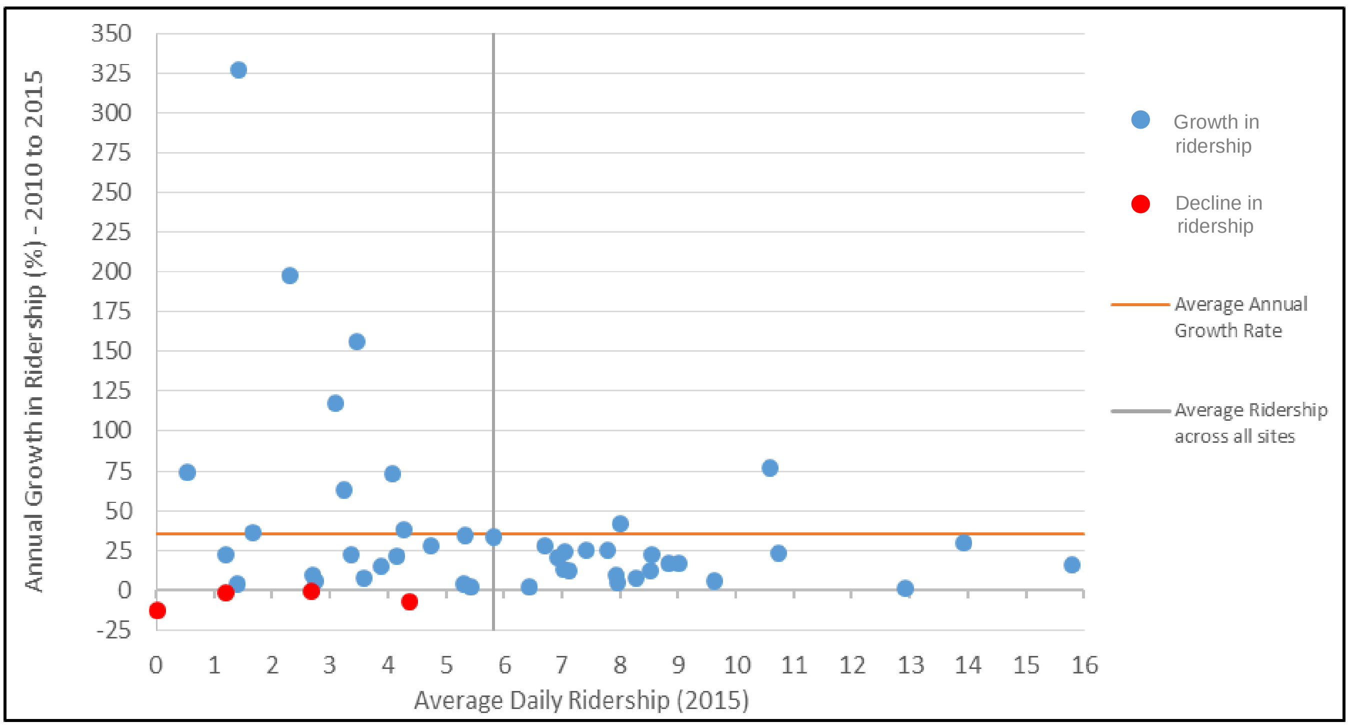


Figure 5-4: Parkiteer ridership and annual growth in use (n=48 stations)

Parkiteers that were operational in both 2010 and 2015 were aggregated along each train line (Figure 5-5). At this aggregate level, Parkiteer usage also varied considerably across train lines. The average daily Parkiteer entry ranged from a low of 3 bikes (Craigieburn line) to 11 bikes (Werribee line). Furthermore, the variability in Parkiteer usage over time, as measured by the standard deviation (indicated by the error bars), increased across all individual train lines over time (2015 compared to 2010), except on the Sandringham line where there was a reduced variance in usage.

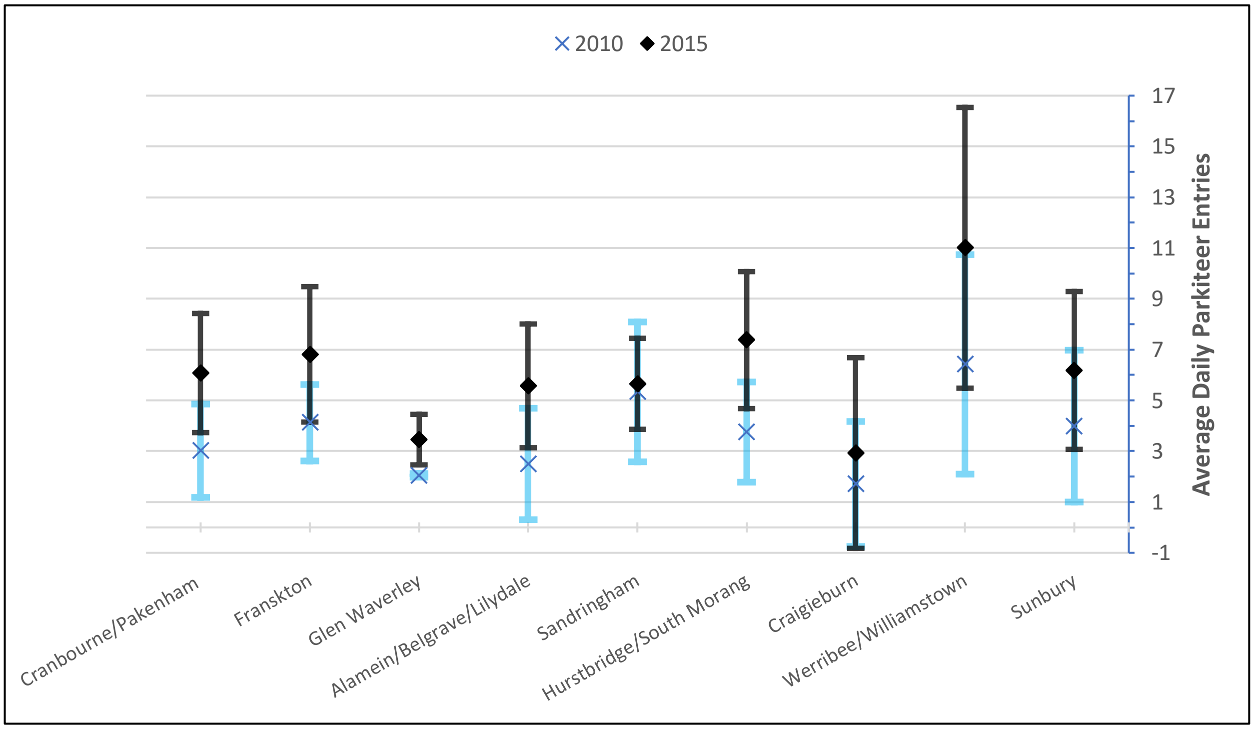


Figure 5-5: Change in Parkiteer use between 2010 and 2015 along train lines

5.2 Research method

The focus of this research study was on station bicycle parking, specifically *Sub RQ2* and RQ2 (Chapter 3). These two research questions were addressed as followed:

- In exploring the parking needs of cyclists at railway stations (*Sub RQ2*), bike-and-ride users' satisfaction levels were gauged through an intercept survey. User satisfaction levels related to attributes affecting bicycle safety (e.g. lighting, proximity to the station entrance) were measured. For each attribute, the satisfaction levels were separately evaluated for participants who had parked in a Parkiteer and those who used open-air facilities. Comparisons of the satisfaction levels between the users of the two bicycle parking facility types were evaluated to better understand their different needs.

- Parkiteer usage rates vary by site, partially due to the parking practices of bike-and-ride users. Given the proposed expansion of the Parkiteer program, *RQ2* aimed to explore the factors which affect bicycle parking choice at railway stations. To maximise the return on investment, the intended outcome was to provide insights to inform operational and investment decisions. Bivariate and multivariate analyses were conducted to identify the factors associated with bicycle parking choice.

5.2.1 Data Sources

This section outlines the data used to address both research questions. This includes detail of primary data collected through an intercept survey in addition to secondary station crime statistics data.

5.2.1.1 Bike-and-ride user intercept survey

Bike-and-ride users were intercepted and invited to complete a questionnaire. The aim of the survey was to explore current cyclists' parking practices and their experiences of riding to the station. Due to the marginal nature of cycling as a station access mode, a census sampling approach was adopted. With assistance from over 100 undergraduate students, every cyclist who parked at a survey location during the survey period was approached and invited to participate in the study. A prize draw of a $200 shopping voucher was used as an incentive to encourage participation. Intercepts of bike-and-ride users took place at 36 metropolitan railway stations and 326 surveys were distributed. In the following section, detail of the survey design, intercept site selection and the distribution phase are outlined.

Survey design

A self-completion questionnaire was designed to better understand the bicycle parking practices of both Parkiteer and open-air facility users. Respondents had the option of completing the survey online, either through a weblink or QR code provided in the explanatory statement, or by filling out a paper copy handed to them and sending it back in a reply-paid envelope. To minimise the need to digitise handwritten responses, participants would double their chances of winning the $200 shopping voucher if they responded online.

Completion of the questionnaire took about five minutes and included questions related to the respondents' travel behaviour and parking practices. Specifically linked to RQ2, the questionnaire included statements designed to gauge the levels of satisfaction related to bicycle parking at stations. Attributes tested broadly related to bicycle parking security and amenity, including: the parking area being highly visible, well-lit storage area, secure point to lock bicycle, undercover weather protection, parking facility monitored by CCTV and the proximity of the parking to the station entrance. For each attribute, cyclists were able to indicate their level of satisfaction on a five-point Likert scale.

The questionnaire also included questions about bike-and-ride users' trip details (trip purpose, frequency of riding a bike to the train station, frequency of using rail services, origin of the trip to the station), availability of a motor vehicle, value of bicycle ridden to the station, history of bicycle(s) vandalised or stolen, perceptions about caged bicycle parking facilities (such as the ease of registration), type of bicycle parking facility used (Parkiteer or open-air) and demographic characteristics (date of birth, gender). These questions were utilised to address RQ2, and broadly fell into four broad categories including perceptions about the registration process, cyclists' demographics, travel behaviour and the characteristics of the bicycle ridden (see Table 5-1). A copy of the full questionnaire is included as Appendix B.

An inherent issue in all research methods, including an intercept survey, is the lack of data from non-respondents. Typically, insights of the population from which the sample is drawn are not known and this questions the reliability and representativeness of the data. To minimise this bias, observational data was recorded. The total number of cyclists who rode to the station including their gender and the parking facility used were recorded. These data enabled the representativeness of the sample to be determined for gender and parking practices of bike-and-ride users.

Site selection

Stations were selected based on high levels of cycling activity as well as the availability of a Parkiteer facility and open-air parking facilities. Two key datasets were used to identify the expected cyclist activity levels at stations. First, Parkiteer usage rates were gathered from Bicycle Network (the organisation that manages the Parkiteer facilities). Second, cycling access counts at stations across the rail network were obtained from Public Transport Victoria. Additionally, another issue that needed to be considered was the level crossing removal works that were being undertaken. Starting from 2015 and expected to be completed by 2022, the planned removal of 75 level crossings across the network resulted in temporary closure of stations during construction. Site selection was, therefore, limited among the stations operational during the survey periods. Figure 5-6 outlines the location of the 36 stations where the surveys were distributed. These stations represent a mix of geographic regions within Greater Melbourne to provide a sample representative of the wider cycling population's parking practices at stations. All the stations are indicated with a black dot and the stations where a survey was conducted are circled in green.

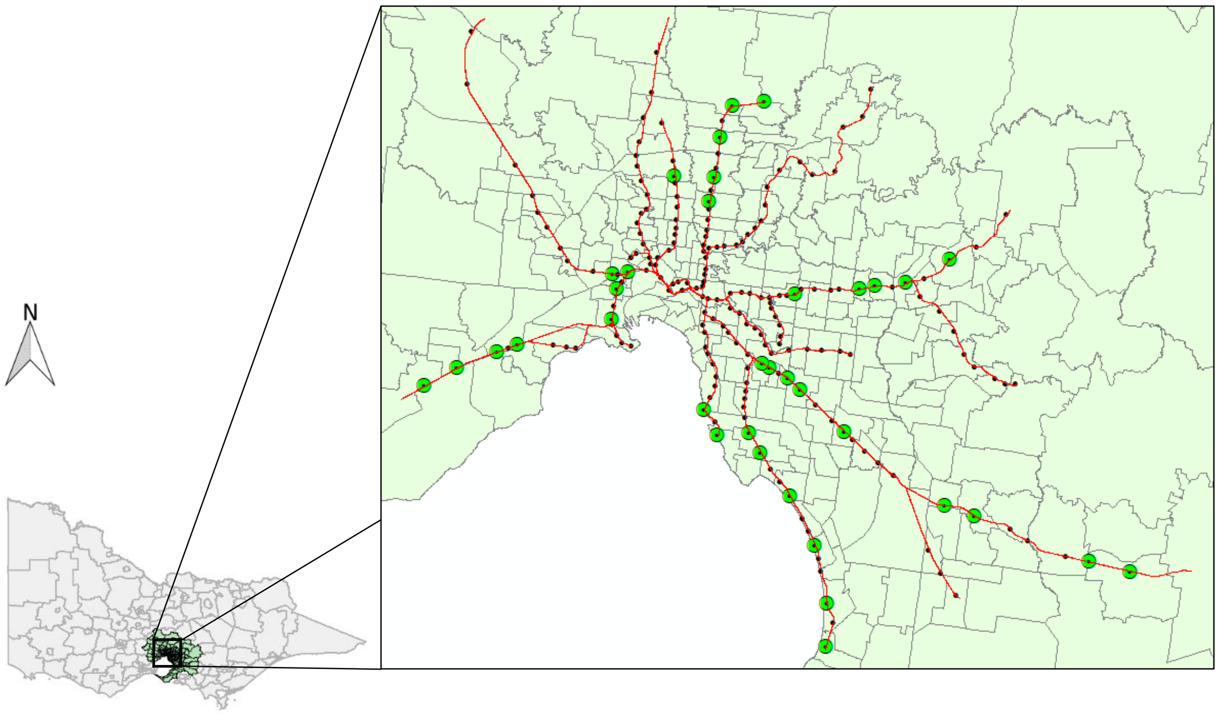


Figure 5-6: Bicycle parking survey locations

Survey distribution

The survey distribution was conducted over a period of a year to maximise the opportunity for assistance from undergraduate university students. Initially, a small-scale survey was conducted at five stations along the Cranbourne/Pakenham line with the help of two final year civil engineering students in April 2016 (late autumn). The survey was distributed during peak morning travel times (7-9 AM). Ideal cycling conditions were present with a morning temperature of 14ºC and an expected high of 27ºC, rain was not forecast. The questionnaire was distributed to all cyclists who rode to the five target stations and parked within the station precinct. Survey staff approached potential participants, over the age of 18 years, briefly described the survey and invited them to participate. A total of 76 questionnaires were handed out.

In September 2016, with the help of over 100 final year civil engineering students, questionnaires were distributed at 30 railway stations across the metropolitan rail network at the start of spring. During the distribution phase, in the morning peak period (7-9 AM), it had rained. Due to the extensive logistics involved in coordinating the large group of students, it was not possible to reschedule the survey, particularly given the university semester teaching deadlines. Given rain is known to reduce the levels of cycling (Martens, 2007), it is likely to have had a negative impact on the number of rail commuters cycling to the station. A total of 165 questionnaires were distributed as part of this data collection effort.

In March 2017, with the assistance of three final year civil engineering students, a third survey distribution exercise was undertaken at five railway stations. During the intercept survey, in the morning peak period, conditions were dry and a total of 85 questionnaires were handed out. At four of the five stations, a survey had already been conducted as part of the September 2016 recruitment. Previous participation was an exclusion criterion so potential participants were screened based on whether they had previously completed the same questionnaire. Furthermore, contact details of respondents were compared to ensure no single participant completed the survey previously.

5.2.1.2 Police crime statistics

Open source data, made available by the Crime Statistics Agency, Victoria Police, on station crime statistics was used to explore the levels of bicycle theft at railway stations at a postcode level between October 2004 and September 2016 (Crime Statistics Agency, 2016). As the theft rates were not able to be disaggregated beyond the postcode level, an assumption was made that all stations within a single postcode experienced the same number of bicycle thefts. The number of reported thefts were noted at the 36 stations where the surveys were distributed, these counts were used as an explanatory variable in modelling the factors affecting bicycle parking choice.

5.2.2 Analysis techniques

This section outlines the analysis methods employed in this research study.

5.2.2.1 Sub RQ2 – Bicycle parking satisfaction levels

The satisfaction levels related to bicycle parking attributes were gauged through a five-point Likert scale (very dissatisfied, slightly dissatisfied, neutral, slightly satisfied, very satisfied). Each response was coded into an integer value between -2 for very dissatisfied to 2 for very satisfied. Mean scores were calculated, enabling comparisons to be drawn between the satisfaction levels of open-air facility users and Parkiteer users. Chi-square difference tests were conducted to identify which attributes varied significantly between people who parked in a Parkiteer and people who used open-air parking facilities. An assumption made, as part of this analysis, is that parking satisfaction is able to be measured on a linear Likert scale (Allen & Seaman, 2007; Likert, 1932).

5.2.2.2 RQ2 – Bicycle parking choice

The aim was to identify the factors affecting bicycle parking choice at stations that is, either the use of a Parkiteer facility or an open-air facility. In modelling bicycle parking choice, the explanatory variables (Table 5-1) were investigated and represented five broad categories including perceptions about the registration process, cyclists' demographics, travel behaviour and the characteristics of the bicycle ridden as well as police crime statistics.

Table 5-1: Explanatory variables included in the model

Input category	Variable
Parkiteer registration process	Wait time for Parkiteer swipe card is acceptable
	Registration process to use a Parkiteer is convenient
Rider demographics	Age
	Gender
Travel behaviour	Number of days cycled to the station
	Distance from the CBD
	Metropolitan region where bike was parked
	Distance to station from home cross street
	Distance from parking facility to station entrance
Bicycle characteristics and theft/vandalism history	Number of times a bicycle was stolen or vandalised at a station
	Number of bicycles owned
	Value of the bicycle ridden to the station
Police crime statistics	Historic station theft count (2004-2016)

Preliminary analysis of the data involved conducting hypothesis testing (chi-squared and t-tests) to calculate which variables were significantly associated with bicycle parking choice at a bivariate level. Following this, a forward stepwise binary logistic regression model was developed. This type of model was used because of the dichotomous nature of the dependent variable (parking in a Parkiteer or an open-air facility). The parameters in each model are estimated using a maximum likelihood approach. A binary logistic regression model is defined in the following manner:

$$log\left[\frac{P(Y=1)}{1-P(Y=1)}\right] = log\left[\frac{\pi}{1-\pi}\right] = \log it(\pi)$$

$$= a + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n$$

Where $P(Y = 1) = \pi$ describes the probability of a bike-and-ride user parking their bicycle in a Parkiteer. The probability falls between 0 and 1 for all possible independent variables. a is the intercept term in the model and β_i $(i = 1,2,3, \dots, n)$ are the regression coefficients for a matrix of covariates X_i $(i = 1,2,3, \dots, n)$.

5.3 Results and interpretation

The results of this study are presented in this section. It begins with an outline of the survey response rate, followed by a review of the sample characteristics and travel behaviour. Bicycle parking satisfaction levels are then explored followed by the factors affecting bicycle parking choice.

5.3.1 Survey response rates

A total of 326 questionnaires were distributed to cyclists at 36 stations across all distribution stages. Of those, 170 were completed and returned resulting in an overall response rate of 52.2 percent. The response rate varied geographically across the regions with the highest being in the South-East (70%) compared to the lowest in the inner-city region (26%). Most of the respondents (71%) filled the questionnaire online with the remainder returning it via post (29%).

Of the 170 respondents, the majority (n=106, 62.3%) had parked their bicycle in a Parkiteer. The most common reason was because they wanted greater security for their bicycle at the station. Of the one third (n=64, 37.6%) of respondents who had used alternative parking facilities the main reason for their choice was the fact they were satisfied with the levels of security provided by the alternative facilities. The most common reason for not using a Parkiteer was because they were unsure how to register for Parkiteer access (n= 28, 45.2%). Open-air facility users' knowledge of Parkiteer use was low, only a third (34%) of respondents knew about the requirement to pay a one-off $50 bond to gain key card access to Parkiteer facilities and only about half (45%) believed this cost to be refundable.

5.3.2 Sample characteristics, travel behaviour and descriptive statistics

The survey sample characteristics and travel behaviour are outlined in this section.

Gender

As in most countries where cycling has a low share of total commuter trips, there was an under-representation of female cyclists in this study (Pucher & Buehler, 2008). On the dates of the survey 21 percent of all observed cyclists were female. Of those who responded, it was noted 22 percent of the participants were female, this indicates the sample is representative of the gender split apparent in the population. Focussing on bicycle parking choice by gender, 65 percent of female cyclists who rode to the station and responded to the survey had parked their bicycle in a Parkiteer, slightly higher than male cyclists (61%).

Age

Respondents ranged from 18 to 69 years of age. On average, female respondents were younger (37.5 years) than male respondents (40.5 years). Cyclists who parked in a Parkiteer were, on average, slightly younger than those who used open-air facilities, 39.6 years compared to 40.1 years respectively.

Trip purpose

Given the surveys were distributed during the morning peak travel times, the majority of respondents rode to the train station to commute for employment (85%) or education (11%) purposes.

Bicycle value

The value of bicycles ridden to the station ranged from up to a $150 to in excess of a $1,000. The largest segment of bicycles was valued between $301 and $700 (34%), followed by low-cost bicycles valued up to $150, colloquially referred to as 'pub bikes'[1] (27%) and then those valued between $151 to $300 (23%).

Train use and bicycle access frequency

A third of the respondents (65%) indicated they travel by train on five or more days in a typical week. Half of the respondents (52%) stated they tend to access the station by bicycle on five or more days in a typical week (see Figure 5-7). This indicates the bicycle is a relatively 'sticky'[2] access mode, where it is often always used to get to the station among those who currently ride to the station.

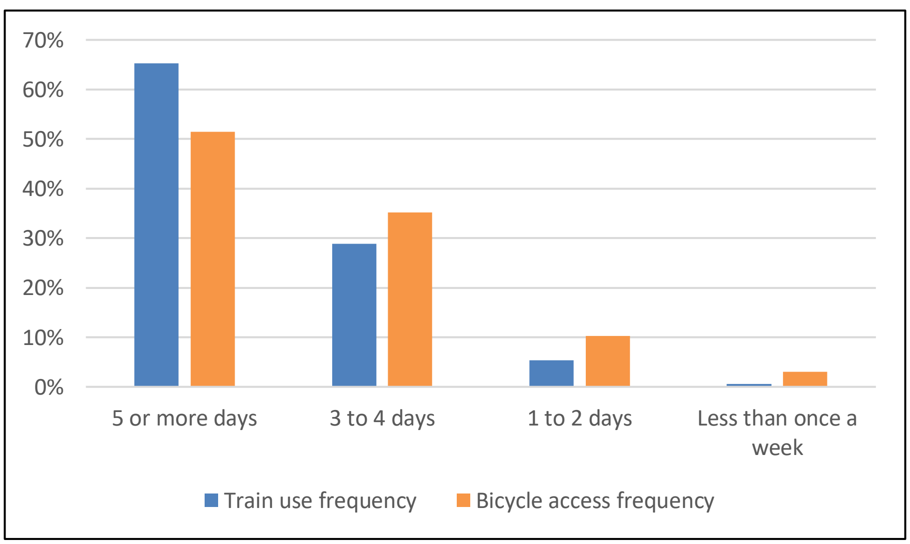


Figure 5-7: Train use and bicycle access frequency

[1] Pub bikes refer to cheap and simple bikes which require low maintenance or upkeep

[2] 'Sticky' is defined as the consistency in which a particular mode is used for the station access task

Cycling distance

The cycling distances between the respondents' home-end cross street to the station were calculated. On average cyclists rode 2.22 km to the station. People who parked in a Parkiteer rode slightly larger distances on average (2.33 km) compared to those using open-air facilities (2.04 km) (see Figure 5-8).

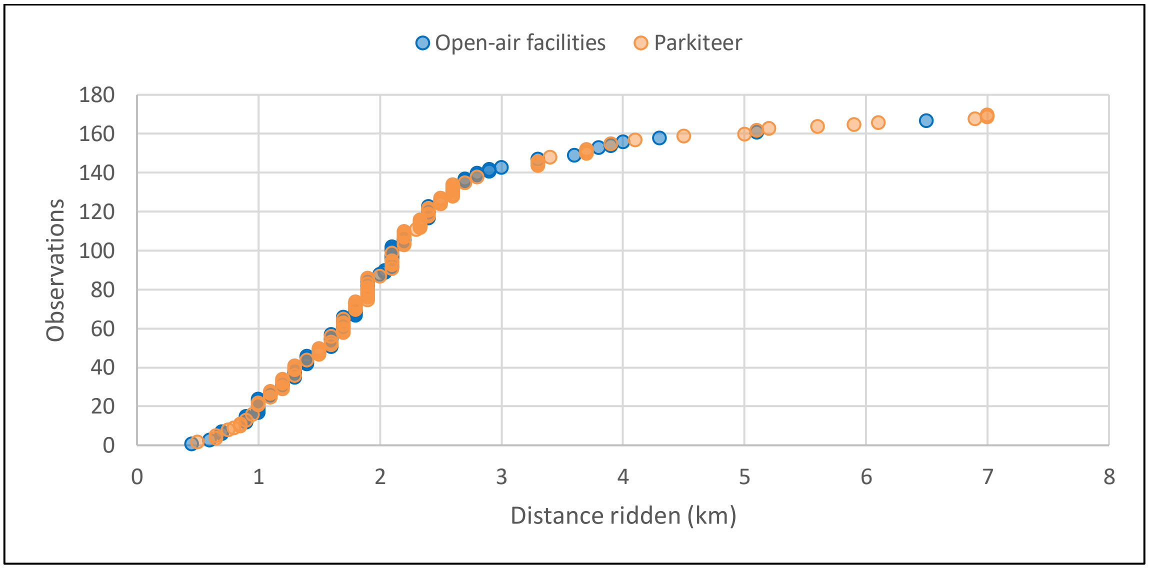


Figure 5-8: Parking facility used at the station compared with the distance ridden

5.3.3 Parking feature satisfaction

Measures of satisfaction levels have traditionally been employed in transport related research to identify cost effective improvements that can be made to increase rail patronage (Brons et al., 2009; Givoni & Rietveld, 2007). The same principal is utilised in this study to identify satisfaction levels related to bicycle parking at railway stations.

By gauging the parking needs of cyclists, measures can be implemented to:

- Improve aspects of the current and future provision of bicycle parking facilities at train stations; and
- Provide parking facilities which meet the security needs of people cycling to the station, potentially encouraging greater levels of bicycle access to stations.

Table 5-2 outlines the satisfaction scores related to several attributes of bicycle parking. These primarily relate to aspects of security (e.g. highly visible) but also include parking amenity (e.g. provision of undercover parking).

Table 5-2: Station bicycle parking satisfaction scores by bicycle parking location (n=140)

Attributes related to parking security and amenity	Parkiteer users	Open-air facility users	Chi-square tests of independence
Parking area is highly visible	1.51	-0.07	0.016
Parking facility monitored by CCTV	1.47	1.11	0.005
Parking close to the station entrance	1.4	1.28	0.423
Secure point to lock bicycle	1.31	-0.04	<0.001
Undercover weather protection*	1.29	0.94	<0.001
Well-lit storage area*	0.66	-0.19	0.187

*n=139; Mean score scale: -2 (Very dissatisfied) to 2 (Very satisfied)

A total of 140 respondents indicated their levels of satisfaction. Overall, people who parked in a Parkiteer were more satisfied with all aspects of the Parkiteer parking compared to people who parked in open-air facilities.

The attribute with the highest satisfaction score among Parkiteer users was the parking area being highly visible, which is important in providing passive levels of security for bicycles left at the station (Arbis et al., 2016). Bike-and-ride users who used a Parkiteer were weighted towards being very satisfied whereas those using open-air facilities were more neutral albeit weighted toward being slightly dissatisfied. A chi-square difference test indicated the satisfaction levels related to the visibility of parking were significantly different among the two facility user groups. Similarly, a significant difference in satisfaction was noted among the two groups for CCTV monitoring. People who used a Parkiteer were more satisfied compared to people who locked their bicycle to open-air facilities.

Significant differences in satisfaction levels were also noted for attributes related to the availability of a secure point to lock the bicycle as well as parking providing undercover weather protection. In both cases, Parkiteer users were more satisfied than open-air facility users. Satisfaction levels relate to parking being close to the station entrance and having a well-lit storage area were not significantly different between Parkiteer users and open-air facility users. Both user types were generally satisfied with the proximity of the parking to the station entrance, however, satisfaction related to lighting of the storage area was poor for both Parkiteer and open-air facility users.

The above satisfaction levels indicate bicycle parking tends to be close to the station entrance. However, historical decisions to prioritise other station facilities have resulted in parking facilities and subsequent locations being relegated to obscure locations. This has resulted in a lack of passive and active forms of security particularly for open-air bicycle parking facilities. At some stations, this issue can be made worse, where bicycle hoops are not provided, and cyclists are required to chain their bicycle onto fences, railings or street furniture. This emphasises the need for secure points to lock the bicycle, for open-air facility users, while also providing other amenities such as undercover weather protection with ample lighting. While Parkiteer users were much more satisfied with their parking experience compared to open air users, there is scope for improved lighting.

When considering improvements to bicycle parking, the priority should be placed on provision of appropriate open-air facilities which address the needs of its users. This presents an opportunity to drastically improve the satisfaction levels of open-air facility users while promoting the use of low-cost bicycle parking (per bike cost: Parkiteer, $4,600; bike hoop, $125-500).

5.3.4 Bicycle parking choice

This section addresses RQ2, which aimed to explore the factors influencing bicycle parking choice. Bivariate and multivariate analysis is used to gain insights into the factors affecting the choice of parking facility used, to better inform operational and investment decisions about expanding the Parkiteer program.

The variables discussed in Section 5.2.1 and outlined in Table 5-1 were incorporated into this analysis. These variables broadly accounted for five categories including perceptions about the registration process, rider demographics, travel behaviour, characteristics of the bicycle ridden to the station as well as station crime statistics.

5.3.4.1 Bivariate analysis

Preliminary analysis involved examining the association of several variables of interest with the choice of bicycle parking facility used. Bivariate analysis in the form of chi-squared tests and t-tests were utilised. Table 5-3 presents the results of the chi-squared tests for the categorical variables while The distance from the parking facility to the station entrance was significantly associated with the facility used. On average (mean), Parkiteer users parked farther away from the entrance than open-air facility users. Furthermore, parking facility used was significantly associated with the distance from the home station to the Melbourne CBD. Parkiteer users, on average, were farther away from the Melbourne CBD than those using open-air facility.

Table 5-4 summarises the results of the t-tests for the continuous variables. Several variables were significantly associated with the bicycle parking facility used.

Perceptions related to the Parkiteer registration process was strongly linked with the bicycle parking facility used. A significant association was noted between the use of parking facility and level of agreement in relation to the wait-time for a Parkiteer swipe card being acceptable and the registration process being convenient. This indicates the importance of a streamline registration process to maximise the return on Parkiteer investment. The value of the bicycle ridden to the station was also significantly associated with facility used. On average (mode), the value of bicycles parked in Parkiteer was higher than the value of bicycles parked in open-air facilities.

Table 5-3: Descriptive statistics - chi-squared analysis of categorical variables

Variable	**Parkiteer users (mode)**	**Open-air facility users (mode)**	**Significance (p value)**
Wait time for Parkiteer swipe card is acceptable	Agree	Neutral	<0.001
Registration process to use a Parkiteer is convenient	Agree	Neutral	<0.001
Bike value	$151 to 300	Up to $150	0.006
Typical number of days cycled to the station	5 or more days	3-4 days	0.079
The region of Melbourne where the bicycle is parked	South	South	0.100
Number of times a bicycle was stolen at a station	Never	Never	0.107
Gender	Male	Male	0.698

The distance from the parking facility to the station entrance was significantly associated with the facility used. On average (mean), Parkiteer users parked farther away from the entrance than open-air facility users. Furthermore, parking facility used was significantly associated with the distance from the home station to the Melbourne CBD. Parkiteer users, on average, were farther away from the Melbourne CBD than those using open-air facility.

Table 5-4: Descriptive statistics - t-test analysis of continuous variables

Variable	**Parkiteer users (mean)**	**Open-air facility users (mean)**	**Significance (p value)**
Distance from parking facility to station entrance (m)	78.24	28.15	<0.001
Distance to CBD from the station used/parked at (km)	20.54	17.69	0.033
Distance from home to station (km)	2.33	2.04	0.125
Historic theft counts at station (2004 to 2016)	58.98	55.66	0.448
Number of bicycles owned	1.86	1.97	0.594
Age	40.06	39.58	0.778

Among the non-significant variables in bicycle parking facility used, included cyclist demographics (e.g. age, gender) nor historic theft counts. This may indicate bike-and-ride users are not aware of thefts that have occurred at the station; hence the number of reported thefts is unlikely to affect the parking choice at a macro level.

5.3.4.2 Multinomial regression modelling

A binary logistics regression model was developed to identify the key variables affecting bicycle parking choice at railway stations. This modelling approach was primarily chosen given the dichotomous nature of the dependent variable: parking in either a Parkiteer facility or open-air facility.

A forward stepwise variable selection approach was adopted to narrow the list of variables to those that were significantly associated with bicycle parking choice. The final model included four independent variables. The goodness of fit statistics for this model is provided in Table 5-5. The model is statistically significant, indicated by the Omnibus test. While the Omnibus test is a comparison to the simplest model (the null model), the Hosmer-Lemeshow test provides further validation as it indicates the model adequately fits the observed data. Furthermore, the Nagelkerke R^2 specifies the model is able to explain 56.6 percent of the variance in bicycle parking choice.

Table 5-5: Model goodness of fit

Goodness of fit statistics	
Chi-square	63.229
df	8
Omnibus test	<0.001
Log likelihood	90.883
Hosmer- Lemeshow test	>0.05
Nagelkerke R Square	0.566

The factors which were significantly associated with bicycle parking choice at railway stations related to: value of the bicycle ridden to the station, cyclist's perception of wait time for a Parkiteer access card, distance ridden from home to the station and distance from the parking facility to the station entrance. The extent to which these variables affect bicycle parking choice varied as seen in the resulting model, outlined in Table 5-6.

The model indicates the value of the bicycle ridden to the station has the greatest influence on bicycle parking choice at railway stations. Compared to the reference category of bicycles worth up to $150, cyclists who rode a bicycle of greater value were significantly more likely to use a Parkiteer facility. This may suggest people riding to the station on more expensive bicycles are either not having their security needs, or perceived needs satisfied by open-air parking facilities.

Given the scalability and cost effectiveness of open-air bike hoops, the future policy direction should be to provide more bicycle hoops at railway stations. However, with a low share of cycling, there is a limited number of bicycles parked at stations, resulting in a lack of 'safety in numbers'. In this context, the Parkiteer has a role to play during this transition phase, for people seeking additional security measures.

Table 5-6: Forward stepwise binary logistic model

	Exp (B)	Significance	Lower 95% CI	Upper 95% CI
Value of the bicycle ridden to the station	-	0.004***	-	-
$151 to 300	7.232	0.006***	1.749	29.903
$301 to 700	20.239	<0.001***	4.040	101.391
$701 to 1000	9.376	0.038**	1.135	77.436
More than $1000	16.701	0.009***	1.997	139.672
Up to $150	Reference	-	-	-
Access card wait time acceptable	-	0.001***	-	-
Strongly/agree	5.673	0.040**	1.084	29.686
Neutral	0.440	0.350	0.078	2.466
Strongly/disagree	Reference	-	-	-
Distance to station from home cross street	1.926	0.008***	1.189	3.119
Distance from parking facility to station entrance	1.024	<0.001***	1.011	1.037
Intercept	0.070	0.040**	-	-

*** Significant at a 99% confidence level, ** Significant at a 95% confidence level

Cyclists' perceptions of the registration process to use a Parkiteer facility is also influential in the choice of parking facility used. Specifically, the perception of whether it is acceptable to wait up to five days for a swipe card. Cyclists who (strongly) agreed the wait time was acceptable were significantly more likely to park in a Parkiteer than those who (strongly) disagreed. This indicates streamlining the registration process could contribute to maximising the return on Parkiteer investment. Furthermore, accessibility could be improved by integrating the public transport smartcard ticketing system (Myki card) and Parkiteer. Linking Myki and Parkiteer would eliminate the need to wait for a separate Parkiteer swipe card.

The "first mile" link between home and station played a role in the choice of bicycle parking facility used, specifically the distance ridden from home to the station. With each unit kilometre increase in the distance ridden to the station the odds of parking in a Parkiteer almost doubled. This indicates that as the distance between home and station increase, the commuter making that trip may be more reliant on the bicycle to get to/from the station, hence the more likely they are to seek additional security. To maximise the return on the investment required to expand the number of Parkiteer facilities, stations with a large cycling catchment area should be prioritised for future development.

Parking choice was also significantly related to the proximity of the parking facility to the station entrance. As distance between the station entrance and a given parking facility increased, provided the choice, commuters were more likely to park in a Parkiteer than an open-air facility. Generally, increased distance from the station entrance is likely to reduce active and passive forms of security and increase the desirability of a restricted access facility. At stations where space may be limited close to the station entrance, Parkiteers may be a desirable option rather than open-air bicycle parking that is father away from the station entrance.

5.4 Conclusion

In summary, this study provided valuable insights into cyclists' parking needs at railway stations and the factors affecting bicycle parking choice. Insights gained include the disparity in satisfaction levels between those using open-air facilities and Parkiteers, specifically in relation to the visibility of the parking location, CCTV monitoring, undercover weather protection and the provision of sturdy frames for bicycle parking. By improving parking attributes with low satisfaction scores, the provision of facilities is likely to better meet the needs of current cyclists and assist to lower parking related barriers for those contemplating cycling to the station.

Exploration of bicycle parking choice identified several factors significantly associated with parking facility used and included: value of the bicycle ridden to the station, cyclist's perception of the wait time for a Parkiteer access card, distance ridden from home to the station and distance from parking facility to the station entrance. With plans for greater investment to expand the number of Parkiteers, this insight can be used to prioritise which stations are best placed to maximise return on that investment.

Chapter 6 Rail commuter recruitment and online survey

In this chapter, the focus is on the recruitment and data collection methodology used to inform Study 3 and Study 4. Aspects discussed relate to the recruitment method (logistics, site selection) and selection of a survey method (survey design, sampling technique, biases). The questionnaire was inclusive of all station access modes. This ensured that the study objectives identified in Chapter 3 could be examined, specifically, to understand the latent factors influencing the intention to cycle (Study 3) and to identify the potential market share of cycling (Study 4). As such, this chapter focused on rail commuters who access the station by car (driver and passenger), bus, bicycle and on foot (see Figure 6-1).

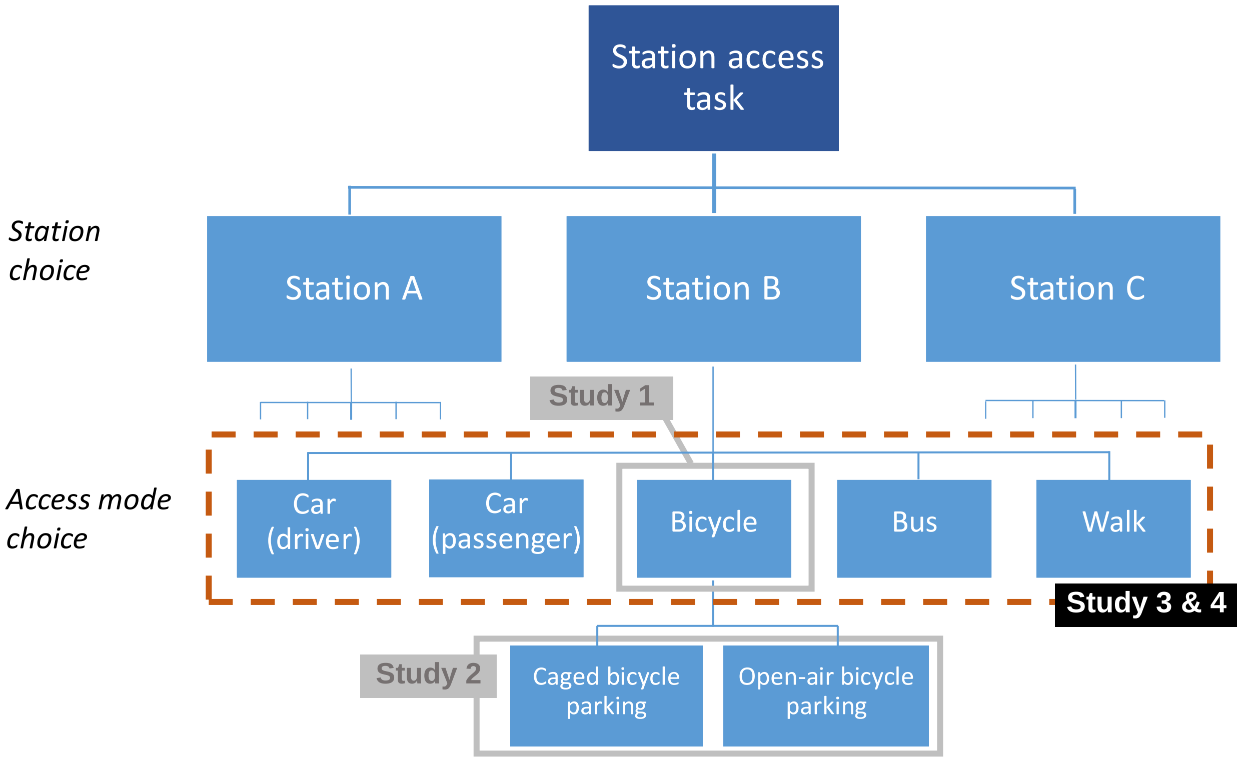


Figure 6-1: Access mode(s) under investigation

As the focus is on the survey methodology, detail of the questionnaire content is limited in this chapter. Detailed discussion of the questions is included within the relevant chapter for Study 3 (Chapter 7) and Study 4 (Chapter 8).

6.1 Participant recruitment

To investigate station access mode choice, primary data needed to be collected. Critically, potential participants needed to be identified and a targeted recruitment approach used. Several methods for participant recruitment were evaluated, including:

- Household survey: Mailbox delivery of a recruitment postcard to households within a cycling catchment (up to 5km) of a select number of stations, inviting the recipient to participate in the study. While relatively low cost through the use of mail delivery services, this blanket recruitment method would not target commuter rail service users as no data was available to identify rail use in the households surrounding the station;
- Interception: This technique would take place at a select number of stations. Rail commuters would be intercepted and handed a postcard inviting them to participate in the study. Recipients would be at liberty to fill out the questionnaire at their convenience. An Intercept survey would maximise the recruitment of the target group (rail commuters) compared to the Household survey. However, there are issues related to this approach as it would fail to collect information from people who were approached but did not respond. Furthermore, there would be an inherent lack of knowledge of the population from which the sample is drawn. These issues need to be addressed and minimised to improve the reliability and representativeness of the data; and
- Passive recruitment at stations: Consideration was also given to recruit participants through passive means. Namely, having posters up around metropolitan railway stations inviting rail commuters to participate. This approach was less labour intensive and time consuming than other evaluated methods, however, the associated cost of developing professional grade posters were expected to be high. While this approach maximised the recruitment of the target group, the lack of an active prompt to encourage participation was a concern, particularly given the busy nature of commuting. Furthermore, it would not be possible to determine the representativeness of the survey sample due to a lack of insights concerning the rail commuter population.

Each of the recruitment methods considered had strengths and weaknesses. The data collection itself, had to be efficient, targeting the population of interest, particularly given the cost and time constraints of a doctoral research study. Having considered these factors, an intercept survey was deemed most appropriate for this data collection exercise.

6.1.1 Recruitment and sampling frame

Interception was used to recruit participants for Study 3 and Study 4. This involved intercepting rail commuters at 13 suburban stations. Final year engineering students from Monash University (n=135) assisted in the participant recruitment. This ensured, on average, 10 students were allocated to each station for the recruitment task and are hereafter referred to as field staff.

Invitation

Participation of the survey was prompted by handing out a DL sized postcard inviting rail commuters to complete the survey through their smartphone or internet enabled device using a URL or QR code (Figure 6-2). A physical copy of the survey was not distributed to reduce printing cost, eliminate paper waste and save the cost of reply-paid postage.

Figure 6-2: Postcards used for distribution (top: front, bottom: back)

All commuters

In conducting intercept recruitment, there were several potential methodological biases that needed to be avoided. A key challenge was to choose a sample that was randomly selected and representative of the population at large (Richardson et al., 1995). To evaluate the representativeness of the sample, the gender split was recorded across the total passengers observed and those who were handed a postcard. A majority of the sample were male (58.25%) and females comprised 41.75 percent. This was similar to the gender split observed across the total passengers and those who were intercepted (see Table 6-2, page 83). This indicates the representativeness of the sample, at least by gender. Representativeness is assumed as population characteristics, across different dimensions (age, station access mode type, ethnicity) are not known.

To ensure a random sample was selected, a systematic approach was adopted in which a postcard was offered to every fifth person exiting the station platform. This sampling approach ensured survey or sampling bias was minimised (Richardson et al., 1995), as the participants who were recruited were not chosen by the surveyors but rather the sampling frame (1 in every 5 commuters). Furthermore, due to the large influx of commuters that flow out of the station platform with the arrival of each train, repeatedly over short periods of time, a systematic sampling approach made the intercepts more manageable for the field staff.

Cyclists

Separately, a census approach was adopted when intercepting cyclists. The need to oversample bike-and-ride users was due to the marginal nature of its mode share. Dedicated field staff were allocated to monitor bicycle parking facilities at each station and distribute an invitation postcard to every exiting commuter unlocking/locking their bicycle, if they did not have a postcard already.

6.1.2 Study setting: site selection and survey logistics

To maximise the responses, recruitment was conducted during the peak PM period, between 4:30 PM and 7:30 PM, on a single day (11 September 2017). The PM peak period was selected as a majority of commuters were expected be on the returning home-bound journey and less likely to be in a hurry than in the AM peak (e.g. when rushing to catch an incoming train). It was important to ensure the potential participants were not rushed and had time to decide if they wanted to participate. In addition, an incentive of a $200 prize draw was offered.

In selecting a candidate set of stations to conduct the survey, a range of factors were considered including:

- **Weekday daily patronage levels** needed to be sufficient to maximise the potential pool of participants. PTV's 2013/14 metropolitan station passenger activity dataset was used to prioritise the list of stations based on weekday entry counts;
- **A diverse mix of access modes**. Stations of interest had to have a mix of access modes including walking, by private vehicle, bus and bicycle. PTV's 2013/14 metropolitan station passenger activity dataset was referred to again, to ensure a mix of station access modes were recorded at the stations of interest;
- **Major train service disruptions** due to major works and the level crossing removal project. At the scheduled survey period, construction had commenced along the Pakenham/Cranbourne line (south-east) and so this line was not prioritised for the survey; and
- **Field staff proximity to the station**. As many of the field staff lived close to campus, stations in the south and east of the CBD were preferred. Several stations from the west were also included due to high bicycle access counts.

Following the evaluation process, 13 candidate stations were selected (see Figure 6-3), selected stations are indicated by the red circles). A data request was made to Public Transport Victoria (PTV) to provide ticketing (touch off) data for September 2016. The patronage counts for the same month in the previous year was examined to ensure that seasonal effects were accounted for.

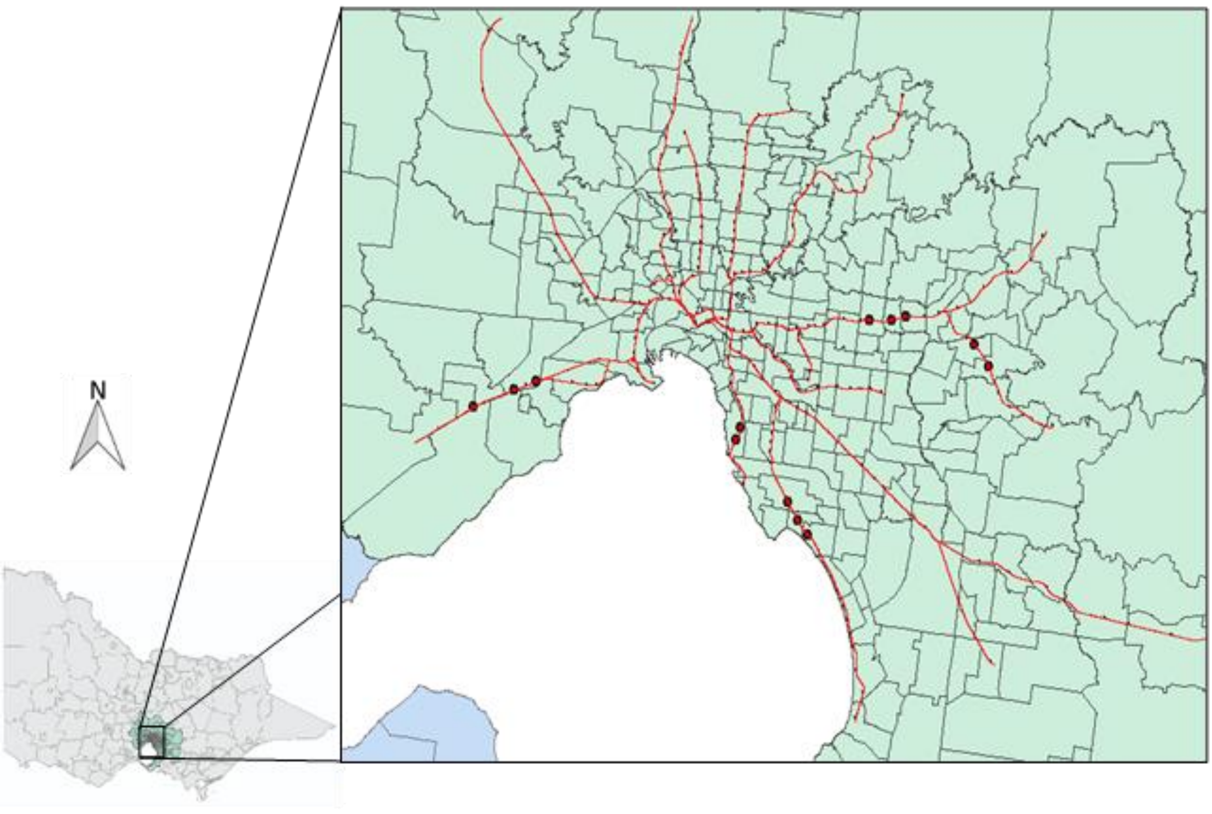


Figure 6-3: Intercept survey locations

A site inspection of the 13 stations were carried out prior to the survey (see Table 6-1) (by HW). This provided an opportunity to identify the intercept locations at each station to maximise safety and efficiency of postcard delivery. The field staff intercepted commuters along exiting corridors of the outbound platform with care taken to ensure pedestrian flow was not impeded.

Due to the anticipated influx of passengers with each trainload, at least 10 field staff were allocated to tasks at each station which included: intercepting commuters along the platform exits (n=6); counting all observed rail commuters by gender (n=1); counting commuters who were given a postcard by gender (n=1); intercepting commuters at the bicycle parking facilities (n=1) and circulating between the groups for the station leader (n=1). This approach was employed to ensure quality control and to maximise the possible response rate of the survey. Furthermore, this rigorous methodology aimed to gather information about the total passengers and those handed a postcard so as to record the total sampling frame to be used to calculate the representativeness of the sample.

Table 6-1: Station layout details

Station	Survey staff	Platforms		Number of exits	Commuter activity	Bicycle parking facilities	
		Number	Type			Parkiteer	Bike hoops
Bayswater	10	1	Island	1	Mixed outbound/inbound	✓	✓
Blackburn	10	1	Island	2	Mixed outbound/inbound		✓
Boronia	10	1	Island	2	Mixed outbound/inbound		✓
Cheltenham	10	2	Single	1	Outbound only	✓	✓
Hoppers Crossing	11	1	Island	1	Mixed outbound/inbound	✓	✓
Laverton	12	3	Island, Single	Multiple	Funnelled inbound/outbound	✓	✓
Mentone	10	2	Single	2	Mixed outbound/inbound		✓
Middle Brighton	10	2	Single	1	Only outbound commuters		✓
Mitcham	10	2	Single	2	Mixed outbound/inbound	✓	✓
North Brighton	10	2	Single	1	Outbound only		✓
Nunawading	11	1	Island	2	Mixed outbound/inbound	✓	✓
Parkdale	10	2	Single	1	Outbound only		✓
Williams Landing	11	1	Island	2	Mixed outbound/inbound	✓	✓

In determining the intercept locations, outbound platforms were given priority, as the majority of commuters travel from the CBD to the suburban areas during the PM period. However, at some island stations, a mix of inbound/outbound passengers may have been intercepted as the passengers alighting would be funnelled into a single exiting walkway.

6.2 Online survey design

The survey was conducted online to accommodate the complexity of the question structure and branching required for the different mode types. Commuters could access the survey via the survey link or QR code. Once they accessed the survey, it was presented in sections as detailed below.

6.2.1 Questionnaire flow and structure

The structure of the online survey is illustrated in Figure 6-4. The introductory pages contained the explanatory statement and informed consent was taken as the submission of the response. The survey comprised a total of 55 questions, including instances of skip branching logic and was split into four key parts: Parts A, B, C and D.

Part A – all mode types

All respondents answered questions in Part A, which related to station access trip characteristics. These included the journey purpose on the day of the survey, train use habits in a typical week and the regular home-end station where they boarded the train. The latter was particularly important, as the respondents' home cross streets were also collected in this section, allowing for the station access distances to be calculated to a high degree of accuracy. Next, the respondents were asked which transport mode was usually used to access the station from home. Based on the response to this question, branching logic applied. Respondents who get to the station by bicycle continued to Part B while other access mode users were directed to Part C.

Part B – cyclists only

Part B was only for commuters who accessed the station by bicycle and was split into three sections. **B1** explored the motivations for riding to the station, cycling infrastructure used to get to the station and the frequency of bicycle use in a typical week for the station access task. **B2** focused on the comfort and likelihood of cycling on different facilities (arterial roads with/without bike lanes, shared paths etc.) and in varying speed zones. **B3** focused on attitudes and perceptions about cycling to the station, beliefs about making environmentally friendly travel decisions, associated health benefits and safety. Respondents were also asked if they would continue cycling to the station and their interest level in maintaining the use of the bicycle to get to the station.

Part C – non-cyclists

Respondents who accessed the station by foot, car (driver or passenger) or bus were directed to Part C. The questions covered a similar scope to those asked of cyclists. **C1a** explored reasons for current access mode choice and frequency of using that mode in getting to the station in a typical week. Specifically oriented for non-cyclists, **C1b** asked respondents about the extent to which they agreed with several statements about trip characteristics (travel time, safety concerns, etc.) if they were to ride a bicycle to the station instead of their current access mode. **Unable to ride a bicycle**: Participants were also asked if they were physically able to ride a bicycle. Respondents unable to cycle were directed to Part D, the demographic section and subsequently the end of the survey.

If the current non-cyclists were able to ride a bicycle, they were forwarded to **C2** (similar to B2) which asked about the comfort levels and likelihood of cycling to the station on different infrastructure facilities and varying speed zones. **C3** (similar to B3) focused on attitudes and perceptions of cycling to the station. These respondents were asked about their level of interest in riding a bicycle to the station and how likely they were to shift station access modes to the bicycle.

Part D – all mode types

After completing the previous sections of the survey, all respondents were guided to Part D, which gathered demographic characteristics (age and gender).

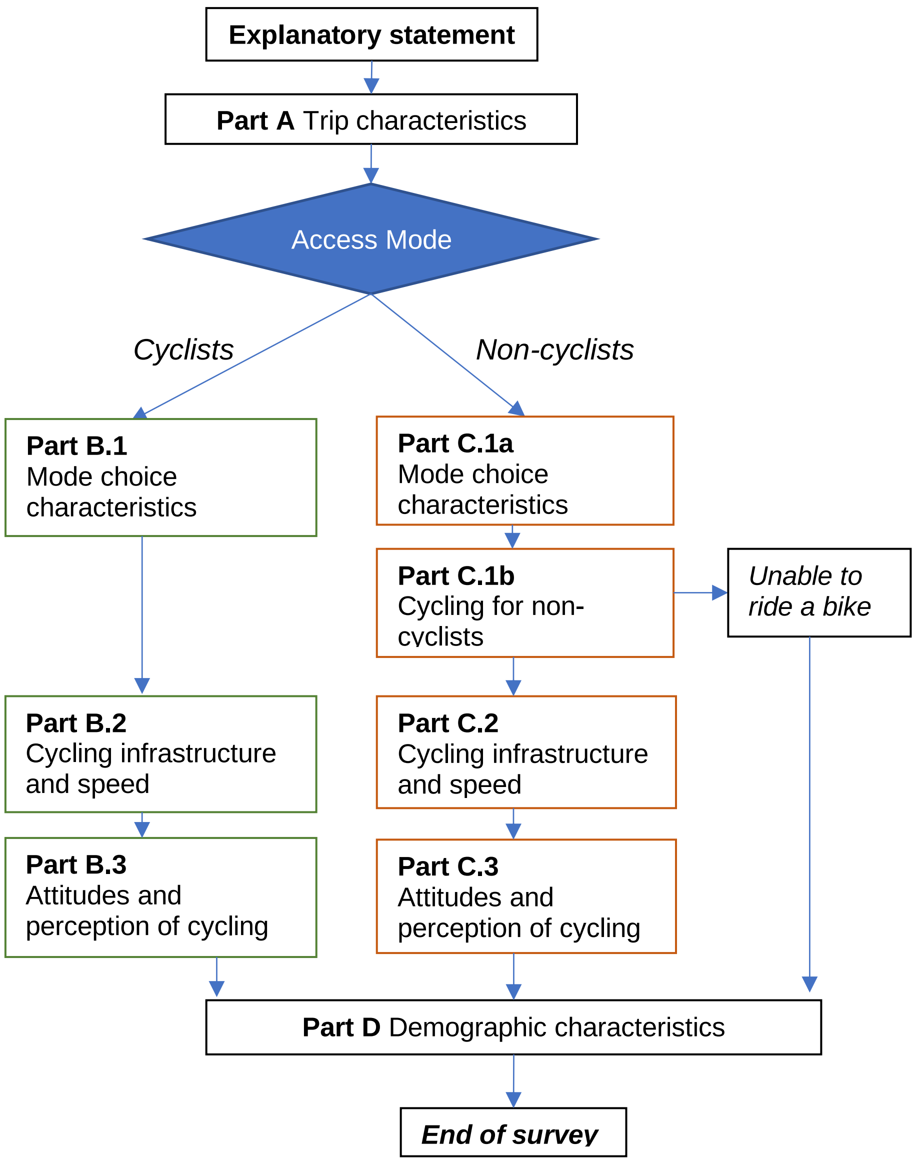


Figure 6-4: Questionnaire flow and structure

6.3 Survey response rate

A total of 19,462 passengers were observed within the station precinct across the 13 metropolitan railway station. Of this population, 3,890 (19.9%) commuters were offered a postcard, a ratio of almost 1 in every 5 exiting commuters.

In total, 827 completed responses were received, resulting in a total response rate of 21.2 percent. At individual stations, the response rate varied from a low of 14.1 percent to a high of 29.5 percent, generally with the stations in the west fairing a lower response rate. The majority of respondents used the URL link (80%) with the remaining participants using the QR code (20%) to access the survey. Response rates for self-completion questionnaires typically vary from 20 to 50 percent, with higher response rates reported for studies which incorporate a series of reminder notifications (Richardson et al., 1995). This indicates the response rate obtained for this study was in line with what is expected in the literature.

Table 6-2: Survey response rates

Selected stations	Total passengers observed			Postcards distributed			Surveys completed	Response rate (by station)
	Male	*Female*	*Total*	*Male*	*Female*	*Total*		
Nunawading^	899 *(60.50%)*	587 *(39.50%)*	1,486	115 *(57.50%)*	85 *(42.50%)*	200	59	29.50%
Middle Brighton#	611 *(66.49%)*	308 *(33.51%)*	919	57 *(47.11%)*	64 *(52.89%)*	121	34	28.10%
Blackburn^	1,082 *(56.95%)*	818 *(43.05%)*	1,900	168 *(53.67%)*	*145* *(46.33%)*	313	83	26.52%
North Brighton#	471 *(51.20%)*	449 *(48.80%)*	920	61 *(48.03%)*	66 *(51.97%)*	127	31	24.41%
Bayswater^	419 *(54.84%)*	345 *(45.16%)*	764	66 *(54.10%)*	56 *(45.90%)*	122	29	23.77%
Mitcham^	1,270 *(57.21%)*	950 *(42.79%)*	2,220	331 *(58.69%)*	233 *(41.31%)*	564	116	20.57%
Mentone#	594 *(54.70%)*	492 *(45.30%)*	1,086	123 *(52.12%)*	113 *(47.88%)*	236	47	19.92%
Cheltenham#	825 *(45.94%)*	971 *(54.06%)*	1,796	164 (60.97%)	105 (39.03%)	269	52	19.33%
Parkdale#	323 (52.10%)	297 *(47.90%)*	620	82 *(56.16%)*	64 *(43.84%)*	146	28	19.18%
Laverton*	1,161 *(54.79%)*	958 *(45.21%)*	2,119	203 *(60.24%)*	134 *(39.76%)*	337	55	16.32%
Boronia^	482 *(48.01%)*	522 *(51.99%)*	1,004	117 *(52.23%)*	107 *(47.77%)*	224	36	16.07%
Williams Landing*	1,610 *(55.59%)*	1,286 *(44.41%)*	2,896	426 *(66.05%)*	219 *(33.95%)*	645	93	14.42%
Hoppers Crossing *	848 *(48.96%)*	884 *(51.04%)*	1,732	326 *(55.63%)*	260 *(44.37%)*	586	83	14.16%
Total	**10,595** ***(54.44%)***	**8,867** ***(45.56%)***	**19,462** ***(100%)***	**2,239** ***(57.56%)***	**1,651** ***(42.44%)***	**3,890** ***(100%)***	**827****	**21.26%**

* Western stations, ^ Eastern stations, # South Eastern stations
** 81 records did not indicate the home-end station

6.4 Linking the survey to Study 3 and 4

The focus of Study 3 and Study 4 was to:

- Explore the effects of latent variables influencing the intention to cycle to the station;
- Identify the market share and mode shift potential of the bicycle.

The questionnaire was formulated to address the aims of Study 3 and 4.

6.4.1 Study 3 – Latent factors and the Theory of Planned behaviour

The primary objective of Study 3 was to use the TPB as a framework to identify the influence of latent variables on the choice to access the station by bicycle. As such, the development of the online survey questionnaire was guided by the elements of TPB (*attitudes*, *social norms* and *perceived behavioural controls* influencing the *intention* to ride to the station). Respondents' attitudes to cycling to the station were gauged in relation to environmentally friendly travel decisions, safety and health benefits. Interest in cycling to the station and likelihood of shifting/continuing the station access task by bicycle reflected the intention to ride. Social norms were examined through what family and friends thought about the participant cycling to the station. Other questions relating to social norms included the perceptions of road users when cycling on roads. Perceived behavioural control questions asked respondents to indicate the extent to which they agreed with a range of statements such as ‘there are adequate cycling facilities connecting my home to the station’ and ‘having bicycle parking facilities at the station would encourage me to ride to the station’.

6.4.2 Study 4 – Market segmentation: types of cyclists

Study 4 focused on the segmentation of rail commuters into types of cyclists with specific reference to the station access link. Through typologies and classification, populations are able to be understood (Dill & McNeil, 2013), providing further insights into the market share and mode shift potential of the bicycle as an access mode. The classification of commuters into a type were determined based on their cycling ability, comfort levels on different cycling facilities and interest in cycling as an access mode. The questionnaire was formulated to inquire about the above aspects from the various station access mode users and drew on previous research which explored types of cyclists (Geller, 2009).

6.4.3 Data cleaning

Prior to the analysis of Study 3 and Study 4, a high-level data cleaning exercise was carried out on the online survey responses. Of the 827 responses, 758 responses were retained. Of the 69 records that were deleted, more than 10 percent of the questionnaire responses were missing. Specific data cleaning efforts for each study are detailed in Chapter 7 and 8.

Chapter 7 The influence of latent factors

Behaviour is influenced by a complex amalgamation of factors including subjective preferences, cognitions and emotions. These unobserved factors have been noted to influence travel behaviour and by extension are expected to play a crucial role in station access mode choice decisions. In this chapter, the focus is placed on understanding the latent factors which influence rail commuters' intention to access the station by bicycle. As this study deals with human behaviour, the research is grounded in the theoretical framework of the Theory of Planned Behaviour (TPB). Structural equation modelling (SEM) was utilised to make inferences of causal relationships between the latent constructs of the TPB. Multi-group comparisons were made to establish whether relationships among the latent constructs differ based on commuters' station access mode type. The data required for the analysis draws from the rail commuter survey. As identified in Figure 7.1, the key station access modes are under investigation including car, walk, bicycle and bus users.

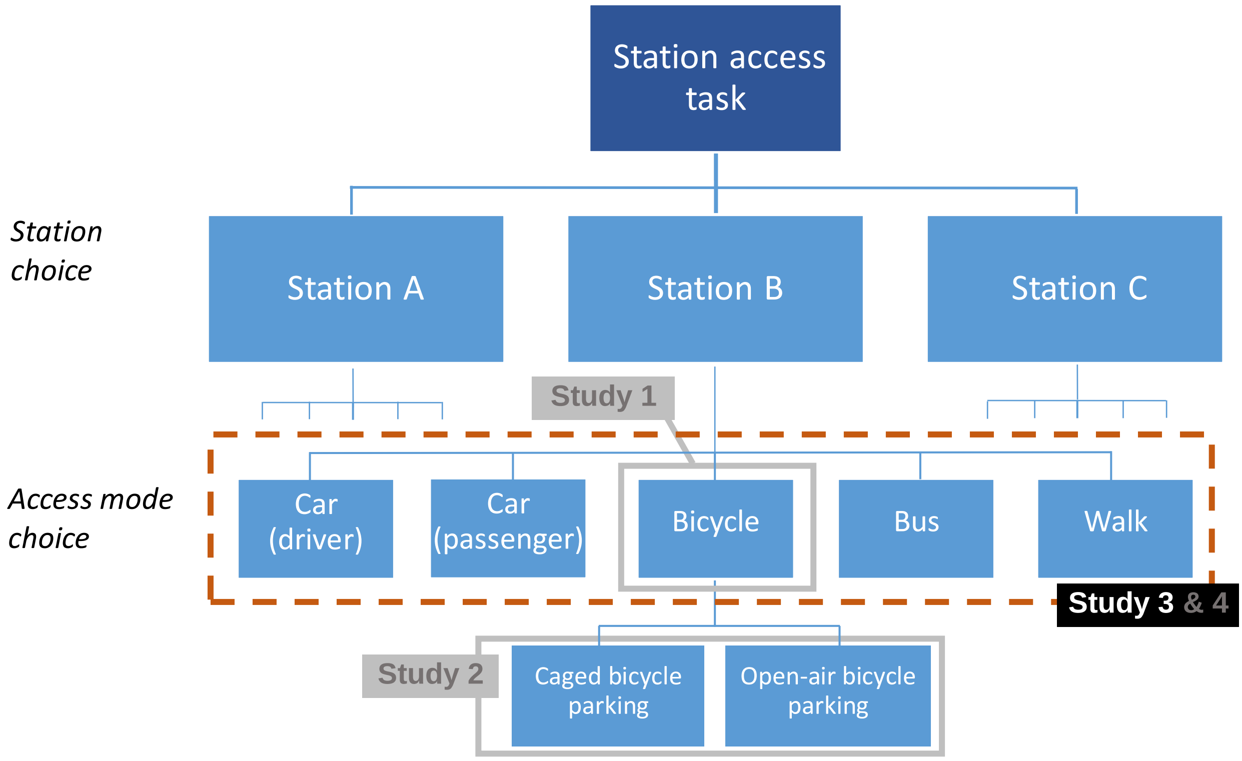


Figure 7-1: Access mode(s) under investigation

7.1 Introduction

Transportation is considered a derived demand, often resulting in the lack of choice regarding the need to travel. However, within this context commuters are often at liberty to choose their mode. Ben-Akiva et al. (1999) noted such choice behaviour can be outlined by a decision process, which is informed by perceptions and beliefs based on available information, and the influence of attitudes, motives and preferences. This implies both observed and latent elements can affect behavioural choice (La Paix Puello & Geurs, 2015). Specifically the observed component can be attributed to the available information (e.g. travel time, bicycle parking availability etc.) whereas attitudes, motives and preferences form the latent elements influencing choice. In this doctoral research program, the effects of observed factors have already been explored (Study 1 and Study 2); this chapter aims to focus on the influence of latent or unobserved constructs on the choice to access the station by bicycle.

The need to consider the effects of unobserved factors is gaining prominence in the literature. A critical aspect motivating a person to undertake tasks involving physical activity, including cycling, are unobserved or latent factors (Titze et al., 2008). In the literature that explores the effects of latent factors, the primary focus has been on cycling as the main mode of travel. Dill and Voros (2007) noted individual attitudes play a key role in the choice to commute by bicycle. Attitudes related to car use tend to be more positive among current motorists whereas positive attitudes towards cycling increases the likelihood of commuting by bicycle. Similarly, Gatersleben and Appleton (2007) identified those people contemplating riding a bicycle to work are more positive about cycling than others. Furthermore, perceptions related to safety, particularly in mixed traffic infrastructure layouts can also influence the choice to cycle. Shankwiler (2006) noted people tend to remember route segments perceived to be more dangerous than other segments. These studies have identified specific attitudinal dispositions exist among current cyclists.

In the literature that specifically explores bike-rail integration, limited consideration has been placed on the effects of unobserved factors on the choice to cycle to the station. Heinen and Bohte (2014) noted bicycle-transit users have a positive attitude towards both cycling and transit use independently. When asked about attitudes related to cycling and catching public transport, bike-transit users tend to agree both modes are environmentally friendly and pleasant to use. Puello and Geurs (2015) used a hybrid choice model to explore how perceptions related to the quality and availability of bike parking influences the choice to ride. A further extension to the scope in a subsequent study reported perceptions related to rail service and the station environment may affect the choice to cycle to the station (Puello & Geurs, 2016).

When considering the effects of unobserved factors, Heinen et al. (2009) noted the importance of framing the research around psychological theories. Of the existing literature related to bike-rail integration, there is a lack of behavioural models used to understand access mode choice. This study aims to address this gap in knowledge by grounding the research within the framework of the TPB.

Furthermore, this study aims to fill a methodological gap identified in the bike-rail integration literature by empirically measuring the relationship between the latent constructs of the TPB using SEM. SEM provides a quantitative approach to illustrate causal links between Attitudes, Subjective norms, Perceived behavioural control (PBC) on Intention. Multi-group comparisons, based on station access mode groupings, can help to gain insights as to how these causal relationships and the relative strengths of the associations vary among the modes. Such a robust approach provides an evidence base to inform policy and practice.

As part of Study 3, the effects of Attitudes, Subjective norms and PBC on the Intention to use the bicycle as a station access mode, among current rail commuters, were examined using the TPB as a-priori model. Intention to access the station by bicycle was the fundamental measure as the TPB states that Intention is the central determinant and direct antecedent of behaviour.

Structural equation modelling was utilised to make inferences of causal relationships between the latent constructs of the TPB. A measurement model was constructed, where confirmatory factor analysis was utilised to ensure that the survey measures had good validity and reliability. Establishing a measurement model was important to empirically validate survey measures exist within a distinct latent construct. Following this, the relationship between the latent constructs were tested using a structural model. In this research program, as part of Study 3, TPB provides a useful framework for understanding the station access mode choice by bicycle, specifically the influence of latent underlying psychosocial factors influencing choice.

7.2 Research method

In this section the research method employed for this study is outlined.

7.2.1 Theoretical framework

A key part of this study was to address a methodological gap in the bike-and-ride literature and frame the research around an established behavioural theory. Several psychological models were evaluated including the health belief model (HBM), the TPB and extended TPB.

The process of evaluating the theoretical models involved examining the literature, specifically applied in the context of transportation. Quine et al. (1998) compared the TPB and HBM in a study predicting bicycle helmet use. The results indicated the TPB was a more robust model able to explain a higher proportion of the variance (43%) compared to the HBM (18%).

Furthermore Torquato Steinbakk et al. (2012) evaluated the TPB, extended TPB and the HBM for seat belt use and identified the TPB resulted in a better fit compared to the other two theoretical models. On this basis the TPB was regarded as a relevant theoretical model for this research.

The TPB is a validated model used to explain transport mode choice, as outlined in Figure 7-2 (Donald et al., 2014; Ajzen, 2011; Bamberg et al., 2003; Armitage & Conner, 2001). Transport-related behaviours have extensively been predicted and explained using the TPB, ranging from personal car use (Anable, 2005; Aarts & Dijksterhuis, 2000), public transport use (Bamberg et al., 2007; Heath & Gifford, 2002) and the choice to commute by bicycle (Lois et al., 2015; de Bruijn et al., 2009). TPB asserts that people's intention to participate in a given activity primarily influences and shapes whether the activity is performed (Ajzen, 2005). It contends that behaviour is directly influenced by a person's intention and that intention is the closest determinant of behaviour (Walsh et al., 2007). Intention and behaviour are subsequently influenced by three latent factors:

- *Behavioural attitudes* towards the specific act or behaviour, these can be positive or negative;
- *Subjective norms* refer to an individual's perception of societal pressure to perform a given behaviour; and
- *PBC* which takes into consideration an individual's perception of the ease or difficulty in performing a particular behaviour. This has a direct influence on behaviour.

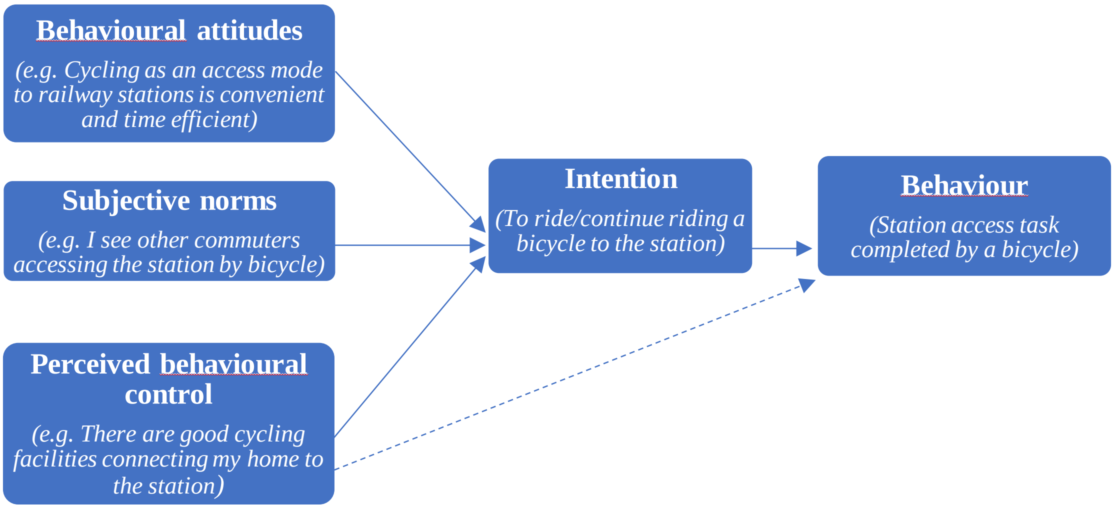


Figure 7-2: Theory of planned behaviour

The central premise of this model is that the sequence leading from beliefs to behaviour is a rational process where individuals consider the available information systematically to form a behavioural decision.

7.2.2 Data collection

Data for this study was collected from the rail commuter online survey (Chapter 6). This online survey targeted rail commuters accessing the station using a variety of access modes including walking, by car, bus and bicycle. The survey was guided by the TPB and inquired about Attitudes, Subjective norms, PBC and the Intention to access the station by bicycle (see Table 7.1).

Table 7-1: Survey measures

	Measure	Scale[1]
Behavioural intention		
I am/would be interested in cycling to the station	INT 1	1-5
I am likely to (continue to) cycle to the station in my current circumstances	INT 2	1-5
Instrumental attitude		
It is important to make environmentally friendly travel decisions	ATT 1	1-5
Environmental concerns (will) motivate me to cycle	ATT 2	1-5
It is difficult to ride to station in the clothes I wear	ATT 3	1-5
It is important to arrive at my destination well dressed	ATT 4	1-5
Cycling to station is a safe task	ATT 5	1-5
Safety considerations influence how I get to the station	ATT 6	1-5
Enjoyment riding a bicycle will/has encourage(d) me to ride to the station	ATT 7	1-5
Cycling to the station enables a more active lifestyle	ATT 8	1-5
A more active lifestyle is desirable	ATT 9	1-5
Cycling to the station is good for my health	ATT 10	1-5
Health benefits of cycling would encourage me to ride to the station	ATT 11	1-5
PBC		
Comfort riding to the station on off road shared paths	PBC 1	1-4
Comfort riding to the station on local residential street	PBC 2	1-4
Comfort riding to the station on residential collector street	PBC 3	1-4
Comfort riding to the station on arterial roads without a bike lane	PBC 4	1-4
Comfort riding to the station on arterial roads with a bike lane	PBC 5	1-4
Comfort riding to the station on footpaths	PBC 6	1-4
Comfort riding to the station on 40 kmph speed zones	PBC 7	1-4
Comfort riding to the station on 50 kmph speed zones	PBC 8	1-4
Comfort riding to the station on 60 kmph speed zones	PBC 9	1-4
Comfort riding to the station on 80 kmph speed zones	PBC 10	1-4
Likelihood of riding to the station on off road shared paths	PBC 11	1-5
Likelihood of riding to the station on local residential streets	PBC 12	1-5
Likelihood of riding to the station on residential collector streets	PBC 13	1-5
Likelihood of riding to the station on arterial roads without a bike lane	PBC 14	1-5
Likelihood of riding to the station on arterial roads with a bike lane	PBC 15	1-5
Likelihood of riding to the station on footpaths	PBC 16	1-5
Likelihood of riding to the station on 40 kmph speed zones	PBC 17	1-5
Likelihood of riding to the station on 50 kmph speed zones	PBC 18	1-5
Likelihood of riding to the station on 60 kmph speed zones	PBC 19	1-5
Likelihood of riding to the station on 80 kmph speed zones	PBC 20	1-5
Subjective norms		
Family/friends (would) approve of me cycling to station	SUB N 1	1-5
Family/friends would be willing to cycle to station in my situation	SUB N 2	1-5
What family/friends think about how I get to the station is important to me	SUB N 3	1-5
Other road users (would) disapprove of me cycling on roads to station	SUB N 4	1-5
What other road users think about me cycling on roads is important to me	SUB N 5	1-5

[1] Under the PBC latent construct, the measures used to examine the comfort of riding to the station were gauged using a four-point Likert scale (1-4). The four-point scale excluded the neutral option and forced the respondent to state their preference. This approach was adopted to ensure a preference was stated for the comfort related questions as they were vital in segmenting respondents into a cyclist typology in Study 4 (Chapter 8).

Of the 758 valid survey responses, 556 were used for the SEM analysis as these participants were physically able to ride a bicycle. The remaining 202 valid responses were excluded from the SEM analysis as these participants were unable to ride a bicycle and as such determined to not be able to accurately indicate their level of PBC. Of the 556 included response, the modes used were: walking (n=209; 38%), car (driver/passenger) (n=189; 34%), bus (n=79; 14%) and cycled (n=79; 14%).

7.2.3 Structural equations modelling

SEM is a multivariate statistical analysis technique used to examine the underlying structural relationship between measured variables and latent constructs. As part of this study the TPB is used as an a-priori model for the SEM analysis. This enabled for the empirical verification of causal links between the different TPB constructs including Attitudes, Subjective norms, PBC and Intention. Given the number of constructs when dealing with the TPB, SEM was chosen as it estimates multiple, interrelated dependencies in a single analysis framework. As part of this analysis two types of variables are used: latent variables and observed variables.

Latent variables are theoretical constructs which cannot be directly observed. In this study these relate to the fundamental components of the TPB which are: Attitudes, Subjective norms, PBC and Intention. Such latent constructs are abstract in nature and not able to be observed directly and hence measured directly. Instead they are inferred through a mathematical model from observed variables.

Observed variables are items which measure the underlying latent construct. Multiple indicators from the survey were used to measure the latent constructs of the TPB. These are discussed below and outlined in Table 7.1.

Behavioural intention

This construct measured the intention to access the station by bicycle. Two items in the survey assessed this construct: “I am likely to cycle to the station under the current circumstances” and “I am/would be interested in cycling to the station”. Participants were able to indicate their level of agreement on a five-point Likert scale from strongly disagree (1) to strongly agree (5).

Instrumental attitude

Attitudes related to cycling as a station access mode were assessed indirectly using a belief-based measure. This involved calculating the product of the *belief* component with its corresponding *outcome evaluation*. Respondents were presented with several behavioural *beliefs*, including “I believe it is important to make environmentally friendly travel decisions” and “It is important to arrive at my destination well dressed”. Measures assessing the *outcome evaluation* included “Being more environmentally friendly could motivate me to cycle to the station” and “It is important to arrive at my destination well dressed”. For each item the responses ranged from strongly disagree (1) to strongly agree (5) on a five-point Likert scale. Where relevant, the product of the *belief* and *outcome evaluation* were calculated.

PBC

PBC as a construct was measured as a product of two dimensions: *self-efficac*y and *controllability*. The *self-efficacy* component addressed the perceived level of difficulty riding to the station on different infrastructure facilities and speed zones. This was measured using a four-point Likert scale gauging the comfort level associated with riding on different conditions. Respondents were able to indicate their score on a scale from very uncomfortable (1) to very comfortable (4). Items related to this dimension include “Comfort riding in 40 kmph speed zones” and “Comfort riding on local residential streets”. The *controllability* dimension was concerned with one’s belief they have personal control over the performance of the behaviour. This was measured using a five-point Likert scale based on the likelihood of riding to the station on different infrastructure facilities and speed zones. Respondents were able to indicate their likelihood on a scale ranging from would never cycle (1) to very likely (5). Items related to this dimension include “Likelihood of riding in 40 kmph speed zones” and “Likelihood of riding on local residential streets”. The product of the corresponding measures for *self-efficacy* and *controllability* were calculated.

Subjective norms

Subjective norms were indirectly measured through *normative beliefs* associated with family/friends and other road users as well as the *motivation to comply* with them. Survey items related to *normative beliefs* include “the people who are important in my life (family/friends etc.) would approve of me cycling to the station” and “Other road users would disapprove of me cycling on roads as I ride to the station”. Respondents were able to indicate their level of agreement on a five-point Likert scale from strongly disagree (1) to strongly agree (5). Survey items related to the *motivation to comply* include “What family and friends think about how I get to the station is important to me” and “If I cycled to the station on public roads, what other road users think about me riding would be important to me”. Responses were able to indicate their level of agreement of a five-point Likert scale from strongly disagree (1) to strongly agree (5). Where relevant the product of the *normative belief* and corresponding *motivation to comply* were calculated.

7.3 Results and interpretation

In the following section the results of the SEM analysis are outlined and interpreted.

7.3.1 Model specification and iteration

SEM involved formulating both a measurement model and a structural model. The structural model defines the relationship between the latent variables whereas the measurement model specifies how observed variables come together to represent latent constructs. The measurement model specification is the first of the two stages and involves an iterative process whereby observed variables are added/omitted until the identification of the "best fit" model.

In order to meaningfully discuss the most parsimonious "best fit" measurement model, a brief outline of the starting model (iteration zero) is provided for comparison. Iteration zero formed the initial measurement model, which included all of the observed items identified in Table 7-1. Table 7-2 outlines the initial measurement model fit metrics. Several global fit indices were used to measure model fit characteristics (these metrics are detailed later in the chapter), for each of these metrics the starting model did not meet the required threshold. This indicates the initial model did not adequately account for the correlation between the variables in the dataset. Following this determination, an iterative process commenced to identify a measurement model which satisfies model fit conditions. The iterative process involved systematically removing observed variables with factor loadings less than 0.7 onto their parent latent construct.

The "best fit" model was identified and noted to satisfy the required global fit criteria (see Table 7-2).

Table 7-2: Measurement model fit

Global fit indices	Initial model	"Best fit" model	Model fit recommendations
CMIN	1725.677	474.431	-
DF	183	234	-
CMIN/DF	9.430	2.027	< 5 permissible
CFI	0.792	0.958	>0.95 for acceptance
NFI	0.773	0.954	>0.95 for acceptance
RMSEA	0.123	0.047	< 0.06 to 0.08 with 90% CI

The material discussed from hereon in is in relation to the "best fit" measurement model.

7.3.2 Descriptive statistics

Table 7-3 presents the observed variables used in the measurement model. The mean and standard deviation of the item scores are outlined for all rail commuters collectively as well as at a more disaggregated station access mode level.

Items which measured PBC (Item 1-6) accounted for the interaction of likelihood and comfort, with respect to cycling on various infrastructure facilities and speed zones. This related to the self-efficacy (*comfort*) and controllability (*likelihood*) components of PBC. Across all access mode types, local residential streets were noted to have the highest mean interacting score of any infrastructure facility. Possibly due to the low traffic volumes and low speeds on local streets, rail commuters were more comfortable and likely to ride to the station, relative to other infrastructure types. Interestingly, a greater mean score was noted for arterial roads with a bike lane than for residential collector roads among car users and those who walk. This indicates the presence of dedicated cycling infrastructure facilities may be more influential in fostering a sense of comfort and an increased likelihood of being ridden en route to the station than on roads without dedicated cycling infrastructure. Furthermore, lower speed environments were associated with greater interacting levels of cycling likelihood and comfort across all mode types. As the posted speed environment increases from 40 to 50 kmph the mean scores across all modes decrease, this decrease was noted to be even more substantial between an increase in speed from 50 to 60 kmph.

Attitudes related to the task of accessing the station by bicycle were measured using two survey items: Item 7, the enjoyment of cycling motivating commuters to ride to the station and Item 8, the interacting effect of wanting a more active lifestyle and the ability to achieve this by cycling to the station. For both items current cyclists were noted to have the highest mean score. Other mode users, on average, agreed with the statements albeit not to the same extent as current cyclists.

Subjective Norms were also measured using two survey items. Of these, Item 9 related to whether the respondents' family/friends would ride to the station. Item 10 focused on the interacting effect of family/friends' approval of the respondent cycling to the station and the importance placed on their approval. Of all respondents, only cyclists were in agreement with Item 9, albeit weakly ($\mu_{bicycle} = 3.15$), in contrast those accessing the station by car were the least likely ($\mu_{car} = 2.61$). With respect to Item 10, the mean interacting score across all modes were noted to be low ($\mu_{bus} = 10.00$, $\mu_{bicycle} = 9.99$, $\mu_{walk} = 9.67$, $\mu_{car} = 7.93$). This indicates either family/friends disapproved of the respondent riding to the station or that the approval of family/friends is not influential in affecting the station access mode choice.

The Intention to ride to the station was measured by Item 11 and Item 12. Item 11 focused on the interest of the respondent in cycling to the station. Current cyclists almost unanimously agreed with the statement ($\mu_{bicycle} = 4.73$). Respondents who accessed the station by bus and car also slightly agreed with the statement ($\mu_{bus} = 3.24$, $\mu_{car} = 3.12$). When asked if it was likely the respondent would (continue to) ride a bicycle to the station (Item 12), respondents who accessed the station by car, bus and on foot disagreed whereas current cyclists strongly agreed.

7.3.3 Correlation matrix

Table 7-4 presents the correlation matrix for all of the variables included in the measurement model. Items measuring PBC, Attitudes and Subjective norms were all positively correlated with those measuring Intention. Furthermore, items within the same construct were highly correlated with values greater than 0.5.

Table 7-3: Mean and standard deviation values for each item

		All rail commuters		Car		Walk		Bus		Bicycle	
Code	Measure	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
Item 1	PBC2xPBC12	8.28	5.95	6.24	4.69	7.74	5.49	7.99	5.25	14.90	5.99
Item 2	PBC3xPBC13	7.23	5.61	5.46	4.18	6.73	5.13	6.29	4.39	13.71	6.37
Item 3	PBC5xPBC15	7.51	6.09	6.22	5.48	6.57	5.78	7.63	5.50	12.95	5.94
Item 4	PBC7xPBC17	11.51	6.52	10.43	6.25	10.34	6.43	10.75	5.66	17.96	4.10
Item 5	PBC8xPBC18	9.39	6.16	8.04	5.49	8.45	5.76	8.08	5.16	16.43	4.86
Item 6	PBC9xPBC19	6.44	5.36	5.19	4.33	6.11	5.15	5.19	4.47	11.58	6.01
Item 7	ATT7	3.28	1.30	3.04	1.23	3.09	1.36	3.41	1.21	4.23	0.91
Item 8	ATT8xATT9	16.36	6.80	16.50	6.64	14.12	6.80	17.14	6.14	21.20	4.88
Item 9	SUBN2	2.88	1.22	2.61	1.20	3.00	1.21	2.91	1.18	3.15	1.19
Item 10	SUBN1xSUBN3	9.17	5.87	7.93	5.50	9.67	6.00	10.00	5.84	9.99	6.02
Item 11	INT2	2.59	1.49	2.15	1.18	2.25	1.30	2.19	1.13	4.92	0.31
Item 12	INT1	3.22	1.40	3.12	1.29	2.73	1.39	3.24	1.13	4.73	0.75

Table 7-4: Correlations among the items (n = 556)

	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Item 11	Item 12
Item 1	1	.805**	.504**	.614**	.654**	.583**	.414**	.306**	.279**	.167**	.516**	.512**
Item 2		1	.608**	.640**	.704**	.643**	.445**	.314**	.286**	.206**	.576**	.526**
Item 3			1	.596**	.591**	.551**	.445**	.357**	.265**	.258**	.553**	.550**
Item 4				1	.866**	.684**	.530**	.439**	.315**	.268**	.561**	.611**
Item 5					1	.841**	.448**	.372**	.277**	.202**	.581**	.549**
Item 6						1	.341**	.250**	.195**	.142**	.513**	.419**
Item 7							1	.652**	.355**	.366**	.525**	.684**
Item 8								1	.270**	.291**	.447**	.590**
Item 9									1	.526**	.288**	.369**
Item 10										1	.263**	.313**
Item 11											1	.686**
Item 12												1

** Correlation is significant at the 0.01 level (2-tailed)

7.3.3 Data reliability and validity

Confirmatory factor analysis (CFA) was used to assess and ensure measurement model validity and reliability using the statistical package AMOS 24. For the factor structure based on the TPB, reliability and validity are established through the following measures: composite reliability (CR), average shared variance (AVE), maximum shared variance (MSV) (Gaskin, 2016). Hair (2006), outlined the threshold requirements which need to be met to satisfy the following conditions: reliability (CR > 0.7), convergent validity (AVE > 0.5) and discriminant validity (MSV < AVE and square root of AVE > inter-construct correlation).

The results for these tests are outlined in Table 7-5. For each construct there is good internal consistency as indicated by CR values of greater than 0.7. This indicates responses to items within a given latent construct produce similar results. Convergent validity was also met, with the AVE for each latent construct above the 0.5 limit. This indicates each measured item has a high level of correlation with other items measuring the same latent factor. Lastly, discriminant validity aims to confirm measures between different latent factors are not substantially correlated. Checks for this condition calculated that discriminant validity was not satisfied for latent factors PBC, Attitude and Intention. This can be attributed to the correlation of measured items between constructs Intention and Attitude as well as Intention and PBC. Furr (2017) indicated measures between constructs are likely to be highly correlated if the latent factors are strongly correlated with each other. As seen in Figure 7-2 the TPB stipulates Intention is directly the result of Attitudes, Subjective norms and PBC. This causal relationship is proposed as a systematic reason for the discriminant validity issue. Having satisfied reliability and convergent validity checks while also outlining an inherent reason for a lack of discriminant validity, it was appropriate to proceed with the SEM analysis.

Table 7-5: Data reliability and validity metrics

	CR	**AVE**	**MSV**	**MaxR(H)**	**PBC**	**Intention**	**Norms**	**Attitude**
PBC	0.910	0.628	0.646	0.917	0.792			
Intention	0.818	0.692	0.724	0.834	0.804	0.832		
Norms	0.933	0.874	0.178	0.956	0.276	0.359	0.935	
Attitude	0.795	0.661	0.724	0.821	0.628	0.851	0.422	0.813

7.3.4 Invariance testing for multi-group analysis

An objective of this study was to test for any group differences which may exist within the model. Multi-group analysis involved splitting the dataset along certain groups to establish whether the relationships between the latent constructs significantly varied across these groups. Two separate multi-group analyses were conducted. The first grouped the dataset by the *actual* *station access mode* (car, walk, bus and bicycle) and the other grouped the dataset into *cyclists and non-cyclists*.

Prior to the multi-group analysis, configural and metric invariance testing was performed during the CFA. Configural invariance tested the factor structure across groups to determine equivalence. If configural equivalence is established this indicates the latent constructs can be meaningfully discussed across the groups. Adequate goodness of fit metrics were obtained when analysing a freely estimated model across both multi-group classifications, indicating configural invariance is established (*actual station access mode grouping*: Cmin/DF = 1.839, CFI = 0.967, RMR = 1.432, RMSEA = 0.039; *cyclist and non-cyclist grouping*: Cmin/DF = 2.525, CFI = 0.970, RMR = 1.772, RMSEA = 0.052).

Metric invariance was also checked to establish if relationships between the latent factors and their measured items are equal between groups. A lack of metric invariance may imply some items are more important to the construct of one group than for the other (Campbell et al., 2008). Given the nature of this study in which rail commuters were asked about their intention to cycle, and with participants using a range of different access modes, it was hypothesised metric equivalence will not be satisfied. Having constrained the grouped models to be equal, a chi-squared difference test between the fully constrained and unconstrained models found both grouping classifications to be metrically variant (*actual station access mode grouping*: $p < 0.001$; *cyclist and non-cyclist grouping*: $p < 0.01$). This indicates across the different modes, some measures were more important to certain groups and hence the relationships between the latent constructs would also be different across groups. It was important to identify how the relationships between latent constructs vary across the groups, as such the analysis continued.

7.3.5 Specification of the structural model

Following the specification of a measurement model which meets the model fit criteria, the structural model is defined in which the paths relating the latent variables to one another are determined. The structural form was based on a-priori model of the TPB. AMOS 24 was used as the statistical analysis package for model building and testing. Maximum likelihood estimation methods were used. Figure 7-3 shows a visual representation of the global structural model. PBC, Attitudes and Subjective norms form the independent variables (IV) in the model while the dependent variable (DV) is the Intention to access a station by bicycle. The single headed arrows from the IV to the DV indicates a unidirectional causal dependency while the double headed arrows indicate a correlational relationship. Ovals represent the latent constructs while rectangles represent the measured items. The residual error terms are unobserved and as such they are also represented within ovals. Figure 7-3 indicates several error terms are covaried within the single construct of PBC. The items for which the error terms are correlated are noted to be highly similar in nature, close together in the survey and similarly worded. This indicates a logical reason may be present for the systematic relationship between these error terms.

Establishing model fit is vital and ensures the a-priori model of the TPB adequately accounts for the correlations observed in the dataset. Several measurements of model fit were used (see Table 7-6). It should be noted the threshold outlined for each metric is simply a guideline and that goodness of fit is inversely related to sample size. For the global model, the comparative fit index (CFI) was 0.974 and the normed fit index (NFI) was 0.966, both greater than the suggested 0.950 indicating the model is a good fit. The root mean square of the error approximation (RMSEA) was 0.073, considered a reasonable fit (MacCallum et al., 1996). The chi-square to df metric based on Hu and Bentler (1999), also indicates the model is permissible with an obtained ratio of 3.987.

Table 7-6: Structural model fit metrics

Global fit indices	Default model
CMIN	179.415
DF	45
CMIN/DF	3.987
CFI	0.974
NFI	0.966
RMSEA	0.073

Following tests of model fit, the focus was on evaluating the variance explained by the global model. This was measured by the R-squared value. Overall, a large proportion (84%) of the variance in the dependent variable is explained by this model, indicating the robustness of the TPB in the context of station access mode choice behaviour.

Focussing on the local measures of fit, all observed items in the model showed highly significant ($p < 0.01$) relationships to their respective latent variables. The items for Subjective norms had the strongest relationship with their construct, ranging from 0.90 to 0.97. The relationships between the other measured values and their corresponding latent constructs were also strong with values between 0.74 and 0.88.

Attitudes and PBC were significant predictors of Behavioural intention, at a 99 percent confidence level. Attitudes, related to the use of a bicycle as a station access mode, had a strong positive bearing on Intention to ride to the station as indicated by a factor loading of 0.56. PBC had a positive, yet weaker, relationship with Behavioural intention with a factor loading of 0.47. However, at -0.01, the causal relationship between Subjective norms and Intention negligible and not statistically significant.

The correlation among the latent variables were also relatively strong, particularly among PBC with Attitudes and Attitudes with Subjective norms. This indicates the latent constructs are closely related with one another.

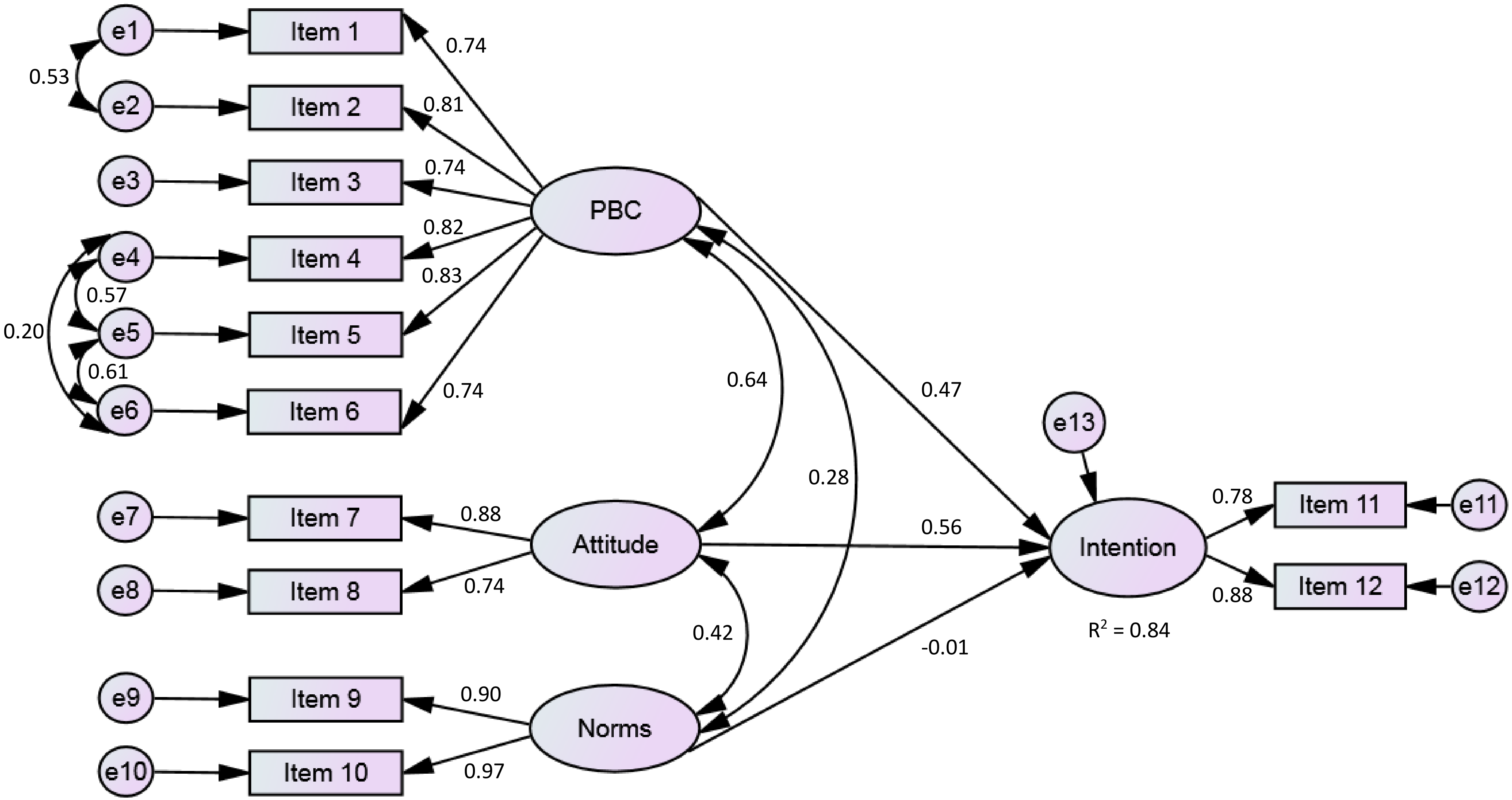


Figure 7-3: Specified global structural model

7.3.6 Multi-group analysis sub-models

Building on the findings from the above structural model, further insights were gained through multi-group comparisons. In this research study, the grouping variable was across *actual station access mode types* and separately as a *cyclist and non-cyclist* classification. The multi-group analysis identified the relationship between several latent constructs varied significantly between the groups.

Grouping by actual access mode types

The results from the multi-group comparison of the actual mode types are presented in Figure 7-4. The models classifying car, walk and bus users explain a large proportion of the variance in the DV with R^2 values of 0.87, 0.77 and 0.71 respectively. The model for current cyclists explain a comparatively lower proportion of the variance in the DV with an R^2 value of 0.32.

Car, walk and bus users have higher factor loading from Attitude to Intention with values ranging from 0.73 to 0.77. The relationship between Attitude and Intention is also positive, yet weaker, for current cyclists with a value of 0.37. This indicates for people who currently access the station on foot, by car or by bus, encouraging a change in the attitudes related to cycling to the station may have the most beneficial impact on the intention to access rail services by bicycle. This also implies having unfavourable attitudes in particular can play a critical role on the intention not to cycle. Across all mode users, Attitudes influence Intention more strongly than PBC and Subjective norms on Intention.

With respect to the causal relationship between PBC and Intention, car, walk and bus users have a positive but weaker relationship with factor loadings between 0.22 and 0.23. This indicates for current non-cyclists the intention to ride to the station is also influenced by their perception of whether they could cycle to the station on different infrastructure facilities and speed zones. Although this is not as strongly influential on Intention as Attitudes. Such a level of insight suggests while bicycle friendly infrastructure leading to the station is important in shaping the intention to ride, focusing on attitudinal change through behavioural change programs may have a more substantiative impact on encouraging greater levels of bike-and-ride. With respect to current cyclists, the influence of PBC on Intention is stronger comparatively to the same relationship for car, walk and bus users. Across the four mode type groups the influence of Subjective norms on the Intention to bike-and-ride is negligible with values between 0 to -0.01.

A chi-squared difference test was completed to identify whether the four structural models were significantly different across groups. As seen in Table 7-7, a p value less than 0.001 is obtained for the structural model comparison. This indicates the four models, classified by current access mode type, are significantly different at a confidence level greater than 99 percent. In order to further unpack this and identify which latent paths are significantly different across the groups, chi-squared tests were conducted. Single paths between the latent constructs were tested as outlined on Table 7-7. The relationship between PBC on Intention and Subjective norms on Intention were not statistically significant, indicating no differences were noted for these relationships across the mode types. Attitudes influence on Intention was statistically significant at a confidence level over 99 percent. This indicates that Attitudes play a significantly different role on the Intention to ride to the station across the four mode type users.

Table 7-7: Chi-squared results (access mode grouping)

Relationship	DF	CMIN	P
Structural model	3	33.218	**<.001**
PBC on Intention	3	5.518	.138
Attitude on Intention	3	33.218	**<.001**
Norms on Intention	3	4.887	.180

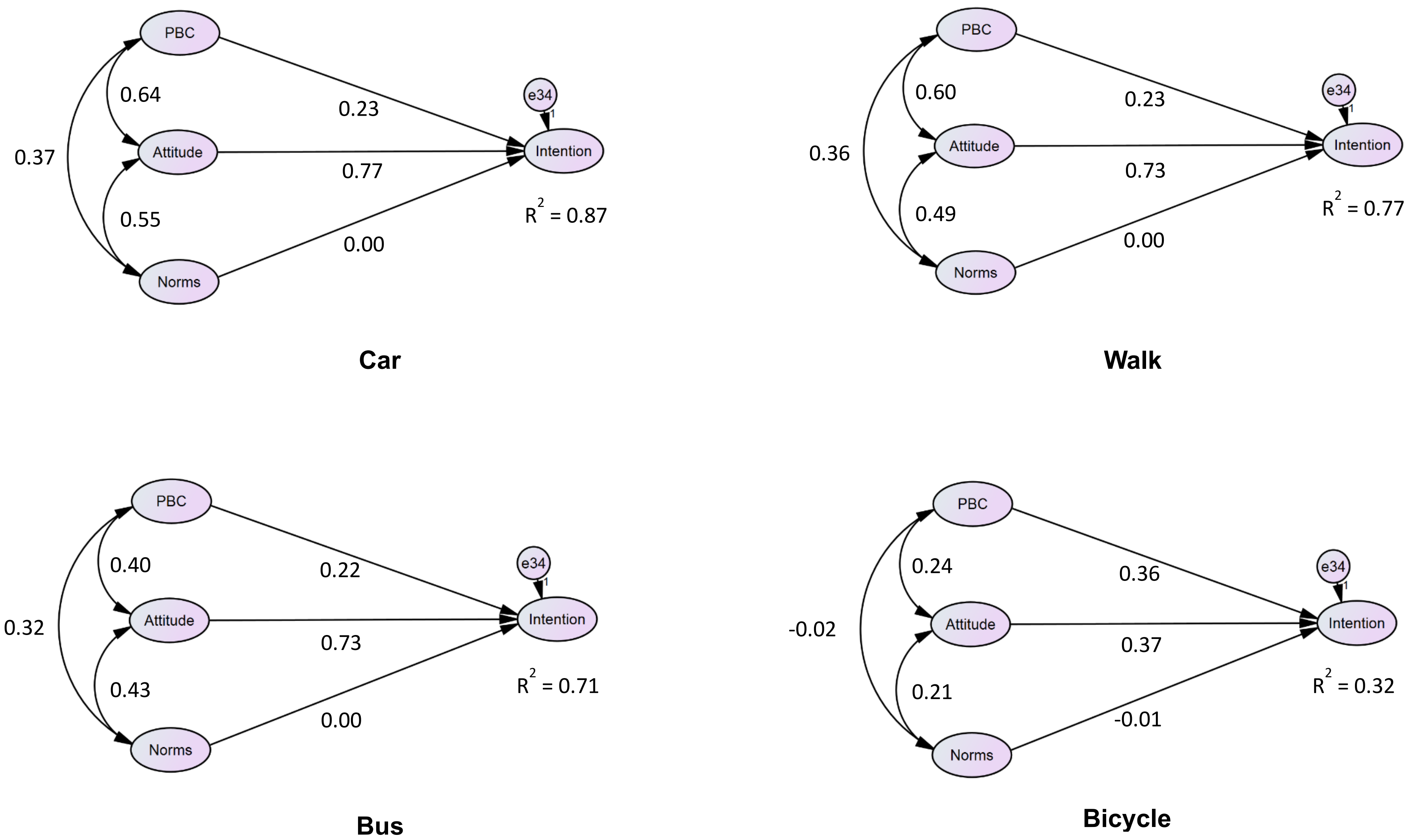


Figure 7-4: Grouped models by access mode

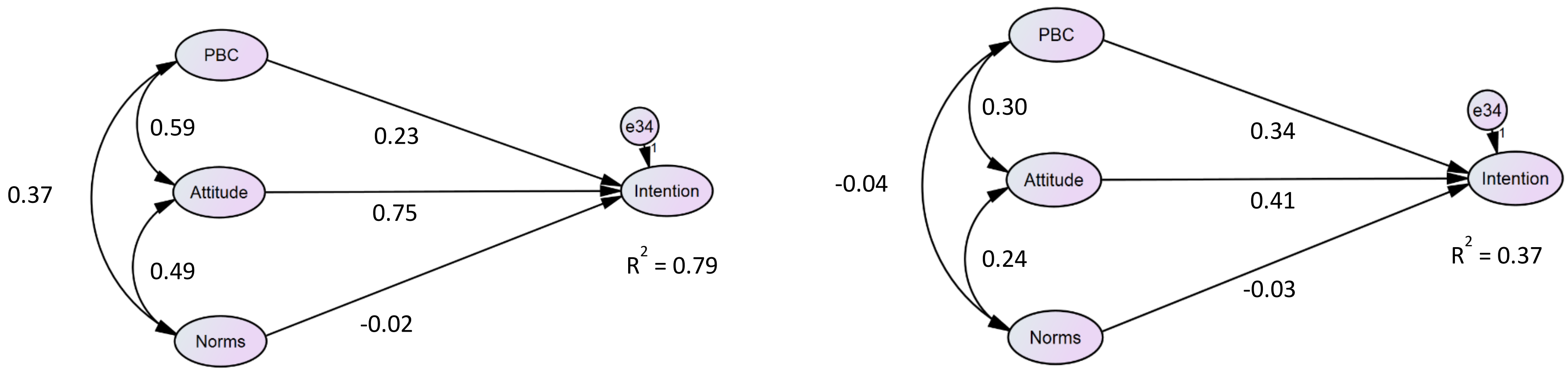
Cyclist and non-cyclist grouping

Building on the previous findings, an additional multi-group analysis was undertaken grouping cyclists and non-cyclists. As seen from Figure 7-5, similar factor loadings to the four group model were obtained. This indicates a similar interpretation can be made regarding the relationships between the latent constructs and their relative strengths. Attitudes were a strong predictor of Intention, particularly for non-cyclists compared to cyclists with loadings of 0.75 and 0.45 respectively. PBC had a positive relationship with Intention, the level of influence for this relationship was stronger for current cyclists than non-cyclists. As before, Subjective norms had a negligible influence on the Intention for both groups.

Across the cyclist and non-cyclist groups, a chi-squared difference test indicated the two structural models were significantly different (see Table 7-8). Further chi-squared tests were undertaken at a structural weights level to identify differences in the relationships between latent constructs across the two groups. Similarly, the relationship between Attitudes and Intention was significantly different among cyclists and non-cyclists, indicating attitudes are more important for non-cyclists' formation of cycling intention. Interestingly, the relationship between PBC and Intention was also significantly different, at a 95 percent confidence level, between cyclists and non-cyclists. This shows that for cyclists, PBC has a substantial influence on their Intention compared to non-cyclists' level of PBC.

Table 7-8: Chi-squared difference test (cyclists and non-cyclists)

Relationship	DF	CMIN	P
Structural model	11	72.212	**<.001**
PBC on Intention	1	4.048	**.044**
Attitude on Intention	1	30.027	**<.001**
Norms on Intention	1	.002	.964



Non-cyclists **Cyclists**

Figure 7-5: Cyclists and non-cyclists grouped models

7.3.7 Comparison of the global structural model and sub-group models

In this section a comparison is made between the different structural models (the global model and sub-group models) with respect to how they fit with the observed data and their ability to explain the variance of the DV.

The global model in effect outlines a structure, based on the TPB, explaining the causal influence of latent constructs on the intention to ride to the station, among current rail commuters collectively. This was achieved by constraining all parameters to be equal across the different mode types. The resulting model yielded appropriate model fit criteria (Cmin/DF = 3.987, RMSEA = 0.073), indicating adequate fitness. However, considering the differences in perceptions held related to bike-train integration among the different access mode users (see Table 7-3), it was expected developing sub-group models would enhance model performance. By allowing parameters to be different based on the grouping variable, two separate sub-group models were developed by *actual access mode type* and by *cyclist and non-cyclist* groups. Both of these grouped models were able to better account for the correlations observed in the dataset, indicated by the model fit metrics (Cmin/DF = 1.839, RMSEA = 0.039 and Cmin/DF = 2.525, RMSEA = 0.052).

Table 7-9 outlines the variance explained by each of the structural models. The global model was able to explain 84 percent of the variance in the intention to access the station by bicycle across current rail commuters. When broken down by current access mode type, the sub-group model was able to explain the variance in the DV for car (87%), walk (77%), bus (71%) and cycle (32%) users respectively. The variance explained for cyclists increases (37%) when all other access modes are combined, as seen in the cyclist and non-cyclist model. This indicates the structural models, based on the TPB, can better explain the variance in the intention to ride to the station for rail commuters who walk or use either a car or bus compared to current cyclists.

The comparative low variance explained for cyclists' intention to keep riding to the station may be attributed to the "best fit" measurement model used for this analysis. The "best fit" model, while satisfying global model fit criteria, had a reduced number of observed variables. As a result, measured items such as those that gauged environmentally friendly travel behaviour were omitted. Inclusion of such variables may have resulted in a stronger explanatory power of the DV for cyclists. Furthermore, the framework adopted for this study was based on the TPB. The latent constructs considered for the IV were therefore Attitudes, PBC and Subjective norms. It may be possible Attitudes, PBC and Subjective norms are robust at modelling the Intention related to a behaviour that is yet to be undertaken. Whereas, these latent constructs may not be as influential once the behaviour in question has been performed over a period of time. The inclusion of other latent constructs such as Habit may, therefore, help to better explain the intention to continue an existing behaviour such as riding to the station (Heinen et al., 2010). This may also contribute to the low variance explained by the cyclist subgroup structural models. To account for this, it may be possible to explore the inclusion of additional latent constructs in future research studies through the use of extended TPB models.

Table 7-9: Variance explained in each structural model

Structural model	**Variance (R^2)**
Global model (all modes combined)	0.84
Model distinguishing cyclists from those who walk, take the bus or drive	
Car	0.87
Walk	0.77
Bus	0.71
Bicycle	0.32
Model distinguishing current cyclists from non-cyclists	
Non-cyclists	0.79
Cyclists	0.37

7.4 Conclusion

This study applied a framework of the TPB to examine the intention to cycle to access the train station. SEM was utilised to empirically test for causal relationships among the latent constructs of the TPB. Results indicate Attitudes and PBC are significant predictors of the Intention to ride to the station. The insights from the models provide an evidence base to inform policy and practice. In particularly the findings have implications for designing interventions and behavioural change programs that aim to encourage greater levels of access to public transport services by bicycle. Re-emerging cycling nations such as Australia may benefit greatly from the implementation of such programs that encourage mode shift behaviour.

Chapter 8 Bike-and-ride market share and mode shift potential

In this chapter the focus is placed on examining the latent market share of bicycle use to access the train station and its mode shift potential. A market segmentation approach has been utilised to classify all rail commuters into a cyclist type, regardless of their current access mode. After classifying rail commuters into cyclist types, different motivations and group characteristics were identified. This chapter strengthens the understanding of behavioural aspects related to station access mode choice decisions, with a particular emphasis on the potential for change to the use of a bicycle. As noted in Figure 8-1, a typology was applied to all rail commuters therefore key station access modes were considered in this study.

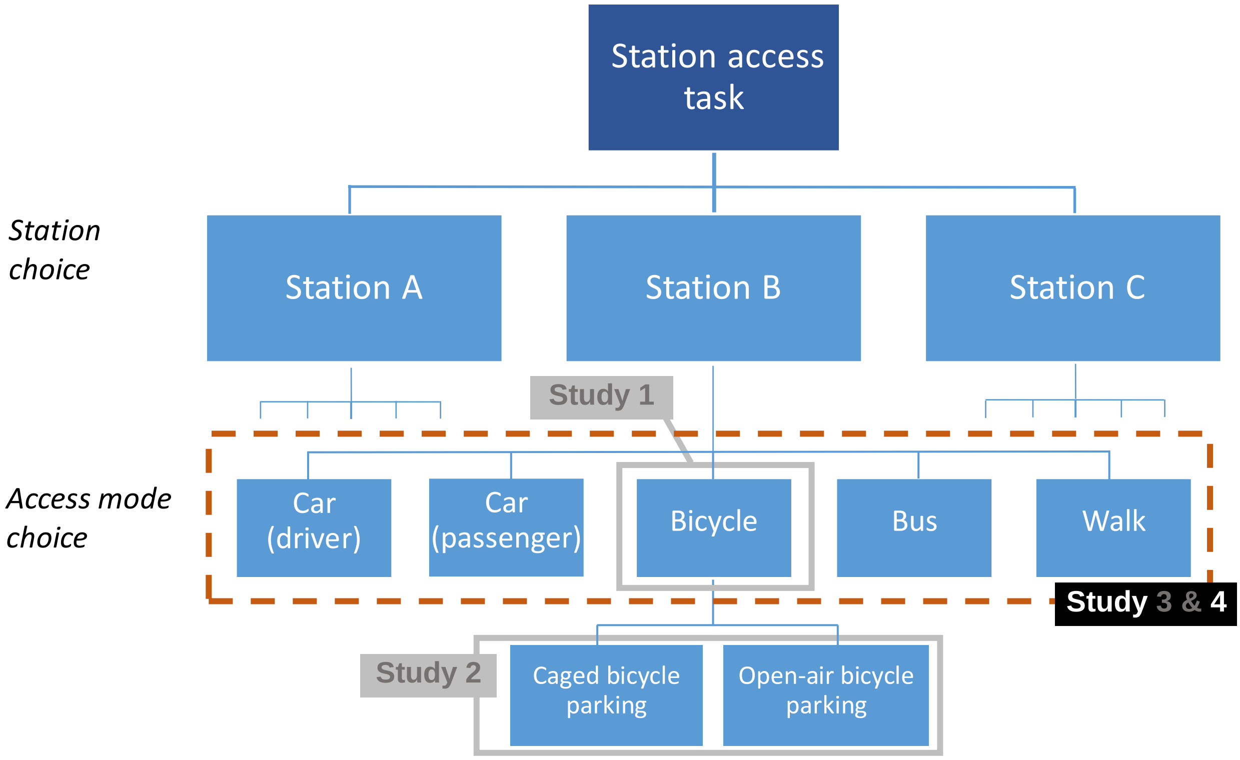


Figure 8-1: Access mode(s) under investigation

8.1 Introduction

In nations like Australia where cycling is a marginal station access mode, what is the latent demand for the use of a bicycle to access rail services? This question goes to the heart of Study 4, which explored the potential of the bicycle in catering for “first mile” station access trips. To achieve this, a market segmentation approach was taken, where a cyclist typology was adapted for integrated bicycle-train users. Rail commuters accessing the station on foot, by car, bus and bicycle were segmented into five types of cyclists. This enabled the exploration of:

- The potential market share of the bicycle as a station access mode;
- The potential mode shift to the bicycle and the displacing of non-cycling access modes; and
- The needs, attitudes and perceptions of the different types of cyclist groups.

The umbrella term ‘cyclist’ encompasses a broad range of preferences, skills and abilities. Cyclists do not all react similarly to various infrastructure facilities or changing cycling conditions (Larsen & El-Geneidy, 2011; Bergström & Magnusson, 2003; Nankervis, 1999). Such differences which exist within a population are better able to be understood by segmenting the whole into groups. Kroesen and Handy (2014) demonstrated that classifying cyclists into groups with shared commonalities, can lead to more nuanced findings and provide richer insight compared to more aggregate analysis. They clustered cyclists into groups and the resulting parameter estimates of variables revealed more complex patterns and insights compared with unsegmented analysis. Furthermore, social marketing approaches highlight market segmentation is able to provide insights into the different motivations, attitudes, needs and behaviours which may exist within segments of a group (Maibach et al., 2002). Understanding such differences can help to shape behaviour change programs, communication campaigns and policy initiatives where tailored solutions can meet the specific needs of the different segments.

Cyclist typologies have been widely used to study cycling behaviour. Jensen (1999) combined cyclists and public transit users to explore mode selection, specifically to identify whether the integration of cycling and transit was due to captive reasons or by choice. Jensen classified bicycle-public transport users into three groups:

- Heart: cycles for the experience and decide not to own a car;
- Convenience: cycles due to the convenience; and
- Necessity: cycles as they cannot afford a car.

Damant-Sirois et al. (2014) established a typology for current cyclists, based on several determinants related to cycling. This included infrastructure preferences, encouragement to ride a bicycle and motivations. Based on a clustering of participants, four types of cyclists were defined:

- Dedicated cyclists: not deterred by a lack of cycling infrastructure or by poor weather conditions;
- Path-using cyclists: prefer to ride on cycling infrastructure and only slightly affected by the weather;

- Fairweather utilitarians: contextual users who do not cycle in bad weather and prefer paths; and
- Leisure cyclists: ride for the enjoyment and are influenced by weather.

Another cyclist typology developed by Geller (2009), for the city of Portland, aimed to identify the market for bicycle transportation. He developed a typology of four types: Strong and Fearless, Enthused and Confident, Interested but Concerned and No Way No How. Dill & McNeil (2013) analysed this typology across Portland and used primary data collected to refine the estimated market share.

With established past work related to cycling as the main mode of travel, this research applied a similar approach specifically for intermodal trips combining cycling and rail use. In the next section, the types of cyclists applied in this study are discussed.

8.1.1 Five types of cyclists

The choice of the types of segmentation used is fundamentally shaped by the purpose of the examination (Christmas et al., 2010). As the intended purpose of this study was to explore the potential market share of cycling as a station access mode, the process needed to apply to all rail commuters across multiple access modes. The typology used in this study was, therefore, applicable to those who access the station on foot, by car, bus and bicycle (key station access modes studied in this research program).

The objective of this study was closely aligned with Geller's original intention when formulating the four types of cyclists:

> *"The intent behind its development was to get a better handle on our market for bicycle transportation. As such, it has been a useful tool, providing an organizing principle for understanding our target market and what we surmise their concerns and needs to be" (Geller, 2009).*

The study aimed to apply the classification across a whole population, not just current cyclists, an adapted typology based on Geller's work was utilised for this study.

A modified version of Geller's typology, developed by Johnson and Rose (2015), was used that included an additional classification, *'Enthused but Not Confident'*. This new classification fits in between *'Enthused and Confident'* and *'Interested but Concerned'*. The 'not confident' aspect may particularly relate to new or returning cyclists, who may not be confident as of yet, but not concerned enough to not ride. A description of the five types of cyclists, and their preference of infrastructure facilities are outlined in Table 8-1.

Table 8-1: Five types of cyclists

Typology	Description of cycling conditions	Infrastructure used
Strong and fearless	Very comfortable on arterial roads without cycling infrastructure	Main roads (e.g. arterials) without dedicated cycling infrastructure
Enthused and confident	Very comfortable on roads with cycling infrastructure. Not comfortable on arterial roads without cycling infrastructure	Main roads (e.g. arterials) with dedicated cycling infrastructure
Enthused but Not Confident	Very comfortable on local residential roads. Not comfortable on arterial roads with or without cycling infrastructure	Residential roads
Interested *but Concerned*	Not comfortable cycling on arterial roads with or without bike lanes and on local residential roads	Dedicated bicycle paths or footpaths
No way no how	Uncomfortable riding or physically unable to ride a bicycle	Will not cycle

8.2 Research method

Data gathered from the rail commuter intercept survey, described in Chapter 6, was utilised to implement the typology. A total 758 valid responses were collected from the survey of which 757 participants had the necessary information required to be classified into the typology. Of the 757 respondents, the largest proportion accessed the station by car (n=303, 40%) followed by those who walked (n=262, 35%), caught a bus (n=113, 15%) and rode a bicycle (n=79, 10%).

8.2.1 Segmentation approach

The method used to segment the respondents into one of the five types of cyclists was based on the classification system applied by Dill & McNeil (2013). Two key aspects played a role in the segmentation process, the first related to comfort level (fearless, confident, not confident, concerned) of cycling on infrastructure facilities most common en route to railway stations in Melbourne. The second relates to the participants' intention to access the station by bicycle (enthused, interested, no way).

The respondents were asked to specify their level of comfort with cycling to the station on the footpath, off-road shared paths, local residential streets, local collector roads and arterial roads, the latter with and without bike lanes. This choice of infrastructure options represents the typical alternatives available to ride to the station in Melbourne. For each of the hypothetical scenarios the respondents were able to indicate their level of comfort on a four-point Likert scale from very uncomfortable, slightly uncomfortable, slightly comfortable to very comfortable.

A summary of the description for each of the five cyclist types used in Study 4 and the responses used to classify respondents into each segment are outlined below.

Strong and Fearless

Are people who cycle in all roadway conditions. This segment included respondents who indicated they are very comfortable riding on arterial roads without cycling infrastructure to access the station.

Enthused and Confident

Geller noted *'Enthused and Confident'* cyclists are comfortable sharing the roadway with motor vehicles, however, prefer to ride on dedicated cycling infrastructure. This segment included respondents who were very comfortable riding to the station on arterial roads with bike lanes were put into this category.

Enthused but Not Confident

Are people who are new cyclists or returning to cycling after an extended period. This segment included cyclists who were not comfortable riding on arterial roads with or without cycling infrastructure, but weremvery comfortable cycling to the station on local residential streets, often with low traffic volumes and low speeds (generally 50 kmph).

In segmenting respondents into either the *'Interested but Concerned'* or *'No Way No How'* categories, multiple dimensions were considered. These included the level of interest in using the bicycle as a station access mode, comfort riding on off-road shared paths as well as the physical ability to ride a bicycle.

No Way No How

Respondents who indicated they were very uncomfortable cycling on off-road shared paths were grouped into the *'No Way No How'* segment along with those that were unable to ride a bicycle. This left a share of respondents who were still uncategorised and could fall into either the *'Interested but Concerned'* or *'No Way No How'* groups.

Interested but Concerned

The next step involved segmenting the remaining uncategorised respondents based on their level of interest in accessing the station by bicycle. The survey gauged this particular aspect through the following statement 'I would be interested in cycling to the station' in which the participants could indicate their level of agreement on a five-point Likert scale ranging from strongly disagree to strongly agree. Those who agreed (strongly or somewhat) were grouped into the *'Interested but Concerned'* category. If the respondents disagreed (strongly or somewhat) or were neutral to the statement, they were segmented into the *'No Way No How'* category.

8.3 Results and interpretation

In this section the results of this study are presented and interpreted. Prior to the examination of the five types of cyclists, the analysis focused on participants' current station access mode choice behaviour as well as the perceptions related to cycling to the station.

8.3.1 Current station access mode choice characteristics

The station access trip can be made using a multitude of modes. Insights into the motivations which affect the choice to use such access modes are important when considering the mode shift potential to the bicycle. Participants in the commuter online survey indicated the influential factors which affected their choice of station access mode. A pre-set list of options including travel time savings (fastest), cost savings, convenience and the influence of other commitments were provided (see Figure 8-2). Respondents were able to select multiple options in addition to providing an open-ended response as part of 'other' reasons.

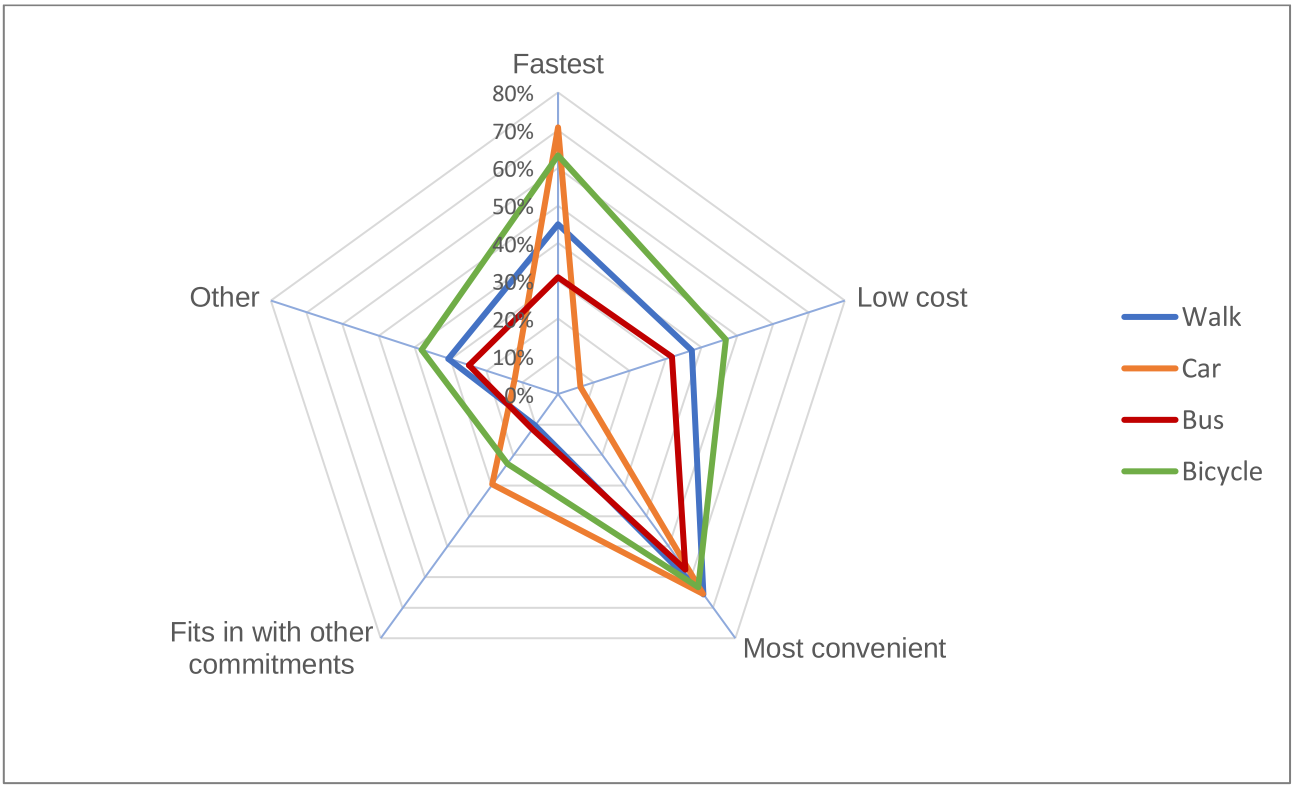


Figure 8-2: Reasons for current station access mode choice

Fastest

The majority (71%) of all respondents who accessed the station by car noted travel time savings played a key role in the station access mode choice. Almost two thirds of cyclists (63%) indicated the bicycle was the fastest access option. Less than half of the commuters accessing the station by bus and on foot indicated those options were the fastest mode available to them. Of note, we did not explore whether people who accessed the station by car considered the time required to park in their assessment of time savings. While unlikely to impact passengers, this next level of detail is important to consider in future studies of people's perceptions about driving to the station.

Low cost

Cyclists were the highest proportion (47%) to report cost savings as a factor affecting access mode choice, followed by walkers (37%) and bus users (32%). Fewer than ten percent of car users indicated travel cost savings played a role in their choice to use a car.

Most convenient

Convenience offered by the different station access modes played a role in the mode choice decision. Across all modes, almost two thirds users (60%) mentioned convenience as a reason. This suggests convenience plays a crucial role is mode choice, further research is needed to determine what aspects of the different modes contribute to the level of convenience.

Fits in with other commitments

With respect to the modes allowing the user to fit in other commitments, car users were the most likely to agree (30%), followed by cyclists (23%). Approximately, one in ten commuters who walk or catch the bus indicated the ability to fit in other commitments played a role in their station access mode choice decision.

Other

Other variables also influenced the choice of a relatively high proportion of people who cycled (38%), walked (31%) and used a bus (25%) had indicated the influence of 'other' variables. For cyclists, the key reason was incidental exercise, in addition to a lack of available car parking at stations. For walkers, the key reason was the ability to exercise and improve their health and fitness. For bus users, a lack of available car parking at stations was also a key reason. This indicates some people who are currently cycling or taking the bus to the station, may prefer to drive. It is possible that an expansion of car parking facilities at train stations, some cyclists or bus users may shift access mode to a private car. Of those people who did not drive to the station, the majority (70%) had access to a car which could have been used to access the station.

The next section explores the travel behaviour of the respondents who rode a bicycle to the station.

8.3.1.1 *Bike-and-ride users' travel behaviour*

Trip characteristics and attributes of the participants who currently cycle to the station were explored. Given that a majority of cyclists have access to a private car (52%), access by bicycle may be a choice, rather than a decision made due to captive reasons (e.g. lack of car access, cost etc). Particularly as the majority of cyclists (79%) had been riding to the station for over a year. Whereas a small portion were new to using the bicycle as an access mode (14%), including people who started riding in the last week (8%) or in the last 3 months (6%).

With respect to the infrastructure facilities used in accessing the station, Figure 8-3 outlines the relative proportions of infrastructure types used by current cyclists. The majority (87%) of cyclists used local residential streets to access the station. Footpaths were the second most common piece of infrastructure used (37%), although by law in Victoria, adults are not permitted to cycle on the footpath, unless accompanying a child aged under 13 who is also riding a bicycle. This is likely to indicate cyclists wish to physically separate themselves from motor vehicle traffic in areas perceived to be a high crash risk. Further research is needed on route choice decisions, particularly the use of footpaths and if the motivation is to avoid high crash risk areas. Only about a third of cyclists indicated using off road shared paths (37%) or arterial roads with cycling infrastructure (34%), this may be due to the lack of such facilities en route to the station as indicated in Study 1.

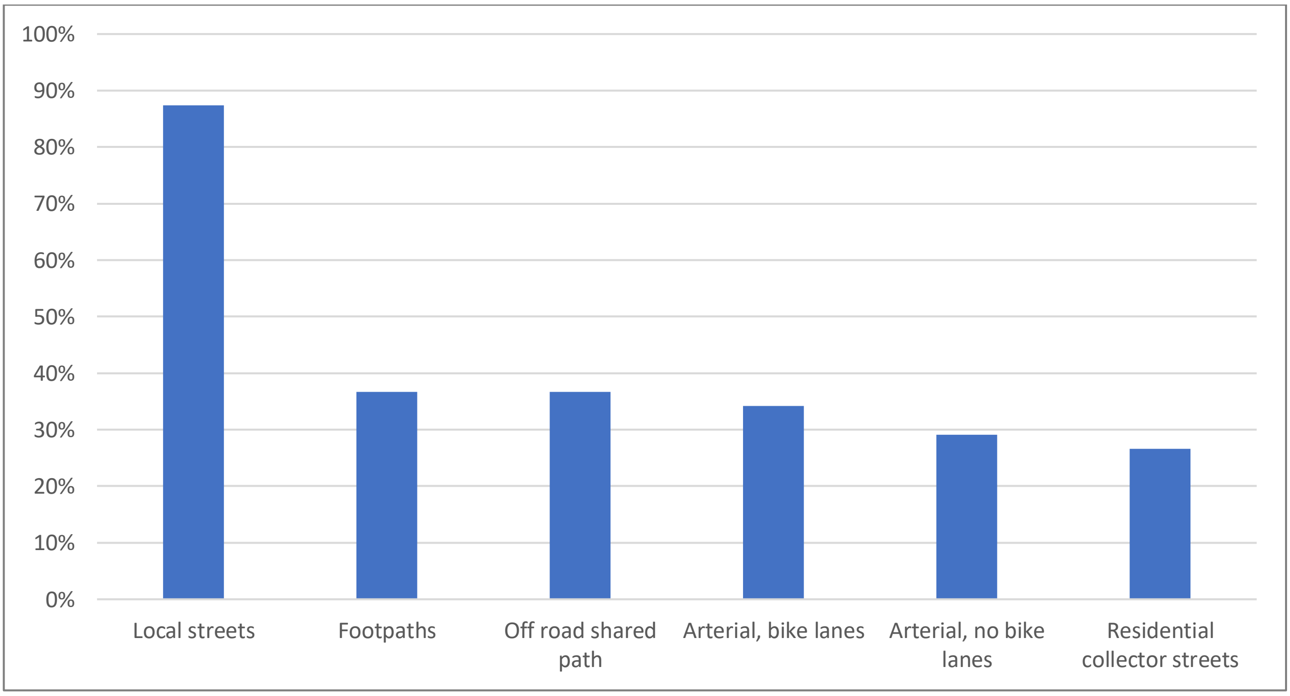


Figure 8-3: Infrastructure used by current cyclists

8.3.1.2 Non-cyclists' perceptions of riding to the station

In this section current non-cyclists' access mode choice was explored. The emphasis was placed on the relevant respondents' reasons for not accessing to the station by bicycle as well as their perceptions of riding to the station.

"What are the main reasons you do not cycle to the station"

- It's too far;
- Too much to carry;
- Don't have enough time;
- Not fit enough;
- Other;

Respondents were able to select multiple options. Not having enough time to access the station by bicycle was indicated by over half the respondents who travelled by car (driver or passenger, 57%) and half of bus travellers (49%) (see Figure 8-4). This may indicate a key barrier to the uptake of the bicycle as an access mode is the perception cycling is slower than their current access mode. This is despite only a third of current bus users indicating the bus is the fastest access mode. Interestingly, all non-cycling station access mode users, particularly car and bus users, mentioned a reason for not accessing the station by bicycle was due to having too much to carry. Car users were the most likely to state cycling would not fit in with their other commitments (37%).

Over 60 percent of commuters who currently walk had indicated 'other' reasons influenced their choice not to cycle to the station, substantially greater than bus (37%) and car users (32%). Of these reasons, half of walkers (52%) mentioned they lived too close to the station to warrant the use of a bicycle. Bus and car users noted key other reasons for not cycling to the station were weather (car:29%; bus users: 30%) and clothes (car: 19%; bus: 23%).

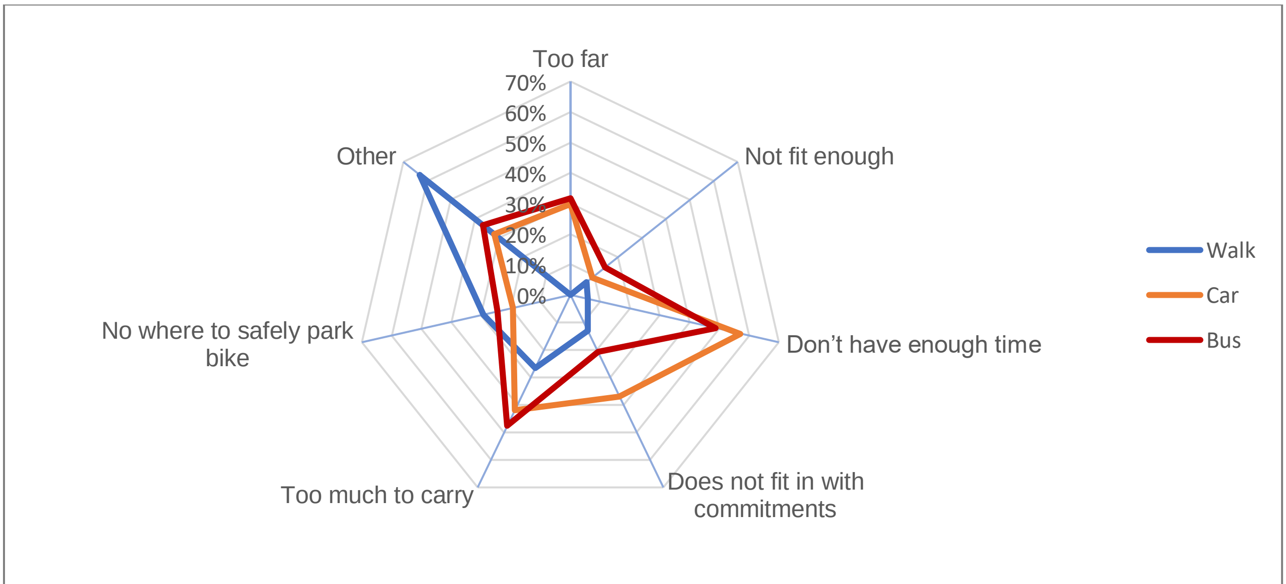


Figure 8-4: Reasons of not cycling to the station

"Compared to how you usually travel to the station, if you did ride a bicycle to the station, to what extent do you think it would be:"

- Faster;
- Result in a more reliable travel time;
- Cheaper;
- Better exercise;
- Safer;
- Easier to park; and
- Easier to securely park.

Respondents answered using a five-point Likert scale ranging from strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree or strongly agree. Each of the survey scales were coded an increasing integer value ranging from -2 for strongly disagree to +2 for strongly agree. For each of the non-cycling station access modes, the coded values were averaged. These averaged values indicate the collective level of agreement of a particular mode for a particular trip characteristic. The results are presented in Figure 8-5.

Car users were more likely to disagree that cycling would be faster, similar to bus users who lean towards disagreeing albeit not to the same extent. In contrast, walkers were more likely to agree that cycling would be faster. Both car users and walkers disagreed that cycling would result in a more reliable travel time to access the station, compared to bus users who agreed. There was consensus in relation to safety as all non-cycling mode users disagreed that cycling to the station would be safer than their current access mode. Interestingly car and bus users agreed that by riding a bike it would be easier to park at the station, however, disagreed that it would be easy to securely park a bicycle at the station. Security concerns for bicycle at stations may therefore prevent commuters from riding to the station.

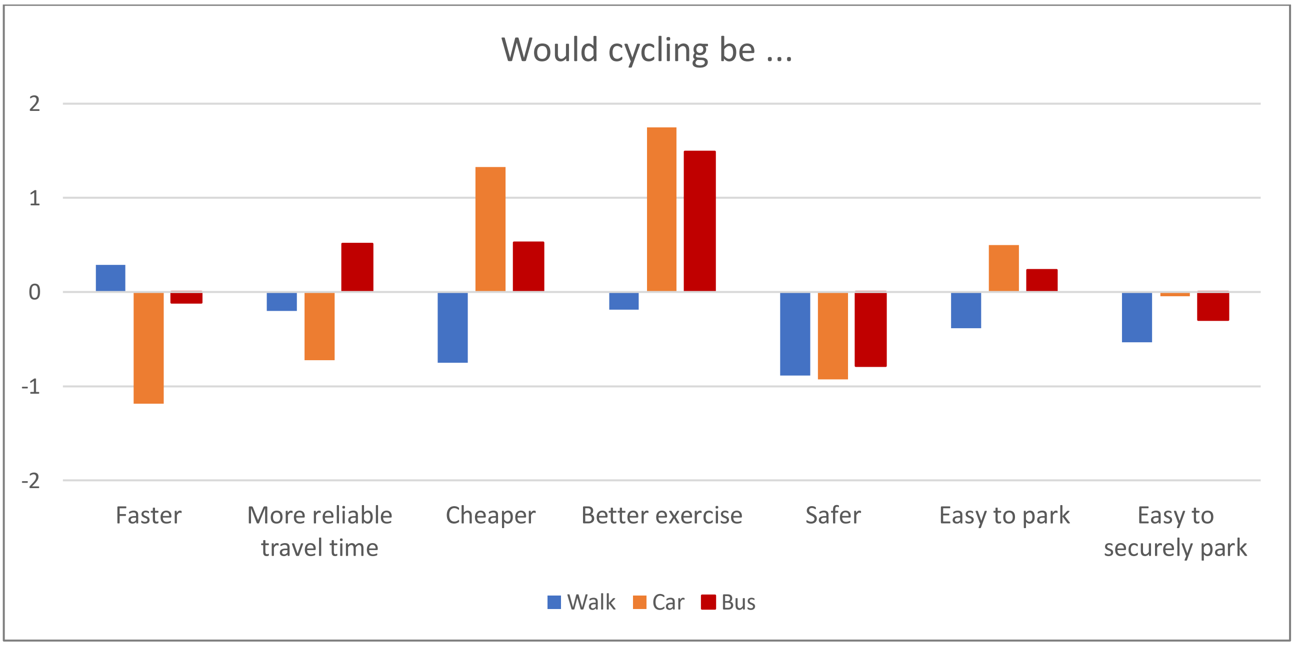


Figure 8-5: Perceptions of riding to the station among current non-cyclists

8.3.1.3 *Station access distance*

Home cross street locations were reported in the commuter intercept survey. This provided an opportunity to identify station access distance by mode type. In Figure 8-6 the station access distance is plotted against the cumulative percentage for each access mode. For shorter station access distances, walking is by far the most popular mode. Almost two thirds of respondents who accessed the station on foot did so within 1 km of a station. In comparison, across each of the other access modes fewer than 10 percent of trips originate within 1 km of a station. After walking, cycling is the second most common mode for shorter station access trips. Almost half of bicycle access trips were within 2.5 km of the station. The data collected in the context of Melbourne, supports the findings of Martens (2007) in which the typical cycling catchment to heavy rail, in the Dutch context, is between 3 to 5 km. This catchment accounts for about 60 to 80 percent of all bicycle access trips to the station.

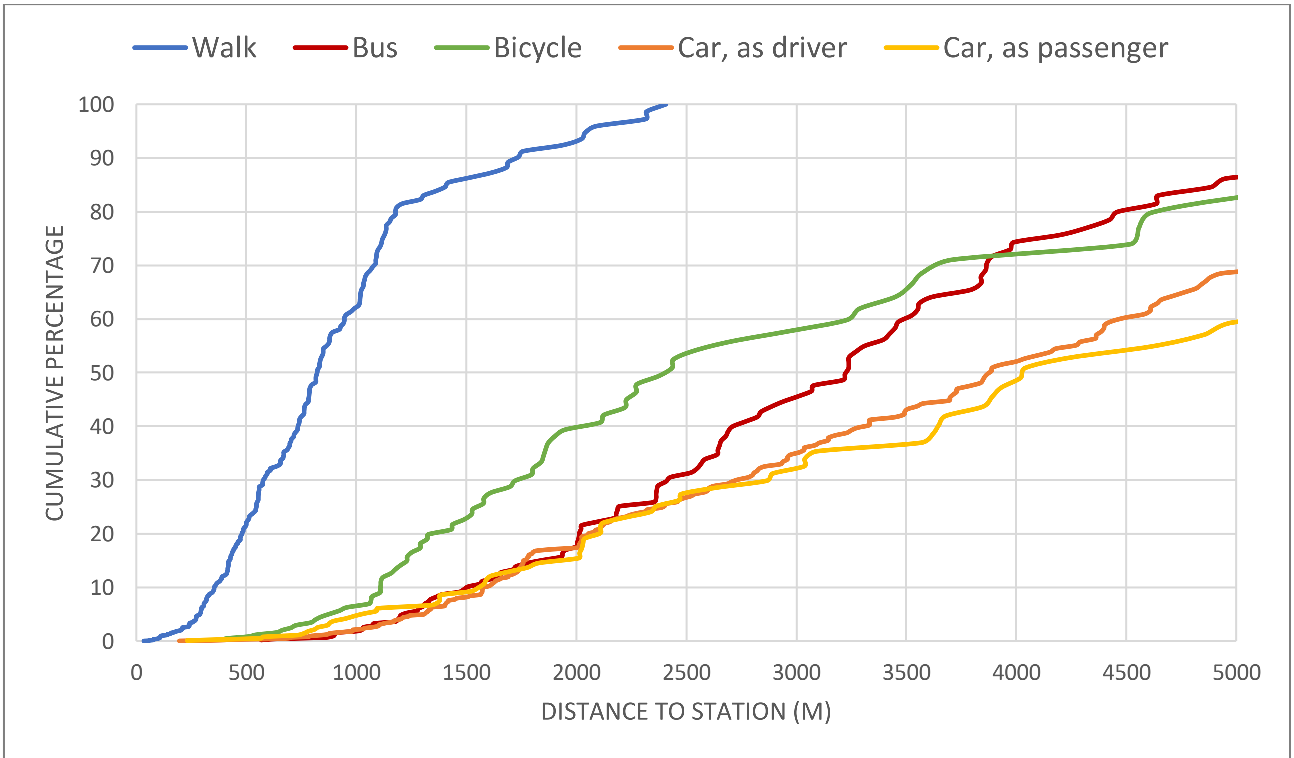


Figure 8-6: Cumulative access distance by mode in Melbourne (n=746 responses)

Car-based station access trip distances originate from as close as 200 metres. Almost half of park-and-ride trips in Melbourne are within 4 km of a station, similar to the proportion in Perth, the capital of Western Australia (Evans et al., 2004). Assuming that 3-5 km is the range that can be easily travelled by bicycle, the data suggests a large proportion of current non-cyclists live close enough to a station that they could make the journey by bicycle. With about 35 to 70 percent of car-based access trips originating within 3 to 5 km, purely based on access distance alone, there is substantial potential to encourage shifting station access modes to cycling. However, mode choice is not solely based on trip distance, but also on human behaviour, preferences and perceptions. This dimension is unpacked in the next section with the market segmentation analysis through the types of cyclists.

8.3.2 Five types of cyclists – the potential of the bicycle

The key objectives of this study were to identify the possible market share of the bicycle as a station access mode and to explore the mode shift potential of the bicycle. To achieve these objectives, participants from the rail commuter intercept survey were segmented into five types of cyclists.

Applying the typology resulted in the shares outlined in Table 8-2 across the different segments. *'Strong and Fearless'* cyclists (4%) had the smallest share, with almost one in ten respondents identified as either *'Enthused and Confident'* (11%) or *'Enthused but Not Confident'* (11%) and almost a fifth identified as *'Interested but Concerned'* (19%). The largest single segment was *'No Way No How*' (55%).

Earlier estimates of types of cyclists by Geller as well as Dill and McNeil's work focused on cycling for transportation as the main mode of travel in Portland, Oregon. Although different to the intermodal nature of this study, a comparison of the proportions indicate a similar share of *'Strong and Fearless'* and *'Enthused and Confident'* cyclists. The largest difference in shares between the studies can be noticed among the *'Interested but Concerned'* and *'No Way No How'* segments. While the share of *'Interested but Concerned'* may have been affected by the inclusion of the *'Enthused but Not Confident'* segment, over half of the commuters were classified into the *'No Way No How'* group. This is substantially higher than the one third reported in the other studies (Dill & McNeil, 2013; Geller, 2009). This is potentially related to the nature of cycling as a station access mode, where with the intermodal aspect of the journey, people are less likely to combine cycling and transit than to cycle for transportation alone. In total, however, the market for the use of a bicycle as a station access mode makes up 45 percent of all commuters and is composed of *'Strong and Fearless'*, *'Enthused and Confident'*, *'Enthused but Not Confident'* and *'Interested but Concerned'* segments. This accounts for users with different preferences and comfort levels cycling on various infrastructure facilities as well as people who are interested in riding to the station.

Table 8-2: Market share of the five types of cyclists

Cyclist Category	Five types of cyclists (Study 4)	Dill & McNeil (2013)	Geller (2009)
Strong and Fearless	4%	4%	<1%
Enthused and Confident	11%	9%	7%
Enthused but Not Confident	12%	-	-
Interested but Concerned	19%	56%	60%
No Way No How	55%	31%	33%

In order to explore the mode shift potential of the bicycle for the station access task, the focus is placed on the cross tabulated values between the participants' current access mode and the five types of cyclists (see Table 8-3). Current non-cyclists who are comfortable riding on various infrastructure facilities or are interested in cycling to the station represent users who have the potential to shift modes to the bicycle. Therefore, those who walk, use a car or bus and are in either the *'Strong and Fearless'*, *'Enthused and Confident'*, *'Enthused but Not Confident'* or *'Interested but Concerned'* have the potential to shift station access modes. For comparative purposes, current cyclists' classification proportions are included in Table 8-3.

Table 8-3: Mode shift capability for non-cyclists

	No Way No How	Interested but Concerned	Enthused but Not Confident	Enthused and Confident	Strong and Fearless	Total share of mode shift potential segments
		Mode shift potential segments				
Walk	53%	12%	17%	13%	5%	*47%*
Car	68%	19%	4%	7%	2%	*32%*
Car (< 5km)	64%	22%	4%	8%	2%	*36%*
Bus	61%	19%	10%	10%	0%	*39%*
Bicycle	0%	37%	28%	20%	15%	*N/A*

Commuters who currently walk are the most receptive to shifting their access mode to the bicycle. Almost half (47%) of people who access the station on foot are classified within a mode shift potential segment. Bus users account for the next highest share of commuters capable of shifting access modes to the bicycle. Over a third (39%) of bus users are potential mode shift candidates. Car access mode users are the least likely to shift modes and use a bicycle. A third of all car users are within a classification capable of shifting access modes (32%), this was only slightly higher for car users who live within 5 km of a station (36%). This indicates distance from the station plays a role in the choice to shift station access modes to the bicycle.

Across the *'Strong and Fearless'*, *'Enthused and Confident'*, and *'Enthused but Not Confident'* segments the largest modal shift share was among people who currently access the station on foot. As for the *'Interested but Concerned'* classification, both car and bus users have the largest share of potential mode shift candidates. This suggests providing off road shared paths leading to the station has the most influential effect on car and bus users' mode shift behaviour.

Current bike-and-ride users are classified in each segment except for the *'No Way No How'* group. This suggests even among cyclists the levels of comfort related to cycling on different infrastructure facilities tend to be different. Furthermore, this highlights that non-cyclists belonging to those groups are capable of shifting access modes.

However, this raises an important question: If non-cyclists are within a mode shift potential segment, why don't they ride to the station? For segments *'Enthused and Confident'*, *'Enthused but Not Confident'* and *'Interested but Concerned'*, the lack of appropriate cycling infrastructure, connecting the station, may prevent mode shift behaviour. Non-cyclists belonging to the *'Strong and Fearless'* segment, however, should be comfortable riding to the station on any infrastructure type. To examine this issue further, the reasons for not cycling to the station, among this subset of participants, were explored. As seen on Figure 8-7, the most common reasons for not cycling to the station, among mode shift potential candidates, was due to a lack of bicycle parking infrastructure to securely store their bicycle, not having enough time for the journey by bicycle and having too much to carry.

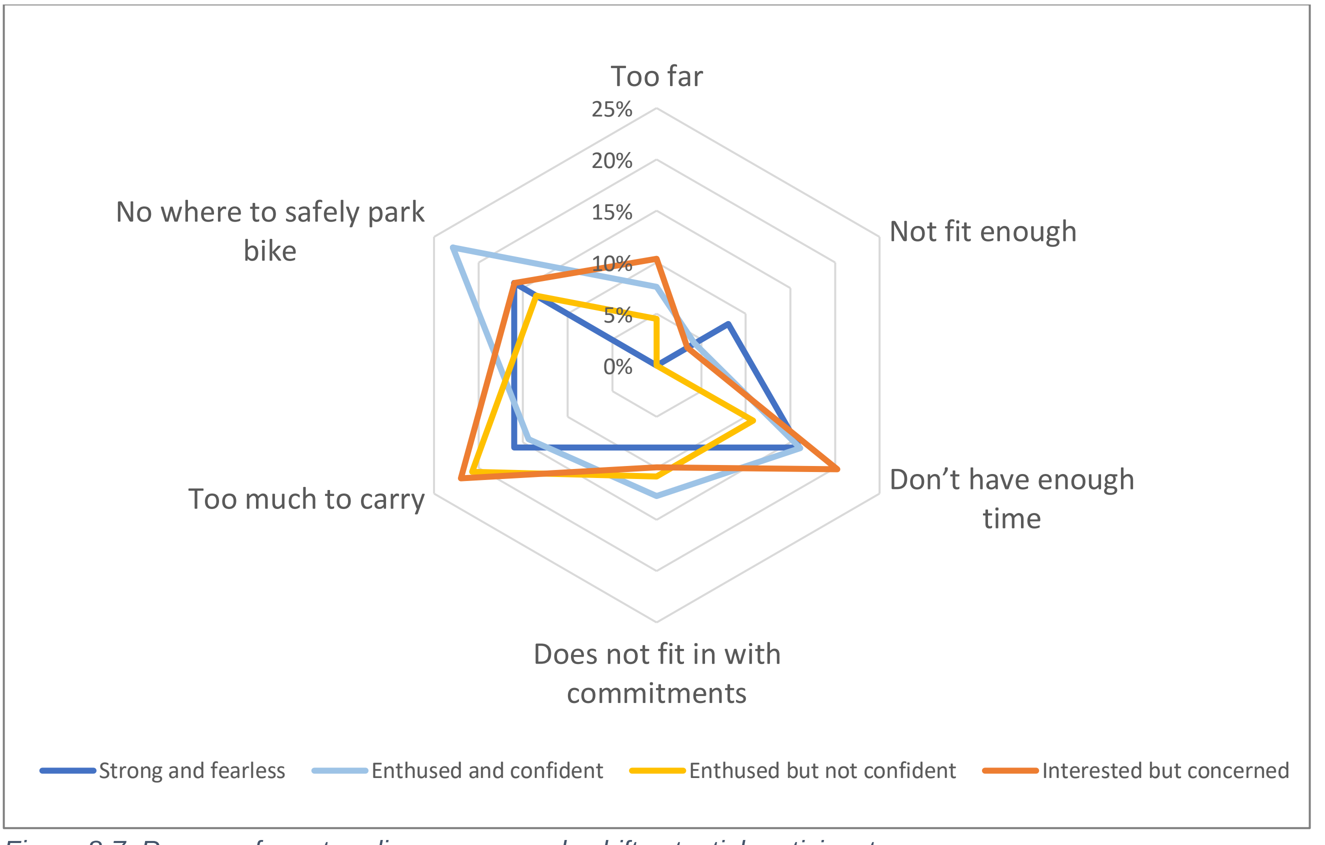


Figure 8-7: Reasons for not cycling among mode shift potential participants

Following the classification of rail commuters into the 'five types of cyclist' typology, the potential market share of the bicycle for station access journeys and its mode shift capability were identified. In the following section, the characteristics and attributes related to each segment were analysed.

8.3.2.1 Demographics of the five types of cyclists

The influence of gender and age were examined across the segments. When focussing on gender, the majority of females (70%) were classified into the *'No Way No How'* segment, compared to half of the males (48%). This suggests that there may be additional barriers for females in taking up cycling as a station access mode. This could include variables considered in this study (comfortability on infrastructure, lack of infrastructure, perceptions about time, cost or security) or it may indicate additional barriers that were not explored in this research (e.g. personal safety, family/parental responsibilities at the start/end of the day). Encouragingly, a third of female respondents (30%) and a half of male participants (52%), who currently do no ride to the station, were within a segment where there is the potential for mode shift behaviour.

As seen in Figure 8-8, for each age bracket, the *'No Way No How'* segment contained the highest proportion of respondents. The proportion of *'No Way No How'* was greatest among young commuters (18-24 years: 66%) and older commuters (65-74 years: 95%; over 75 years: 100%). Respondents 35-44 years old are more likely than users in other age brackets to be within a cyclist typology with a potential to shift station access modes.

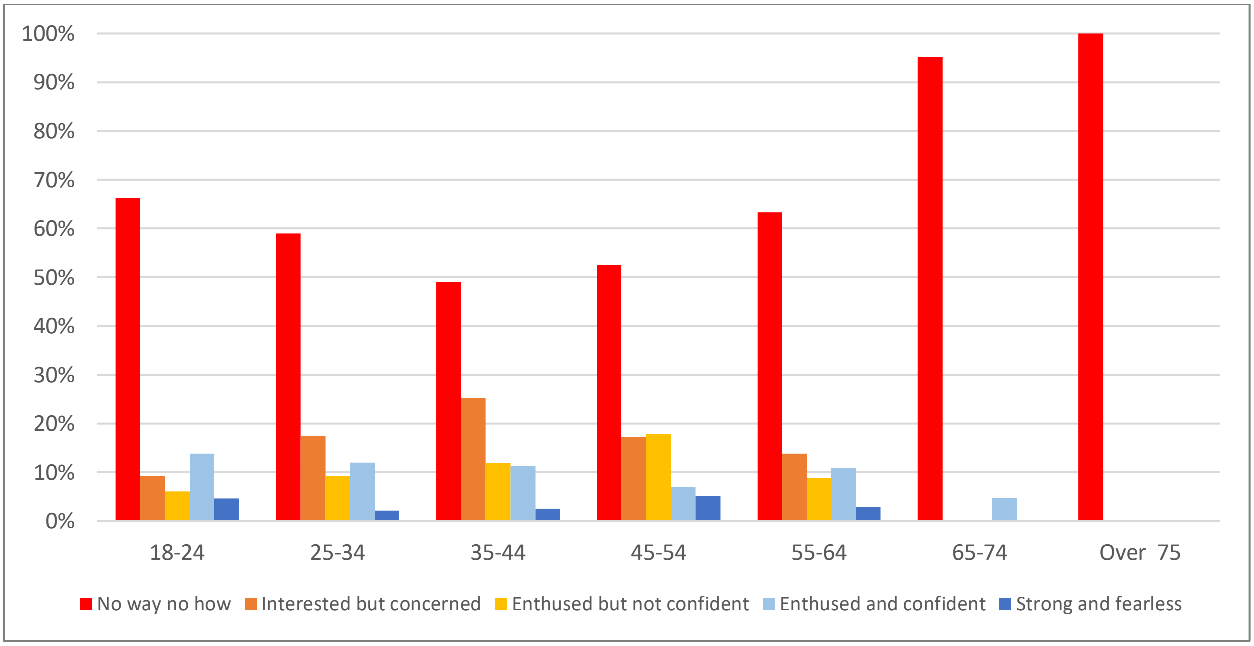


Figure 8-8: The types of cyclist by age

8.3.2.2 Trip characteristics

The availability of a car to access the station was examined through the lens of the cyclist typology. Commuters in the *'No Way No How'* category were more likely to have access to a car (88%) than users in all other segments: *'Interested but Concerned'* (81%), *'Enthused but Not Confident'* (81%), *'Enthused and Confident'* cyclists (78%) and *'Strong and Fearless'* (70%).

Figure 8-9 outlines the last time respondents rode a bicycle within each segment. Across all segments in which mode shift to cycling was a possibility, the majority had ridden a bicycle in the last week. Almost two thirds of *'Strong and Fearless'* (63%) had ridden in the last week, compared to about a third of *'Enthused and Confident'* (38%), *'Enthused but Not Confident'* (38%) and *'Interested but Concerned'* (33%). In the *'No Way No How'* segment over half (54%) had last ridden a bicycle more than a year ago. This suggests the level of interest and comfort associated with riding on different infrastructure facilities to the station is likely influenced by the (in)frequency of bicycle use.

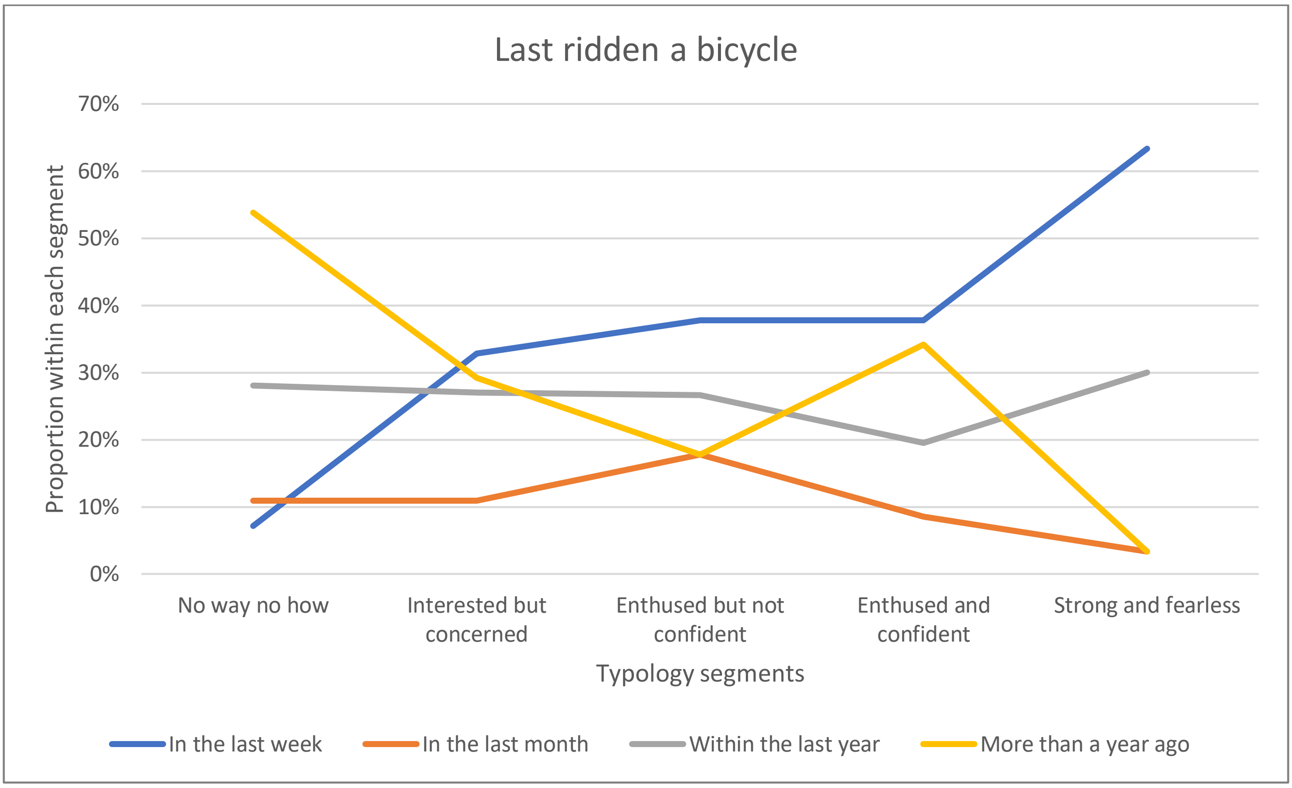


Figure 8-9: Bicycle riding frequency

8.3.2.3 *Weather*

The segments of the typology were analysed to see how they were influenced by weather (see Figure 8-10). All respondents were asked to indicate their likelihood of riding to the station in conditions from warm weather to heavy rain. Respondents indicated their likelihood ranging from very unlikely to very likely on a five-point Likert scale. The survey scales were coded an increasing integer value ranging from -2 for very unlikely to +2 for very likely. Following this the averaged numerical score was calculated for each cyclist segment.

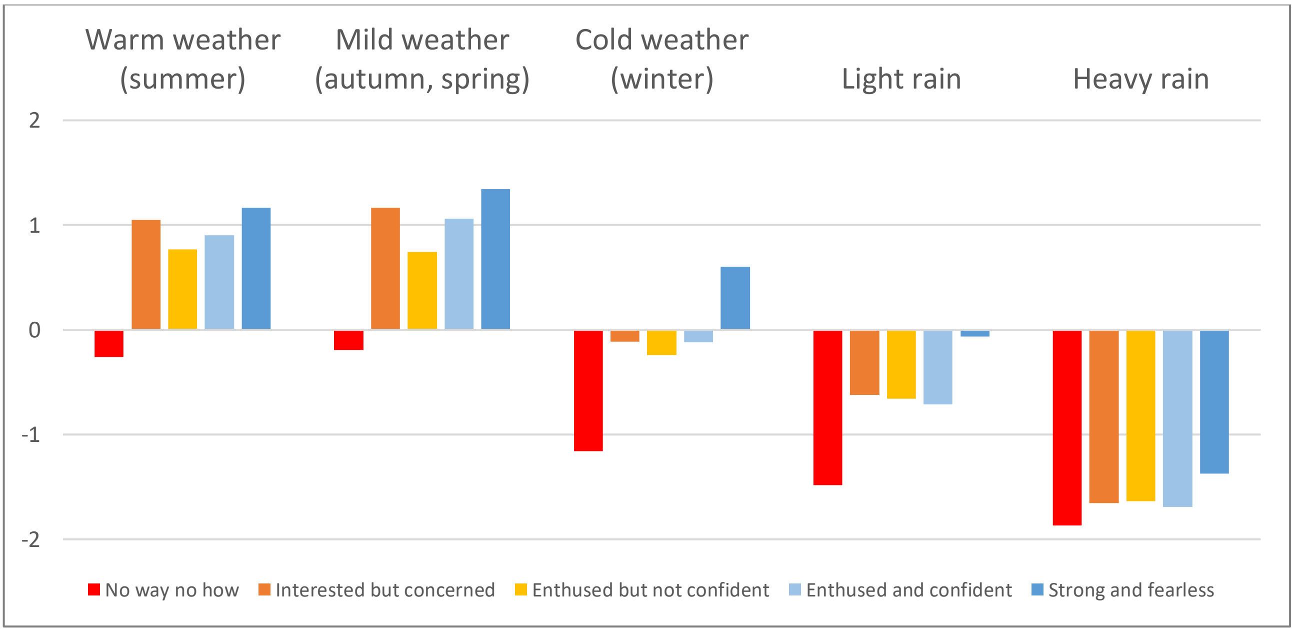


Figure 8-10: Impact of weather on the likelihood of riding to the station

The data indicates in the summer months with warmer weather, all cyclist segments, except for *'No Way No How'*, have a positive averaged numerical score, indicating the positive likelihood of riding to the station. The *'No Way No How'* segment had negative scores across all weather conditions reinforcing that respondents in this segment were unlikely to cycle to the station. During the autumn and spring periods, all segments barring the *'No Way No How'* type, indicated their highest level of likelihood riding to the station. However, during colder periods in winter, only the *'Strong and Fearless'* had a positive likelihood of riding to the station. This suggests there is a seasonal influence on the likelihood of riding to the station, with this effect being felt differently across the various segments. The presence of rain, both light and heavy, resulted in all of the typologies having negative average scores, indicating the barrier presented by adverse weather conditions is substantial particularly during heavy rain.

While not addressed in this study, future broader systems issues could be considered such as whether flexible work times may result in commuters attempting to wait the rain out and then ride to the station.

8.3.2.4 Infrastructure

While the classification of participants into the five types of cyclists relied on segmenting respondents based on their comfort levels riding on different infrastructure facilities, the survey also asked about the likelihood of riding on those facilities. Respondents were able to indicate their likelihood on a five-point Likert scale (would never cycle, very unlikely, slightly unlikely, slightly likely and very likely). A similar coded approach was taken with -2 for 'would never cycle' to +2 for 'very likely'. For each segment the average numerical score was calculated and is shown in Figure 8-11.

The *'No Way No How'* segment has negative average numerical scores across all infrastructure facility types. Of the infrastructure types, *'No Way No How'* users are least likely to ride on arterial roads without cycling infrastructure and 'most' likely to ride on off road shared paths. This may indicate that lack of confidence related to cycling on roadways and sharing the space with motorised vehicles and pedestrians, where even with dedicated cycle infrastructure or low speed environments, this behaviour is perceived as dangerous. The *'Interested but Concerned'* segment is noted to have positive scores related to cycling to the station on off-road facilities, footpaths and local residential roads. This indicates, while there is interest in riding to the station, these users tend to avoid busy road environments with high volumes of traffic and speed.

'Enthused but Not Confident' cyclists are more likely to ride on off-road paths and local residential streets while avoiding footpaths, collector roads and arterial roads with or without bike lanes. This segment indicated they were unlikely to ride on footpaths, which may be related

to the fact these cyclists are new or returning. As such, these users may be vigilant about motor vehicles entering and exiting driveways or even perhaps more stringent in abiding the law.

The *'Enthused and Confident'* were likely to ride to the station on off-road paths, footpaths and arterial roads with bike lanes. Counter intuitively, this segment was relatively neutral with respect to riding to the station on local residential streets and local collector roads. This may be related to the fact these roads generally do not have dedicated cycling infrastructure to physically separate cyclists and motor vehicles. Furthermore, as cyclists occupy the left hand side of these local roads, the risk of dooring[1] increases. This might have also contributed to the likelihood level indicated by the *'Enthused and Confident'*. The *'Strong and Fearless'* as expected, indicated the likelihood of riding to the station across all infrastructure facilities. Only this segment was noted to have a positive likelihood of riding on an arterial road without cycling infrastructure.

This suggests for the different segments of cyclists, certain types of infrastructure facilities may act as severance points (Mindell et al., 2017), highlighting the need for connected and continuous infrastructure facilities to encourage cycling to the station. Furthermore, the provision of a mix of infrastructure facilities leading to the station could encourage riding to the station across a variety of cyclist segments.

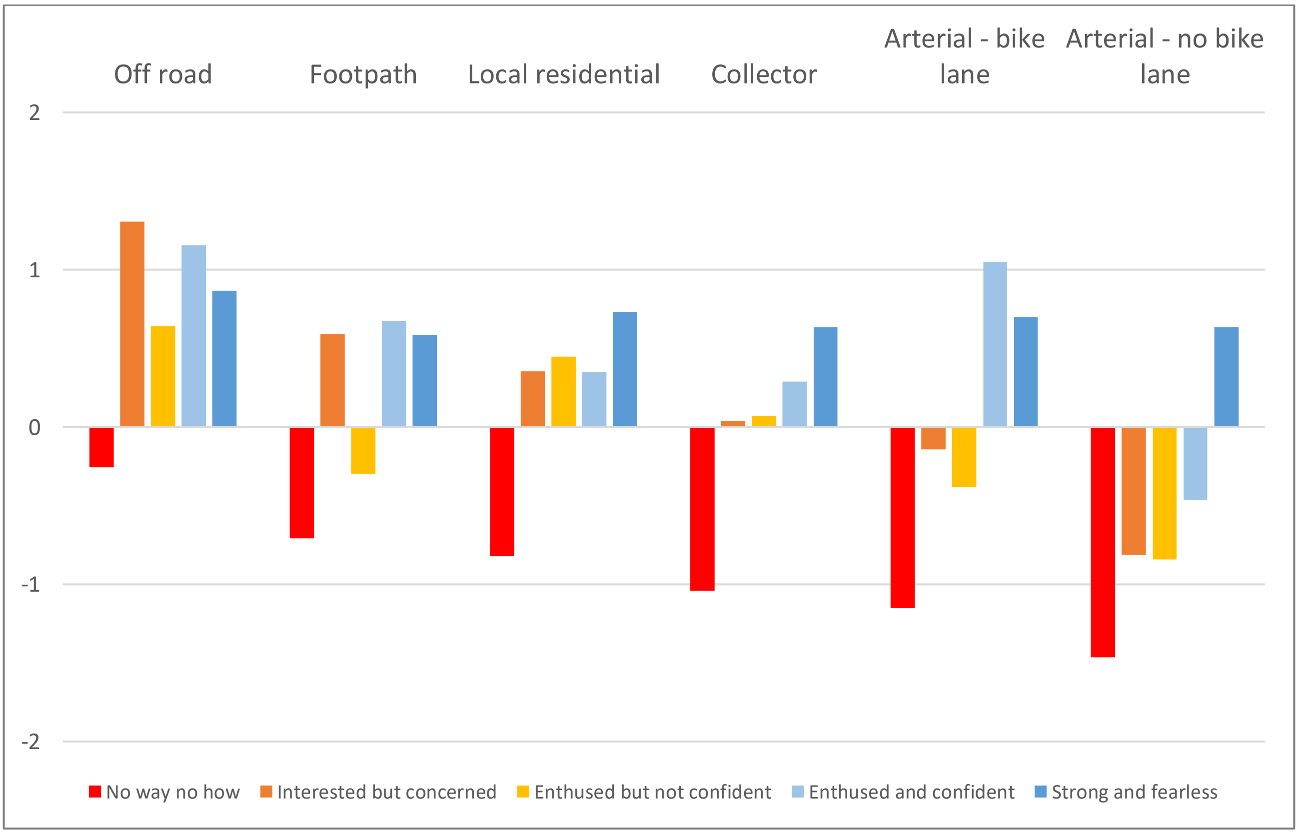


Figure 8-11: Influence of infrastructure on the likelihood of cycling to the station

[1] Dooring is a traffic collision in which a cyclist rides into a motor vehicle's door, is struck by the door or swerves to avoid the door as a result of the vehicle occupant not checking for approaching traffic.

8.3.2.5 Speed

Respondents indicated the likelihood of riding in varied road traffic speed zones using a five-point Likert scale. A similar method of a numerical averaged score was implemented for each cyclist segment across the most typical speed zone categories. As seen on Figure 8-12, *'No Way No How'* cyclists were towards the very unlikely end of the spectrum of riding to the station in speed zones ranging from 40, 50, 60 and 80 kmph. The *'Strong and Fearless'*, *'Enthused and Confident'*, *'Enthused but Not Confident'* and *'Interested but Concerned'* cyclists had positive average numerical scores indicating the likeliness of riding to the station in speed zones of 40 and 50 kmph. At 60 kmph only the *'Strong and Fearless'* segment had indicated a slight likelihood of riding to the station. Whereas at 80 kmph the *'Strong and Fearless'* segment is slightly unlikely to ride with the other types of cyclists leaning towards being very unlikely.

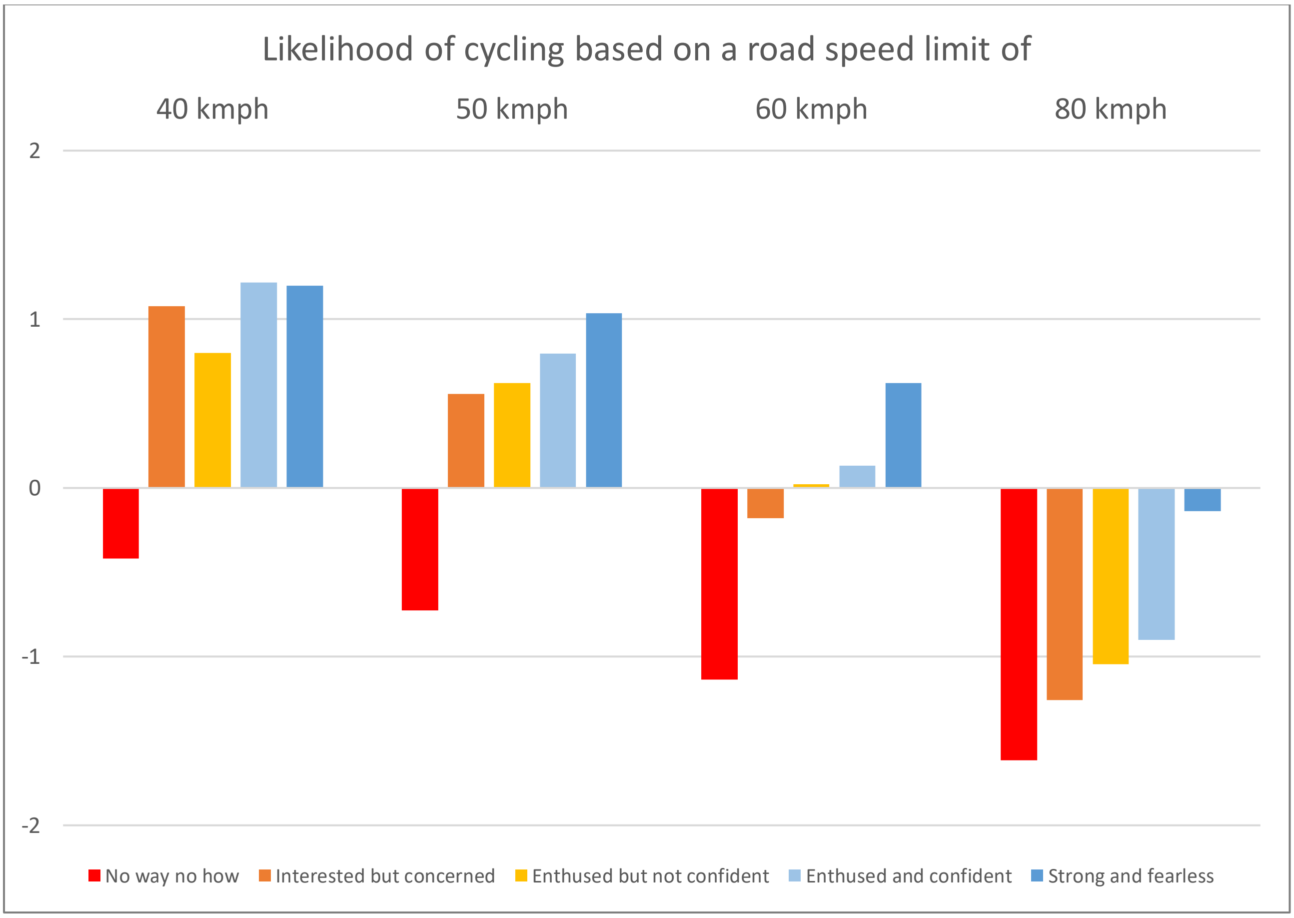


Figure 8-12: Likelihood of cycling on different speed zones

8.3.2.6 Attitudes

The attitudes related to the station access by bicycle were examined across each cyclist segment to identify similarities and differences (see Figure 8-13). All respondents were requested to indicate their level of agreement related to several attitudinal questions using a five-point Likert scale. Values were coded within a range from strongly disagree (-2) to strongly agree (2), and subsequently the average numerical score for each type of cyclist segment was calculated.

When asked 'I believe there are adequate cycling facilities (on-road or off-road) connecting my home to the station', cyclists in the *'Strong and Fearless'* had the highest level of agreement of any segment. *'Enthused and Confident'* cyclists also tended to agree, although not to the same magnitude. This may indicate improvements are still needed to connect on-road cycling facilities to railway stations. *'Interested but Concerned'* cyclists were the most likely to disagree with the above statement. Given these cyclists prefer off-road cycling paths, this may indicate such infrastructure facilities are not available en route to the station. The lack of such facilities may prevent current non-cyclists in the *'Interested but Concerned'* segment from shifting modes and riding to the station. This is further compounded by the fact these users tend to agree that other road users disapprove of cyclists riding on the roadway. All of the other segments were either neutral or slightly disagreed with the statement. Particularly those in the *'Enthused and Confident'* segment who were most likely to disagree, perhaps as they prefer cycling on on-road cycling facilities which may create a social norm of cycling on the roadway.

All segments, particularly those in the *'Strong and Fearless'* classification, agreed with the statement 'The people who are important in my life would approve of me cycling to the station'. However, when asked if cycling to the station is safe, only the *'Strong and Fearless'*, *'Enthused and Confident'*, and *'Enthused but Not Confident'* were likely to agree albeit with lowering magnitudes. The *'Interested but Concerned'* and *'No Way No How'* segments on average disagreed with the statement regarding cycling to the station being a safe. This confirms findings in Study 3, which indicated social norms were not particularly influential on the choice to cycle to the station.

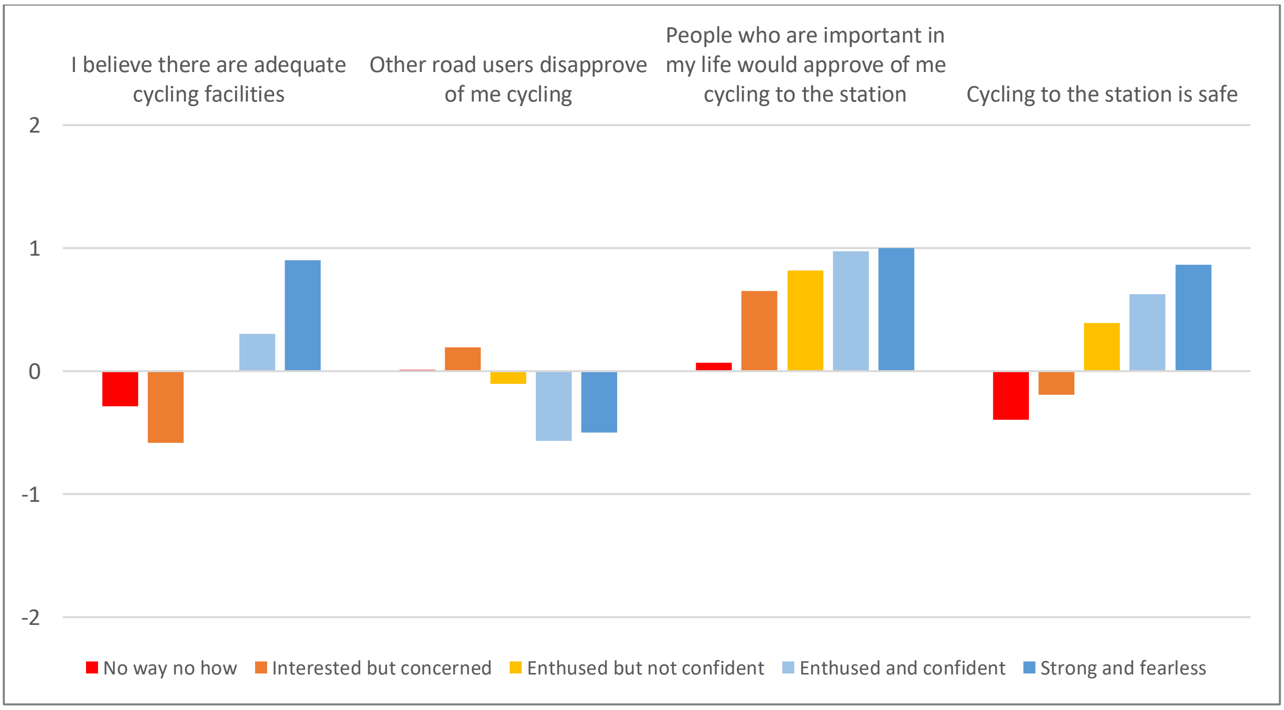


Figure 8-13: Attitudes and perceptions of the types of cyclists

Clothing was a noted barrier across all cyclist segments. As mentioned in Chapter 6, a high proportion of the rail commuters travel for work related purposes, which may explain the perception of difficulty. Cyclists across the *'Strong and Fearless'* to the *'No Way No How'* segment tend to agree that it is difficult to ride to the station as a result of the clothes worn (see Figure 8-14). The magnitude of agreement is however lower across all other groups when compared with the *'No Way No How'* segment.

Making environmentally friendly travel decisions were important for respondents across all segments. However, the extent to which this attitude motivated respondents to ride to the station varied across the cyclist types. *'Enthused and Confident'* and *'Interested but Concerned'* segments indicated the highest level of agreement. Users in the *'Strong and Fearless'* and *'Enthused but Not Confident'* segments also had positive average numerical scores, although not to the same magnitude. *'No Way No How'* cyclists were the only segment likely to disagree with the statement.

For both statements 'Enjoyment I get riding a bicycle would encourage me to cycle to the station' and 'Health benefits associated with cycling would encourage me to ride to the station', all segments barring the *'No Way No How'* type agreed. For the *'Strong and Fearless'* and *'Enthused but Not Confident'* segments the enjoyment related to cycling is more likely to get users to ride to the station. While for *'Enthused and Confident'* and *'Interested but Concerned'* groups the health benefits are more likely to encourage cycling as an access mode. For the *'No Way No How'* segment enjoyment related benefits or health benefits associated with cycling to the station are unlikely to result in mode shift behaviour.

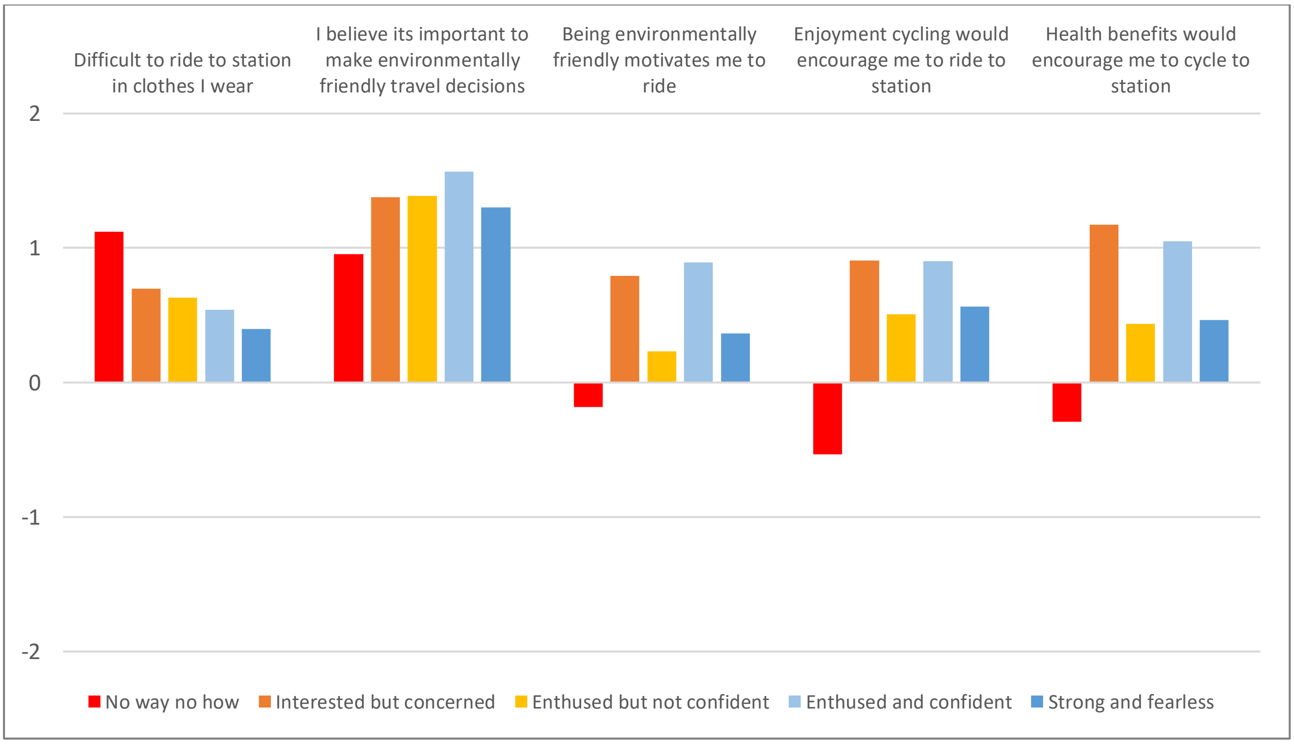


Figure 8-14: Attitudes and perception of the types of cyclists (cont.)

8.3.2.7 Self-classified type of cyclist

All respondents were asked to self-classify into a cyclist segment. A brief description of each cyclist type was provided outlining the levels of comfort associated with riding on different infrastructure facilities and the interest in riding to the station. Differences in segment composition were noted when compared with the researchers' classification method as seen in Table 8-4.

The potential market share based on the self-classification was substantially larger, accounting for 64 percent of all respondents. This indicates rail commuters are more favourable in categorising themselves and base their decisions not only on comfort and interest in riding to the station. Comparing the two segmenting approaches, it was identified 49 percent of users were in the same cyclist segment, 43 percent had overestimated their own classification and 8 percent underestimated their classification.

The comparison provides important insights into how people perceive their likelihood to cycle. Respondent tended to be overconfident, am implication of this being rail commuters may be more receptive to riding to the station.

Table 8-4: Comparison of classification approaches

Cyclist Category	**Five types of cyclists (self-classification)**	**Five types of cyclists (researchers' classification)**
Strong and Fearless	7%	4%
Enthused and Confident	27%	11%
Enthused but Not Confident	13%	12%
Interested but Concerned	16%	19%
No Way No How	36%	55%

8.4 Conclusion

Overall, this component of the research has provided rich insights into station access, particularly by bicycle. Across the various station access modes, mode choice decisions were examined in addition to exploring current cyclists' access mode behaviour and non-cyclists' perceptions of riding to the station.

To explore the latent market share of the bicycle and to identify its mode shift potential for "first mile" station access journeys, a market segmentation approach was adopted. The findings indicate a substantial market exists for the use of a bicycle as a station access mode, accounting for almost half (45%) of rail commuter respondents. People who currently access the station by foot are the most likely to shift to cycling (47%), followed by commuters accessing the station by bus (39%) and private motor vehicle (32%). To support the latent demand for cycling, as a station access mode, a variety of infrastructure facilities are needed connecting commuters from their home-end location to station precincts. Investing in cycling infrastructure is likely to promote bicycle access trips particularly given rail commuters' self-tendency to be more receptive to the integration of bicycle and rail trips.

In the following chapter, a discussion of the key findings and implications related to the four studies of this research program are presented.

Chapter 9 Discussion and Conclusions

The final chapter provides a discussion of the key findings from the doctoral research program. It also outlines the conclusions drawn from this research. The chapter is presented in seven sections, the first is an overview of the background and need for this research, followed by a summary of the research approaches used and the contributions to knowledge, then a discussion of the key findings, research limitations followed by future research directions and, final concluding remarks.

9.1 Background

The need for this research project arose due to the complex pressures faced by the public transport system in Melbourne, Australia. Much like in cities around the world, Melbourne is experiencing an increase in urbanisation and population growth. A consequence of this is the forecast rise in demand for public transport services, particularly on the metropolitan train network (Public Transport Victoria, 2018a; Infrastructure Australia, 2015). The sheer scale of the growth is expected to put tremendous strain on existing infrastructure facilities (Victorian Department of Premier and Cabinet, 2017). To meet this demand, the Victorian government is investing over $70 billion in major infrastructure projects including several multi-billion dollar projects to increase heavy-rail network capacity. However, an issue that has had little attention is the management of station access mode capacity issues that will arise with the expected growth in patronage numbers.

Currently, car-based access is the second most common station access mode, after walking, and accounts for 18 percent of all daily weekday entries. With over 136,000 daily motor vehicle trips, during weekdays, station car parking reaches capacity well before the start of the AM peak travel period, with rail commuter parking overflowing into neighbouring streets, causing parking-related congestion and impacting local residents (Mead et al., 2016b). Demand for car-based station access is expected to rise in the coming years, requiring expensive parking facilities and land intensive solutions. To date, the primary State Government response has been to build new or expand station car parking facilities. However, given the intensity of future growth, the State cannot build their way out of this problem, instead the Government needs to incorporate and promote alternative access options which make economic, environmental and social sense.

An option to manage future station access mode capacity issues is to encourage mode shift from private vehicle use to more efficient modes, including the bicycle. This sustainable option results in considerable capital cost savings, particularly in relation to parking infrastructure costs. Importantly, more station access trips can be accommodated by bicycle compared to cars, due to the smaller parking footprint and this is a critical consideration given the limited space available around metropolitan station precincts.

In Melbourne, cycling has the potential to have a considerable impact on the station access journey given half of the current demand for park-and-ride is generated within a bikeable four kilometre radius of the station (Weliwitiya et al., 2019). Despite this, the bicycle access share remains low at less than one percent (Public Transport Victoria, 2018b). Given that the potential of cycling is not being realised, there is a need to better understand the station access task by bicycle, particularly in the context of re-emerging cycling nations, including Australia.

9.2 Research approach

A systematic literature search and subsequent review, undertaken in October 2016, identified limited empirical insights into the factors that motivate commuters to access the station by bicycle. To address this knowledge gap, the overarching aim of this research program was to identify the contributing factors that influence commuters' choice to cycle to the station and explore the potential market share and likelihood of shifting modes to the bicycle for the "first-mile" station access link. Based on this broad research aim, several research questions (RQ) were formulated, these related to:

- **RQ1**: What objective factors are correlated with the decision to access the station by bicycle?
- **RQ2**: What factors affect the choice of parking facility used at railway stations?
  Sub RQ2: What are the parking needs of bike-and-ride users?
- **RQ3**: What latent factors influence the intention to choose the bicycle as a station access mode?
- **RQ4**: What is the potential market share of the bicycle for station access trips?
  Sub RQ4: What is the likelihood of commuters shifting modes to the bicycle to access rail services?

To address these research questions, primary and secondary sources of data were utilised across four studies. A brief overview of each study is outlined below:

- Study 1: The effects on the rates of bicycle access to stations by demographic, built/natural environment characteristics and station attributes were examined. ArcGIS 10.4 was used to compile, analyse and extract demographic and environmental data based on a cycling catchment area around each metropolitan Melbourne station (n=207 stations). A novel approach was employed to extract the geographical data from non-overlapping catchment areas. These data were used in conjunction with station attribute data as the independent variables for several generalised linear models. Due to the nature of the dependant variable (bicycle access count data), Poisson and negative binomial regression models were developed to identify key objective factors correlated with the rates of cycling to access rail stations.

- Study 2: The use of bicycle parking facilities at stations was central to this study. The provision of safe, secure parking reduces the risk of bicycle theft and vandalism while encouraging rail commuters to access the station by bicycle (La Paix Puello & Geurs, 2015; Pucher & Buehler, 2008). This study focused on two specific components of station bicycle parking. The first explored the parking needs of bike-and-ride users. User satisfaction levels related to aspects of security and amenity of the parking facility were gauged to identify current unmet needs. The second component focused on the factors which influence bicycle parking choice, that is the use of either an open-air facility (hoops, fence/railing, street furniture) or a caged Parkiteer facility at the station. A forward stepwise logistic regression model was developed to identify key variables correlated with bicycle parking choice. The study drew on data collected from intercept surveys of bike-and-ride users as well as police crime statistics (counts of bicycle thefts at rail stations).
- Study 3: An innovative approach was adopted to understand the psycho-social elements influencing the intention to ride to the station. The research approach was based on the Theory of Planned Behaviour. Structural equations modelling was utilised to establish a causal model to explain the influence of latent factors on the intention to cycle to the station. Primary data, needed for the analysis, was collected through an online survey of intercepted rail commuters accessing the station across all modes.
- Study 4: A well-known cyclist typology was modified and applied in the context of cycling trips to the station. The latent market share for cycling and its potential mode shift capability were identified through segmentation. Further characteristics of each segment were explored to identify the different needs of each typology. This approach provided a more nuanced understanding compared to examining the commuter population as a whole. Data was drawn from the same rail commuter survey for both Study 3 and Study 4.

9.3 Broad research contribution

Across the four research stages, all research questions were answered. Through this process, several broad contributions to knowledge were made, including addressing methodological research gaps. The success of these studies in metropolitan Melbourne, could be replicated in other cities and areas in Australia and extended to most international contexts, both in countries with high rates of cycling and re-emerging cycling nations.

Non-overlapping station cycling catchment areas to extract spatial data on GIS

Traditional approaches applied in GIS to extract spatial information have involved formulating uniform circular cycling catchments of 3-5 km around individual stations of a rail network (Mead et al., 2016b; Martens, 2004). This approach is appropriate where stations are spaced far enough apart that the catchments do not significantly intersect and overlap. However, in many international contexts, metropolitan railway stations are spaced in close proximity. For example the average distance between metropolitan railway stations in the former EU-15 countries including the United Kingdom, Germany and the Netherlands are 0.96 km (ERRAC, 2012). Utilising a traditional GIS approach would result in substantial overlapping of the catchment areas. This has implications on the validity of the spatial data extracted, as neighbouring station catchment characteristics may be inaccurately incorporated.

To address the issue of overlapping catchments, non-uniform cycling catchment areas were created for each station by adopting a defined cycling radius and overlaying this buffer with a Thiessen polygon. The resulting non-uniform cycling catchments around each metropolitan train station defined the geographic extent in which demographic and built/natural environment data were extracted. This approach eliminated overlapping of spatial data and the resulting extraction of neighbouring station catchment characteristics.

Furthermore, this approach allowed the size of the station cycling catchment area to dynamically vary based on the proximity of a station to other stations. Often in metropolitan rail networks across the world, the distance between stations vary geographically. In Melbourne, for example, the average distance between stations varies markedly based on whether the station is located within the inner city, middle or outer suburbs. Stations located in the outer suburbs are often spaced farther apart and as such the cycling catchment area would be larger in comparison to stations in the inner city. This mechanism is accounted for in the non-overlapping catchment area approach developed.

Examining the influence of latent factors through the framework of the Theory of Planned Behaviour (TPB)

In the literature that specifically explores bike-rail integration, limited consideration is placed on the effects of latent factors on the choice to cycle to the station. A handful of studies have explored specific attitudinal dispositions which may influence the choice to ride to the station. However, an additional limitation is that most studies which examine latent factors were not informed by established psychological theories (Heinen et al., 2009).

This research program aimed to address this gap in knowledge by grounding the research within the framework of the TPB. TPB asserts people's *intention* to participate in a given activity primarily influences whether the activity is performed (Ajzen, 2005). *Intention* is subsequently influenced by three latent factors: *behavioural attitudes, subjective norms* and *perceived behavioural control*. The research output from this doctoral program has demonstrated the applicability of the TPB in examining the latent factors which influence the choice to access the station by bicycle. There is scope for the TPB to be applied in other global contexts to validate the research output generated through this doctoral research program.

This study generated new knowledge by addressing the gap identified in the bike-rail integration literature by empirically measuring the relationship between the latent constructs of the TPB using structural equations modelling (SEM). SEM provided a quantitative approach to illustrate causal links between *attitudes*, *subjective norms*, *perceived behavioural control* on *intention*. Multi-group comparisons were made to gain insights as to how these causal relationships and relative strengths varied among different station access mode users. This approach could be used in other international contexts to see how the effects of latent factors vary geographically by country. Contextually specific understanding of latent factors is essential for policy action to ensure programs and activities designed to encourage cycling to the train station are socially and culturally resonant to maximise mode shift to the bicycle.

Applying a market segmentation approach to understand the latent demand for bicycle-rail integration

The literature related to bicycle-train integration had not explored the existing latent demand for bicycle-rail trips or its potential mode shift capabilities. To address this gap in knowledge, a market segmentation approach was utilised. A modified version of Geller's '*four types of cyclists*' typology was used. A fifth classification developed by Johnson and Rose was included to account for people who are enthused but may not be confident to cycle beyond quiet residential roads. The inclusion of the additional classification ensured the typology was tailored to the context of cycling as a station access mode, particularly given the importance of local residential roads in bike-and-ride users' route choice.

The typology was applicable to people accessing the station on foot, by car, bus and bicycle ensuring the potential market share and mode shift capability could be explored. In Melbourne, Australia the latent demand was identified to be substantial, comparable to the actual share of bicycle access trips made to the station in the Netherlands. This approach can be utilised in other international settings to benchmark the potential market share for bicycle-rail integration. Knowing the latent demand and the actual share of cycling, will enable road and public transport planning authorities to monitor what additional actions are needed to maximise levels of bicycle-rail integration.

9.4 Insights to promote bicycle access

The contribution to knowledge is discussed in this section and is structured around eight broad thematic headings. Insights for each theme are drawn from across the four research studies. A systematic literature search, with the same search parameters as conducted in October 2016 (Chapter 2), was rerun in July 2019 to update the list of relevant literature. Following the screening process, six additional papers were identified. The key findings from this doctoral research program were evaluated in the context of this broader related scientific literature.

Built and natural environment

The built and natural environment plays a central role in promoting general rates of cycling (Mertens et al., 2017; Vandenbulcke et al., 2011; Dill & Voros, 2007). This relationship is also observed specific to bicycle-rail integration.

Cycling facilities

Melbourne is characterised by a low density of cycling friendly roads and facilities within cycling catchments of metropolitan railway stations. For every 100 metres of road infrastructure, only 19 metres have been allocated to the municipal/principal bicycle network. Additionally, the limited cycling infrastructure that is provided is not well connected. In terms of connectivity, the index rating for Melbourne roads is high (0.93 out of 1) compared to the bicycle network which is poorly connected (0.26 out of 1).

In this context, the modelling analysis conducted in Study 1 did not find the provision of cycling facilities to be significantly associated with increased rates of bicycle access trips to the station. This is contrary to the international findings in Brazil (Tobias et al. (2012) de Souza et al. (2017) and, North America (Cervero et al. (2013) and is likely due to the nature of the current cycling infrastructure available in Melbourne. For cycling facilities to influence behaviour, such as the choice to access the station by bicycle, the infrastructure needs to be well connected and provide seamless access from quiet residential streets to the train station. In the case where cycling infrastructure is sparse and not well connected, multiple severance points may exist, requiring cyclists to ride on road environments which may be unsafe or be perceived as unsafe depending on an individual’s feelings of comfort and experience. Given people tend to remember route segments perceived to be more dangerous (Shankwiler, 2006), the lack of connected cycling facilities may limit many people’s choice to access the station by bicycle.

Poor provision of connected cycling facilities may also have implications on safety. Increased rates of bicycle access trips to stations were correlated with a rise in the occurrence of cyclist crashes. Pucher et al. (2011) noted a similar relationship between general rates of commuter cycling and cyclist crash rates, concluding the ‘safety in numbers’ effect is yet to reach a tipping point (Jacobsen, 2003). The increased risk for bike-and-ride users may be due to a lack of connected cycling facilities requiring cyclists to share roads with vehicles often on high speed environments (Reynolds et al., 2009; Garrard et al., 2008). It is likely that the lack of cycling infrastructure affected travel behaviour of the 37 percent of bike-and-ride users surveyed who indicated they cycled on the footpath. This is despite the road rule in Victoria that limits footpath cycling to children aged under 13 years, or people accompanying a child under 13 years. Regardless, one in three people surveyed in this doctoral research reported that they cycled on the footpath. It is likely that this was motivated by a preference to physically separate themselves from motorised traffic and increase their feelings of safety.

Cycling infrastructure encompasses a broad range of facilities. Segmentation of rail commuters into types of cyclists revealed users in different segments have varying comfort levels associated with riding on the various infrastructure facility types. The findings suggest an increase in the provision of well-designed infrastructure connecting commuters from quiet residential streets to the station is likely to result in increased rates of bicycle access to stations. This could include a mix of on-road and off-road paths.

Posted speed limits

Results from the online survey of intercepted rail commuters indicated that cycling to the station is perceived as an unsafe activity by commuters who currently access the station by car, bus and on foot. An attribute contributing to this perception is an apparent assumption that to ride to the station, people need to cycle on the same road utilised by motor vehicle traffic with high posted speed limits and high vehicular travel speeds. Route choice studies have demonstrated cyclists generally avoid high speed, high trafficked environments (Broach et al., 2012). A similar mechanism is observed specific to bicycle trips to stations. Bike-and-ride users' route choice revealed a majority (87%) ride to the station on local residential streets. In fact, bicycle access rates to railway stations were noted to have a significant positive correlation with the proportion of local residential streets within a cycling catchment area of stations. Local residential streets likely support increased bicycle activity due to their "low" vehicular travel speeds, which is generally 50 km/h in Melbourne. Although a recent Austroads report recommends speed reductions to 30 km/h in local streets, a speed that meets the Safe System principles to reduce the likelihood of a death or serious injury in the event of a crash between a car and vulnerable road user. It is likely that this would increase feelings of safety and have a dramatic impact on the increase in cycling participation including riding to the station. Similar insights are noted in Europe and the USA, where low speed limits encourage greater levels of commuter cycling and cycling to stations (Mertens et al., 2017; Park et al., 2014)

While current 'low' speed environments promote bicycle-rail integration, in order to further encourage mode shift behaviour, posted speed limits around station precincts should be reduced. The influence of different road speed limits on the choice to ride to the station was gauged, the results indicate a dramatic reduction in the likelihood of riding to the station on roadways with higher speeds limits (60 and 80 km/h) compared to lower speed limits (40 and 50 km/h). Traffic calming measures could be utilised to reduce motorised travel speeds within the local residential street network. Implementation of traffic calming measures have been associated with increase rates of cycling trips to the station (Cervero et al., 2013; Replogle, 1993). Where the main function of a road is for movement (primary, secondary arterials and some collector roads) appropriate on-road cycling facilities could be provided to offset the negative impacts of fast-moving traffic.

Land use mix

Encouraging mixed land use development within cycling catchment areas of the station is positively correlated with increased rates of cycling to the station. The finding is consistent with the existing bicycle-rail integration literature and spans multiple countries including the Netherlands, China, Canada and New Zealand (Chan & Farber, 2019; Zhao & Li, 2017; Mackenbach et al., 2016; Puello & Geurs, 2015). As the diversity of land use increases, the easier it becomes to access various services with human scale travel options such as by bicycle and on foot. As a result, travel behaviour habits may form over time diminishing the reliance on vehicular travel. Rail commuters, living in mixed land use areas, may therefore opt to access public transport services by bicycle.

Natural environment

The journey purpose for bicycle-rail integrated trips primarily tend to be for employment and education with an accompanying dress-code requirement. Topography therefore plays a crucial role on whether cycling as a station access mode is considered viable or widely adopted (Semler & Hale, 2010). Analysis of the factors affecting bicycle-train integration revealed the terrain of the station cycling catchment, as measured by the percentage of area above a two-degree slope, negatively affects the rates of cycling to stations. Interestingly, the propensity to commute by bicycle as the main mode of travel is also affected by slopes greater than three to four degrees (Heinen et al., 2010; Saelens et al., 2003). This indicates, bike-and-ride users are not as willing to exert themselves as much as commuter cyclists. This may due to the availability of end of trip facilities such as showers and change rooms at the place of work whereas railway stations do not host such facilities. This insight also has implications on the provision of low stress cycling infrastructure and facilities en route to stations. It is also touches on the broader culture related to clothing, the relationship between clothing, status and workplace expectations and how social and professional constructs impact on transport options. However, examination of these factors was outside the scope of this study.

Station environment

The station environment and the facilities provided play an important role in influencing the choice of access mode. For cyclists riding to the station, provision of parking facilities is paramount, as peak-period overcrowding issues limit the option of taking a bicycle on-board trains (Martin & den Hollander, 2009). It may also be undesirable or unnecessary to have a bicycle at the destination station. As such, many cyclists who ride to the station need to leave their bicycle at the station where there is the potential for it to be stolen or vandalised. Security concerns for bicycles left at the station were reported to be a key deterrent, preventing mode shift behaviour among rail commuters with a propensity to ride to the station. Secure parking facilities are therefore needed to minimise the risk of theft and promote cycling as a viable access option.

In Melbourne, cyclists can either park their bicycle at open-air facilities (hoops, street furniture, fencing and railing) or, where available, in enclosed 'Parkiteer' caged facilities. Increased rates of cycling activity at railway stations were correlated with the availability of 'Parkiteer' facilities. This finding adds robust empirical evidence to indicate secure bicycle parking facilities encourage greater levels of cycling to stations. The rigorous nature of the analysis, conducted across the metropolitan rail network (207 stations), adds to the body of literature, which has predominantly taken a qualitative case study approach to highlight the importance of secure bicycle parking facilities (Rawal et al., 2014; Krizek & Stonebraker, 2011; Martin & den Hollander, 2009; Replogle, 1987; Replogle, 1984).

Provision of facilities at railway stations for competing access modes have been noted to affect the rates of bicycle-rail integration. Chan and Farber (2019) and Kager et al. (2016) identified a negative correlation between the quantity of car parking provided and number of rail commuters cycling to the station. In the context of Melbourne, the provision of official station car parking facilities did not significantly affect the rates of cycling to stations. This may be attributable to contextual differences of the study areas. Chan and Farber (2019) for example based their study in Greater Toronto, Canada where 65,000 car parking facilities were provided across 63 stations (over 1,000 bays per station). In contrast, Melbourne has a total of 38,000 car parking bays across 219 stations (over 170 bays per station). Due to the comparative low supply of designated car parking bays in Melbourne, the increased uncertainty of station car parking availability may result in rail commuters continuing or shifting to the bicycle as an access mode.

Quality of bicycle parking facilities at railway stations

Providing bicycle parking facilities alone is not enough to encourage mode shift behaviour. Instead, the facilities must meet security and amenity needs desired by cyclists and people contemplating riding to the station. To better understand how the existing facilities cater for user needs, satisfaction levels among Parkiteer and open-air facility users were gauged. Significant differences in satisfaction levels were noted between the two user groups. Open-air facility users were, in general, less satisfied than Parkiteer users in relation to the visibility of the parking area, CCTV monitoring of parked bicycles, availability of a secure point to lock a bike and the level of weather protection provided at the parking area. Satisfaction levels related to the parking being close to the station entrance and well-lit were not significantly different between Parkiteer users and open-air facility users. Both user types were generally satisfied with the proximity of the parking to the station entrance, however, satisfaction related to lighting of the storage area was poor among both user types. By improving parking attributes with low satisfaction scores, the provision of facilities will better meet the needs of current cyclists as well as assist to lower the barrier to entry for those considering cycling to the station.

Train service quality

The choice to commute by train broadly encompasses two key hierarchical choice sets: the access mode choice and the station choice (Chakour & Eluru, 2014). In this doctoral program, the scope of research focused on access mode choice decisions, however, elements affecting the station choice set were also identified as influencing access behaviour. This interplay is exemplified in the research findings which outlined a positive correlation between rail transport service levels, specifically during the peak AM period (7-9 AM), and the cycling access rates at stations. This finding provides a new level of insight into the existing body of literature by Kager et al. (2016), Djurhuus et al. (2014), Flamm (2013) and Debrezion et al. (2009) on the effects of public transport service levels and cycling as a station access mode.

Similarly, a positive relation was noted between the rates of cycling to railway stations and the passenger entries recorded at each station. Arbis et al. (2016) noted, similar findings, specific to the number of bicycles parked at the station.

These findings suggest, stations that provide better service levels (shorter headway times and increased train frequency) attract increased levels of passengers. As these stations get busier, there is likely to be more competition for the limited station access resources such as car parking. As a result, commuters may be more likely to shift modes and cycle to the station. The increased levels of passenger flows within station precincts have the added benefit of providing improved levels of passive security for bicycles parked at the station.

Latent factors

Mode choice is affected by an amalgamation of objective and latent factors (La Paix Puello & Geurs, 2015). These choice behaviours are informed by perceptions of available information, and the influence of attitudes, motives and preferences (Ben-Akiva et al., 1999). Therefore, a critical consideration in understanding bicycle-rail integration are the effects of latent unobserved factors. However, this aspect is rarely considered in the literature.

The research conducted to date, has focused on specific attitudinal factors and their correlation with the choice to access the station by bicycle. Heinen and Bohte (2014) noted a positive perception related to cycling and public transport use independently among bicycle-transit users. Whereas Puello and Geurs (2016) identified the influence of perceptions related to rail service quality and the station environment on bicycle-train integration. A limitation of identifying individual factors is that they may be context specific. To obtain a fundamental understanding of the influence of latent factors, Heinen et al. (2009) noted the importance of framing the research around established psychological theories.

To address this gap in knowledge, the research was structured using the framework of the TPB. The TPB accounts for the influence of Attitudes, Subjective norms and Perceived behavioural control (PBC) on Intention to ride to the station. The relationship between the latent constructs specified in the TPB were studied using structural equation modelling (SEM). SEM was adopted to fill a gap identified in the literature while allowing for a quantitative approach to illustrate causal links between Attitudes, Subjective norms and PBC on Intention.

Attitudes and PBC were identified to be significant predictors of Intention. The causal relationship between Attitudes and Intention was slightly stronger than that of PBC and Intention. In contrast, the effects of Subjective norms were negligible on Intention. This indicates the intention to access the station by bicycle is considered to be an individual choice not influenced by societal norms but by the self-reflections of the individual.

Learnings from this insight can inform actions by public transport and road authorities to encourage cycling as a station access mode. A key focus is the provision of appropriate end of trip facilities (parking) and connected cycling infrastructure to promote the sense of perceived behavioural control. Such measures will lead to greater satisfaction levels among current cyclists while promoting a belief of being able to cycle to the station for people currently not using a bicycle. Such measure may also result in fostering positive attitudes towards bicycle-train integration.

Barriers to cycling as a station access mode

A rich understanding of station access mode choice decisions was obtained from the rail commuter survey. This included insights into the barriers reducing the likelihood of rail commuters choosing the bicycle as a station access mode. Commuters accessing the station by car and on bus noted a key barrier to be the lack of time available to ride to the station. This stems from the perception cycling is slower than their current access mode. The literature, however, notes cycling trips are generally competitive with motorised modes for shorter trips (Ellison & Greaves, 2011). This is applicable for most station access trips, as a majority

(94%, n=711) of the observed trip origins, from the rail commuter survey, were less than five kilometres from the station.

Another barrier limiting the adoption of the bicycle as a station access mode was the clothes worn by the commuters. This may be due to perception commuter cyclists wear Lycra, and normalisation of riding to the station in non-sporting or business attire is not well established (Goodman et al., 2014). Current non-cyclists also noted having too much to carry as a barrier. Although this can be easily overcome with a wide range of options to carry items using a basket, bag (e.g. panniers), carrier racks or cargo trailers.

The barriers discussed above primarily relate to potential misinformed perceptions or a lack of awareness on how to remedy such concerns (e.g. having too much to carry). Actions to address these misperceptions (e.g. information campaigns, increase in other people cycling, local bike stores stocking suitable baskets and bags) could represent quick wins to encourage rail commuters to access the station by bicycle.

Additional barriers, which are harder to address, relate to commuters having other commitments requiring them to access the station by a particular mode and adverse weather conditions preventing commuters from cycling to the station. Again this enters into the broader culture of the Australian workplace as more flexibility in start times may allow commuters to wait for rain to pass then ride to the station. However, this was beyond the scope of this doctoral research.

Potential market share for cycling as a station access mode

To understand the potential role the bicycle could play in the station access task, distances travelled by rail commuters as part of the “first-mile” link were examined. For the bicycle to be viable and competitive with motorised modes, access distances need to be relatively short (Ellison & Greaves, 2011). Analysis of the cycling access distance revealed the typical cycling catchment was within 3 to 5 km of the station, which accounted for 60 to 80 percent of trips made by bicycle. These findings reflect much of what Martens (2007) identified in the Dutch context. “First-mile” access trips which originate within such distances are short enough to be made on the bicycle while the resulting travel times would be competitive compared to private motor vehicles. Future research could examine the relative access times of different modes using empirical data

Examination of survey respondent trip origins identified a large proportion of current non-cyclists live close enough to a station that they could make the journey by bicycle. While shorter trips (less than 1km) are dominated by walking, about 35 to 70 percent of car-based access trips originate within 3 to 5 km of the station. Based on access distance alone, there is substantial potential for the bicycle to play a bigger role in the station access mode share.

The latent potential to use the bicycle as a station access mode, is not only influenced by the access distance but also by behavioural characteristics, preferences and perceptions. To account for this a modified version of Geller's four types of cyclists was adapted to the specific context of cycling as a station access mode. The segmentation was based on the interest in cycling to the station, ability and associated comfort riding to the station on various common cycling infrastructure. The typology contained five cyclist types, with all but the "No Way No How" segment classified as having the potential to ride to the station. Based on this approach, the market for the use of a bicycle as a station access mode was identified as 45 percent of all rail commuters, similar to the actual station access mode share by bicycle in the Netherlands (Kennisinstituut voor Mobiliteitsbeleid, 2017).

This signifies a large latent demand exists for station access trips to be made by the bicycle in Melbourne. The body of literature focussing on bicycle-rail integration is sparse, and at the time of this study, no research was identified that examined the potential market share of cycling as a station access mode, especially in the context of a re-emerging cycling nation such as Australia. Therefore, evaluations of such rates can only be made with the existing literature on cycling for transportation as the main mode of travel. Based on the research in North America, over two thirds of the population (67%, Geller (2009); 69%, Dill & McNeil (2013)), were classified as interested and capable of riding a bicycle for transportation. This is substantially higher than the 45 percent of rail commuters identified to be interested and capable of riding to the station. The potential difference may be attributed to the nature of cycling as a station access mode, where with the intermodal aspect of the journey, people are less likely to combine cycling and transit than cycle for transportation alone.

The likelihood of rail commuters shifting station access modes to the bicycle was also examined. Commuters who currently walk to the station were the most likely to shift modes to bicycles (47% of the walking cohort), followed by commuters who access the station by bus (39%) and a third (32%) of respondents who currently accessed the station by car. While these proportions would represent significant increases in the rates of cycling to the station, car users may be less receptive to cycle as a result of the barriers discussed above. Particularly the perception of longer travel times associated with riding a bicycle to the station compared to driving.

The latent market share and mode shift likelihood indicate the bicycle has the potential to be a key access mode with a share well above that of the current proportion (1%). This opportunity, however, is yet to be realised as currently land use and transport policies promote the use of motorised travel with the provision of ample access and car parking infrastructure with a lack of initiatives to encourage mode shift.

Implications for policy and practice

The scope of the doctoral work was formed in terms of the research questions outlined in Section 9.2. The research findings have a range of implications for policy and practice related to bike-rail integration. These are discussed in the following section.

Plan Melbourne 2017-2050

A central feature of the State Government planning strategy, Plan Melbourne 2017-2050 are *20-minute neighbourhoods*. These neighbourhoods aim to offer a majority of services within a 20-minute journey from home by walking, cycling and public transport use. Consequently, the aim is to reduce the reliance on motor vehicles.

A specific metric defining a 20-minute neighbourhood is the connection to public transport services, by either walking or cycling. To accommodate such connections, a particular focus is placed on land use and housing diversity. Planning controls include promoting Mixed Use Zones and Residential Growth Zones in activity areas. However, the extent of development and zoning controls considered are limited to a walkable catchment area of 800 metres around neighbouring activity centres. The Victorian Department of Environment Land Water and Planning (2018, p.2) explicitly states:

> "*While cycling and local public transport provides people with active transport options, these modes do not extend neighbourhood catchments beyond 800m.*"

In the context of bicycle-train integration, land use mix within a cycling catchment area of stations are significantly correlated with the rates of cycling access. The 'effective' radius of the cycling catchment area was 1.89 km. This indicates that expanded mixed use zones, more than double the radius specified in Plan Melbourne, is needed to support and encourage connections to public transport services by bicycle.

Victorian Cycling Strategy 2018-28

The Victorian Cycling Strategy 2018-28 mentions the need to integrate train use and cycling. However, there is limited detail provided on the process intended to achieve this aim. Specifically related to cycling infrastructure provision, the Strategy seeks to promote integration "*by prioritising cycling networks to train stations*" (Transport for Victoria, 2017, p.7). In order to encourage mode shift behaviour across a wider cohort of rail commuters, the doctoral research has identified the need for a variety of cycling facilities. These facilities should be well connected and lead cyclists into station precincts. The likelihood of rail commuters riding to the station substantially diminishes as posted speed limits and motor vehicle travel speeds increase. Appropriate on-road and off-road cycling facilities should be provided to offset the negative impacts of fast-moving traffic along primary, secondary and some collector roads.

Consideration should also be given to lower speed limits along roads that feed into station precincts. Traffic calming measures are needed in local residential areas within railway station cycling catchment areas. Local streets are particularly important in facilitating station access by bicycle, with the majority of current cyclists (87%) riding on them for either a part or the full journey to the station. Furthermore, as much of the road network within station catchment areas are local residential roads (74% on average), implementation of traffic calming measures may have a substantial impact on encouraging integration of cycling and train use. The focus should be to foster a sense of shared space on local streets by reducing the posted speeds and motor vehicle travel speeds to create lower stress street spaces that are conducive to active travel choices.

Various local council car parking management strategies

When considered alone, the provision of official car parking facilities did not influence the rate of bicycle access to stations. However, consideration must also be given to the informal on-street car parking supply on local streets surrounding most suburban stations. These locations accommodate the overflow parking demand which spill into neighbouring streets, impact residents and cause local traffic congestion.

The total station car parking supply, including the informal on-street parking availability is likely shifting demand away from alternative access modes such as cycling. Current cyclists noted a key reason to ride a bicycle to the station was the lack of available car parking at railway stations. To encourage commuting to the station by bicycle, the car parking supply needs to be proactively managed to restrict the demand. Parking controls, either temporal, fee-based or both could be introduced on Council managed local streets. The intention of reduced or restricted parking is to nudge people to consider alternative station access modes. Such actions will also promote equity for those who need to drive to the station because they either live too far from the station, have mobility issues or are not serviced by connecting public transport.

Bicycle parking provision at railway stations

Provision of secure bicycle parking facilities helps to minimise the risk of bicycle theft and vandalism. While the rate of bicycle theft is relatively low, approximately 330 per year from 2004-2016 across the network of over 200 stations, the rate is increasing. While bicycle theft rates were not negatively associated with cycling activity at railway stations, safety concerns do influence station access mode choice. Rail commuters with a potential of shifting station access modes to the bicycle noted the lack of parking infrastructure to securely store their bicycle, as a key reason for not riding to the station.

Therefore, to remove the barrier for latent cyclists, it is paramount that bicycle parking facilities are provided at railway stations. A comparison of the satisfaction levels among Parkiteer and open-air facility users revealed differences in satisfaction levels related to security and amenity needs. Open-air facility users were generally were more dissatisfied in the visibility of the parking area, CCTV monitoring of parked bicycles, availability of a secure point to lock a bike and the level of weather protection provided at the parking area. Changes should be made to improve these characteristics for open-air facility users. Simple actions can include positioning parking facilities in areas with higher passive surveillance (i.e. close to where people walk in and around the station) and providing sheltered parking. Such actions will improve the satisfaction levels of current cyclists and may reduce the perceived risk of bicycle theft, thereby lowering the barrier to entry for people considering cycling to the station.

Furthermore, there are plans for expansion of the Parkiteer program across the rail network. However, a large variability in usage is noted across the different stations with Parkiteer storage. This is, in part, attributable to the bicycle parking choice of bike-and-ride users. Research conducted as part of this doctoral program focused on identifying the factors affecting bicycle parking choice, to address a gap in the literature (Arbis et al., 2016; Van der Spek & Scheltema, 2015). Findings provide valuable insights to inform operational and investment decisions in relation to siting of Parkiteers. To maximise the return on investment, Parkiteers are best placed at stations which have a large cycling catchment area, where due to space constraints bicycle parking can only be provided further away from the station entrance. The signup process should also be made more user friendly with a focus on streamlining the wait time for a Parkiteer access card or integration of access with the public transport access card (i.e. Myki card).

Department of Transport, Station Access Behavioural Change Program

The Victorian Department of Transport is in the process of planning a behavioural change program to encourage rail commuters to access the station by bicycle. Possible directions of the program include targeted advertisements promoting the use of a bicycle as an access mode. Insights obtained from the study of latent factors and their influence on the choice to cycle to the station could be leveraged to inform such a program. Attitudinal characteristics had the strongest causal link with the intention to ride to the station among current non-cyclists. To promote mode shift, the focus of the behavioural change program should prioritise messaging with a positive attitude of bicycle-rail integration, over other alternatives such as promoting cycling as a social norm. Opportunities also exist to address barriers which may be rooted in perception such as the inability to ride in work clothes, not having enough time or having too much to carry.

9.5 Research limitations

Several limitations have been identified with the research undertaken as part of this thesis. The limitations relate to the data collection method employed for the rail commuter survey and the nature of the police crime statistics data used.

To facilitate Study 3 and Study 4, a data collection effort was required. The recruitment method involved intercepting rail commuters making the station access journey on various modes. Due to the complexity of the questionnaire developed, with branching and display logic, the data collection method selected was an online survey approach. While this reduced the cost (printing and reply-paid postage) and eliminated paper waste, not distributing a paper-based survey may have excluded some people from participating. This is particularly the case for the cohort of the population who are not technologically savvy or do not have access to either a smartphone or internet enabled device.

Study 2 was supplemented with the use of police crime statistics. This was made available by the Victoria Police Crime Statistics Agency. The data in question related to the levels of bicycle theft at railway stations between October 2004 and September 2016. To ensure anonymity at a station level, the theft rates were provided at an aggregated postcode level. A postcode defines a geographic boundary, often large in nature, which may contain multiple railway stations. Due to the inability to further disaggregate the data, an assumption was made that all stations within a single postcode experience the same number of bicycle thefts. Station level theft data is preferred to generate a more accurate understanding of the impact of bicycle theft across the rail network.

9.6 Future research directions

Several opportunities were identified to build on and extend the work conducted as part of this doctoral research program. These are discussed in the following section.

Influence of built environment in neighbourhoods

Investigations into the characteristics of neighbourhoods surrounding station precincts and its influence on the rates of bicycle access could provide further insights to inform mode shift behaviour. Specifically, examining factors which account for the competition between different station access modes may enhance understanding and modelling of station access behaviour. This is particularly relevant in a re-emerging cycling nation where non-cycling access modes currently dominate. For example, there is the potential to consider the effect of overflow car parking availability. With official station car parking facilitating the parking needs for only a limited share of current car-based access users, unofficial parking locations (e.g. adjacent local streets) provide a readily available and often free alternative. Future research could explore the opportunities of restricting parking and the subsequent influence on mode shift behaviour. Examples of measures include limited or timed parking on roads surrounding station precincts and station car parking pricing. More targeted measures that could be tested include replacing prime car parking locations with bicycle parking or geofencing that limits car park access so only motor vehicles registered to homes more than two kilometres away from the train station are able to park during peak travel times.

Additionally, factors related to the built/natural neighbourhood environment and station attributes can be combined and weighted accordingly to form a station bikeability index. A measuring metric of this nature can be used to evaluate and prioritise investment within particular station catchment areas, identify “problem” stations with low bikeability and track the effects of infrastructure improvements and improved bikeability on cycling rates. The latter is particularly applicable in the current context of Melbourne, which is seeing rapid changing station environments and the accessibility to them.

Integrated station design

With the level crossing removal works and associated station rebuilds, Melbourne is undergoing substantial changes to its public infrastructure. These changes are having an impact on bicycle parking provisions at newly constructed stations. Often bicycle parking facilities are integrated into the station design, with improved forms of active and passive surveillance, increased lighting and priority parking close to the station entrance. Few studies have evaluated station environmental changes on bicycle parking practices and resulting security concerns of leaving a bicycle at the station. This provides scope for future research endeavours.

Another aspect which could be considered for further research is the influence of bikeshare schemes along metro transport corridors. This option utilises public bicycles, eliminating most concerns about theft and vandalism related to privately owned bicycles left at the station. Adapting and trialling international models of public bike share at train stations (e.g. the Dutch OV-fiets) in the Australian context could identify how these services change station access and egress behaviour, parking practices and the possibility for it to encourage the home-end station access trips.

Behaviour change

Yang et al. (2010) noted community wide promotional activities can increase rates of cycling, however, further research is needed particularly in areas without an established cycling culture. Related to this, there is scope to build on the theoretical findings of this research study, to inform the formulation of a behaviour change program to promote cycling as a station access mode. Further research could explore such interventions and experimentally validate the identified theoretical relationships between latent factors of the TPB and the intention to access the station by bicycle.

Furthermore, the influence of latent factors considered in this research program was limited to those specified by the TPB. Other latent factors important in influencing behaviour such as habit can be further analysed in the context of station access mode choice. This also opens the scope for future research activities to consider other theoretical frameworks beyond the TPB.

Network planning

As part of Study 4 in this doctoral research program, the requirement for various cycling facilities catering for the different needs and abilities of cyclists and potential cyclists were noted. Future research could explore aspects related to the network planning, placement and curating a mix of cycling infrastructure needs to maximise the uptake of cycling as a station access mode.

Cyclist typology

The cyclist typology utilised in this research program was derived from Geller's 'four types of cyclists'. The classification process was based, in part, on the comfort levels of commuters riding to the station on a single infrastructure type. Future research could modify the classification approach to be based on the comfort of riding to the station on a mix of infrastructure facility types. This would better reflect the existing cycling conditions in Australia and other re-emerging cycling nations where there is a lack of connected cycling infrastructure. As a result, such an approach may yield a more nuanced understanding of the mode shift capability and market share potential of the bicycle. Additionally, this would provide valuable insights into network severance points and their influence to inhibit the uptake of cycling for station access journeys.

The classification developed by Geller, is often widely used by policy makers due to the intuitive nature of the typology. However, this typology has not been derived through empirical research. This provides another avenue for future research which could utilise primary data to develop a cyclist typology based on the results of a cluster analysis or latent class analysis.

Gender

The issue of gender and cycling is very broad and presents opportunities for a range of future research projects. The role of gender and the uptake of cycling as a station access mode has been briefly examined with respect to a limited number of variables including comfortability on infrastructure, perceptions about cycling journey times and bicycle parking security concerns. Opportunities exist to expand the understanding of gender and bicycle-rail integration by considering a host of other barriers including personal safety, family/parental responsibilities at the start/end of the day and feelings of increased vulnerability.

9.7 Concluding remarks

Integrating the bicycle with public transport services offers a convenient urban mobility option that has many benefits. However, in Melbourne, these advantages are yet to be realised with low rates of cycling activity at railway stations. While cycling as a main mode of travel is steadily increasing, station access rates by bicycle are lagging behind. This presented an unmet need, for research into the integration of cycling and train use, specifically in the context of a re-emerging cycling nation.

This doctoral research program has addressed several research questions and made a significant contribution to knowledge in the field of bicycle-rail integrated travel research. It has produced tangible outcomes highlighting contributing factors that influence commuters' decision to ride to the station as well as the latent demand present for bike-and-ride behaviour. These findings have scope to inform policy and practice.

In Melbourne, as in many other Australian and international cities, we rely on the rail network to safely and efficiently move thousands of people every day. For many people, the trip from their home to the station is short and could be targeted as a first step in more frequent, active transport choices to encourage incidental exercise and reduce car dependency. Ultimately there are substantial personal and societal benefits that are yet to be realised through increased cycling to access train stations. This doctoral research shows there is a latent demand, almost half of commuters were willing to try cycling. Findings also pinpoints the barriers that need to be addressed to support that shift. The next step is for policy levers to be pulled to nudge people away from privatised motorised travel and prioritise cycling.

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Appendices

A1 Ethics approval

Monash University Human Research Ethics Committee

Approval Certificate

This is to certify that the project below was considered by the Monash University Human Research Ethics Committee. The Committee was satisfied that the proposal meets the requirements of the *National Statement on Ethical Conduct in Human Research* and has granted approval.

Project Number: 7805

Project Title: Bicycle parking choice at railway stations in Melbourne

Chief Investigator: Hesara Weliwitiya

Expiry Date: 20/01/2022

Terms of approval - failure to comply with the terms below is in breach of your approval and the *Australian Code for the Responsible Conduct of Research*.

1. The Chief Investigator is responsible for ensuring that permission letters are obtained, if relevant, before any data collection can occur at the specified organisation.
2. Approval is only valid whilst your hold a position at Monash University.
3. It is responsibility of the Chief Investigator to ensure that all investigators are aware of the terms of approval and to ensure the project is conducted as approved by MUHREC.
4. You should notify MUHREC immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
5. The Explanatory Statement must be on Monash letterhead and the Monash University complaints clause must include your project number.
6. Amendments to approved projects including changes to personnel must not commence without written approval from MHUREC.
7. Annual Report - continued approval of this project is dependent on the submission of an Annual Report.
8. Final Report - should be provided at the conclusion of the project. MUHREC should be notified if the project is discontinued before the expected completion date.
9. Monitoring - project may be subject to an audit or any other form of monitoring by MUHREC at any time.
10. Retention and storage of data - The Chief Investigator is responsible for the storage and retention of the original data pertaining to the project for a minimum period of five years.

Thank you for your assistance.

Professor Nip Thomson

Chair, MUHREC

CC: Professor Geoffrey Rose, Dr Marilyn Johnson

Bicycle parking choice at metropolitan railway stations in Melbourne

What is the survey about and who is undertaking the study?

The aim of this survey is to investigate the factors that influence bicycle parking choice at Melbourne suburban railway stations. In particular, the focus will be on bike parking at a Parkiteer facility (*figure on the right*) and other alternative parking facilities such as bike hoops and street furniture. This survey is part of a project being conducted by final year Engineering Students at Monash University. The project is being completed under the supervision of Professor Geoff Rose, Director of the Institute of Transport Studies in the Department of Civil Engineering.

You can respond to this survey either by	QR Code
• Completing this hardcopy version and mailing it back in the enclosed postage paid envelope, OR • Completing the questionnaire on-line from a PC or mobile device by either scanning the QR code on the right or entering the following URL into a web browser: **https://www.surveymonkey.com/r/frankston_station**	

Please read this Explanatory Statement in full before making a decision about completing this survey.

Why have I been invited to take part?
You have been invited to participate in this study because you have parked your bicycle at one of the stations where we are conducting this survey and because you are at least 18 years old.

Possible benefits
This survey will help us understand bicycle parking choices and the factors that influence your parking decisions. The data collected from this survey will be used for research purposes only to better understand the extent to which bicycles can provide an effective access mode for public transport.

How much time will the survey take?
It should take about 3 to 5 minutes to complete this questionnaire.

How will this information be stored and protected?
Your responses are completely anonymous (unless you consent to be contacted for future research) and data will be stored in accordance with Monash University regulations, on a password-protected computer, for five years. Only the researchers and their staff will have access to the information. You will not be identifiable in any documents published about the study.

Thank you for your participation. You will be entered into a <u>$200 prize draw.</u>

If you would like to contact the researchers about any aspect of this study, please contact the Chief Investigator:	If you have any concerns or complaints about the conduct of the project (Project Number: CF12/0717 2012000307), please contact:
Professor Geoff Rose Department of Civil Engineering Phone: +61 3 990 54959 Email: geoff.rose@monash.edu	Executive Officer Monash University Human Research Ethics Committee (MUHREC) Room 111, Building 3e, Research Office Monash University VIC 3800 Phone: +61 3 9905 2052, Fax: +61 3 9905 3831 Email: muhrec@monash.edu

1. What is the main purpose of your train trip today?

Travel to work ☐
Study ☐
Shopping ☐
Recreation ☐

Other (Please state)………………………………………

	Less than once a week	1 to 2 days	3 to 4 days	5 or more days
2. How many days per week do you travel by train?	☐	☐	☐	☐
3. How often do you cycle to the train station?	☐	☐	☐	☐

4. So we can estimate how far you ride to the station please tell us your residential postcode AND the nearest street corner to your home:

Postcode: ___ ___ ___ ___ AND

Nearest street corner to your home: ……………………………………… and …………………………………………….

5. Did you have access to a car that you could have driven to the station today? Yes ☐

No ☐

6. Please indicate the level of agreement with the following statements - even if you did not use a Parkiteer (a caged, weatherproof bicycle storage facility)

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
The registration process for Parkiteer access is convenient (must be completed online and requires activating your access card)	☐	☐	☐	☐	☐
Waiting time for a Parkiteer access card is adequate (currently up to 5-7 business days)	☐	☐	☐	☐	☐
I believe a Parkiteer provides the most secure location to park my bicycle at a train station	☐	☐	☐	☐	☐
I believe the station I ride to is a safe place to leave my bicycle unattended	☐	☐	☐	☐	☐
I believe the transfer time to catch a train is greater if I use a Parkiteer facility	☐	☐	☐	☐	☐
A Parkiteer facility at the train station provides the best protection against the rain	☐	☐	☐	☐	☐

7. What is the value of the bicycle you rode to the station today?

Up to $150 ☐
$151 to 300 ☐
$301 to 700 ☐
$701 to 1000 ☐
More than $1000 ☐

8. How many working bicycles do you own? _________

9. In the past how many times have you had your bicycle(s):

	At a train station			At another location		
	Never	1-5 times	6+ times	Never	1-5 times	6+ times
Stolen	☐	☐	☐	☐	☐	☐
Vandalised	☐	☐	☐	☐	☐	☐

10. Did you store your bicycle in a Parkiteer facility at the station you rode to today? (Tick 'Yes' or 'No')

Yes ☐ ↓ No ☐ ↓

Answer if you parked in a Parkiteer

11. How did you come to start using the Parkiteer facilities? (select all that apply)

Saw others store their bicycle in a Parkiteer ☐

Family/friends use or used a Parkiteer ☐

Saw promotional material about Parkiteer ☐

Wanted more secure bicycle parking than available elsewhere at the station ☐

Wanted better weather protection for my bicycle than available elsewhere at this station ☐

Other ....

Go to Question 15 Below ↓

Answer if you did not park in a Parkiteer

12. To what extent do you agree that the following factors influenced you in your decision to not park in a Parkiteer?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Did not know about Parkiteer	☐	☐	☐	☐	☐
Unsure how to register for Parkiteer access	☐	☐	☐	☐	☐
It is difficult to register for Parkiteer access	☐	☐	☐	☐	☐
Registration cost too high	☐	☐	☐	☐	☐
Satisfied with the security of my bicycle at the place I parked in the station today	☐	☐	☐	☐	☐
Parkiteer is not conveniently located at the station I parked today	☐	☐	☐	☐	☐

13. How much do you think it costs to use the Parkiteer facility?

Free ☐ $5 per use ☐ $25 one off fee ☐

$50 one off fee ☐ $100 per year ☐ I don't know ☐

14. Do you think the fee to use the Parkiteer facility is refundable?

Yes, it is refundable ☐ No, it is not refundable ☐

Go to Question 15 Below ↓

15. Please state the importance of the following attributes in a place you intend to park your bicycle at a station **AND** whether you are satisfied with your current experience

	Not important	Slightly important	Moderately important	Very important	Extremely important	Very dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Very satisfied
Secure point to lock bicycle	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Parking area is highly visible	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Well-lit storage area	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Under cover weather protection	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Parking facility monitored by CCTV	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Secure access via smart card	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Parking close to the station entrance	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

16. To what extent do you agree that the following factors influenced your decision to ride to the station today?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Availability of a place to securely park my bike	☐	☐	☐	☐	☐
Few motor vehicles travelling on the roads I use to get to the station	☐	☐	☐	☐	☐
On street cycling paths connecting my home to the station	☐	☐	☐	☐	☐
Off road cycling/shared paths connecting my home to the station	☐	☐	☐	☐	☐
It is difficult to find a vacant car parking space at the station	☐	☐	☐	☐	☐
Infrequent tram/bus services to the station	☐	☐	☐	☐	☐
Cycling to the station is quicker than catching a tram/bus to the station	☐	☐	☐	☐	☐

Finally, we would like to know a bit more about you.

17. In what year were you born?

☐☐☐☐

18. Which gender do you associate with?

Male ☐

Female ☐

19. Apart from riding to the station, how often do you ride a bicycle? *(circle the most appropriate answer)*

Never/Hardly ever   A few times a year   Monthly   Weekly   Daily

Are you are interested in receiving information about this and future cycling related research studies at Monash University?

☐ Yes, please send me a summary of the results of this study

☐ Yes, please contact me to participate in future cycling related research studies

☐ No thankyou

To go into the draw to win a **$200 Coles Myer Gift Card** please provide your email address so we can contact you:
(You double your chances of winning by replying on-line)

Your email address: ____

Thank you for your time in answering this questionnaire.

If you have misplaced the reply paid envelope you can send it back to:
Bike and Ride Survey, Department of Civil Engineering, Reply Paid 90325, CLAYTON, VIC, 3168

A3 Commuter intercept survey

Travel to the train station survey

This survey is being undertaken by the Institute of Transport Studies at Monash University. Your answers will help us understand what influences your decision about how you get to the train station and to identify options that best suit a variety of commuter's station access needs.

All responses will be anonymous. Only summary findings from the study will be published in a way that no individual will be able to be identified. Findings will be shared with Victoria's transport agencies (e.g. Transport for Victoria) who are interested in the research.

The survey takes about 5 minutes to complete and if you complete the survey by 20 September you can choose to enter a prize draw to win a $200 Coles Myer voucher.

You have the option to view the full explanatory statement for this study or proceed directly to the survey. By going straight to the survey, you have given consent to participate.

View the full explanatory statement for this study
Go straight to survey Go to Q1

Next page

About the study
This study is a travel survey that examines factors influencing station access mode choice. This project is being completed under the supervision of Professor Geoff Rose, Director of the Institute of Transport Studies in the Department of Civil Engineering.

Why have I been invited to take part?
You have been invited to participate in this study as you have exited the train platform at one of the train stations in metropolitan Melbourne that has been selected for this study. People who exited the train, aged 18 years or older, were randomly invited to participate.

Possible benefits
Apart from the option to enter the prize draw, you are unlikely to get any other personal benefit from completing this survey. Your responses could benefit the community. The results will be shared with government transport agencies which are responsible for planning station access options. The insight from the survey will help us better understand the factors which influence how commuters get to railway stations and that could result in access options being designed to better suit commuter's needs.

How much time will it take to complete the survey?
It should take about 5 minutes to complete the survey.

How will this information be stored and protected?
Your responses are completely anonymous and data will be stored in accordance with Monash University regulations, on a password protected computer, for five years. Only the researchers and their staff will have access. You will not be identifiable in any documents published about this study.

If you would like to contact the researchers about any aspect of this study, please contact the Chief Investigator: Professor Geoff Rose Institute of Transport Studies
Department of Civil Engineering Monash University VIC 3800 Phone: +61 3 9905 4959
Email: geoff.rose@monash.edu

If you have a complaint concerning the conduct of the project, please contact: Executive Officer
Monash University Human Research Ethics Committee (MUHREC) Room 111, Building 3e, Research Office, Monash University VIC 3800, Phone: +61 3 9905 2052, Email: muhrec@monash.edu

Next page

1. At which train station were you handed the study postcard?

   Drop down option (all target stations)

---

2. Is this the station where you regularly catch the train?

   Yes   Go to Q4
   No

Next page

---

3. Which station do you regularly catch the train?

   Open text box

Next page

---

4. When you left home and travelled on the train on Monday 11 September (the day you were handed the postcard) what was the main purpose of that journey?

   Employment
   Education
   Recreation
   Other (text box limited to 20 characters)

---

5. In a typical week, how often do you travel by train?

   Less than once a week
   1-2 days
   3-4 days
   5 or more days

---

6. So we can estimate how far you have travelled to get to the train station, please tell us the nearest cross street to your home

   Cross street 1 (open text box)
   Cross street 2 (open text box)

---

7. How do you usually get to the train station from home?

Walk	Go to Q24
By car as the drive	Go to Q28
By car as passenger	Go to Q28
By bus	Go to Q31
By bicycle	Go to Q8

Part B – Cyclists

Next page

8. In a typical week, how often do you cycle from home to the station?

Less than once a week
1-2 days
3-4 days
5 or more days

9. Why do you choose to cycle to the station?

Multiple responses
Fastest
Low cost
Most convenient
Fits in with other commitments
Other (open text box, limited 50 characters)

10. What infrastructure do you currently use when riding from home to the station?

Multiple responses
Off road shared bike path
Local streets
Residential collector streets
Foothpaths
Arterial (main) roads, no bike lanes
Arterial (main) roads, with bike lanes

Next page

11. When you travel by train is there a car available at home that you could have driven to the station?

Yes
No Go to Q13

12. If you did drive to the station, are parking spaces usually available at or near to the station at the time you usually arrive?

Yes
No

Part B.1 – Cyclists: infrastructure

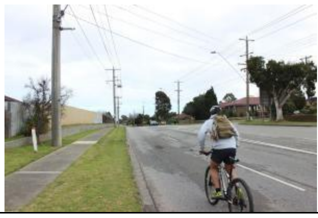
Next page

13. How would you describe yourself as a cyclist?

Strong and fearless, identify as a cyclist, cycle on all roadway conditions
Enthused and confident - comfortable sharing the road with motor vehicles, prefer a bike lane
Enthused but not confident - new/returning cyclist
Interested but concerned - currently not a cyclist but interested in riding, concerned about safety
No way no how - not interested in cycling at all

Next page - Comfort

14. How **comfortable** would you be cycling on each of the following types of infrastructure if it was nearby your house and connected to the train station?

		Very uncomfortable	Slightly uncomfortable	Slightly comfortable	Very comfortable
A	Off road shared path 				
B	Local residential street - no centre lane marking (50km/h) 				
C	Residential collector road - center lane marking (60km/h) 				
D	Arterial road - no bicycle lane 				
E	Arterial road- with a bicycle lane 				
F	Footpath 				

15. How **comfortable** would you be cycling to the station on a road with motor vehicles in the following speed zones.

		Very uncomfortable	Slightly uncomfortable	Slightly comfortable	Very comfortable
A	40km/h				
B	50km/h				
C	60km/h				
D	80km/h				
E	over 80km/h				

Next page – How likely

16. **How likely** are you to cycle to the station on the following types of infrastructure if they were nearby your house and connected to the station?

		Would never cycle	Very unlikely	Slightly unlikely	Slightly likely	Very likely
A	Off road shared path 					
B	Local residential street - no centre lane marking (50km/h) 					
C	Residential collector road - center lane marking (60km/h) 					

D	Arterial road - no bicycle lane 					
E	Arterial road- with a bicycle lane 					
F	Footpath 					

17. **How likely** you are to cycle to the station on a road with motor vehicles in the following speed zones.

		Would never cycle	Very unlikely	Slightly unlikely	Slightly likely	Very likely
A	40km/h					
B	50km/h					
C	60km/h					
D	80km/h					
E	over 80km/h					

Next page

Part B.2 – Cyclists: Attitudes

18. Indicate how strongly you agree with the following statements

		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
A	I believe there are adequate cycling facilities (on road or off road) connecting my home to the station					
B	I would use a public share bike to get to and from the station if it was available					
C	Having bicycle parking facilities at the station has encouraged me to ride to the station					

19. How likely are you to cycle to the station in the following weather conditions

		Very unlikely	Unlikely	Neutral	Likely	Very unlikely
A	Warm weather (summer)					
B	Mild weather (autumn, spring)					
C	Cold weather (winter)					

Next page

20. Indicate how strongly you agree with the following statements

		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
A	The people who are important in my life (family, friends etc.) would approve of me cycling to the station					
B	People who are important in my life would be willing to cycle to the station if they were in my situation					
C	What family and friends think about how I get to the station is important to me					
D	Other road users would disapprove of me cycling on roads to the station					
E	What other road users think about me riding on public roads to the station is important to me					

Next page

21. Indicate how strongly you agree with the following statements

		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
A	I believe it is important to make environmentally friendly travel decisions					
B	Being more environmentally friendly motivates me to ride to the station					
C	It is difficult to ride to the station in the clothes I wear					
D	It is important to arrive at my destination well dressed					
E	Cycling to the station is safe					
F	Safety influences my choice about how I get to the station					

Next page

22. Indicate how strongly you agree with the following statements

		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
A	The enjoyment I get riding a bicycle has encouraged me to cycle to the station					
B	By cycling to the station, I have a more active lifestyle					
C	A more active lifestyle is desirable					
D	Cycling to the station is good for my health					
E	Health benefits associated with cycling encourage me to ride to the station					

23. Indicate how strongly you agree with the following statements

		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
	I am interested in cycling to the station					
	I am likely to continue to cycle to the station in my current circumstances					
	I would stop riding my bike and use a public share bike to cycle to and from the station if one was available					

Go to Q53

Next page - Walking

Part C – Non-cyclists

24. In a typical week, how often do you walk from home to the train station?

Less than once a week
1-2 days
3-4 days
5 or more days

---

25. Why do you choose to walk to the station?

Multiple responses
Fastest
Low cost
Most convenient
Fits in with other commitments
Other (open text box, limited 50 characters)

---

26. When you travel by train, is there a car available at home that you could have driven to the station?

Yes
No

---

27. If you did drive to the station, are parking spaces usually available at or near to the station at the time you usually arrive?

Yes
No

Go to Q37

Next page – Car to station – driver/passenger

28. In a typical week, how often do you travel by car from home to the station?

Less than once a week
1-2 days
3-4 days
5 or more days

---

29. Why do you choose to travel by car to the station?

Multiple responses
Fastest
Low cost
Most convenient
Fits in with other commitments
Other (open text box, limited 50 characters)

---

30. Are parking spaces usually available at or near to the station at the time you usually arrive?

Yes
No
Go to Q35

Next page – Bus to station

31. In a typical week, how often do you travel by bus from home to the station?

Less than once a week
1-2 days
3-4 days
5 or more days

32. Why do you choose to travel by bus to the station?

Multiple responses
Fastest
Low cost
Most convenient
Fits in with other commitments
Other (open text box, limited 50 characters)

Next page

33. When you travel by train, is there a car available at home that you could have driven to the station?

Yes
No

34. If you did drive to the station, are parking spaces usually available at or near to the station at the time you usually arrive?

Yes
No

Next page – Walking for non walkers

35. Are you physically able to walk from home to your regular train station?

Yes
No Go to Q37

Next page

36. What are the main reasons you do not walk to the train station?

Multiple responses
Too far
Not fit enough
Don't have enough time
Does not fit in with commitments
Other (open text box, limited to 50 characters)

Next page – Cycling for non-cyclists

37. Are you able to ride a bike?

Yes
No Go to Q42

Next page

38. When you travel by train, is there a bicycle available at home that you could have ridden to the station?

Yes
No

---

39. Compared to how you usually travel to the station, if you did ride a bicycle to the station, to what extent do you think it would be:

		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
A	Faster					
B	More reliable travel time					
C	Cheaper					
D	Better exercise					
E	Safer					
F	Easy to park					
G	Easy to secure so it would not be stolen					

---

40. What are the main reasons you do not cycle to the train station?

Multiple responses
Too far
Not fit enough
Don’t have enough time
Does not fit in with commitments
Too much to carry
It’s difficult to cycle in the clothes I usually wear
No where to safely park my bicycle
Other (open text box, limited to 50 characters)

---

41. When did you last ride a bicycle?

In the last week
In the last month
Within the last year
More than a year ago

Part C.1 – Non-cyclists: Infrastructure

Next page

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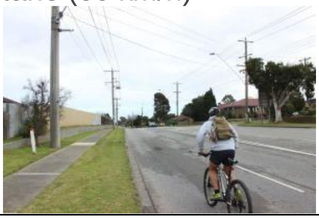
42. How would you describe yourself as a cyclist?

Strong and fearless, identify as a cyclist, cycle on all roadway conditions
Enthused and confident - comfortable sharing the road with motor vehicles, prefer a bike lane
Enthused but not confident - new/returning cyclist
Interested but concerned - currently not a cyclist but interested in riding, concerned about safety
No way no how - not interested in cycling at all

Next page - Comfort

These questions relate to **how comfortable** you are riding to the train station.

43. If the following types of infrastructure were available nearby your house and connected to the train station how **comfortable** would you be cycling to the station?

		Very uncomfortable	Slightly uncomfortable	Slightly comfortable	Very comfortable
A	Off road shared path 				
B	Local residential street - no centre lane marking (50km/h) 				
C	Residential collector road - center lane marking (60km/h) 				
D	Arterial road - no bicycle lane (60 km/h) 				
E	Arterial road- with a bicycle lane (80km/h) 				
F	Footpath 				

44. How comfortable would you be cycling to the station on a road with motor vehicles in the following speed zones.

		Very uncomfortable	Slightly uncomfortable	Slightly comfortable	Very comfortable
A	40km/h				
B	50km/h				
C	60km/h				
D	80km/h				
E	over 80km/h				

Next page – How likely

These questions relate to **how likely** you are riding to the train station.

45. If the following types of infrastructure were available nearby your house and connected to the train station how **likely** would you be to cycle to the station?

		Would never cycle	Very unlikely	Slightly unlikely	Slightly likely	Very likely
A	Off road shared path 					
B	Local residential street - no centre lane marking (50km/h) 					
C	Residential collector road - center lane marking (60km/h) 					
D	Arterial road - no bicycle lane (60 km/h) 					

E	Arterial road- with a bicycle lane (80km/h) 					
F	Footpath 					

46. **How likely** are you to cycle to the station on a road with motor vehicles in the following speed zones.

		Would never cycle	Very unlikely	Slightly unlikely	Slightly likely	Very likely
A	40km/h					
B	50km/h					
C	60km/h					
D	80km/h					
E	over 80km/h					

Next page

Part C.2 – Non-cyclists: attitudes

47. Indicate how strongly you agree with the following statements

		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
A	I believe there are adequate cycling facilities (on road or off road) connecting my home to the station					
B	More cycling facilities connecting my home to the station would encourage me to cycle to the station					
C	Availability of public share bikes would encourage me to cycle to the station					
D	I would be willing to use a public share bike to get to and from the station					
F	Having bicycle parking facilities at the station would encourage me to ride to the station					

48. How likely would you be to cycle to the station in the following weather conditions

		Very unlikely	Unlikely	Neutral	Likely	Very unlikely
A	Warm weather (summer)					
B	Mild weather (autumn, spring)					
C	Cold weather (winter)					

Next page

49. Indicate how strongly you agree with the following statements

		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
A	The people who are important in my life (family, friends etc.) would approve of me cycling to the station					
B	People who are important in my life would be willing to cycle to the station if they were in my situation					
C	What family and friends think about how I get to the station is important to me					
D	Other road users would disapprove of me cycling on roads as I ride to the station					
E	If I cycled to the station on public roads, what other road users think about me riding would be important to me					

Next page

50. Indicate how strongly you agree with the following statements

		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
A	I believe it is important to make environmentally friendly travel decisions					
B	Being more environmentally friendly could motivate me to ride to the station					
C	It is difficult to ride to the station in the clothes I wear					
D	It is important to arrive at my destination well dressed					
E	Cycling to the station is safe					
F	How I get to the station will be influenced by how safe the access option is					

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51. Indicate how strongly you agree with the following statements

		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
A	The enjoyment I get riding a bicycle would encourage me to cycle to the station					
B	Cycling to the station would enable me to have a more active lifestyle					
C	A more active lifestyle is desirable					
D	Cycling to the station is good for my health					
E	Health benefits associated with cycling would encourage me to ride to the station					

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52. Indicate how strongly you agree with the following statements

		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
A	I would be interested in cycling to the station					
B	I am likely to cycle to the station in my circumstances					
C	I am likely to cycle to the station if bicycle parking was improved at the station					

D	I am likely to cycle to the station if better facilities for cyclists were available between my home and the station					
E	I am likely to cycle to the station if better facilities for cyclists were available between my home and the station and bicycle parking was improved at the station					

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Part D – Demographics

Finally a few question about you.

53. What gender do you associate with?

Male
Female
Gender diverse or non-binary gender
Prefer not to say

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54. What is your age range?

18 – 24
25 – 34
35 – 44
45 – 54
55 – 64
65 – 74
Over 75

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55. Do you have any additional comments you would like to add?

(Open text box, limited to 200 characters)

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Please tick all the boxes you are interested in below and add your email address to:

Tick boxes

Go into the prize draw to win a $200 Coles Myer voucher (so long as your response is received by 20 September 2017)
Receive a summary of the study findings
Be contacted for future studies at Monash University

Email

Open text box (email address verified)

SUBMIT

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Thank you for your completing this survey. We appreciate your time and your responses will provide valuable insights into how access options to train stations might be improved.