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PEDESTRIANS AND CYCLISTS MOBILITY MODELS

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STATEMENT OF ORIGINALITY

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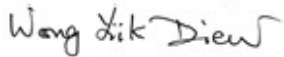
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I certify have reviewed the content and presentation style of this thesis and declare it is free of plagiarism and of sufficient grammatical clarity to be examined. To the best of my knowledge, the research and writing are those of the candidate except as acknowledged in the Author Attribution Statement. I confirm that the investigations were conducted in accord with the ethics policies and integrity standards of Nanyang Technological University, Singapore and that the research data are presented honestly and without prejudice.



Assoc. Prof. WONG YIIK DIEU

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AUTHORSHIP ATTRIBUTION STATEMENT

This thesis contains material from 3 papers published in peer-reviewed journals and 1 conference paper where I was an author and/or presenter at the conference. The thesis also contains material from other journal papers now being under consideration for publication.

An early version of the study presented in Section 4.1 has been presented in the *Velo-City Conference 2017* (Rojas López, M. C., & Wong, Y. D. (2017b). Pedestrian and cyclists sharing facilities in Singapore. In *International Velo-City 2017 Conference, The Freedom of Cycling*. The Netherlands, Arnhem-Nijmegen).

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The mentioned papers are jointly authored with Assoc. Prof Wong Yiik Diew, who provided guidance through the research methodology and edited the manuscript drafts.

In addition, some issues regarding trip distribution, presented in Section 6.4, are published as Poyil, R. P., Rojas Lopez, M. C., & Wong, Y. D. (2017). Non - motorised transport prioritisation model using spatial intelligence. *Proceedings of the Institution of Civil Engineers – Transport*. As second author my main contribution was on providing feedback on the methodology and writing sections of the manuscript draft. The first author overviewed general aspects of manuscript development and Assoc. Prof Wong Yiik Diew provided guidance and edited the drafts.



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ABSTRACT

With the increasing transport demand and the raising of environmental awareness, tools for analysing travel demand are constantly being reviewed and updated. Active mobility rates, such as walking, cycling, and riding personal mobility devices (PMDs), are increasing in Singapore as in many countries in the world. In Singapore, active mobility users share off-road travelling spaces as necessitated by the limited land space in the urbanised island-nation, which is not common in other countries. As previous transport research was mostly focused on motorised modes, a knowledge gap regarding pedestrians' and cyclists' travel quality needs and travel demand analysis has become apparent. Concepts from several fields have been utilised to explain travel-related theories. However, not many of the theories specifically address decisions related to walking and cycling. In addition, many are based on specific local context and thus are not transferable to the unique urban layout and transport characteristics of Singapore.

In this research, to understand pedestrians' and cyclists' quality needs in the local context, three studies were developed (due to the different nature of the factors being studied) utilising: [1] intercept qualitative surveys (202 participants); [2] mixed-method – qualitative and quantitative questions (277 participants); and [3] qualitative interviews (46 participants). Overall, walking was described as a safe and convenient “mode of transport” but the distance limitations reduce its attractiveness. Cycling was perceived as an enjoyable “activity” and its limitations could be addressed with enhancement of infrastructure and/or provision of cycling-centric policies. Off-road delineated paths were found to be the preferred mobility facility by cyclist and pedestrian respondents, as these spaces can be dynamically used, shifting between pedestrian and cycling paths in response to traffic or perceived obstructions. In addition, the provision of bicycle-sharing scheme, in combination with infrastructural improvements, was found to be associated with a rapid increase in cycling demand in the recent years with most of the trips being used for transport purposes.

The findings from the three studies, together with knowledge from a comprehensive review of 27 theories that are applicable to travel-behaviour, were used to develop a holistic and dynamic “process and determinants of mobility decisions (PDMD)” framework. The PDMD framework considers how the different aspects vary according to different locations and people, and thus how these can be applied into different contexts. This was found to be missing in most travel behaviour theories. Then, utilising the PDMD framework, a refined household travel survey questionnaire was developed, which was then utilised to collect data for analysing travel demand, with strong emphasis on active mobility movements.

For the demand analysis, modifications to the traditional Four-Step Method (4SM) were introduced by shifting the order of the steps and a computer intelligent neural network model (using Bayesian regularisation as training function) was developed for mode choice modelling. The order of the steps has previously been modified for demand analysis, but few studies have mainly focussed on active modes trips, and usage of the off-road (formal) transport network. Neural networks were selected for this study in view of the complex travel behaviour as this method allows for multiparametric modification of factors to estimate changes in travel demand. Data from 1,119 households (and corresponding 9,316 trip-stages) in 4 residential towns in Singapore was utilised for modelling.

The thesis provides an overview of the many capabilities of neural network models regarding scenarios modifications to estimate changes in demand. Besides current scenario (encapsulated in the survey data), three modified scenarios were considered and the changes in travel demand were estimated. A good fit of the neural network model was found ($R > 0.96$, and normally-distributed errors between -2 and 2). It was found that policies and programmes (e.g. reducing vehicle ownership, increasing access to bicycles and PMDs, etc.) have stronger influence in increasing active mobility demand as compared to modifications to the built-environment (e.g. reduced distance to public transport, enhanced cycling paths, etc.) while a combination of policies/programmes and infrastructure improvements yields the best outcomes regarding active mobility.

PUBLICATIONS AND AWARDS

The following publications, papers and articles are presented in chronological order of publication (older to newer). Contribution of the thesis author in each paper is specified, where by:

- as **Principal Investigator**, the author of this thesis oversaw formulation of study methodology, data collection, analysis and interpretation, and manuscript writing; and
- as **Co-investigator**, the author of this thesis oversaw partial design of the study, collaboration in data collection techniques, and discussion of analysis procedures and findings with principal investigator.

JOURNALS

Rojas Lopez, M. C., & Wong, Y. D. (2017). "Children's active trips to school: a review and analysis". *International Journal of Urban Sustainable Development*, 9(1), 79-95. <http://dx.doi.org/10.1080/19463138.2016.1264405> [*Principal Investigator*]

Rojas Lopez, M. C., & Wong, Y. D. (2017). "Attitudes towards active mobility in Singapore: A qualitative study". *Case Studies on Transport Policy*. <http://dx.doi.org/10.1016/j.cstp.2017.07.002> [*Principal Investigator*]

Poyil, R. P., **Rojas Lopez, M. C., & Wong, Y. D.** (2017). "Non - motorised transport prioritisation model using spatial intelligence". *Proceedings of the Institution of Civil Engineers - Transport* [*Co-Investigator*]

Rojas Lopez, M. C., & Wong, Y. D. (2018). "Users' preferences and determinants of active mobility in Singapore". *International Journal of Sustainable Transportation* (Under review) [*Principal Investigator*]

Rojas Lopez, M. C., & Wong, Y. D. (2018). "Process and determinants of mobility decision – A holistic and dynamic travel behaviour framework". *Travel Behaviour and Society* (Under review) [*Principal Investigator*]

Rojas Lopez, M. C., & Wong, Y. D. (2018). "Active mobility spaces in Singapore's urban planning". *Habitat International* (Under review) [*Principal Investigator*]

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Rojas Lopez, M. C., Trinh, T. D. & Wong Y. D. (31 Oct-01 Nov 2019). “Transitioning through different stages of transport planning in urban areas”. Congrès International de Géotechnique - Ouvrages -Structures – CIGOS 2019, Hanoi, Vietnam. (Abstract accepted) *[Principal Investigator]*

TECHNICAL REPORT

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Yuo, P. H., **Rojas Lopez, M. C.**, Wong, Y. D., & Gopinath, M., (December 2015). “Research study into first/last mile trips (with focus on cycling) at Jurong Lake District, Phase IV Report” – Prepared for LTA by CIS-NTU

Rojas Lopez, M. C., Herdiningrum, S. W., Wong, Y. D., & Hong, X. (March 2017). “Walking-cycling demand model at neighbourhood level, First Working Report” – Prepared for LTA by TRC-NTU

Rojas Lopez, M. C., Poyil P. R., Herdiningrum, S. W., Wong, Y. D., & Hong, X. (September 2017). “Walking-cycling demand model at neighbourhood level, Second Working Report” – Prepared for LTA by TRC-NTU

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Rojas Lopez, M. C., Poyil P. R., Wong, Y. D., & Hong, X. (October 2018). “Walking-cycling demand model at neighbourhood level, Final Report” – Prepared for Land Transport Authority by TRC-NTU

AWARDS

Rojas Lopez M. C., Cheung H., Zhang K., Chen K., Poddar S., Dong Y., “A framework for optimizing environmental performance of buildings”. Aspire Forum 2016 – Developing Sustainable Urban Environment and Low Carbon Economy. 3-9 July 2016 Hong Kong University of Science and Technology (Best Presentation Award) *[Principal Investigator; Co-Presenter at Forum]*

Rojas Lopez, M. C. & Wong Y. D. (January 2016 – January 2017). Project “Cyclists visual behaviour model”. From Mitsui Sumitomo Insurance Welfare Foundation (MSIWF) Research Grant Call 2016. *[Project Principal Investigator: Rojas Lopez, M. C., Co-Investigator: Wong, Y. D.]*

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GLOSSARY AND ABBREVIATIONS

Glossary

An alphabetical list, and their corresponding definition, of relevant terms utilised in this thesis is presented in the following.

Active mobility or active travelling – Travelling by active (mainly human-powered) modes of transport, such as walking, cycling or riding a Personal Mobility Devices (PMD).

Active trip/trip-stage – Full-trip or trip-stage performed using an active mode of transport.

Bicycle lane – On-road travelling space dedicated to cyclists. Demarcated by specific road marking, but not physical barrier such as raised kerb.

Bicycle path – Off-road travelling space dedicated to cyclists and PMD riders. Usually adjacent to footpaths, with or without physical separation.

Bicycle-sharing scheme – Bicycle rental services which allow commuters to rent a bicycle for a rental fee for their commuting/travel purposes. The scheme can be with docking stations (i.e. bicycles are parked at designated stations and can only be rented/returned to/from there) or dock-less (i.e. bicycles have individual unlock/lock systems allowing commuters to pick up any available bicycle and unlock/lock it using a mobile App, and bicycle can be parked (and locked) anywhere).

Building-block – Singapore public housing building comprising different type of flats/apartments. From 1 to 5 rooms each flat. Also known as Housing and Development Board (HDB) blocks.

Delineated path – Off-road travelling space comprising footpath and bicycle path adjacent to each other without physical separation but delineated by means of painted marking on the pavement.

First/Last Mile (FLM) – Initial and final stages of a trip aimed to reach a motorised mode of transport. FLMS are commonly made by active modes of transport.

Footpath – Off-road travelling space dedicated primarily to pedestrians. In the absence of bicycle path, cyclists and PMD riders can make use of footpaths following specific speed limits.

Formal mobility network – Paths formally built for mobility purposes. For active mobility, the formal network includes footpaths and bicycle path

Grounded Theory (GT) – Method to analyse data systematically to “discover” new theories/knowledge. Commonly used in social science and human behaviour related studies.

Informal mobility network/spaces – Areas built for recreation or social gathering that are often used by active mobility users as thoroughfare.

Land use – Allocation of parcels of lands for different purposes e.g. residential, industrial, educational, recreational, etc.

Non-cyclist – Someone who reported not to cycle for transport nor for recreation in Singapore. Non-cyclists can be pedestrians, PMD riders and/or motorised transport users.

Neural Networks (NN) or artificial neural networks – models designed in 1940s to mimic neurones behaviour and assist with pattern recognition and classification studies (Gonzalez et al., 2010).

Park Connector Network (PCN) – An island-wide path network of linear open spaces that link up major parks and nature sites in Singapore, usually located away from roads and serving as recreational areas for activities such as jogging, cycling and in-line skating (NParks, 2009).

Pathway – Generic term for off-road travelling space, including footpaths, delineated paths, and segregated paths.

Peak period – Busiest travel period characterised by heavy human and motorised traffic. There are morning peak (2 hrs – 07:30 to 09:30) and evening peak (2 hrs – 17:30 to 19:30) periods.

Personal Mobility Device (PMD), – A wheeled vehicle that can be used to transport people and is propelled by human power, an electric motor attached, or both. Including skateboards, hover-boards, unicycles, etc. and not including bicycles, power-assisted bicycles, cars, pram/stroller/trolley, or wheeled toys.

Recreational mobility network – Formally built paths that are more commonly used for recreation purpose than for transport purpose.

Regular cyclist – Someone who cycles (using private bicycles or as part of the dock-less bicycle-sharing programme) for a full-trip or for a trip-stage, for at least once a week. Regular cyclists can be further classified as utilitarian cyclists – those who cycle as a mode of transport and for a specific purpose – or recreational cyclists – those who cycle for recreation.

Process-models – Elaborated transport models with main interest on the processes underlying travel choices (travel behaviour) and not just the outcome (Jahanshahi & Hall, 2013).

Quality needs – Infrastructural, personal, and social factors aimed at enhancing travelling experience and thus cause a user/user-group to select a specific mode of transport.

Segregated path – Off-road travelling space comprising footpath and bicycle path adjacent to each other with physical separation.

Traffic Analysis Zone (TAZ) – land parcels for traffic analysis. In this thesis, TAZs are designed of 600 metres by 600 metres on average, and at least one road access serving each TAZ.

Trip (Full-trip) – One-way movement from an origin to a destination with one single purpose.

Trip-stage – Portions of a full-trip made by different modes of transport. The first (from origin to transport station) and last trip-stages (from transport station to destination) are known as first-last mile (FLM) trip-stages.

Void decks – Ground level of public housing that is aimed at encouraging social interaction, which is quite unique to Singapore. These are currently also utilised as thoroughfare by active mobility users, mainly pedestrians, for mobility purposes.

Abbreviations

An alphabetical list of abbreviations and acronyms, and their corresponding definition, utilised in this thesis is presented the following.

4SM	Four-Step Method
BMST	Behaviour Model of School Transportation
CADM	Comprehensive Action Determination Model
CIS	Centre for Infrastructure Systems
COE	Certificate of Entitlement
DoS	Department of Statistics
ECAC	Ecological and Cognitive Active Commuting
ERP	Electronic Road Pricing
FLM	First/Last Mile
GPS	Geographical Position System
GT	Grounded Theory
HBE	Home-Based Education
HBM	Home-Based Maintainance
HBO	Home-Based Others

HBR	Home-Based Recreation
HBW	Home-Based Work
HDB	Housing and Development Board
HITS	Household Interview Travel Survey
ITB	Ipsative Theory Behaviour
LTA	Land Transport Authority
M-CAT	Model of Children Active Travel
MRT	Mass Rapid Transit
NDM	Normative Decision-Making Model
NHB	Non-Home Based
NN	Neural network
NTU	Nanyang Technological University
OD	Origin-Destination
PCN	Park Connector Network
PDMD	Process and Determinants of Mobility Decisions
PMD	Personal Mobility Device
PSUs	Primary Sampling Units
RUM	Random Utility Maximisation
SCT	Social Cognitive Theory
SWOT	Strengths, Weaknesses, Opportunities, Threats
TAZs	Traffic Analysis Zones
THM	Theory of Human Motivation
TIB	Theory of Interpersonal Behaviour
TPB	Theory of Planned Behaviour
TRA	Theory of Reasoned Action
TRB	Theory of Repeated Behaviour
TRC	Transport Research Centre
URA	Urban Redevelopment Authority
USA	United States of America

Chapter 1. Introduction

In this Chapter, the background information, which forms the motivation and basis of this research as focused on active mobility, is presented. Then, the objectives of the research and scope of work are summarised. The significance of the research is explained afterwards, followed by the research framework and overall organisation of this thesis. Active mobility covers walking, and riding bicycle and other personal mobility devices (PMDs). This thesis addresses the gaps identified regarding active mobility users' travel quality needs – factors aimed at enhancing travelling experience and thus select a specific mode of transport – and travel behaviour theories, by introducing the updated “process and determinants of mobility decisions” or PDMD framework. The framework is utilised for data collection and to select inputs for travel demand analysis. Demand analysis is aimed to understand factors that would increase demand for active mobility by applying modifications to the development and applications of the traditional Four-Step Method (4SM). This also serves to re-evaluate existing infrastructure for active trips/trip-stages.

1.1. Research background

In this section, a broad overview of research related to active mobility movements, travel behaviour research, and transport analysis/planning tools, is provided. These issues motivated this research and form the basis for the work presented in this thesis. An exhaustive review of local and international literature (extending on some of the key points mentioned in this section) is provided in Chapter 2 on literature review.

In the quest to cope with the steadily increasing transport demand and the raising of environmental awareness, authorities, researchers, and planners in Singapore and other countries/cities are advocating efforts to make transport as sustainable and socially inclusive as possible. Herein, tools aimed for analysing, measuring, and forecasting travel demand are constantly being reviewed and updated. Since 1990s, significant amount of research has focussed on active modes of transport, mainly walking and cycling (Cervero et al., 2009; Ewing & Cervero, 2017; Maring & Van Schagen, 1990; Pucher & Buehler, 2010; Tolley, 1990). Walking and cycling are sustainable modes of transport that can provide myriad of benefits to individuals and the society, and they help to reduce negative effects from private motorisation, such as traffic congestion and higher space requirement as compared to active modes (Koh & Wong, 2013b; Marshall et al., 2014; Pucher & Buehler, 2010; Susilo et al., 2007). Some of the benefits of active trips and how these are interrelated can be seen in Figure 1.1.

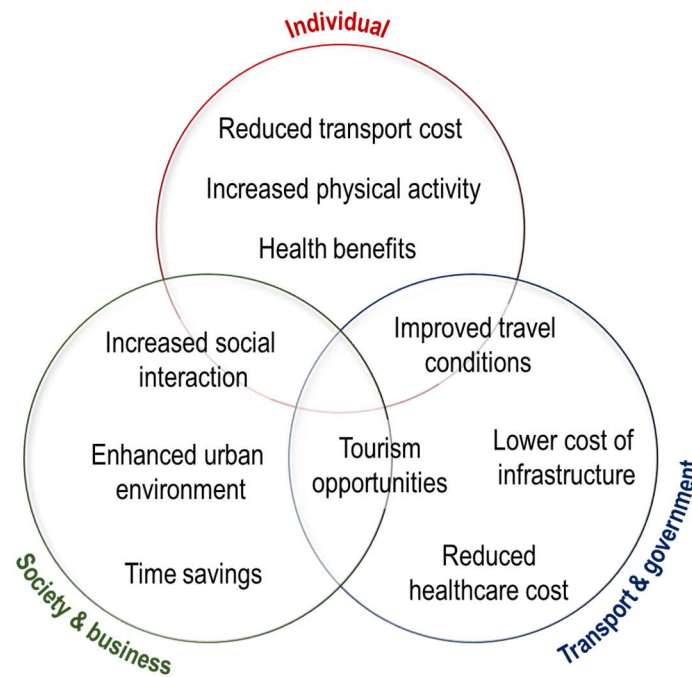


Figure 1.1. Benefits of active trips

On the other hand, active mobility users (principally pedestrians and cyclists) are the most vulnerable road users, and the increasing amount of active traffic entails increased interaction among users travelling at different speeds (de Vries et al., 2010; Tolley, 1990; Wong & Koh, 2014). This is especially true in Singapore where mixed-stream active traffic (active mobility users sharing same off-road travelling spaces) is common, whereas in most countries off-road facilities are usually dedicated to pedestrians while cyclists commonly share space with motorised vehicles. The attention on active mobility at an intense level is quite recent. Thus, planners and policy developers are still facing many challenges on related developments.

Previously, motorised modes of transport were the centre of attention of transport planning and forecasting tools. Decisions related to transport facility provision and policy development have mostly been made considering motorised-centric transport tools, leading to under- or mis-representation of walking and cycling trips. While more and more models are considering active trips, a knowledge gap regarding pedestrians' and cyclists' **travel quality needs** remains to be plugged. Travel quality needs refer to infrastructural, personal, and social factors aimed at enhancing travelling experience which bear on the user in selecting a specific mode of transport (Ettema et al., 2016; Rojas López & Wong, 2017; Yeung et al., 2013). In many cases, walking and cycling have not been considered as actual modes of transport, which also impacted on **data collection methods** and hence the quality of active mobility data. Walking and cycling trips or trip-stages, especially short-range trips, are commonly under-represented, either due to deficiencies in data collection methodologies (e.g. not placing

enough attention in the questions for walking and cycling) or due to respondents themselves not considering some walking and cycling trips as transport trips.

Furthermore, many of the tools for analysing active travel demand are subservient upon the motorised modes, and walking and cycling modes are captured only when they are the sole trip made (Griffin, 2009; Kitamura, 1996; Ortúzar & Willumsen, 2011; Wedderburn, 2015). However, active mobility-related decisions are influenced by complex factors, individual perceptions, and trades-off that differ from those of motorised modes. The absence of a dedicated analysis method/tool can reduce the reliability of assessing mode choice (demand) and network capacity. Some analysts have “borrowed” theories and frameworks from other fields (e.g. economy or psychology) to explain the **complex travel behaviour and decision-making process** (Clifton et al., 2013; Panter et al., 2008; Primerano et al., 2008; Singleton, 2013) and several frameworks – descriptive and predictive – specifically focusing on active transport have been introduced recently (Ogilvie et al., 2011; Pucher & Buehler, 2010; Tight et al., 2011).

Some authors have discussed applications of the frameworks to understand demand for active modes of transport. Descriptive models provide clear insights to occurred events and can be used to search for alternatives to improve future trends (Clifton et al., 2016; Hanley et al., 2002; HDR & CAMPO, 2013; Khan et al., 2014; Kim & Susilo, 2013). On the other hand, predictive models, which aim to forecast future trends, and particularly those that focus on active mobility, are less common and the limited knowledge has constrained the analysis of **demand for active trips** (Ahmed, 2012; Chen et al., 2010; Porter et al., 1999; Raveau et al., 2012), let alone the more complicated scenarios of mixed-stream active traffic as in Singapore where active mobility users share common off-road facilities (mainly due to limited land available).

The techniques and mathematical/statistical models utilised for transport and demand analysis are usually outcome-driven in approach. The intrinsic characteristics of active travel behaviour has called for a shift on interest from “outcome” of transport models to “processes” that lead to specific behaviour (decision). Transport researchers choose statistical or computer-intelligent models (or a combination of both methods), yet these methods have certain limitations (which are discussed in detail in the literature review). Neural networks are computer-intelligent models that have been utilised for travel demand analysis (Karlaftis & Vlahogianni, 2011). Neural network has been successfully used in a number of transport projects, yet the literature regarding usage of neural network in modelling active mobility demand is sparse. The usage of neural networks appears as a suitable approach to model the complexity of active travel behaviour.

This thesis addresses the afore mentioned issues by introducing a holistic approach to understand active mobility users' travel quality needs by formulating and utilising the PDMD framework, collecting comprehensive travel data, and analysing travel demand. Deliveries for this research are assembled using information from exhaustive reviews, scientific theory development, and empirical data (quantitative and qualitative) collected in the field. It analyses the overall situation and the needs of different active trips as well as the trip-makers. For the demand analysis, computer-intelligence by means of artificial neural networks is utilised, suggesting modifications to a traditional transport tool (the 4SM) to holistically include active and short-range trips/trip-stages. Possible applications of the findings in the local and international context are discussed when possible.

1.2. Research objectives and scope

Objectives

With the burgeoning population of pedestrians and cyclists, it is important to understand crucial factors related to their travel characteristics. In this research, usage of the active transport network and common travel patterns in Singapore are explored. These are used to identify travel quality needs for active modes of transport (e.g. factors that encourage/deter its usage; enhance travel comfort and safety) and suggest alternatives to improve them in the local and international context. The relationship among relevant factors are presented conceptually in the PDMD framework which is utilised for selecting inputs for demand analysis (using empirical travel data). An overview of the research framework is shown in Figure 1.2.

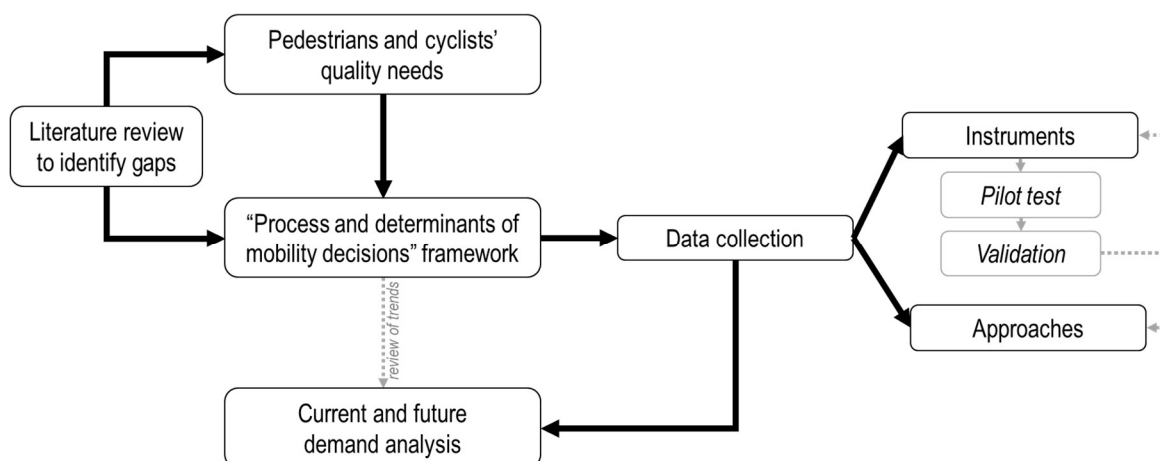


Figure 1.2. General thesis research framework

In essence, there are four main objectives considered and developed in the thesis research. The methodology to achieve each task, and results obtained are presented and discussed in detail in subsequent chapters. The four objectives are:

- Determine travel quality needs of active mobility users;
- Introduce a mobility decision framework to aid travel data collection and demand analysis;
- Apply the mobility decision framework for the development of travel data specially focused on active mobility users and as inputs for travel demand analysis; and
- Test usage of computer-intelligent neural networks to estimate changes in travel demand based on changes in the built-environment and policy/programme implementation using a modified 4SM.

Scope

The scope of this thesis covers active mobility users' (principally pedestrians and cyclists) quality needs, mobility decisions, and demand analysis. PMD riders are included only in some parts of the analyses, mainly for current and modified scenarios demand analysis. Noticing that to a large extent, provision of infrastructures for cycling shall fulfil the needs of PMD rides as both have to adhere to similar regulations and speed limits. In addition, some of the developed models are of general application for all modes of transport while others are focused on specific active mobility users, principally pedestrians and cyclists. Findings are focused on Singapore's context and where applicable, comparisons and applications to overseas situations are made, including Paraguay – Capital Asunción city (author's home place).

Pathway is the generic term utilised for footpaths, widened paths, delineated paths and segregated paths as defined in the Glossary. Shared facilities refer to off-road transport infrastructures that are jointly used by pedestrians and bicycles and PMD riders. For this thesis, cycling trips are considered to take place off-road (this being the case for most cycling activity in Singapore) unless otherwise specified. Across the thesis, travel behaviour refers to the factors that affect people's decisions regarding different transport choices. Only certain aspects of motorised travel behaviour are considered, in particular those that could lead to a possible shift from motorised modes of transport to walking or cycling modes. In addition, certain research aspects are focused on a specific segment of users (e.g. young users) while other conclusions are applicable to the overall population.

1.3. **Significance of research**

As more and more travellers are shifting to active mobility for whole trips or trip-stages, it is timely to research into well-integrated approach to analyse travel-related decisions, especially those that affect walking and cycling trips. A great amount of details has been placed on travel demand analysis and possible schemes to improve such models. A lesser amount of research exists in regard to the different factors that affect travel behaviour which affects travel demand. To address this gap, the current research scientifically reviews and audits available theories, analyses ground situations, and formulates the “process and determinants of mobility decision (PDMD)” framework. This is then utilised as a guide for travel data collection for inputs into demand analysis models.

Moreover, neural networks analysis has been utilised in several transport studies, yet its application in active mobility demand analysis is still rather unclear. While the usage of neural network to analyse demand of different modes of transport, including walking and cycling, as in this research, can establish the positive value-add of such technique to estimate changes in demand based on external changes, the limited explanatory power of the method should be acknowledged. Notwithstanding, the versatility of neural networks allows modification to include features of the different scenarios and thus estimation of changes in demand for different modes of transport, while noting that these predictions might change as neural network models do produce different solutions for a same problem.

The enhanced understanding gained from the PDMD framework development led to application of innovative approach by introducing new methodologies (mainly for demand analysis), thus, broadening academic knowledge. In addition, the issues of current usage of walking and cycling, potential growth in active mobility, and attendant spatial and temporal distributions, are captured and modelled with certain modifications into a well-established transport tool as consistent with the traditional 4SM. The contribution of the current research and its findings can be utilised and applied by academics as well as practitioners to make more informed decisions regarding planning, designing and operating the active mobility infrastructure network for maximal safety, accessibility and efficiency.

1.4. **Research framework**

There are different tasks covered in the current research as presented in Figure 1.3, while noting that the presented tasks overlap and strengthen each other. There is a total of 7 Chapters in this

thesis, including this introductory chapter where the background, objectives and scope of work, and significance of the research are described.

In **Chapter 2**, a synopsis of findings from previous research is provided as covering the local and international contexts, travel behaviour (pedestrians' and cyclists' quality needs, and human behaviour theories), and demand analysis. Issues related to data collection and transport techniques and methods are discussed. Gaps found in the literature are highlighted which motivate the direction of this research.

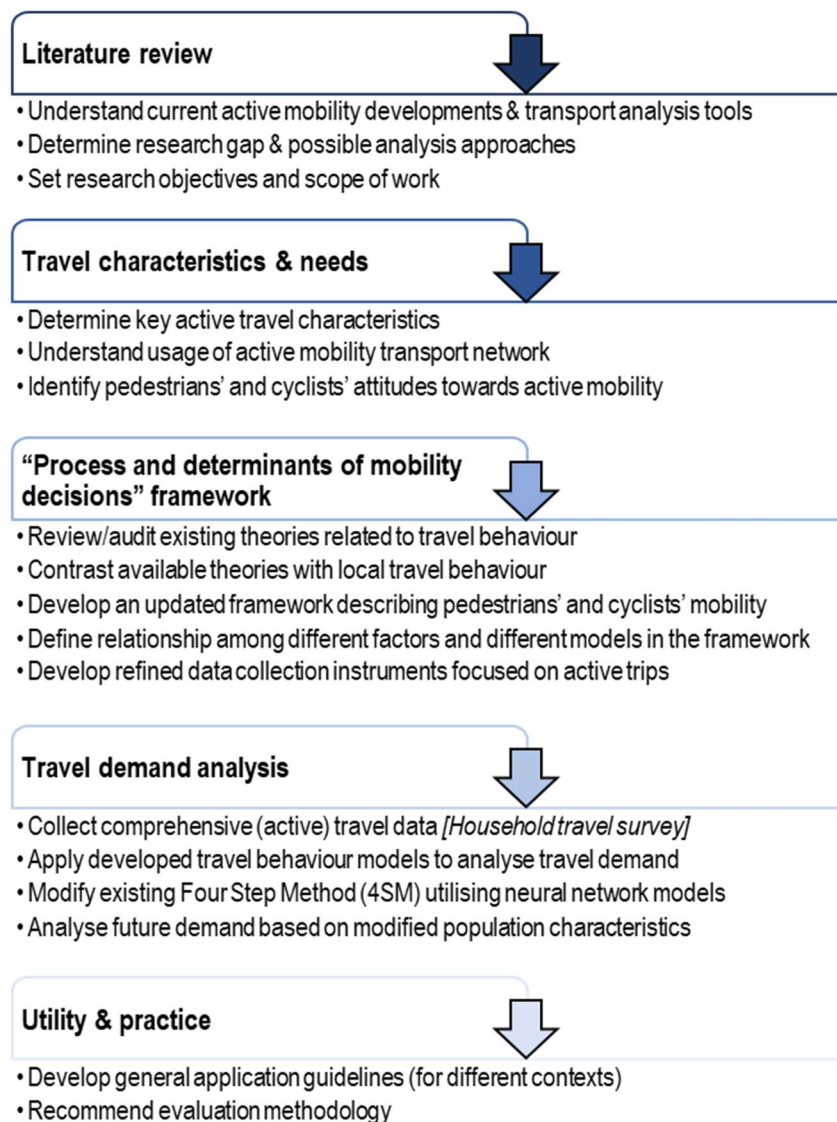


Figure 1.3. Thesis research tasks

In **Chapter 3**, the different methodologies utilised for data collection, data analysis, and modelling are described. Three main tasks are covered; namely: [1] understanding and meeting pedestrians' and cyclists' quality needs; [2] developing a mobility decision framework focused on active modes of

transport and that can be used for data collection for demand analysis; and [3] use neural network to estimate changes in travel demand based on external changes. The various research questions considered in this thesis and the problem statements are highlighted within the appropriate sections.

In **Chapter 4**, findings related to active mobility users' fundamental travel characteristics and travel quality needs based on empirical research conducted by the author are presented. Many findings are qualitative in nature and serve to provide the background information for the development of travel behaviour framework and demand models with special interest in walking and cycling.

In **Chapter 5**, the developed "process and determinants of mobility decisions (PDMD)" framework is introduced. The PDMD framework presents two major divisions which are: (1) the process, that illustrates what generates demand for a trip, and (2) the determinants, that conceptualises different factors that affect travel behaviour and their relationship with each other. Factors within each division are presented at different levels based on their impact on travelling decisions. The framework is built based on empirically collected data and a scientific audit of previously developed research and established theories. Key components of the PDMD framework are measured, highlighting the possibility of scaling it to different contexts and their value-add in survey instruments (household travel survey questionnaires). Characteristics of the developed survey instrument are also presented in the chapter.

In **Chapter 6**, modifications to traditional transport analysis tools, i.e. 4SM, is introduced to understand factors that would increase the demand for certain modes of transport. The order of the four steps (generation, distribution, mode choice and network assignment) are modified by considering mode-choice prior to trip-stage distribution. The main interest is placed in mode choice characteristics, and demand for different modes of transport for current and modified scenarios. Remaining steps are considered in order to gain a general view of the transport network usage. With the goal of holistically including active and short-range trips/trip-stages in demand analysis (for different modes of transport), neural network models are utilised. Current travel demand is analysed using household travel survey data as input components of the neural network model. Characteristics of the developed PDMD are considered to select the input components. Then, changes in demand for active modes of transport is estimated based on three different scenarios.

In **Chapter 7**, a concluding summary and achievements of different objectives are given. Research methodology and findings are also discussed, pointing the limitations and providing recommendations for future work.

Chapter 2. Literature review

In this chapter, an overview of active mobility is given first, followed by urban and transport planning, as well as travel characteristics of the local (Singapore's) context. Thereafter, findings from previous research works related to pedestrians' and cyclists' travel behaviour and their "quality needs", which form the basic information utilised in the development of the "process and determinants of mobility related decisions" scientific framework, is presented. Afterwards, current available knowledge (as reported in the literature) related to transport planning and demand forecasting is summarised. Then, various methods for data collection, with main interest in walking and cycling trips, are presented. Finally, the knowledge gaps that form the basis and motivation of this research and its related methodology are highlighted.

2.1. Active mobility at a glance (international context)

Countries worldwide are rapidly evolving and adapting to today's globalised and competitive world. This is prevalent in the field of transport, an area where authorities and researchers in many countries/cities are advocating substantial efforts to develop sustainable and efficient transport networks. Around 1960s, private car usage was in vogue. Yet, the negative aspects of motorisation rapidly became hard to tolerate. The number of traffic accidents increased, air and noise pollution intensified, and people had more sedentary lifestyles (Banister, 2007; Jacobsen, et al., 2009; Tolley, 1990). In response, mass public transport and active modes of transport, mainly walking and cycling, began to be promoted. Active mobility involves space-efficient modes of transport that can help to reduce many of the negative aspects of motorisation while encouraging people to undertake some physical activities (Hatfield & Boufous, 2016; Pucher & Buehler, 2010; Song et al., 2013).

Research regarding active mobility is increasing rapidly, as shown in Figure 2.1, and the topic is being analysed from different perspectives and fields. Recognising benefits of active modes, countries from all continents are working hard to become walking- and cycling-centric countries/cities. European countries/cities, in general, still keep the lead, with Amsterdam (The Netherlands) being the "best walking city" and Copenhagen (Denmark) the "best cycling city" (Pucher & Buehler, 2008). In those cities, walking and cycling is an inherent activity to inhabitants and well-fitting infrastructure is provided accordingly. Countries like Singapore and Japan are going towards the same direction investing capital and efforts to the development of facilities for active modes and implementing programmes to encourage their use (Faiezah et al., 2012; Yamaguchi et al., 2008). Yet others have

not even started developing active mobility plans, like Paraguay. The best practices from successful cases serve as value-add guides for planning of walking and cycling transport; however, theoretical knowledge of walking and cycling planning remains limited (Koglin, 2015; Koglin & Rye, 2014).

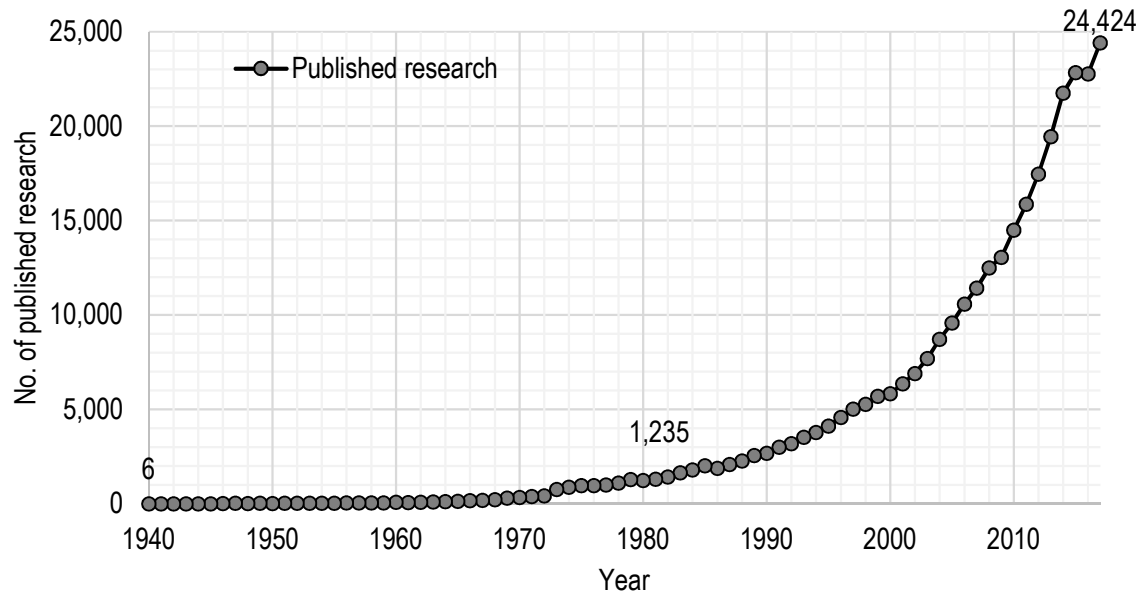


Figure 2.1. Research regarding active mobility – Scopus search in early 2018
(Keywords: Active mobility or walking or cycling)

Several researchers have studied walking and cycling infrastructure preferences (Cervero et al., 2009; Elias, 2015; Pizarro et al., 2016; Pucher & Buehler, 2008; Simons et al., 2014), with most focus being on cyclists using on-road facilities. Very few have considered mixed-stream active traffic (pedestrians, cyclists, and PMD riders sharing same off-road travelling/commuting off-road facility) on off-road facilities and how this affects overall active mobility, which is considered in this study. Preference and attendant travel behaviour vary a lot across age groups of users, with young adults being more inclined to adopt change to active modes of transport and assume different (better) lifestyles (Laska et al., 2009; Simons et al., 2014; Wang et al., 2016).

In addition to emerging systems, services related to active mobility are relaying more and more on technologies and usage of mobile Apps. In this regard, adult population, particularly the young adults, are again the “core” movers of such systems/services. Furthermore, research has highlighted that habit formation occurs at a rather young age (Yang, 2015). Thus, it is strategic to foster active mobility usage among the younger groups. Herein, certain areas of the present research focus on young users while some conclusions are applicable to the overall population. A specific line of research is

focused on developing schemes and programmes to entice users to shift to active modes of transport (Ermagun & Samimi, 2015; Zuniga, 2012).

The decision to shift to active modes of transport can occur at a personal level (e.g. to improve health condition or have a healthier lifestyle) and/or due to influence of external factors (e.g. provision of enabling infrastructure; newly implemented transport policies; influx of shared-bicycles). By increasing one's physical activity levels (by walking and/or cycling), a person can attain health benefits such as improved cardiovascular health and reduced obesity (Carver et al., 2014; Pucher & Buehler, 2010). Again, this is particularly important for the young adults group who have been found to be prone to inactivity and weight gain (Laska et al., 2009; Simons et al., 2014). Walking and cycling also engender social benefits such as increased interaction and neighbourhood cohesion (McDonald, 2007). Travel behaviour has a strong impact in demand for active mobility. Various methods that have been utilised for active mobility demand analysis and how they vary across countries and users are presented in Section 2.4.2.

2.2. Singapore's transport and travelling characteristics

Singapore is a small and densely-populated island country with 716 km² land area and 5.47 million habitants (SINGSTATS, 2014; Tham, 2014). With more than 12% of the available land dedicated to motorised transport infrastructure, mostly roads (Faezah et al., 2012; URA, 2013) and about 14% to housing, clearly, sustainable housing policies and space-efficient modes of transport are necessary. Making urban landscape and infrastructures environmentally friendly (Rojas López & Wong, 2018a), economically competitive and socially sustainable is one the principal challenges. Ever since the beginning of national developments, just over 50 years ago, Singapore has always put in place rigorous planning schemes. This has served to ensure efficient usage of limited land space.

Urban planning in the country is performed in two main streams: residential and urban planning, and transport and green spaces planning (Tay, 2009). Local agencies work in tandem to develop a scientific and rigorous inverted pyramid framework consisting of three layers of planning, where needs and preferences of the multi-ethnic population are considered in each layer (Meng et al., 2015; Rojas Lopez & Wong, 2017; Tay, 2009). Public housing programmes and policies related to development of green spaces, financial support and transport usage are designed, for unbiased implementation, in the master and detailed plans as described in Table 2.1

Table 2.1. Singapore urban planning framework (adapted from Meng et al., 2015b)

Layer	Planning period	Review period	Task
Concept plan (1 st Layer)	40 to 50 yrs.	Every 10 yrs.	Ensure land space is available to meet population & economic growth requirements
Master plan (2 nd Layer)	10 to 15 yrs.	Every 5 yrs.	Designate land use pattern & transport/mobility network layout
Detailed plan (3 rd Layer)	5 to 10 yrs.	Project based	Consider near-term developments based on current situations

Regarding housing, many high-rise residential buildings are developed for inhabitants to live in. Most of them are public housing complexes, also known Housing and Development Board (HDB) blocks, where more than 80% of the population resides. Singapore has been growing vertically, and in its efforts to avoid “vertical sprawl”, void decks have been introduced at the ground level of public housings (HDB, 2017; Rojas López & Wong, 2018a).

Void decks, as shown in Figure 2.2, are open spaces designated for social interaction and gathering, yet availability of these spaces has afforded a somehow unrestricted movement of active mobility users, especially pedestrians. Usage of these informal spaces (i.e. void decks, green areas, playgrounds) serve to reduce travel distance. Yet, the burgeoning population of active mobility users in informal spaces have impacts on accessibility. Thus, it is timely to develop policies and regulations for the use of such spaces (Rojas López & Wong, 2018a). A comprehensive review of formal mobility network, recreational mobility network and informal mobility spaces is presented in Appendix A which summarises active mobility spaces in Singapore’s urban planning landscape.

Singapore operates a world class public transport (mass rapid transit (MRT) system and buses) since 1991 (LTA, 2015e). The MRT has 200 km rail and 149 stations island wide (LTA, 2016c), in addition to a (mostly feeder) bus network serving the shorter-range travel between transport nodes and the residences. The public transport system is run on a distance-based fare determined on the total distance travelled regardless the number of transferred stations or modes (PTC, 2017), and is generally accessible to majority of the population. The efficiency and accessibility of the public transport system explains its high mode share of 44% on average and 67% mode share during peak periods and aiming to increase to 75% by 2030 (MOT, 2017). Also, MRT rails are being expanded so that by 2030, MRT stations are within 10 minutes’ walk for 80% of the households (LTA, 2015a),

which will further increase the active mobility demand that usually forms the first/last mile (FLM) trip-stages of public transport trips.



Figure 2.2. Void decks in Singapore

As part of the national agenda to foster “car-lite” travel, different types of infrastructures and facilities are provided for pedestrians and cyclists as well as PMD riders. Pedestrian infrastructure development has received strong attention since the early days of Singapore nation-building (LTA, 2011). Pathways are provided alongside most roadways while pedestrian crossings and overhead bridges are common infrastructure (Chin & Menon, 2015; Koh et al., 2014). In addition, sheltered footpaths are provided for areas with high levels of pedestrian traffic. This has resulted in an elevated walking rate of 22% usage as a main mode of transport (CLC; ULI, 2015; LTA, 2011).

For cycling, the construction of the Park Connector Network (PCN) in 1992, as means of providing recreational off-road cycling facilities, contributed to “reviving” cycling activities (when cycling mode share was close to zero) (CLC & ULI, 2015; Koh & Wong, 2012). Today, cycling takes up between 1% to 2% as a principal mode of transport (Cheong 2016) and authorities are continuing efforts to further increase cycling mode share. As the number of utilitarian cyclists and PMD riders on off-road facilities have rapidly increased in the last few years, footpaths (in the absence of dedicated cycling space) are jointly used by pedestrians, cyclists, and riders of PMDs (such as kick scooters, hoverboards, etc.) (Active Mobility Advisory Panel, 2016; Chin & Menon, 2015). Authorities are earnestly

improving the mixed-traffic infrastructure to enhance travelling convenience and safety by retro-fitting available pathways. Some footpaths (traditionally 1.5 metres wide) were widened, and in some cases, delineated or segregated paths were built (Meng et al., 2015; Nguyen et al., 2015). In addition, some on-road bicycle lanes were introduced at locations with relatively low motorised traffic. A variety of formal facilities used for active mobility in Singapore are shown in Figure 2.3.



Figure 2.3. Active mobility formal facilities in Singapore

Other related developments aimed at increasing active mobility include the Building Act that requires developers to facilitate access for walking and cycling (BCA, 2013) and the Walk-Cycle-Ride programme which encourages usage of active modes for the first/last mile (FLM) trip-stages to connect to the public transport (LTA, 2017b). Moreover, bicycle-sharing has been rolled out by several companies since early 2017 (Abdullah, 2017), all in the form of dock-less scheme, thereby

by-passing the traditional station-based system. By end of 2017, there were seven bicycle-sharing service providers, with bicycles available all over the nation which can be rented via a mobile phone App (Abdullah, 2018; Lim, 2017b). Using the App, nearby bicycles are presented on a map, so users can easily locate them. The rental cost is competitive against public transport distance-based fare.

To date, there are yet well-established policies related to the use of these shared bicycles in Singapore. It can be seen that travellers are drawn to using shared bicycles for travelling, and for FLM trip-stages, as many shared bicycles can be found parked at the MRT stations. Although the high growth rates have a positive effect in elevating the usage of bicycles, development of cycling infrastructure is progressing at a slower pace. This can be seen in the way people leave the bicycles “parked” haphazardly at random locations and even obstructing pedestrians’ rights-of-way (Hong, 2017; Tan, 2017) which is partly due to under-provision of parking spaces. To tackle this situation, one scheme consists of virtual bicycle parking stations that are demarcated by geo-fenced perimeters. This scheme is being implemented nationwide by mid-2018 (Hong, 2017; Ng, 2018). The implementation of this scheme has caused one of the seven company to withdraw their bicycles from Singapore as they found it hard to comply with the regulations.

Regardless the transport provisions, congestions and crowding at MRT trains and buses frequently occur, particularly during peak periods (7:00 – 9:00 and 17:30 – 19:30 hours). To ameliorate this situation, the Land Transport Authority (LTA) has introduced the “Travel Smart” Scheme in 2014. This scheme encourages companies to create flexi-travel environments (LTA, 2014). Employees of companies that have pledged to this scheme and companies themselves can obtain rewards based on a point-based system, with more points assigned to trips made during off-peak periods and fewer points to trips during peak period. Results have shown that around 12% of the involved travellers modified their travel behaviour to travel during off-peak periods (LTA, 2014). To date, not many companies participate in the Travel Smart scheme, and in general the programme is more focused on trips by public transport. Points are assigned per km travel (by public transport, walking or cycling), which makes the scheme much more attractive to public transport users than to pedestrians or cyclists who only travel a few km each trip.

Interestingly, while several recommendations and advisories for safe and respectful behaviour dedicated to pedestrians and cyclists have been applied, yet not many schemes or campaigns are implemented to promote walking or cycling in Singapore. Herein, authorities and stakeholders could assess the feasibility of implementing pro-active mobility campaigns based on users’ perceptions of the current environment and attitudes towards active mobility in general. Moreover, with the impetus

of on-going infrastructure upgrades and other improvements, one can expect some shift in users' perception, travel behaviour and actual usage of off-road paths. How all these factors affect travel demand remain to be well studied, which forms the motivation and basis of this research.

2.3. **User's quality needs and travel behaviour**

Most research studies agree that environmental characteristics of residential neighbourhoods play a big role in "shaping" the travel behaviour of pedestrians and cyclists (Cervero et al., 2009; Kemperman & Timmermans, 2014; Lewicka, 2005). In addition, some affirm that specific programmes and policies can motivate changes in behaviour, especially if these are targeted at specific groups and if users perceive that the provided infrastructure meets the required level-of-service (Dell'Olio et al., 2014; Song et al., 2013; Tolley, 1990; Zuniga, 2012). Thus, a deeper understanding of current and potential users' attitudes and preferences towards different active modes can help researchers and authorities to develop suitable transport schemes and attractive infrastructures for active mobility (Bordagaray et al., 2015; Hume et al., 2009; Ibeas et al., 2011; Nair, 2016). However, measurements of factors affecting travel behaviour (by all modes of transport) have shown to be difficult to quantify and these vary a lot from user to user (Alton et al., 2007; Beirão & Sarsfield, 2007; Cervero et al., 2009; Mfinanga, 2014).

Quality needs refer to infrastructural, personal, and social factors aimed at enhancing travelling experience and thus motivate a user to select a specific mode of transport. Quality needs are greatly affected by attitudes and preferences. Definition of attitudes and preferences varies a lot, for this thesis, attitudes refer to people predisposition to act (or not) in a particular way towards selecting a mode of transport and it is influenced by belief, perception, and opinion. While the last 3 are similar, belief is the acceptance of something without necessarily having reasons or proofs thereof, perception is the way something is understood or interpreted based on experiences or facts, and opinion refers to the expression of the judgment about a particular set of facts regarding something specific (e.g. mode of transport, infrastructure). Attitudes towards specific modes causes preference (higher priority or greater liking) for one mode of transport or infrastructure over others.

Travel behaviour is the "study" about the factors (and the relationship with each factor) that affect users and their households' mobility/travel characteristics (including quality needs) and commonly-described as a set of variables in a theoretical framework. Common factors that (positively) affect trip safety and comfort are mentioned as key travel quality needs. Researchers have advocated efforts to determine quality needs and provide schemes and policies to meet and support such needs

(Methorst et al., 2010). Economic, psychological, and social science theories and frameworks have been applied to describe travel behaviour (Fuller, 2005; Palanisamy, 1997; Primerano et al., 2008; Singleton & Clifton, 2015). From the economic theories, the most common technique is the utility maximisation theory – select the alternative that yields the highest utility (Ortúzar & Willumsen, 2011).

Recently, greater interest has been placed on the underlying processes that lead to a specific behaviour (e.g. “process-model” of selecting a specific mode of transport), with less interest placed on the outcome of a specific analysis or model (Alfonzo, 2005; Fujii & Kitamura, 2000). This is particularly true in the area of active mobility, where the limited literature has focused on the process-models, this aspect is covered in this thesis with the development of the PDMD framework. Psychological theories regarding behaviour introduces factors such as attitudes and preferences, suggesting that these have strong effect in the decision-making processes. Not surprisingly, most travel theories are drawn from the area of psychology (Cervero, 2002; Ogilvie et al., 2011; Primerano et al., 2008; Singleton & Clifton, 2015).

Moreover, geography theories have introduced a shift to activity patterns over decisions, where these theories (e.g. time-space prism and Chapin’s activity pattern model) have impacted the development of activity-based planning (Castiglione et al., 2015; Clifton et al., 2016). The general theories from these fields have led the development of specific travel behaviour theories, with focus on the process of transport-related choices. The most closely related to active mobility are the “Hierarchy of walking needs” (Alfonzo 2005) and the “Theory of travel decision-making” (Singleton, 2013). In addition, some theories have been developed to specifically describe children travel behaviour; Rojas Lopez and Wong (2016) presented a good review of those theories. Some of the main theories that have been applied in studies related to travel behaviour or decision-making are presented in Table 2.2. Many other theories have been utilised, but the ones mentioned in the table can be considered the main and the most influential ones for travel behaviour studies

Some travel behaviour theories are based on local characteristics, making them hard to apply across different populations and countries. This is particularly true in cases where the local context differentiates greatly from another city/country in the world such as the case of Singapore. The tropical island of Singapore does not only present a unique urban layout, with high-rise buildings and ubiquitous presence of void decks, but also has unique transport settings with active mobility users sharing off-road mobility spaces. In addition, the vehicle ownership level and public transport usage is different from most places in the world. Thus, there is a need for the development of a scientific framework that takes into consideration different environments and thus can be applied for different

(or even contrasting) local contexts. This thesis introduces the PDMD framework, a dynamic framework (accounting for effects of individual characteristics, built environment and others into travel behaviour) where the factors that are applicable in the Singapore's context are highlighted. Section 3.2 contains the comprehensive review of the methodology, while details on model build-up and findings are covered in Chapter 4.

Table 2.2. Main theories that have been utilised in travel behaviour or decision-making studies

Theory	Year	Possible application in transport	Field
Random utility maximisation theory	1970	Choice modelling	Economy
Activity pattern model	2000	Decision process analysis	Geography
Time-space prism	1974	Spatial movement analysis	
Comprehensive action determination model	2010	Decision process analysis	Psychology
Integrated behavioural model (IBM)	2008	Decision process analysis (partial model only)	
Theory of planned behaviour (TPB)	1991	Choice modelling / Decision process analysis	
Theory of repeated behaviour (TRB)	1989	Decision process analysis	
Social cognitive theory	1986	Decision process analysis	
Normative decision-making model	1981	Choice modelling	
Theory of intrapersonal behaviour (TIB)	1977	Choice modelling	
Theory of reasoned action (TRA)	1975	Decision process analysis	
Theory of human motivation (hierarchy of needs)	1943	Decision process analysis	
Hierarchy of walking needs	2005	Choice modelling / Decision process analysis	Transport
Theory of routine mode choice decision	2013	Choice modelling	
Theory of travel decision-making	2013	Choice modelling / Decision process analysis	

Provisions of facilities for walking and cycling, locally and elsewhere, are mostly developed considering acceptable levels of safety and convenience. In addition, several policies exist to encourage users to make use of these active modes for short trips or for constituent stage(s) of longer trips. However, in contrast with facilities provisions for motorised transport especially public transport facilities, facilities and policies for active modes are rarely set to be “market-oriented” and able to compete with motorised modes of transport. To determine strengths and weaknesses of the active mobility transport network, it is essential to understand attitudes of pedestrians and cyclists for

prevailing conditions. Such knowledge can help policymakers and authorities to evaluate the level-of-service of current active mobility network. In addition, it can be used to: [1] estimate the importance of service improvements from users' perception, and [2] develop transport schemes, infrastructures, and policies, aimed to increase the "market share", i.e. number of pedestrians and cyclists.

2.4. Transport planning and demand analysis

Transport planning provides information about the impact of different transport alternatives on current and future traffic. It considers land use investments and policies, as well as demographic and socio-economic trends (Barnes & Davis, 1999; Castiglione et al., 2015). The main input for transport planning is demand analysis which is based on collected data. This section summarises characteristics of different transport planning approaches and currently-used techniques for demand analysis, with main interest on walking and cycling trips.

2.4.1. Transport planning approaches

Previously, the focus of transport planning was on motorised modes of transport (Wedderburn, 2015), being trip-based planning widely used for analysing and predicting inter-city motorised traffic. However, planners are now searching for well-fitting alternatives to accommodate active mobility users (Braun et al., 2016; Koglin & Rye, 2014). Indeed, in some countries, pedestrians and cyclists have become the core of planning attention since 1990s (Gössling et al., 2016; Koike et al., 2000; Pucher & Buehler, 2008). Commonly-used transport planning techniques and their applicability for active modes planning in the local and international context are summarised in Table 2.3. In addition, specialised models and techniques have been developed by international researchers and planners to account for local factors.

Conventionally, cyclists share roadway space with motorised vehicles while riding on the roads, with or without bicycle lanes. In a few places (countries/cities), for example Singapore, most cyclists ride on footpaths amidst the pedestrians or on off-road cycling tracks. Limited knowledge and techniques have been reported to plan for active trips and/or to estimate (accurately) future demand for walking and cycling as an integral part of transport and let alone demand estimation for PMDs ridership. In effect, pedestrians and cyclists sharing transport facilities is an uncommon phenomenon. At the same time, active mobility is still under-represented in most transport planning tools, e.g. data collection, analysis, and modelling stages. Different types of planning can be used to assess feasibility of transport alternatives.

Table 2.3. *Types of transport planning (adapted from FHWA, 1999b)*

Types of transport planning	Pros	Cons	Data requirements
Sketch planning	Relatively simple to apply	Low sensitivity to other factors; rely on general assumption	Variety of existing sources: census, local land use databases
Strategic planning	Simple statistical requirements; easy to apply	Low explanatory power; not transferable; ignores influences of other factors	Active mode counts; Surrounding population and land uses
Activity-based planning	Detailed prediction of activity and travel	Complicated; require big amount of data collection; dedicated software and longer running time	Detailed personal & household activity patterns; Infrastructure/ facility characteristics; Socio-economic & land use data
Trip-based planning	Commonly accepted; thorough prediction of traffic – volume, modes, flow; potentially high sensitivity to design factors	Complicated; require big amount of data collection; more application in motorised transport forecast; much depend on data availability & quality of data	Personal & household travel patterns; Infrastructure/ facility characteristics; Socio-economic and land use data

Sketch planning is one of the simplest transport planning techniques. It is designed to obtain fast responses that can be used to draw conclusions even with small sample sizes. For this reason, the approach relies heavily on travel assumptions (e.g. regularities in human movement on transport network) and transfer of parameters from a specific area or context to another (Castiglione et al., 2015; FHWA, 1999b; Ortúzar & Willumsen, 2011). However, parameters established for a specific area/context are rarely applicable to other areas/contexts. Assumptions and such transfers limit the applicability of sketch planning. The method is more commonly-used to analyse specific policies and not for large-scale longer-term policies. It is also used as an initial (coarse) stage of planning to select alternatives for more detailed consideration. For instance, it has been previously used to estimate pedestrian activity at shopping centres and usage of bicycle lanes (FHWA, 1999b; Griffin, 2009; Porter et al., 1999).

Strategic planning is a straight-forward planning technique that considers specific details of an area of analysis. It is commonly-used when a rapid analysis of different scenarios is required. This technique is relatively cheap, easy to apply, and useful for testing different transport schemes/policies and infrastructure investment alternatives (FHWA, 1999b; Richardson et al. 2005; van Houten & Seiderman, 2005). There are two types of study commonly-used in strategic planning: [1] before-and-after study; and [2] similar-condition study. By being simple, easy to understand, and with low data requirements, strategic planning is advantageous and widely used. However, its inability to isolate specific effects of specific factors, such as the effect of improvement of infrastructure itself rather than in combination with other factors in the area, makes the technique's scope overly narrow, thus limiting its application.

The two types of studies involved in strategic planning that have been applied to measure transport schemes that affect active mobility are:

- “Before-and-after” study which compares level of walking and cycling activity before, during, and after improvement of infrastructure or facilities. Such type of study has been commonly used in Europe and in Singapore to estimate mode choice and perception impact of different programmes targeting active mobility users (FHWA, 1999b; Wedderburn, 2015). One local example is the ongoing project “Before-and-After Evaluation of Implementing Bicycle-Centric Infrastructure in a Township” (Shi et al., 2016).
- “Similar-condition” study which compares travel levels at a specific location or facility and uses this as a base to estimate pedestrian and/or cyclist traffic at a proposed facility with similar characteristics (FHWA, 1999a).

Activity-based planning focuses on activity generation (rather than trip generation), and trips are considered as a consequence of the activity. It works at disaggregated (person) level, incorporating person-level and household-level attributes (Castiglione et al., 2015) and it can help to explain trip characteristics, time constraints, and the linkages among activities and travel. In addition, using activity-based data, specific issues and its relation to activity participation – such as environmental issues (e.g. emissions and exposure to pollution), and road pricing – can be efficiently and accurately modelled (Asri & Hidayat, 2005; Ortúzar & Willumsen, 2011c). Activity-based modes do have big data requirements on individuals’ activity participation, which may not always be available/accessible (Castiglione et al., 2015; Ortúzar & Willumsen, 2011).

Trip-based planning or regional travel planning is most commonly referred as four-step model (4SM). This approach includes four primary components presented in Figure 2.4: trip generation, trip distribution, mode choice or split, and route choice or assignment. At the 4SM, trip-chains are usually treated as independent entries from a particular user, thereby failing to recognise the relationship among different trips. The 4SM usually works at an aggregate (zonal) level. It relates characteristics of an area (e.g., population, employment, or average income) to travel characteristics of that area (e.g., average number of trips per household, or the number or proportion of trips made on foot or by bicycle) (McNally, 2007; Ortúzar & Willumsen, 2011; Train, 2009).

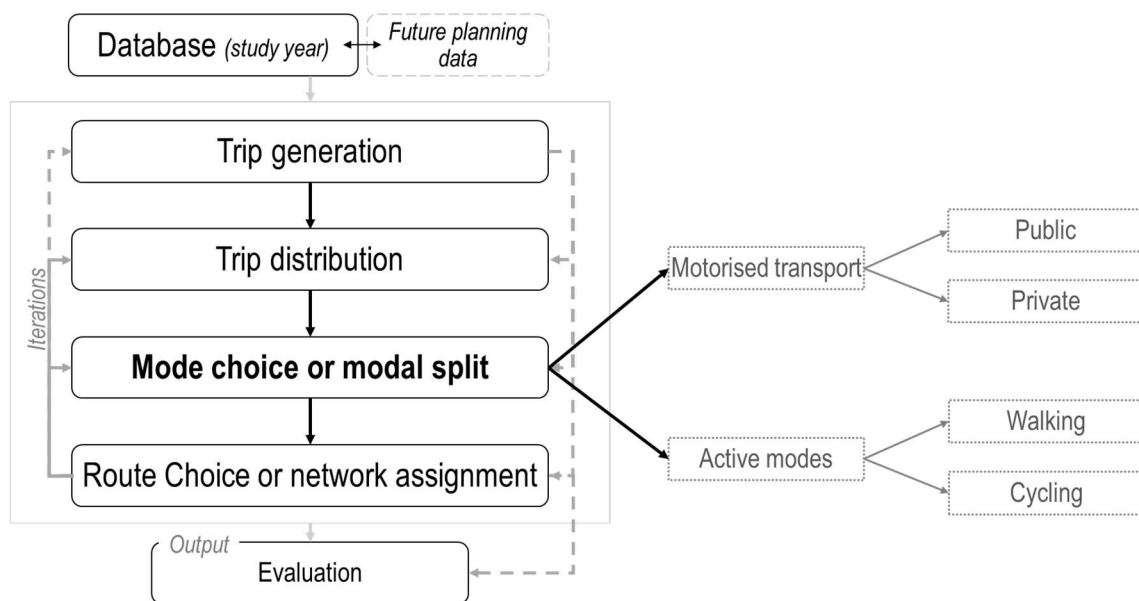


Figure 2.4. Traditional 4SM transport model (adapted from Ortúzar & Willumsen, 2011)

Using this approach, various aspects of travel pattern are integrated, such as mode choice with information about geographical land use, or transport network and socio-economic conditions. This is generally used to forecast how travel patterns will change as a result of changes in transport conditions (Porter et al., 1999). This planning method was originally developed for general transport planning, especially motorised transport. However, modifications (mainly at methodology used for analysing mode and route choice) have been made so that it can include active mobility as an integral part of the transport network. This allows researchers to forecast walking and cycling trip demand (Ahmed, 2012; FHWA, 1999b; Train, 2009). In addition, this model can be used to examine the relationship between specific factors, such as effects of age or gender, on preferred route.

The 4SM also requires extensive area and individual information which, while not always be available, is usually gathered from large-scale travel surveys (e.g. Household Interview Travel Survey (HITS)

in Singapore) (Griffin, 2009; McNally, 2007). It is noted that travel surveys can oversee some recreational trips. Another limitation of the method is the complexity and time requirement to modify or adjust model to consider local conditions, and these limitations can be overcome with comprehensive data collection and strong modelling techniques. Cities in United States of America (USA), Canada, and Europe have successfully developed projects using the 4SM to estimate active mobility usage (FHWA, 1999a), although many are still facing high error percentage.

A pertinent dimension of mobility planning is concerned with the politics of mobility which refers to the environment and social relations forming the space where mobility takes place and how these affect transport planning (and not to matters handled by politicians) (Cresswell, 2010). The “modified politics of cycling mobility” or vélomobility politics highlights the need to: [1] provide obstacle-free movement (cycling) facilities; [2] consider interaction between different groups that share facilities; and [3] positively represents cycling as a mode of transport (Cresswell, 2010; Koglin, 2015). The first point is mainly related with infrastructure provision and the remaining two are/can be addressed by planning, service provision, and policy development. Some of the possible services, policies, and programmes are discussed in this study, and these are considered as different scenarios under demand analysis as presented in Chapter 6. In Singapore, most cycling activity takes place off-road in which attendant facility is jointly used (on shared-facility basis) by all active mobility modes while authorities are earnestly improving such mixed-traffic infrastructure to enhance travelling convenience and safety. Herein, policies related to codes of conducts and regulations about travelling speed have been implemented recently (Active Mobility Advisory Panel, 2016).

2.4.2. Demand analysis techniques

Planning and demand analysis goes hand-in-hand. For planning, many demand analysis models for active transport are subservient upon motorised-mode models (Cervero & Kockelman, 1997; Clifton et al., 2015). In other words, limited knowledge and techniques have been reported to (accurately) model current and future/modified demand for walking and cycling trips, let alone scenarios where pedestrians and cyclists share off-road facilities, along pathways and crossings, as necessitated by the limited land space in Singapore. Several of the descriptive and predictive models mentioned entail a set of steps and specific data analysis techniques that yield an estimation of current demand and future analysis. Output of demand analysis is commonly the trip rates performed by the (generalised) population (de Jong et al., 2007; Saadi et al., 2016). Number of trips can be presented by modes, time of the day, infrastructure facility and so on and these are forecasted for a specific timeline based on evolving situations on the analysis area. Demand analysis and forecasting is as

accurate as the input data and is usually judged based on the validation outcome of utilised equations and the operational framework derived from findings (Chen et al., 2010; Erath et al., 2012; Kuzmyak et al., 2014).

Countless techniques and mathematical/statistical structures have been utilised for transport demand analysis. Most of them are based on personal and trip information (e.g. income, household size, vehicle ownership, trip distance, travel time, etc.), perceived factors (e.g. safety, level of service, trip comfort, accessibility, etc.), and local context data (e.g. population and employment, land use, access to transit, etc.), observed or reported travel behaviour in the area, with application of extensive statistical analysis (Clifton et al., 2013; Singleton, 2013). Research has demonstrated that demand for walking and cycling trips are highly affected by geographical characteristics (e.g. location, type, intensity of land use, distance away from active travelling facilities, etc.). Transport planning approaches are now more comprehensive and include walking and cycling as part of transport model, giving these modes the same priorities as motorised modes.

As mentioned, models can be descriptive or predictive. Descriptive models are usually concerned in reviewing available data which are classified or summarised to present a clear description of what have happened in the past (a decade ago, year ago, yesterday, etc.). Predictive models on the other hand, as hinted by the name, study historical data to make predictions about the future. These are probabilistic by nature and utilise available data to predict unknown future outcomes. In essence, descriptive analysis is a prerequisite for predictive models (Ortúzar & Willumsen, 2011; Richardson et al., 1995; Train, 2014).

Furthermore, models can also be prescriptive, which is a type of descriptive analysis that considers different actions and shows the likely (future) outcome. The model is usually selected based on desired outcome and type of data or variables under consideration. Variables can be parametric or non-parametric and researchers have utilised both types of variables. Those who suggest the use of non-parametric variables argue that these can yield more accurate outcomes for noisy and chaotic settings and they are computationally less demanding (Jabot, 2015; Smith et al., 2002). However, as less information is available, developed models can be weak, thus, these are not so suitable for forecasting. In contrast, those advocating usage of parametric variables do so because these provide more theoretical understanding and the failure probability can be checked using simple statistical models (Clark et al., 2002; Lewbel & Linton, 2002; Smith et al., 2002).

Statistical approaches, computer-intelligence or a combination of both methods are commonly used for transport analysis. Neural networks (NN) are computer-intelligent models that have been utilised for accurate and convenient demand analysis and forecasting (Dougherty, 1995; Hinton & Nowlan, 1987). The common neural network models are those with a structural flexibility that allows for the construction of powerful models (Edara, 2003; Karlaftis & Vlahogianni, 2011). While transport researchers commonly may apply one method over another, these methods have certain similarities as shown in Table 2.4.

Table 2.4. Comparing Neural Network and Statistical Approaches

(adapted from Cantarella & de Luca, 2003; Frosst & Hinton, 2017; Karlaftis & Vlahogianni, 2011)

	Neural Networks	Statistical Approaches
Terms	• Input/output • Training values • Errors • Training, learning, adaptation • Error function, cost function • Patterns or training pairs • Weights • Neuron orders • Functional links • Supervised learning • Unsupervised learning • Competitive learning	• Independent/predicted variable • Dependent variables • Residuals • Estimation • Estimation criterion • Observations • Parameter estimates • Interactions • Transformations • Regression-discriminant analysis • Data reduction • Cluster analysis
Procedures	1. Problem definition & formulation 2. Collection, pre-processing & partition 3. Architecture-learning type selection 4. Structural & learning optimisation 5. Evaluation using test data set, comparison with other methods	1. Problem definition & formulation 2. Collection & pre-processing 3. Selection of close-form equation 4. Parameter estimation 5. Testing using goodness-of-fit tests & residual examination
Topology	• Feed-forward NN - 0 hidden layer • Feed-forward NN - 3 hidden layers • Generalised regression NN • Probabilistic NN • Competitive learning networks	• Generalised linear models • Projection pursuit regression • Kernel regression • Kernel discriminant analysis • k-mean clustering

Neural network has been utilised for time-series predictions (e.g. traffic volume, moving speed, etc.), planning, and infrastructure management. Some literature (Lingras, et al., 2000; Tseng et al., 2002; Vlahogianni et al., 2004; Zhong et al., 2005) suggests that, for complex data with possible non-linearity/missing data, neural networks are preferred over statistical approaches and can be more reliable for multiple-step ahead predictions due to its constraint-free form (Chen et al., 2001; Dougherty, 1995; Edara, 2003; Stathopoulos et al., 2008). However, there are cases when statistical models can outperform neural network models due to neural network's limited explanatory power (high accuracy but not necessarily clear "explanation"). Hybrid structures (e.g. neural network in combination with discrete choice model) have also been suggested, especially for short-term flow prediction, and these have shown improved results in modelling datasets from different dimensions and developing models with several external parameters (Cantarella & de Luca, 2003; Chen et al., 2001; Chen et al., 2016; Karlaftis & Vlahogianni, 2011).

While some have already incorporated the use of neural networks into different steps of the 4SM (Edara et al., 2003; Rasouli & Nikraz, 2013), fewer have utilised it to specifically analyse active travel demand. The author foresees the usage of this method as a suitable alternative to handle the complexity of active travel behaviour. Potentially, neural network could be better able to mimic active travel behaviour within hidden layers and suggest suitable outcomes (output). In most domains, including travel demand analysis, the estimation of a heterogeneous model is a main task. With increasing access to data, this is more and more accomplishable, and many have suggested approaches to use machine learning (including neural networks) to do so (R. Chen, 2018).

Neural networks can be of different architectures and several types of training functions can be used to train the model. Specific details of neural network set-up for this thesis and modelling for active travel demand analysis is presented in Section 3.3.

2.5. **Travel data collection and active trips**

Sample size and sample selection should be carefully considered in travel demand analysis as these should be representative of the overall population. In most cases, population size is reviewed (or estimated) and a sampling method that ensures that participants (individuals or households) are randomly selected, yet representative of the study population, is developed (Ampt et al., 2008; Kim & Susilo, 2013; Ortúzar & Willumsen, 2011). This ensures that different attributes (e.g. income, perception, etc.) of a population, which are not economically or technically feasible to survey in totality, are represented (Ortúzar & Willumsen, 2011).

Sampling stratification methods are commonly developed taking population, type of housing, transport infrastructure, and type of transport users at each area of study into consideration (Ortúzar et al., 2000). When modelling active mobility demand, a balance between representation of population and big enough sample size to achieve statistically significant findings shall be considered (Griffin, 2009; Maligalig & Martinez, 2013).

Transport behaviour is rapidly changing due to people shifting to sustainable and/or active modes of transport for full-trips or trip-stages (Koh & Wong, 2015; Ogilvie et al., 2004; Wedderburn, 2015). Thus, data collected from household travel surveys, or similar approaches, needs to be judiciously reviewed. Previously, (as in planning and demand analysis) travel data was mostly focused on motorised transport and the model outcome was the main interest. Nowadays, elaborate transport models are developed with main interest on the processes of travel choices (travel behaviour) (Jahanshahi & Hall, 2013).

“Process-models” (with adequate data) serve to delineate travel behaviour with respect to different modes of transport and elicit impact of emerging transport technologies such as electric and autonomous vehicles. These modes have different data requirements (Cervero & Kockelman, 1997; Stopher & Greaves, 2007). In addition, thinking and decision-making are elaborate processes that are often difficult to quantify. Researchers and planners are on the constant search to collect high quality and comprehensive datasets without increasing too much burden on the surveys (which will again reduce quality of data).

To select the most suitable technique for each research project, the mode of transport under study, area of interest (geographical and social conditions), and type of model to be developed using the data, should be considered (Richardson et al., 1995). Household travel survey or home interview, intercept survey, and traffic counts are the most widely-used approaches to collect travel data. Household travel surveys are conducted on a regular basis to gather information that can help to shed light into people travel behaviour and its relationship between personal, local and social characteristics (Kitamura & Susilo, 2005; Sperry et al., 2012; Stopher & Greaves, 2007). A typical household survey is shown in Figure 2.5. Travel data is utilised as input for planning methods and policy developments, while noting that models can only be as good as the dataset from which it is based on (Dharmowijoyo et al., 2015; Train, 2014).



Figure 2.5. Ongoing household travel survey in Singapore

Different survey approaches can be conducted using different instruments and approaches as highlighted in Table 2.5. Further description of each type of survey is given in Section 2.5.1. Face-to-face household surveys, using travel diaries, can be said to be one of the best approaches to gather sufficient data for transport planning and demand analysis (Behrens & Masaoe, 2009; Cervero & Kockelman, 1997; Golob, 1998). Household interview surveys can retrieve detailed travel and demographic data, especially when questionnaires are carefully developed to fully capture the required information. Data collected from home interviews have been used internationally and locally to: [1] identify performance level of current transport network by understanding current situation; and [2] to strategically develop transport models (Ampt et al., 2008; Ortúzar & Willumsen, 2011).

Face-to-face household surveys involve big mobilisation of manpower, transport cost, and elevated honoraria for participants (i.e. are costly). Moreover, households (or household members) are becoming harder to reach thus compromising data quality (e.g. by “oversampling” households with similar characteristics) and the models developed from it. In addition, the growing use of diary methods has brought to light a number of problems of travel definitions such as: the definition of a trip (e.g. minimum length, activities which do/do not count as a trip terminator, as there may be an element of self-censorship in travel diaries, whereby respondents exclude journeys either because they were not construed as travel (e.g. popping down the road to see a friend), or were felt too trivial or rare an event to record); the definition of trip purpose (e.g. should one record the ultimate purpose

of serve passenger trips?); and the method by which multi-purpose stops are handled (e.g. should one allow for the recording of several activities at one destination?) (Ampt et al., 1985).

Table 2.5. Data collection methods, instruments and approaches

Methods	Instruments	Approaches
Household surveys	Travel diaries	Face-to-face interviews, telephonic interviews, self-completed forms, online surveys
Intercept surveys	Short questionnaires	Face-to-face interviews, telephonic interviews, self-completed forms, online surveys
Tracking and counts	Sensors/ trackers, manual counts	Screen line surveys, location specific sensors, GPS tracking

To tackle these issues, several survey approaches have been tested, such as mail-back (self-response) surveys, electronic (self-response) surveys, telephone surveys, and travel tracking. In some cases, household surveys are complemented with other smaller-scale intercept surveys to further strengthen the quality of the data and gain a deeper understanding regarding relationship between travel behaviour and specific factors (e.g. built-environment variables) as described in Section 2.5.1. While improving on some issues, these hybridised techniques have negativities. Some of these have been shown to be successful only for certain groups. Also, using these approaches, trips are commonly under-reported, and/or there are technology-related issues that make data unreliable (Litman, 2009; Wolf, 2000; Wolf et al., 2003). Another issue, mainly with self-response surveys, is the tendency of people to round travel times to nearest 5, 10, 15mins, which has effects in travel demand analysis and forecast (Mori et al., 2015; Susilo & Dijst, 2009). This is particularly pertinent to the increasing number of active trips, such as walking and cycling, that are commonly short trips. An under/over estimation of travel time can translate into under/over provision of infrastructure and affect related transport policies. Thus, household travel surveys, despite possible negativities, are still widely used.

Some have successfully introduced the use of mobile Apps as means to collect travel behaviour, and thus trip characteristics, information (Prelipean, 2018). This is a promising approach that could be used to collect big data with little survey burden. Yet, it must be noted that at initial stages, high involvement of the users is necessary to annotate information into the Apps, such as activity type,

correct mode of transport, to improve performance and for future inferences. In addition, as tracking system of the Apps is based on GPS signal, it is likely that tracking accuracy might be reduced in areas with high rise buildings such as Singapore. This technology limitation is likely to be overcome soon based on improvements of GPS tracking. Another limitation is the access to mobile phones; while most adults and young adults spend high amounts of time caring their mobile phones, the same is not true for children and elders.

Household travel surveys vary a lot from country to country and there is no 'one size fits all' technique. While best practices vary across countries/cities, survey approach and/or data (to be) collected can serve as guidelines to develop strong state-of-the-practice household travel surveys. A comprehensive review of household interview surveys in cities and countries with elevated walking and cycling trips and/or characteristics similar to those in Singapore is presented in Appendix B that presents a review of international and local practices on interview surveys. Surveys from Sydney, London, Tokyo, Hong Kong, The Netherlands, Denmark, Germany and Singapore are reviewed. As mentioned, countries are adapting their surveys to cope with data requirements of evolving transport models. It must be highlighted that a need exists for a specific survey or survey section focussed on walking and cycling modes of transport. Travel diaries are the most common data collection instruments utilised for household surveys. There are three types of travel diaries: trip-based, activity-based, and place-based diaries (Behrens & Masaoe, 2009; Bolger et al., 2003; Prelipcean et al., 2015; Stopher & Greaves, 2007). Although all these travel diaries share similarities, they differ in specific points making one or the other more suitable for different types of modelling.

Trip-based diary was the first travel diary designed (1960s), focusing mainly on trip characteristics from one location (origin – O) to another (destination – D) throughout a specific time period (Behrens & Masaoe, 2009; Bolger et al., 2003). Over time, researchers shifted the focus to activities rather than trips. All information, including travel time, location, modes of transport related to activities is recorded using **activity-based diary**. This type of diary was found to be more efficient in recording the totality of the trips made (Behrens & Masaoe, 2009; Stopher & Greaves, 2007). Moreover, around 1990s, trip-based and activity-based travel survey diaries were combined leading to the **place-based diary**. This diary requires participants to report all trips in chronological order according to the activities on that day (Behrens & Masaoe, 2009; Susilo & Cats, 2014). The rationale behind both the activity-based and place-based diaries is that respondents are better at remembering their activities or visited locations than they are at recalling all of their trips (Hoogendoorn-Lanser et al., 2015). Main characteristics and differences of the travel diaries are presented in Table 2.6.

Initially, most questions in these types of surveys were focused on motorised trips. Yet, today, questionnaire varies according to mode of transport and area under study (Ampt & Hickman, 2015; Ortúzar & Willumsen, 2011; Richardson et al., 1995). During a conventional home-interview travel survey, interviewers record trip information by asking respondents to recall details of their travel behaviour for a pre-determined time period (usually 1 day). Commonly, diaries are completed by surveyors based on information provided by respondents (Prelipcean et al., 2015). Using this technique, interviewer can prompt respondents to report majority of trips and trip-stages. Yet, this comes with the challenge of remembering which trips/activities were made in the past (even just yesterday) (Clifton & Muhs, 2012; Prelipcean et al., 2015; Stopher & Greaves, 2007). Alternatively, diaries can be handed to participants and respondents are asked to complete the diary (self-response survey) for the following day as they do/complete trips or activities. This can help to reduce survey burden, yet incomplete recording remains an issue. Additionally, this approach further elevates the survey cost as it requires interviewers to travel back to participants' households to collect the diaries.

Table 2.6. Type of travel diary (adapted from Behrens & Masaoe, 2009)

	Trip-based	Activity-based	Place-based
Main focus	Origin-to-destination trips movement	Activities of a day in chronological order	Trip movements in chronological order across a specific period
Secondary focus	Trip purpose	Trip movements related to an activity	—
Strength	Provides detailed trip information data Earliest form of travel diary	Improves recall of trips as compared to trip-based; Provides understanding about daily activities within which travel decisions are embedded, thus, can predict users' changes in the transport system	Improves recall of trips as compared to trip-based
Points for consideration	Trips might not be ordered chronologically; Trip-stages can be under-reported <i>(not remembered/not considered a trip)</i>	Survey time and cost can be longer/higher as compared to trip-based diaries <i>(as more information is collected)</i> ; Detailed analysis required to classify some activities and trips <i>(e.g. dropping-off someone; jogging; walking the pet)</i>	
Variation	<u>Stage-based</u> : considering each O-D stage as a trip	—	<u>Stage-based</u> : considering each O-D stage as a trip

Some researchers and planners have considered the possibility of creating synthetic travel data by including currently known characteristics, such as individual demographics, geographical variables

and transport system characteristics, and accounting for variability in the generation phase (Au, 2016; Kitamura et al., 2000; Stopher & Greaves, 2007). This approach could greatly reduce the use of resources for data collection which makes it particularly appealing. Indeed, some research studies have explored this approach using Monte Carlo Simulation techniques to generate artificial travel data for individuals and/or households (Au, 2016; Kitamura et al., 2000). The approach creates data based on needs of traditional transport models. Research can be expanded by including information that could be value add for process-models and those that account for travel behaviour theories. Simulated data can then be modelled using statistical approaches and/or neural networks, and output can be compared to estimate usefulness of the data and analysis techniques.

2.5.1. Types of survey for travel data

While household surveys using the face-to-face approach and diary survey are likely to remain as the key instruments to collect survey data, there are several alternatives, many with promising potentials, to complement current reliance on such surveys and approaches. Commonly-used survey approaches and their advantages and disadvantages are described in Table 2.7. and further explored in this section.

The **face-to-face survey** approach, although relatively/somewhat expensive, can provide detailed travel data (or other types of data required for specific study) and thus increases modelling and/or forecasting accuracy (Koh & Wong, 2013; Ryan et al., 2009; Susilo et al., 2015). **Telephonic interviews** can also provide detailed information about travelling and are cheaper than face-to-face interviews. However, no personal observations can be made regarding respondent's characteristics/reactions and the interviewed sample is biased towards those who own a telephone (Ham et al., 2005; Ryan et al., 2009). Face-to-face and telephonic interviews are commonly completed by the interviewer. Surveys can also be designed for the respondents to self-complete. These surveys usually have fewer questions and are targeted to specific users. Participants can be approached at locations of interest (intercept survey) and/or **via mail for self-completion**. Such surveys can be administered in a quick manner. A limitation is the low response rate and sampling bias (Ampt et al., 2008; Richardson et al., 1995).

Surveys can also be administered online. **Online survey** is an economical alternative that can provide a swift result. The main issue with this type of survey is again the sampling bias (e.g. centric to young generation, computer users, etc.). Online survey can be carefully designed to overcome this bias (Boarnet et al., 2003; Hatfield & Boufous, 2016; Prelipcean, 2018; Rybarczyk & Gallagher,

2014). Mixed-technique approach may be introduced and implemented to prevent/minimise possible under-coverage of certain groups and the selection bias resulting from excluding certain groups (e.g. people who have no access to computers and/or the Internet) (Clifton & Muhs, 2012; Hoogendoorn-Lanser et al., 2015).

Table 2.7. Commonly used survey approaches

Survey type	Advantage(s)	Disadvantage(s)
Face-to-face interview (at households)	Possible to provide explanations & make observations; detailed information (increased accuracy); improved sampling rate	Expensive; interviewer training
Telephonic interviews	Detailed information; cheap	No personal observations; sampling bias
Self-completed	Cheaper per respondent; increased anonymity; quicker results	Low response rate; sampling bias
Online surveys	Cheap; quicker results; fast data processing	Sampling bias; need computing expertise
GPS surveys	Can provide detailed travel data (single day travel data or multiple day travel data) with minimum survey-burden to respondent	Sample bias; data loss & confidentiality issues; inaccurate tracking; relatively high cost; extensive analysis requirement
Panel surveys	Detailed data; effective record of changing patterns/behaviour over time	Low (<i>long-term</i>) recruitment rate; high cost; higher time requirement (<i>especially for longer term surveys</i>)

Many have aimed at combining traditional survey techniques with emerging technologies to simplify data collection and strengthen quality of data. Perhaps the clearest example in the literature is the use of **geographical position system (GPS) surveys**. For these surveys, GPS devices or GPS signals are used to track individual trips (Rasmussen et al., 2015). USA, Australia, Sweden and Netherlands are some of the countries that have undertaken these surveys (Stopher & Greaves, 2007). Using GPS devices have several benefits: [1] they are small and easy to carry by survey participants and they have relatively high storage capacity; [2] can provide much more than just origin-destination information whereby, travel speed, distance, elevation, and even trip purposes can be derived; and [3] data can be collected over several days without increasing survey cost or burden the participant so much (Wolf, 2000; Wolf et al., 2003).

There are some negative aspects of these surveys. GPS signal can be “lost” or there are cases of signal degradation due to the location, such as underground locations, under tree canopies, or at very dense road networks. While data “noise” can be filtered out, questions regarding the accuracy of the data remain. This is especially relevant for provision of infrastructures based on demand (Stopher & Greaves, 2007; Wolf, 2000) and is also of concern in scenarios such as in Singapore where void decks which are used as thoroughfare by active mobility users are heavily shielded from GPS coverage.

Moreover, using GPS survey, while mode of transport can be deduced based on travelling speed, issues arise during peak periods (e.g. bus mode can be as slow as pedestrians and even slower than bicycles). This is something that can be assessed by double checking with the respondent and/or based on the travel path. Moreover, while the use of GPS can provide substantial amount of travel data, the motivation behind these travel activities remain unclear. There is however, merit in combining GPS survey with traditional face-to-face interview surveys.

Panel or longitudinal surveys are those which repeatedly investigate (collect data from) the same variables/factors over short or long periods of time. These are commonly used in several fields of studies and are the most common in medicine and physiology (Bliemer & Rose, 2010; Schlich & Axhausen, 2003; Stopher & Greaves, 2007). In transport studies, the method has been gaining popularity since 1980s (Pass, 1985), mainly for smaller-scale panel surveys, such as those focused on a specific population or adaptation to a mode/infrastructure and travel pattern (Bliemer & Rose, 2010; Dharmowijoyo et al., 2015; Simma & Axhausen, 2003; Vij, Carrel, & Walker, 2013). The main benefit of the method is that it can provide detailed data for effective modelling of changing patterns/behaviour over time. One point for consideration is that panel surveys can have data variability, making it difficult to compare across different periods of survey. Thus, a strong research methodology with sufficient “forward planning” shall be designed prior to data collection. It should also be noted that it can be challenging to recruit and maintain a stable sampling group (for several years) and come with elevated costs. The usage of this technique shall be decided based on characteristics of the population under study and considering the available assets (manpower, data access, etc.).

2.5.2. Capturing and representing active trips

A trip, in transport planning, is commonly defined as one-way movement from an origin (O) to a destination (D), as commonly referring to a motorised trip (Ortúzar & Willumsen, 2011). Due to such

definition, short-range active trips are commonly under-reported which affects demand analysis. As greater amount of attention is being placed on research and transport planning procedures for active mobility, many researchers now analyse trips on trip-stage basis. Trip-stages are portions of a trip made by different transport modes as shown in Figure 2.6 (Wedderburn, 2015).

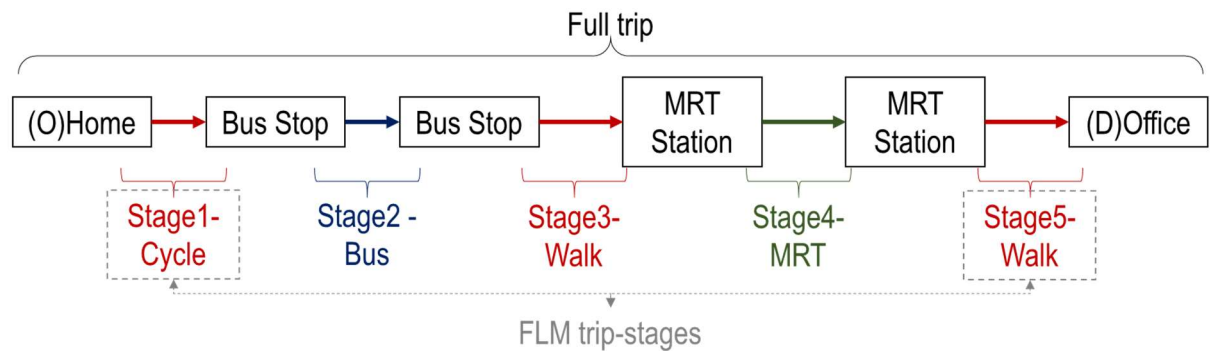


Figure 2.6. Illustration of a full-trip and trip-stages

The first (from origin to transport station) and last trip-stages (from transport station to destination) are known as first-last mile trip-stages (FLM trip-stages). FLM trip-stages are commonly used in analysing active transport modes. Although trips are considered by stages, walking and cycling trips as main modes and as trip-stages will need to be differentiated. Literature has shown that this differentiation (i.e. main trips and trip-stages) can strengthen the distribution of trips (transport network usage) and provides a better explanation regarding average trip length and travelling speed (Bargh and Kelly, 2011; Susilo and Cats, 2014). As highlighted by different researchers, active trips (full-trips and trip-stages) are expected to be mostly of short range and focused around specific locations during peak periods.

Often times, travel surveys fail to record active trip-stages, especially FLM trips. This happens either because participants/interviewers do not consider these as actual trips or due to surveys being designed to record motorised mode trips. Several researchers have encountered this issue and applied various approaches to solve this constraint. Many agree that if using travel diaries, the best remedy is to set questions focussed on trip-stages, and accordingly design specific sections to capture active trips (Clifton & Muhs, 2012). For even better results, it has been suggested to develop intensive interviewers' training to highlight the importance of capturing all trips and trip-stages, especially the active stages in multimodal trips (Clifton & Muhs, 2012; Stopher & Greaves, 2007).

Trips are then classified based on the purpose of each trip or the activity related to that trip. These can be classified, based on their purpose, as mandatory or non-discretionary, maintenance, and discretionary trips (Holz-Rau et al., 2014; Song et al., 2013). Traditionally, mandatory trips are the one with most impact on the travel environment as these have strong effect on infrastructure provision and congestion (Dharmowijoyo et al., 2015; Song et al., 2013). Based on trip purposes, differentiation shall be made between trip-stages (to complete a trip) and trip-chains (sequence of trips for different purposes (Palanisamy, 1997; Primerano et al., 2008)). With the shift to active and public modes of transport, people do trips with more stages and perform more trip chains to maximise travel time, with many of these trips being made by active modes of transport. Survey respondents report their trip purpose usually by selecting from a set/list of predetermined answers. Researchers should refine such list in accordance to local context and provide options that are suitable for active mobility respondents (Mori et al., 2015; Palanisamy, 1997; Stopher & Greaves, 2007). Some researchers have argued that including the options “to change modes” or “to reach motorised transport”, as trip purposes, can help to reduce under-reported active trips, yet not much literature has been found about the usefulness of such options (Mori et al., 2015).

Another issue widely discussed in the literature is the minimum trip length (or travel time) that should be considered for recording cycling and especially walking trips in household travel interview surveys. Researchers commonly search for an optimum and practical minimum travel distance that balances between potential loss of active trip data and convenience of data collection (FHWA, 1999a; Wedderburn, 2015). The minimum trip length varies based on survey location and is of interest in countries where there is a considerable distance (travel time) within buildings such as Singapore to ensure that while all trips are captured differentiation is made between trips/trip-stages on the transport network and intra-building trips.

Moreover, as mentioned in Section 2.4.2, sample size and sample selection should be carefully considered (Ortúzar et al., 2000). In the local context, the population of regular cyclists and regular PMD riders, although increasing, is small. Thus, consideration shall be made in selecting sample size that is representative of the population, yet big enough to draw statistically sound conclusions.

2.6. **Gaps identified**

Active modes of transport are considered “rising” modes of transport, and more researchers and planners are including walking and cycling into transport models, yet, theoretical knowledge of walking and cycling planning remains limited. As active mobility rates continue to increase in the

international and local context, so does the provision of infrastructure for pedestrians, cyclists and PMD riders. While most countries develop off-road facilities for pedestrians and on-road facilities for cyclists, Singapore is developing mostly off-road shared-facilities for pedestrians and cyclists (mixed-stream traffic). Much research has been published in regards of planning and safety measures for different facilities yet the available information on shared-space for mixed-stream traffic is still limited. In addition, emerging dock-less bicycle-sharing schemes in Singapore are quickly expanding bicycle usage, and this requires faster upgrading of facilities to match users' needs.

The literature review has pointed out that transport planning is affected by travel demand analysis, and travel demand analysis is dictated by travel data. Quality data is required to ensure quality needs of all transport users are met. Travel behaviour and related quality needs of pedestrians and cyclists shall be properly recorded considering that they vary according to personal characteristics and the local environment. Several theories have been developed to explain and/or describe travel behaviour. Some theories are already very comprehensive, yet very few have comprehensively included mobility decisions pertaining to short-range active and FLM trips.

As mentioned, Singapore has very unique settings for active mobility users with them mostly sharing off-road facilities. As cities get more urbanised, it will not be surprising that more and more pedestrians and cyclists share commuting/travelling facilities. Hence, it is timely to develop a framework, considering pedestrians' and cyclists' quality needs, to describe travel behaviour in Singapore's context. The framework shall be developed in continuity with previous research so synergies and similarities can be identified and assimilated. In addition, findings can be translated from Singapore to other countries/cities as best practices standards.

Moreover, as affirmed by several researchers, data collection or survey methods need to be reviewed to ensure relevant characteristics about active travel and attendant travel behaviour are recorded. While at a first glance household interview travel surveys using travel diaries seem to be the approach for data collection, some sections of the conventional questionnaire need to be redesigned to gather sufficient quality data to draw conclusions regarding active mobility. Improved survey remarks can be utilised by countries that are also aiming at understanding active travel behaviour and/or increasing usage of active modes. In this regard, the travel behaviour framework serves as a guide to determine information regarding which factors (variables) that shall be collected from participants, and which can be collected/obtained from other sources. By analysing relevant data, authorities and planners can evaluate the level-of-service of current active mobility network, estimate the importance of service improvements, and develop transport schemes, infrastructures, and policies accordingly.

Finally, regarding travel demand analysis and forecasting, the literature has pointed out that active modes of transport have been comprehensively introduced in the models quite recently. Most researchers utilise trip-based analysis to estimate travel demand. Within the model, many choose statistical methods to model travel characteristics. Fewer have utilised computer-intelligence techniques, of which the use of neural network analysis is the most common. Neural networks, as well as statistical analyses, have been found to be applicable to estimate traffic characteristics such as traffic flow and demand analysis for a specific mode. However, the potential of neural networks to analyse active mobility demand are yet to be fully explored. This, as well as the previously mentioned gaps, form the basis for this research where at an initial stage, pedestrians' and cyclists' quality needs are investigated.

Then, overall literature review findings are coupled with an in-depth review of theories and (conceptual) frameworks regarding travel behaviour to develop a comprehensive framework (i.e. The PDMD framework) that dynamically considers local characteristics and yet be contrasted with the international setting. Using this framework, a comprehensive survey questionnaire is developed and implemented to collect household travel data. The survey questionnaire considers active modes of transport as integral modes within the transport network and is carefully designed to collect data from all trips and trip-stages, including short range trips. Data is then used to model travel demand, considering effects highlighted in the PDMD framework and by incorporating the usage of neural networks (to estimate and compare travel data based on 3 different scenarios) into the traditional 4SM. Neural networks were selected as these allow for convenient modification of scenarios to analyse changes in travel demand.

Chapter 3. Methodology

In this Chapter the methodologies and setup for the main tasks of the research are introduced. To get a clear understanding on what are the factors that affect travel behaviour and travel demand, it is important to first study the quality needs of pedestrians and cyclists in the local context. This exercise serves to identify most suitable approaches to analyse the situation and how these can be translated to other contexts (i.e. overseas countries). Three main issues were studied, namely: active travelling characteristics; usage of the network; and attitudes towards active modes. Given the different nature of these issues, three different studies were conducted and the methodology for these studies is presented in Section 3.1.

Using findings regarding quality needs, together with an audit of previously posted theories and frameworks, a mobility decision framework was developed. The framework that depicts travel behaviour of active mobility users, while taking into consideration individual, household and built-environment factors. The utilised methodology is described in Section 3.2. Then, as explained in Section 3.3, the framework is utilised for data collection for travel demand analysis. The methodology used for analysis and modelling of travel demand for current and modified scenarios is also presented in Section 3.3 where, to understand factors that would increase/decrease demand for active modes of transport, modifications to the traditional 4SM are introduced, with main interest focused on the mode choice step. Remaining steps are considered only to gain a general view of the transport network usage.

3.1. Understanding and meeting quality needs

As mentioned, three main studies were developed to understand pedestrians' and cyclists' quality needs. The methodology for each study is outlined in subsequent sections (3.1.1. to 3.1.3), and survey forms and related show cards utilised in these three studies are presented in Appendix C.

3.1.1. Active travelling characteristics

To understand travelling characteristics and behaviour at shared mobility spaces, naturalistic observations and interview surveys were conducted in different locations of two cycling towns in Singapore as shown in Figure 3.1. Naturalistic observations were conducted to identify natural (without intervention of the researcher) behaviour of active mobility users and how these interact with each other. Then, interview surveys were conducted to gather qualitative data regarding the different factors, quantify the usage of the different modes, and estimate impact of different features of the

built-environment in shifting from motorised to active modes. Observations and surveys were conducted taking into consideration the survey questions of this study. These provided a good understanding of the subject matter and allowed for interpretation of travelling characteristics that affect mobility decisions and inputs for selection of different scenarios for demand analysis. The following were the considered research questions:

Q1. Are active mobility users aware of the provision/improvement of active mobility infrastructure?

Q2. How does the enhancement/provision of off-road cycling paths affect active mobility rates? and

Q3. Do current and potential (future) cyclists share similar opinions about cycling?



Figure 3.1. Active mobility facilities at Sembawang and Yishun residential towns

First, observational studies were conducted at different locations that are commonly frequented by active mobility users at different time periods. This allowed the author to gain a deeper understanding

of pedestrians' and cyclists' interactions and determine the most suitable survey locations for intercept surveys conducted at the subsequent stage. Findings from observations were added into the survey questionnaire as possible answers (in multiple-option questions) for motivations to undertake walking and cycling (or not).

At the second stage, participants were randomly approached at different locations within these two towns and invited to participate in the interview survey. Although participants were intercepted while walking or cycling at different areas within Sembawang and Yishun residential towns, survey locations were selected to ensure a good representation of active mobility users as well as public and private transport users. The two towns under study are adjacent to each other and were selected for the study as they are considered mature cycling towns given that the provision of bicycle infrastructure has been completed more than two years ago and there are no plans for further immediate improvement of the cycling network. Sembawang and Yishun are mostly residential in nature and in addition to park connector network have extensive intra-town cycling paths of 10.7km and 15.5km, respectively (LTA, 2013, 2016b).

Survey data was analysed using descriptive statistics and significance tests were performed where applicable to compare differences among users of different modes of transport. The analysis also helped to identify the relationship between users' demographics and willingness to undertake active modes of transport (mainly cycling). Characteristics of the sample were compared with national statistics to estimate how comparable is survey data with the overall population. In addition, the total number of reported cycling trips in the towns and those that were reported to shift from other modes of transport were utilised to calculate a shift rate. The rates were then utilised as input for demand analysis.

3.1.2. Usage of the (formal) active transport network

To investigate current active mobility situations in Singapore and the impact of various "formal facilities" regarding walking and cycling, a comprehensive data collection instrument was designed. The considered research questions include:

- Q1. In Singapore, do cyclists prefer off-road or on-road paths for travelling?
- Q2. In a mixed active traffic setting, what type of spaces are preferred by pedestrians and cyclists?
- Q3. Does bicycle-sharing scheme motivate people to take-up cycling for different purposes? and
- Q4. Do cyclists of different characteristics have different travel behaviour and preferences?

While previous study was aimed at understanding general travelling characteristics by different modes of transport, this study is concerned with pedestrians' and cyclists' actual network preferences and motivations to increase active travelling (based on the built-environment and/or programmes such as bicycle-sharing scheme) as reflected by the survey questions. A mixed-method research approach was used which applied a structured quantitative component as well as an unstructured component with qualitative questions, with the results analysed jointly. This approach can increase the usefulness of findings and affirm answers provided from qualitative responses (Collins et al., 2007; Creswell, 2013).

The questionnaire comprised a total of 20 questions including: commonly-used mode of transport, preferred travelling facilities (illustrations of the facilities under study were provided to the respondents – Figure 2.3), cycling reason, frequency and experience, preferred walking/cycling facilities, and preference regarding sharing paths with other users. For the qualitative part of the questionnaire, four different versions were designed with variation in the order of the responses to each question. This was done to increase randomness and avoid any particular answer being overly selected just for being the “first” answer in the option list.

Survey interviews took place during evening peak periods (on non-rainy and non-school holiday weekday) and participants were randomly intercepted as they moved along pathways in public spaces such as in the vicinity of food centres, transport hubs, and recreational facilities. Respondents who indicated any type of cycling (regardless the frequency) were classified as cyclists otherwise they were classified as non-cyclists. At least one each of the footpath, extended path, delineated path, and segregated path were selected for survey locations. Although participants were randomly approached, mainly young adults participated in the survey. Thus, study analysis was mainly focused on this group of users who are considered good “candidates” to use active transport modes. In addition, this age group accounts for close to 50% of the population in Singapore (SINGSTATS, 2017). These users are characterised as being the most active in terms of transport usage and activity level, being essentially the “mover-and-shaker group” who are leading changes in different areas, including transport-centric activities. A total of 277 people fully completed the quantitative questionnaire and participated in the interview survey. Each interview (qualitative questions and quantitative questions) took about 10 minutes and respondents received a token of appreciation (of 5 SGD=3.7 USD approx.) upon completing the interview survey.

Quantitative answers were analysed using descriptive statistics to determine respondents' preferences (of the travelling facilities), common travel behaviours, and behavioural changes due to

improvements in the cycling facilities and services. T-tests were conducted to compare differences between respondents cycling for transport versus recreation. Qualitative answers were transcribed and analysed using the Grounded Theory (GT) approach. The GT was selected to generate concepts and categories related to factors that can increase preference and usage of active modes – which are then utilised in the PDMD framework and for the selection of inputs for travel demand analysis using neural networks at the mode choice step of the 4SM. This approach is commonly used in social science to “discover” new theories related to human behaviour (Corbin & Strauss, 2008; Ng & Hase, 2008), and is very suitable to analyse active mobility behaviour of elders and adults (Beirão & Sarsfield Cabral, 2007; Ghekiere et al., 2014).

To account for different factors of interest (i.e. infrastructural usage, preferences about different modes, and interaction with other users), questions were designed to introduce these issues for discussion. In addition, during the survey process itself, mentions to these issues were made by the interviewers to encourage further discussion. After survey, based on common or frequent responses provided by the respondents, specific classification categories were created. The findings are discussed considering vélomobility politics and off-road mixed-stream traffic (i.e. pedestrians and cyclists sharing the facilities). Infrastructure provision and other developments for cycling and walking, behavioural changes, travel demand and policy implication to foster a healthy and vibrant lifestyle by cycling and walking, were examined.

3.1.3. Attitudes towards active mobility

Finally, to measure pedestrians' and cyclists' (adults and elders) attitudes towards active mobility, based on their perception of built-environment and policies, qualitative data collection techniques were utilised considering and addressing the following research questions:

- Q1. Do attitudes towards active mobility differ between adults and elders?
- Q2. Are adults and elders, in general, comfortable with active mobility facilities?
- Q3. What are the opportunities and limitations to promote active mobility? and
- Q4. How does public transport service affect active mobility rates?

While many engineers are solely concerned about scientific aspects of transport, it is important to incorporate issues related to individuals and the society. Previous two studies collected data regarding travelling characteristics and network usage and this study serves to complete the picture by providing an overview of attitudes of adults and elders users (which contribute greatly to mobility decisions and for the development of the PDMD framework). Qualitative data collection techniques

are commonly used in research dealing with personal opinions and social experiences (Beirão & Sarsfield Cabral, 2007; Bordagaray et al., 2015; Ortúzar et al., 2000; Yeung et al., 2013). They possess efficiency in providing detailed data to evaluate individuals' attitudes, perceptions, and needs (Bordagaray et al., 2015; Ibeas et al., 2011). These methods are also good in providing sufficient data given a relatively small number of participants, so that data that can be aggregated and compared (Beirão & Sarsfield Cabral, 2007).

In the transport area, qualitative techniques gained popularity not long ago. Previously, pre-selected variables were used to study transport issues, most commonly in the study of mode choice. While pre-selected variables have helped to determine tendencies towards one option over another, they only consider limited attributes. In comparison, qualitative techniques allow users to discuss in detail those factors that affect their travel decision (Bordagaray et al., 2015; Corbin & Strauss, 2008; Ghekiere et al., 2014; Winters, Sims-Gould, Franke, & McKay, 2015). Thus, qualitative studies can help to determine strengths and weaknesses of active mobility network.

Examples of qualitative techniques are focus group discussion as well as individual (one-to-one) in-depth interviews. For this study, three focus group sessions, 20 participants in total, and 26 in-depth interviews, were conducted on adult and elderly subjects. The focus group technique was used to gather information regarding active mobility from adults, and in-depth interviews were to gather individual information from elders. The use of these two techniques provided a clear picture regarding attitude towards walking and cycling among adults and elderly. Sampling and simultaneous analysis of responses took place until data started to be repetitive and no new information was added from new samples, at which point theoretical saturation was reached (Morse, 2004), as achieved in this study for the stated sample size.

Adults between 18 to 50 years-old were targeted to participate in focus group sessions. Groups of 6 or 7 participants were formed. This group size was selected to ensure that all participants had a good chance to speak/discuss, and to gather relevant points in not so long time periods (Rabiee, 2004). It should be noted that 8 participants (4 males and 4 females) were invited per session. This was done to mitigate the often-met situation of a participant not turning up without prior notice, and this strategy ensured that the minimum number of 6 participants was always reached. Focus group is an excellent technique to gather in-depth information from participants (Ibeas et al., 2011). However, given the diverse multi-racial population of elders in Singapore, it is very common that many of them only speak their mother tongue and not English. Such language barrier restricts their possibility of engaging in in-depth discussion with others in focus groups. These constraints, in addition to the much lesser

mobility of the elderly user group, made elders' participation in focus group sessions impractical. Thus, for road users above 50 years-old, one-to-one interviews were employed in surveying older participants.

The focus group sessions were conducted at Nanyang Technological University Singapore and lasted around 50 minutes and consisted of two stages. First, participants were asked to complete a questionnaire regarding walking and cycling in general as well as their socio-demographic information. Then, participants were asked 9 open-ended questions (the questions were shown via an overhead projector, so participants could refer back to them during discussion); around 3 to 4 minutes were given to discuss each question. Participants were prompted to express their opinions and clearly explain their answers. Meanwhile, one-to-one interviews consisted of interviews using a semi-standardised questionnaire (structured questionnaire that allows for unanticipated issues to emerge (Ryan et al., 2009)), and encouraging participants to provide in-depth responses and to discuss their opinions. The same questions used in the focus group sessions were used in one-to-one interviews. General perceptions and demographic information of participants were also collected. Each interview lasted around 35 minutes and was conducted at void decks of public housing blocks. Questions were read and shown to participants and they were encouraged to provide detailed answers.

Focus group sessions were video-recorded while one-to-one interviews were voice-recorded for later analysis and to ensure that no data was lost. Afterwards, these were transcribed and anonymised by assigning each participant a specific ID linked to corresponding participant's responses. Recordings were deleted for privacy protection of participants. The transcriptions were audited using the GT approach (using same approach as described in Section 3.1.2) to determine common concepts and categories regarding attitudes towards active modes in Singapore. After ensuring all factors of interest were included in the survey, "hinting" the respondents regarding the different factors during the sessions and the interviews, responses were classified by frequency and specific classification categories were developed. Categories were created individually for adults and elders. In the final holistic conclusion, categories from both user groups were combined. The categories were compared against findings reported in the literature to ensure that key issues were duly covered and to enhance understanding of active mobility behaviour in the local context.

Furthermore, a SWOT analysis, a common strategic planning tool that is used in human centric studies (Bordagaray et al., 2015; Ibeas et al., 2011), was undertaken to clearly determine factors that affect pedestrians' and cyclists' travel behaviour. Perceived advantages of walking and cycling

(Strengths), perceived disadvantages (Weaknesses), schemes for promotion of the mode or to encourage users to choose walking or cycling from users' perspectives (Opportunities), and perceived risks or unsafe issues (Threats) were carefully considered. The results and findings are presented in Section 4.3.

3.2. **Unifying mobility framework and survey instruments**

The aim of this study is to frame scientific issues related to travel behaviour and present a holistic overview of factors that affect mobility decisions which could be dynamically modified and scaled to different contexts. In the framework, factors that affect travel behaviour in general were discussed with main focus being placed on active travel behaviour and related decision. Dynamism factor was introduced into the framework by adjusting components of previously posted theories/frameworks to capture variation across different and contrasting contexts. The proposed framework is called "process and determinants of mobility decisions" or PDMD for short. To develop the PDMD framework, findings regarding quality needs (as presented in Chapter 4 using methodology explained in Section 3.1) were combined with a comprehensive review of the available theories (mostly in English language domain, with some in Spanish) that describe and/or can be applied to travel behaviour.

The author of this thesis has formulated and was primarily motivated by a set of scientific questions when analysing different published social and scientific theories. In addition, aspects related to different social contexts were also considered. The questions are presented as follows:

- Q1. What have previously posted theories related to travel behaviour covered/ identified/addressed?
- Q2. What are the factors that exert influence on mobility decisions, especially walking and cycling?
- Q3. What are the relationships between those factors and how do they vary for different modes of transport, local context, and/or demographics? and
- Q4. How can the understanding of these factors and their relationship be applied to analyse travel demand for transport planning?

In order to gather a comprehensive database, published transport, geography and social sciences theories that are applicable to human travel behaviour were retrieved and integrated. An online search was conducted using "TRAVEL BEHAVIOUR THEORY/Framework" and "TRIP DECISION THEORY/Framework" as keywords. 'Scopus' platform was utilised as this platform is one of the major database for different types of literature, and it covers international journals for most disciplines (Elsevier, 2011). The search yielded a total of 2,790 publications in English (99%) and Spanish (1%)

domain concerning human or travel behaviour. After a comprehensive review and analysis, a total of **27** theories and frameworks from different fields of study were thoroughly analysed for the development on the PDMD framework.

First, abstracts from publications of the last 10 years were audited and key manuscripts extracted. From this initial exercise, it was found that theories/frameworks published before 2000s are more focused on general human travel behaviour, and these have served as the building blocks of most travel behaviour theories (thus has been well reviewed and criticised). For the development of the PDMD, **6** theories/frameworks proposed/proposed before year 2000 were thoroughly re-reviewed as these are considered of crucial relevance to explain (active) travel related decisions. Moreover, two key frameworks were considered as guidelines for the development of the PDMD framework. The “theory of travel decision-making”, proposed by Singleton (2013) and shown in Figure 3.2, was utilised as it presents a comprehensive review of theories/frameworks related to human and active travelling behaviour and discusses how the theory can be applied for travel demand analysis. In addition, the PASTA framework, conceptualised by Götschi et al. (2017) and summarised in Figure 3.3, was considered as it presents a comprehensive overview of conceptual frameworks related to active travelling and specifically discusses how findings can be utilised for data collection and analysis.

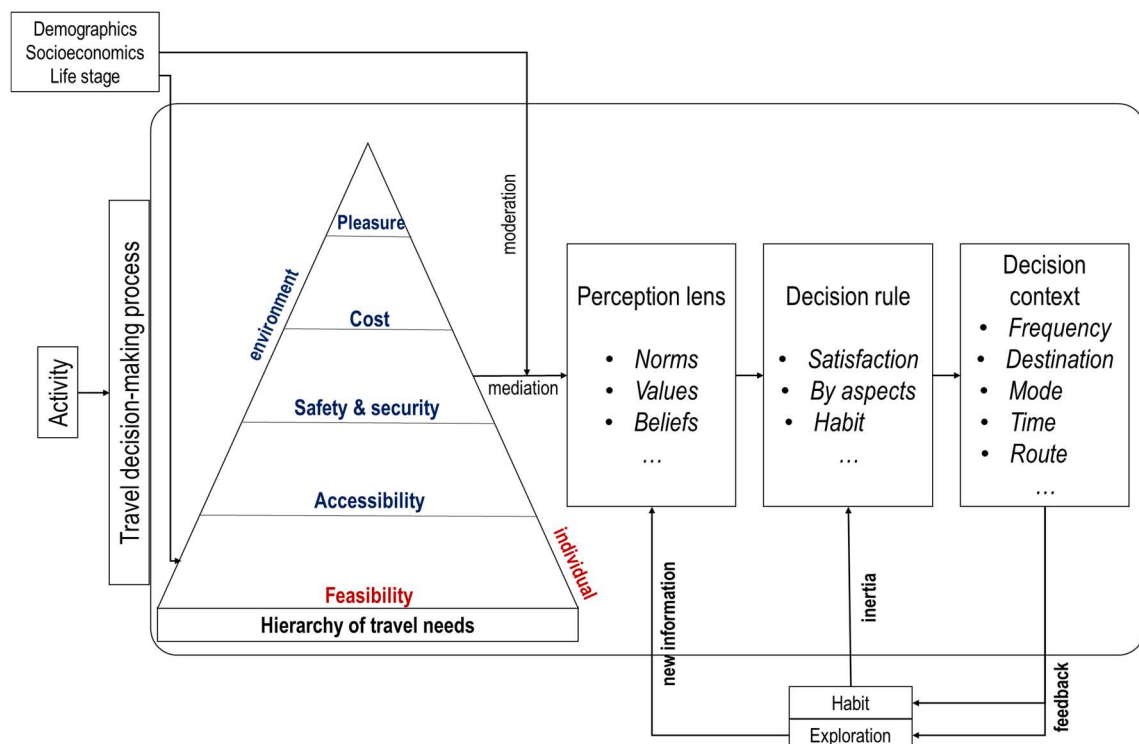


Figure 3.2. Summary of the Theory of travel decision-making (adapted from Singleton 2013)

From the 16 theories that were comprehensively reviewed by Singleton (2013) in the theory of travel decision-making, 7 theories (posted after year 2000) that are more closely related to active travel behaviour were considered and key factors included in the PDMD framework. Then, the PASTA framework was scrutinised, including references lists and citations, upon which 11 additional theories and/or frameworks related to travel behaviour and decision-making were identified. Finally, based on a scan of recent publications regarding travel behaviour theories, 3 additional theories and/or frameworks were considered, with some of these concerned with children and elder travel behaviour. A detailed description of the two main frameworks utilised and a quick overview of other considered theories/frameworks are elaborated in Section 5.1.1, and Section 5.1.2 presents how different aspects have been addressed/enhanced in the PDMD framework.

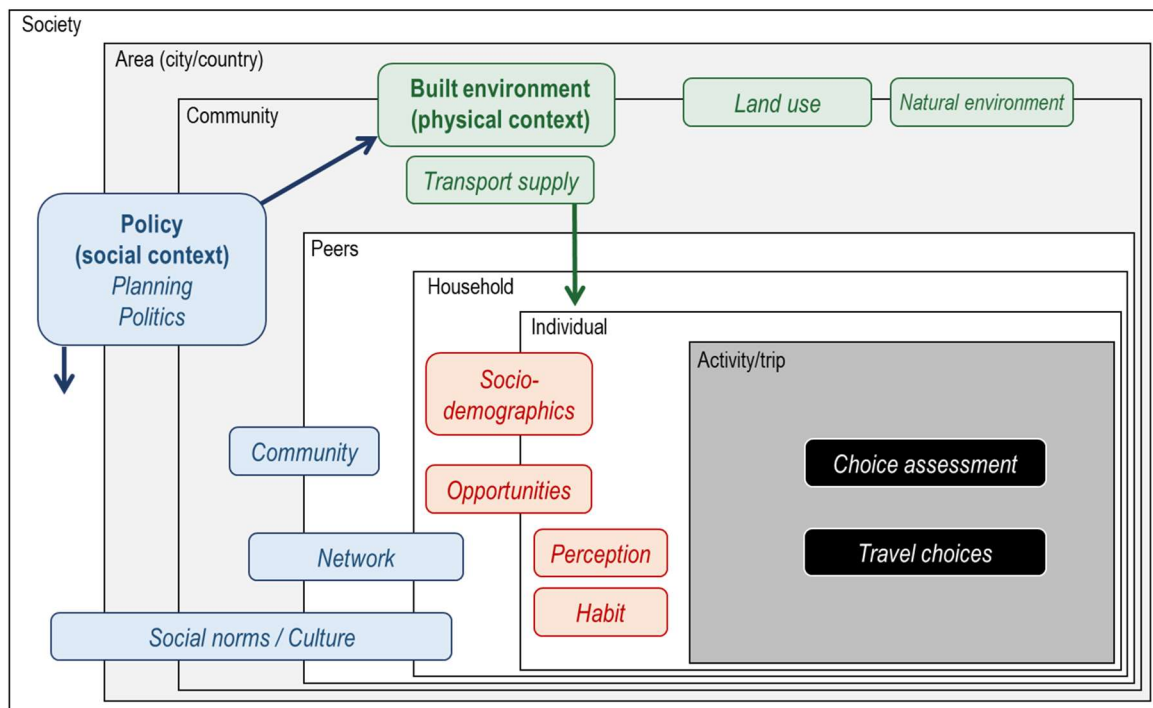


Figure 3.3. Summary the PASTA conceptual framework (adapted from Götschi et al., 2017)

The aforementioned theories were selected as they are considered of relevance for describing travel behaviour and more specifically active travel behaviour. Herein, the potential of value-add areas for further research and those that are specific to certain geographical areas were duly highlighted. The PDMD framework is a science-driven framework that can be utilised in policy development and is mostly concerned with adult travel behaviour. However, by taking a multidisciplinary perspective and considering that children and elders are also shifting to active modes of transport and their travel behaviour differs from those of adults, the author has also reviewed some theories and frameworks related to children's and elder's behaviour and key factors were incorporated into the PDMD framework accordingly.

Understanding that each field of study utilises different terminologies, a summary of terms and their applicable definitions was first collated. Such lexicon of terms helps to merge the knowledge from the different scientific disciplines which serves to improve communication between different scientific disciplines. Then, once most common factors that affect travelling and specifically walking and cycling have been identified, these were compared with findings in different and contrasting geographical contexts (mainly Singapore – first world island country with outstanding public transport and good provision for active mobility, and Asunción – capital of a landlocked type country with high usage of private motorised modes, low usage of public transport, and minimal provision for active trips). The comparison served to identify and address gaps in currently available theories and frameworks and included the dynamic factor.

As indicated by the name, at this stage, the PDMD framework is not a travel behaviour theory but a framework for data collection and demand analysis. More than improving the understanding regarding a phenomenon (in this case travel behaviour) by framing scientific gaps and issues, the author aimed to establish concrete research and policy applications in a framework that can assist in the development of data collection instruments and as guideline for analysing variables related to travel behaviour. In this thesis, the PDMD framework was utilised for the development of refined household travel survey instruments (and techniques), and as a guideline for selecting input components for travel demand analysis.

The refined household travel survey instrument was constructed, and the related methodologies for implementing the survey were outlined. A comprehensive questionnaire comprising three sections and close to 50 questions were developed. The sections were concerned with obtaining information at household level, individual characteristics, and travel behaviour. Specific details of each section are described in Section 5.2. A face-to-face interview was conducted to collect travel data utilising a one-day travel diary using recall method – specific methodology for data collection is presented in Section 3.3.1. In addition, as covered in Chapter 6, the PDMD framework was utilised to determine and classify input variables for current and modified scenarios for travel demand analysis using the neural network model and to improve transport planning and in the development of related policies and programmes, especially those dedicated at increasing active mobility rates.

3.3. **Travel demand analysis**

To analyse travel demand, household travel survey data were collected using the developed questionnaire. To understand factors that would increase active travel demand, modifications to

traditional 4SM were introduced. The greatest interest was placed on mode choice step where neural networks are selected over statistical models. Neural network utilised factors from the developed PDMD framework and the data collected using the refined survey questionnaire. The techniques for data collection and demand analysis are described in detail in subsequent sections.

3.3.1. Data collection approach

Data from 1,119 households in HDB building-blocks, distributed in four residential towns in Singapore, was collected from the household travel survey. Travel and socio-demographic data from these households was cleaned-up and utilised for travel demand analysis. Sembawang, Yishun, Serangoon and Hougang were the selected towns. The data was collected for week-day travel information on a span of 6 months with off-set for school holidays. Sembawang and Yishun are well-suited as study locations as these neighbourhoods are deemed to have full active mobility infrastructure, and they are referred as cycling towns hereafter. In addition, no major active mobility transport network improvements are planned for the two neighbourhoods in the near future. Thus, these can be considered as relatively matured neighbourhoods. On the other hand, Serangoon and Hougang were selected as the “control” locations as they have a relatively minimum/much less provision of cycling paths, but cycling is nevertheless applicable on shared pathways, referred as non-cycling towns hereafter. These four towns are located in north and north-east regions of Singapore, as shown in Figure 3.4.

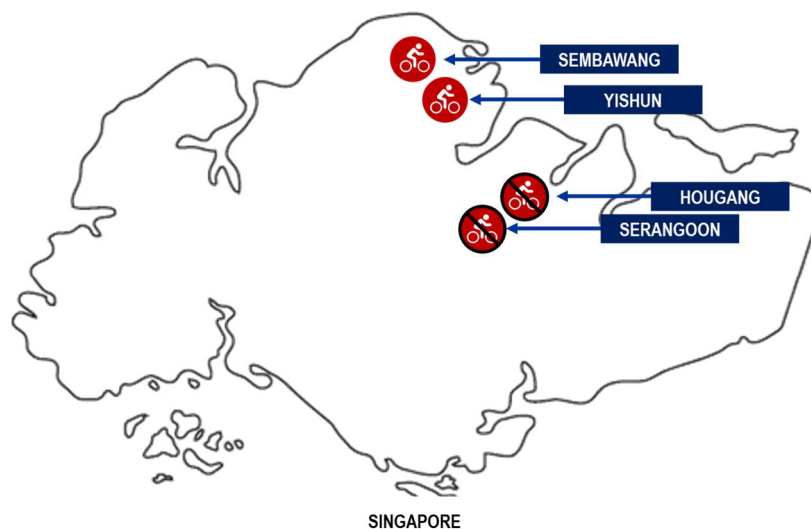


Figure 3.4. Locations of towns under study for travel demand analysis

A comprehensive approach, as depicted in Figure 3.5, was developed to select the households. Data was collected as part of a collaboration project commissioned to the Nanyang Technological

University (NTU) by the Land Transport Authority (LTA). The Nielsen, a survey company in Singapore, was hired for the data collection task. First, a database of 500 randomly distributed addresses in each of the selected towns was acquired from the Department of Statistics (DoS) in Singapore (Department of Statistics, 2011). Then, considering the percentages of dwelling unit types (HDBs, Landed Properties, etc.) in each town, addresses were utilised to select 50 HDB building-blocks as primary sampling units (PSUs). At the final stage, specific households within each selected HDB building-block were approached for survey using a 1:3 approach (i.e. interview 1, skip following 3). This selection process ensures that building-blocks and households were randomly selected and spread throughout the areas under study. Notwithstanding, any type of household with proportioned sample size less than 30 counts have been boosted to 30 numbers so as to give numerical stability of the sample for analysis (MRTC, 1981). This approach has been successfully used in similar studies to enhance analysis results (Murphy, 2008; Thompson, 1991; Wolf et al., 2003).

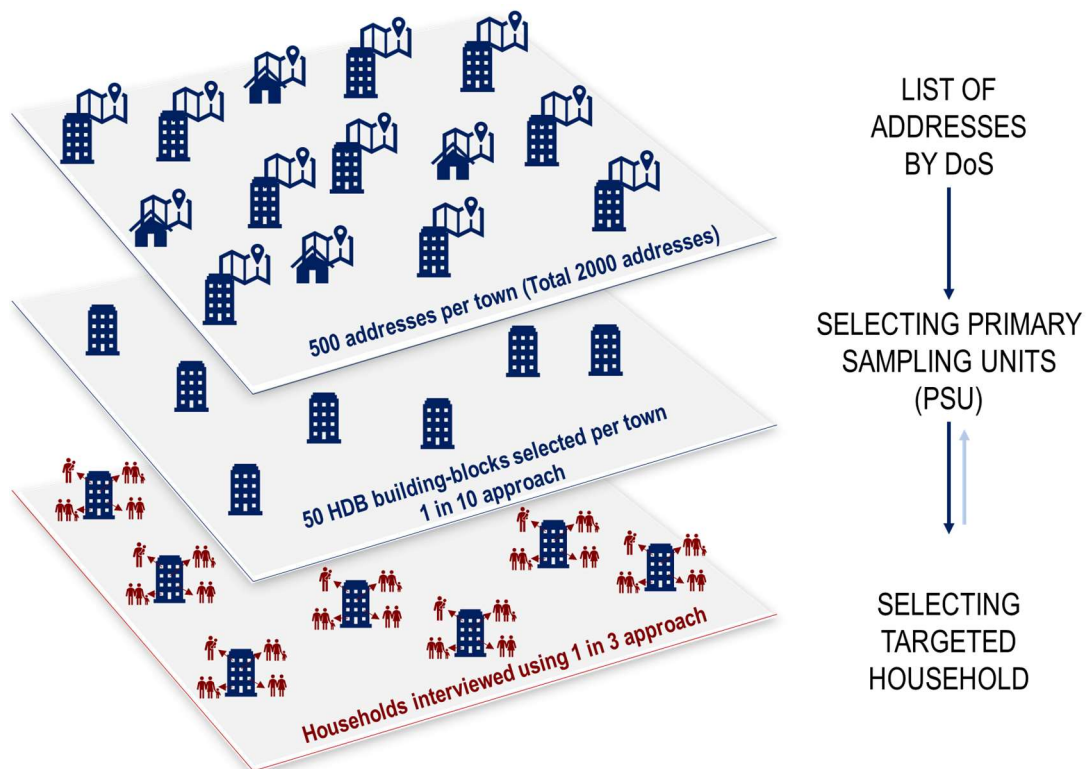


Figure 3.5. Sampling unit and household selection per township

After a household was selected by the interviewer, the interviewer approached an adult household member, introduced him/herself, explained the aim of the survey, and sought permission to collect information from members of the whole household. A letter of support, provided by NTU, was shown to the households. It is to be noted that all documents/approaches related to the study were carefully

reviewed by NTU legal team to ensure compliance with Personal Data Protection Act as well as ethics review. Based on the developed PDMD framework, data was collected accordingly, and these were utilised as input components of neural network models described in the following section. Data from all members of the household who were aged 6 years or above at the time of the survey was collected and head of household or another senior member of the household reported information from members between 6 and 14 years of age. This also helped to reduce self-selectivity bias as all members were interviewed. The role of each of the members within each household and their relationship with each other was not recorded, which limits the analysis of intra-household decision making process. The interview was completed over 15-20 minutes' time span for each member of the household, and the household received an honorarium (S\$20 voucher) for their participation.

If a member of the household was not present at home at the time of the interview, the interviewer took contact details of that person from another member of the household. This member was contacted by the interviewer later through the phone for an appointment for a telephonic/face-to-face interview at a later date. At least 3 call-backs were applied in attempting to complete the household survey. The travel information from any remaining household member (who was not at home at point of interview) was collected for the same week day as previously interviewed household members. If more than 50% of the members of a household refused to provide the necessary information or refuse to participate in the survey, that household was considered as 'incomplete' and dropped from the survey, no honorarium was given out to that household, and the household was replaced by another household in that town.

Prior to actual data collection, a comprehensive training of interviewers was conducted to ensure the scope of the survey was clear for all the interviewers. Interviewers received coaching on four key points related to the project to understand the travel habits of Singapore residents, namely: research objectives, target group and research methodology, sampling methodology, and survey methodology. After survey interview questionnaire was designed, a pilot test was developed to ensure utility of the survey and so that interviewers would gain experience regarding the aim of the survey. A detailed explanation of training session and characteristics of pilot test is presented in Appendix D that covers training of interviewers and pilot test.

3.3.2. Trip-stage geo-location and travel time analysis

Travelling characteristics were recorded for all household members of 6 years and above, and for each reported trip, details of each trip-stage were recorded, including specific origin and destination (O-D) places. Interviewer aimed to record exact location of each O-D. However, in many cases,

respondents did not know or could not recall the exact address or postal code of these locations. In such cases, respondents were asked to report location type and nearest landmark. Reported O-D characteristics data was audited and “cleaned up” to ensure the given information was accurate and could be automatically read by routing engines (for this research Google maps routing engine is utilised), as shown in Table 3.1.

Table 3.1. Examples of reported locations and “cleaned up” locations using developed code.

Reported locations	Cleaned up location	Postal code / Latitude-longitude
HOME	760825	Singapore 760825 / 1.414388 - 103.8328949
BUS STOP NEAR BLK 816 YISHUN	BUS STOP ID: Yishun Sports Hall	1.4123947 - 103.8322877
CAR PARK NEAR HOME	CAR PARK NEAR 530352	Singapore 530352 / 1.372037 - 103.898997

For instance, the O-D reported to be “HOME”, was replaced with the exact postal code of the interviewed household, which was duly geocoded. Other examples of reported locations include “bus stop near HOME”, “carpark near LANDMARK”, or similar; in such cases, the author first replaced the HOME or LANDMARK within the location with the exact postal code. Then, using publicly available data on location of bus stops and carparks, most suitable location was selected based on reported travel time and straight-line distance.

The whole process was automated using sets of codes. After exact O-D location of each trip-stage was determined, latitude and longitude of each point was determined for mapping purposes. Then, travel distance and travel time was calculated from origin to destination, as well as from origin to nearest bus stop and MRT station. To do so, the author developed an additional code that determine travel paths using origin and destination exact location and google maps routing system. Distance and travel time and distance was analysed considering the mode of transport reported by the participant as well as active modes of transport and public transport. This is to calculate accessibility to public transport and estimate feasible shifts to active mode for future demand forecast.

3.3.3. Demand analysis modelling

For the thesis research, the author proposes modifications to the traditional 4SM as previously shown in Figure 2.4. The model was developed utilising data from HDB households in Singapore which was collected using travel diaries as explained in Section 3.3.1. The same steps were considered but these were re-arranged as shown in Figure 3.6.

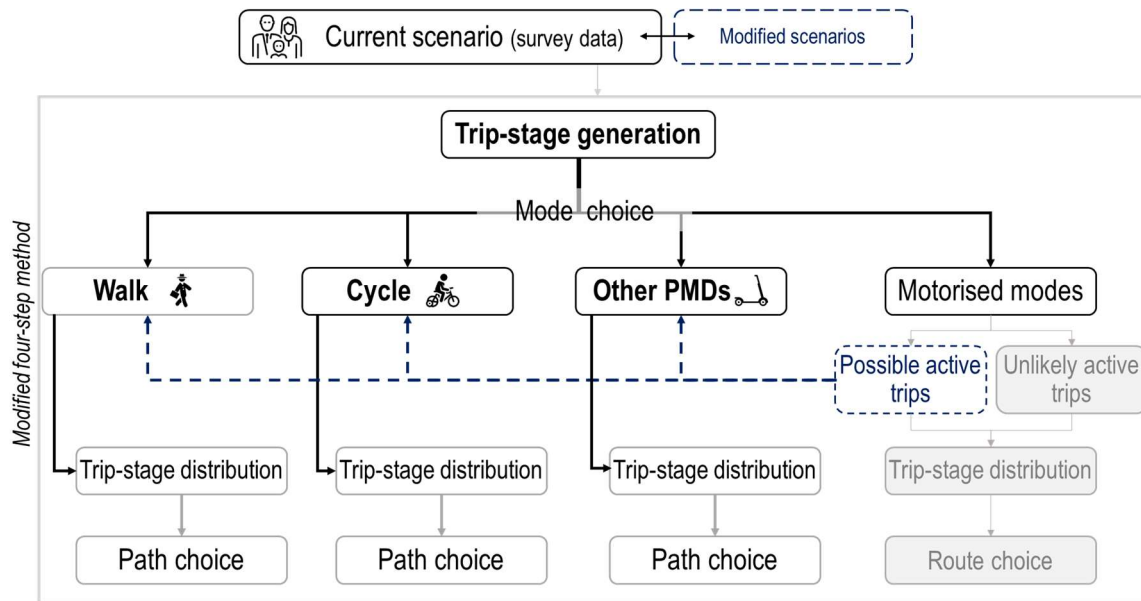


Figure 3.6. Modified 4SM proposed by the author

The modified version of the 4SM involves the mode choice analysis being developed right after generation step (yet still considering all characteristics of trips/trip-stages (i.e. origin and destination, as well as travel distance/time), and not after distribution as in the traditional approach (Clifton et al., 2016). In addition, instead of considering only full-trips' origin and destination information, the origin and destination for each trip-stage was considered for a better representation of active trip-stages. Trip (full-trip) purpose was related to the activity characteristics, and trip-stage purpose was added based on whether the trip-stage was to start the trip, change mode, or reach final destination.

Main interest of this research is on travel demand analysis concerning active modes of transport under different scenarios. Thus, most discussion and analysis were focused on the 2nd step (mode choice) of the modified 4SM while remaining steps were considered only to gain an overview of the transport network usage. In addition, only trips with origin and/or destination within any of the towns under study were considered in this research. Thus, in some cases, transport stations (mainly MRT stations) were considered as pseudo destinations of the trip.

As per standard transport analysis, trip-stage generation analysis was performed based on Traffic Analysis Zones (TAZs). TAZs were defined as land parcels with dimensions of 600 metres by 600 metres on average, and at least one road access serving each TAZ. TAZs at residential areas were of smaller size and bigger at industrial areas. The delineated TAZs for each town under study are presented in Figure 3.7.

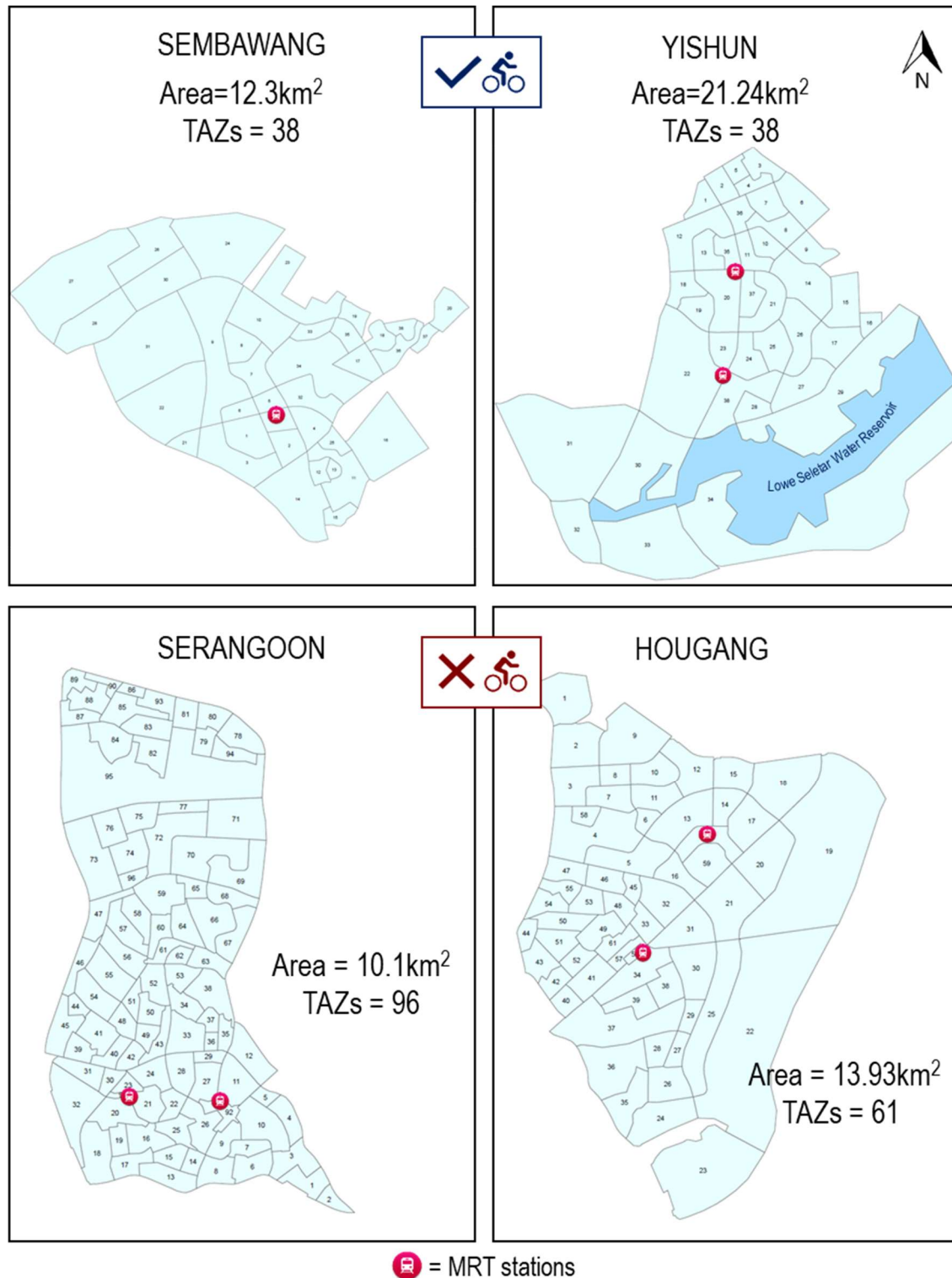


Figure 3.7. Delineated TAZs at towns under study

The TAZs were delineated following the road network in Singapore, and the size was selected considering the approximate size of public housing complexes. In addition, the reported comfortable walking (up to 900 metres) and cycling (up to 1,500 metres) distances in Singapore (Koh et al., 2011)

were taken into consideration. As such, pedestrians could cover the longest TAZ travel distance within 10 minutes travelling on foot (average walking speed in Singapore at 1.4 metres/sec or 84 metres/min) and within 5 minutes travelling by bicycle (average cycling speed in Singapore at 3.3 metres/sec or 198 metres/min) (Koh et al., 2011). While smaller sizes are preferred, TAZs are delineated so that generators and attractors are present. Interestingly, higher number of TAZs were delineated for non-cycling towns. This could be explained by the slightly higher residential land-use density in these towns as compared to cycling towns (where there are also industrial and environmental reserved areas).

Generation

Conventionally, the main function of this 1st step is to generate, with reasonable basis and assumptions, the numbers of trips/trip-stages, that each TAZ produces (P – origins) and attracts (A – destinations) as shown in Equations 3.1 and 3.2, respectively, where T represents number of trips.

$$P = \sum(T_{from\ a\ TAZ}) \quad (3.1)$$

$$A = \sum(T_{to\ a\ TAZ}) \quad (3.2)$$

To do so, cleaned trip-stages' origins and destinations were geocoded in ArcGIS software and mapped using the exact latitude and longitude. These were then compared with the TAZ boundaries to assign each trip-stage O-D to the corresponding TAZ.

Most commonly, travel demand analysis and forecast occur at the generation step, which is performed using techniques such as regression models and category analysis. These are based on survey data from all reported modes of transport and trip rates based on household information that can be aggregated at TAZ levels. Although simple, such methods face the difficulty of not being able to be “amended” when new information/data is available. In this thesis, rather than utilising generation step to analyse and estimate travel demand for different modes, the number of trips generated and attracted from/to each TAZ was utilised to gain better understanding of the travel behaviour in the four towns under study and travel demand analysis and forecast was conducted in following step.

Mode choice

For the 2nd step of the 4SM, instead of the traditional distribution step, in this research mode choice step was considered and a travel demand model was developed utilising computer intelligent neural networks. This modification to the traditional 4SM also allowed outcome from the trip-stage

generation step to feedback into the mode choice step (Clifton et al., 2016). Also, and by conducting the mode split at this earlier stage following the generation stage presents a much better overview of network usage (Bargh & Kelly, 2011; Jeon et al., 2012). In this thesis, collected survey data was utilised as base scenario for model training to understand relationship between input components (household, individual, and travelling characteristics) and outcome (selected mode of transport). Then, to estimate changes in travel demand with main interest in active modes of transport, the effect of three different scenarios on travel demand were considered as follows:

- Scenario 1 (S1): effects of accomplished targets of policies/programmes towards a “car-lite” Singapore (e.g. policies such as reduced car ownership, increased access to bicycles and PMDs, more flexible working hours, etc.);
- Scenario 2 (S2): effects of changes in the built-environment (e.g. full provision of cycling network, reduced travel distance to public transport stations, etc.); and
- Scenario 3 (S3): combination of S1 and S2.

The scenarios were utilised for the modification of some of the input components of the neural network model, then the trained network was re-run to estimate changes in travel demand with main focus on active modes.

For each origin and destination points, characteristics of the built-environment was considered. These are presented as a “friendliness” index, where for the walkability index (environment friendliness index for pedestrians), areas near the origin and destination points were classified as poor, fair, or good based on residential density, intersection density, and density of shelters (Cervero & Kockelman, 1997; Schlossberg et al., 2005). Characteristics for the cycle-ability index (environment friendliness index for cyclists) were also classified as poor, fair or good, thereby adding cycling path density to the walkability index. While the index is calculated per O-D point, characteristics of the TAZ in general are taken into consideration.

The author acknowledges that the pedestrians’ and cyclists’ environment index rates are calculated using a rather simplistic approach (as compared to modern techniques (Miller, 2018; Prelipcean, 2018). However, since environment index is considered for each trip-stage origin and destination (at TAZ level), these fulfil the task of including factors of the built-environment into the mode choice model, which is the main focus of this research. In addition, distance to public transport stations per O-D location and land use type were other factors considered regarding the built-environment. To identify land use, master plans from the Urban Redevelopment Authority (URA) in Singapore were

carefully audited (URA, 2013). Based on master plans, parcels of lands within the study area were identified for different purposes (e.g. residential, industrial, educational, recreational, etc.).

Neural network models were selected for this step instead of traditional statistical models. Neural networks were designed in the 1940s to mimic neurones behaviour and assist with variety pattern recognition and classification studies (Gonzalez et al., 2010; Shmueli et al., 1996) by the network training themselves to recognise relationship between input and output components. This approach was selected as neural networks can include partial relationship among explanatory variables, and account for non-linear relationship (Shukla, 2013). While these relationships are also feasible using traditional statistical approaches, neural network model was selected as research has suggested that this method allows for convenient modification of scenarios to test for practical applications. There are several types of neural network model structures, the most common being multilayer feed-forward neural network, which was utilised in this thesis. A general structure of this type of neural network model is outlined in Figure 3.8.

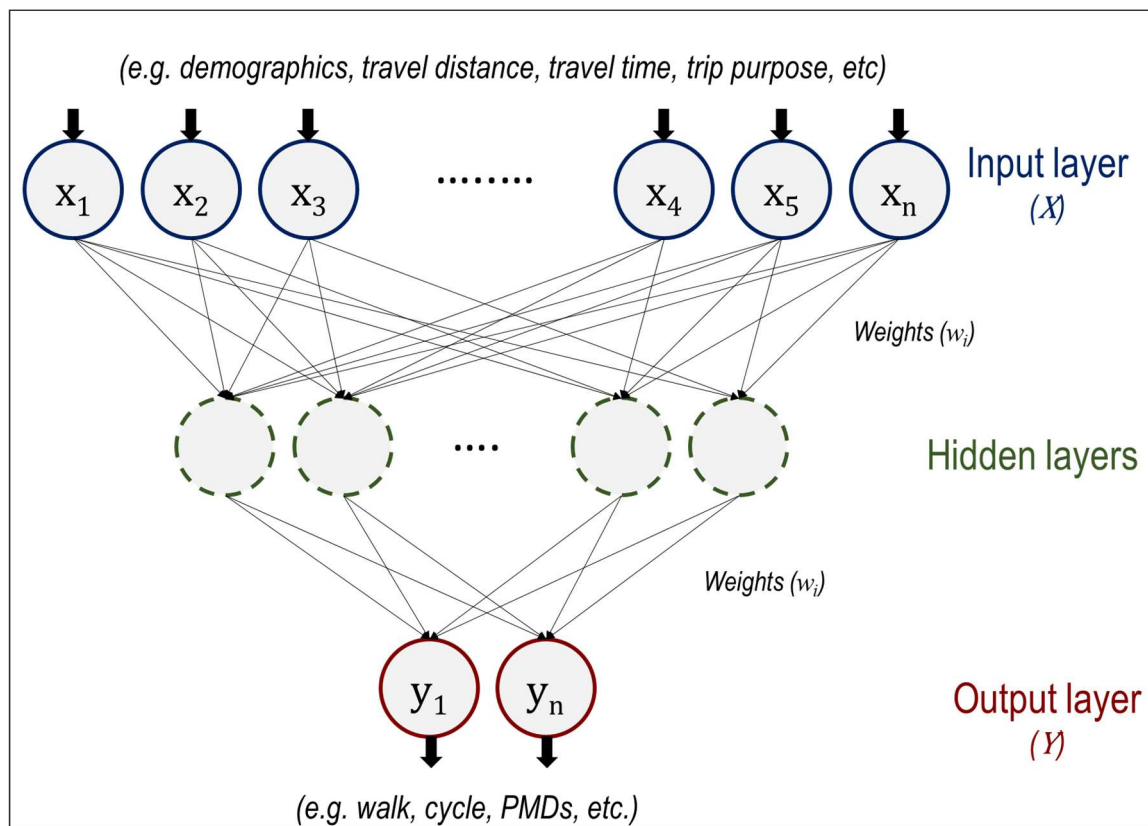


Figure 3.8. General structure of a multilayer feed-forward neural network model

For developing a neural network model for this research, some parameters from the household survey data were assigned as input components ($x_1, x_2, \dots, x_n$ – explanatory variables) of the model

and modes of transport component were selected as the targeted output (y_i – predicted variable). The model analysed these data utilising hidden layers. Within the hidden layers, interconnected nodes or neurones were activated based on input components and these were “trained” to map relationship between each input component and the selected targeted output. During the training process the effect of each input in moving-forward decisions was mathematically estimated by setting weights ($w_1, w_2, \dots w_n$ – parameter estimates) and specific neurone orders (interactions).

Optimal thresholds for these weights were set based on training datasets that represent “correct cases” or patterns. Neurones developed a learning algorithm and weights were dynamically modified within the hidden layers to determine the most suitable weights that approximated the targeted outcome (within the defined threshold). This process is called training iterations or epochs. The settings of the neural network model (e.g. selected weight thresholds, number of hidden layers, number of nodes within each layer) were adjusted through each epoch to obtain optimal weights values. Finally, a calibration step was conducted to ensure errors were compensated but still placing most interest in the actual relationship between the input components and the output, treating all data segments equally. The output values were added and normalised, so they add up to one (1). For demand estimation, some of the input components were modified based on targets of policies/programmes towards a “car-lite” Singapore and changes in the environment based on transport master plan, and model was re-run utilising the trained layers and weights.

Data from 1,119 households was utilised, which represents a total of 2,115 participants (who reported trips), and 5,065 trips constituting 9,316 trip-stages. A description of the sample characteristics is given in Section 6.1. From the final sample, some trip-stages were randomly assigned to be part of the training set (85%) and evaluation set (15%). The neural network model was developed using MATLAB software, for supervised learning, and the model consisted of an input layer (X) with 28 input components or variables (x_i), as represented in Equations 3.3 and 3.4, 3 hidden layers with 28 nodes or neurones within each layer, and an output layer (Y) – mode choice for different modes of transport – as presented in Equations 3.5 and 3.6.

$$X = f(x_1, x_2, x_3, \dots, x_n) \quad (3.3)$$

or

$$X = f(HS, IS, IM, BE, T, W) \quad (3.4)$$

where

HS = Household socio-demographic information;

IS = Individual socio-demographic information;

IAT = Individual mobility characteristics;

BE = Built-environment information;

T = Trip-stages information; and

W = Willingness to shift to active mobility.

$$Y = f(\sum y_i) \quad (3.5)$$

where

$$Y = f(\sum x_i \bullet w_i) \quad (3.6)$$

Input components were variables selected from the survey questionnaire and a comprehensive audit of the built-environment of the towns under study taking into consideration factors highlighted in the PDMD framework introduced in this thesis. In some cases, all of the variables (possible answer option) were selected as inputs and others were subsets of the available options. In addition, some inputs, especially those related to actual travel distance and environmental characteristics, were constructed/measured based on trip-stages' origins and destinations. In Table 3.2., the preliminary input components for the developed neural network model and rationale for doing so are presented. In the same table, modifications for different scenarios that are assumed to affect demand for different modes of transport are indicated. Specific parameters are presented and discussed in Section 6.3.

In deliberating on distance limitation of active trips, only trips below a certain travel distance and only selected trip-stages were considered (mostly first few stages). Modifications of scenarios were based on policies and programmes targets that are in accordance to Singapore "car-lite" goal and built-environment modifications as stated in the goals of the transport master plans released by local authorities. Previous academic transport studies conducted in Singapore were also considered as reference for modifications. Afterwards, inputs were modified for different scenarios and the trained neural network model was re-run to estimate changes in travel demand for different modes of transport for certain trip-stages.

The usage of neural networks within the 4SM to estimate changes in active travel demand is an innovative approach that can be of academic significance to enhance capabilities of the traditional 4SM. Output of the model was the likelihood of selecting different modes of transport such as walking, cycling, PMD or motorised modes of transport. After estimating travel demand for different modes of transport under different scenarios, the outcomes were compared. This established the usefulness of neural networks for demand analysis and understanding of mode choice, especially in already

developed towns/areas were retrofitting/enhancing are planned and allows for recommendations of suitable approaches to increase active mobility rates.

Table 3.2. Inputs variables for neural network training and modifications

Input variables	Rationale	Input source (year 2018)	Modification of different scenarios
Household socio-demographic (HS) information			
Type of HDB household	Determine relationship between different type of housing & active travel behaviour	Survey data	Remains same
Household size	Study how it affects type of trips (individual trips, escorted trips, drop-off/pick-up trips), frequency of trips, number of trips by individuals, & willingness to use active modes	Survey data	
Monthly Income	Determine access to & attitudes towards different modes of transport & how it relates to active mobility usage	Survey data	
Motorised vehicle ownership	Understand current & future access to private transport	Survey data	S1: reduced motorised vehicle ownership, increased access to bicycles and PMDs
Access to bicycle	Encourage usage of active mobility & creates positive attitudes towards such modes of transport; Develop programmes accordingly	Survey data	
Access to PMDs	“New” transport mode that encourage usage of active mobility; Develop programmes accordingly	Survey data	
Individual socio-demographic (IS) information			
Age	Determinant of mobility; Active travelling behaviour of different age groups to be compared; Introduction of “life stages changes”	Survey data	Remains same
Gender	Determine preferences based on gender; Develop programmes accordingly	Survey data	Remains same
Work schedule	Determine work schedules that positively affect active travel; For possible development of future programmes to promote active mobility usage	Survey data	S1: increased flexible working hours
Education level	Understand changes in behaviour based on different education level	Survey data	Remains same
Driving licence	Determinant of private motorised mobility; Assess possibility/likelihood to travel by private transport	Survey data	Remains same
Individual mobility (IM) characteristics			
Bicycle usage	Mobility trend & characteristic of user, in “competition” with walking mode; Understand its effect on active travel behaviour, to be related with age, work schedule, & education level	Survey data	S1: increased frequency of bicycle & PMD ridership
PMD usage		Survey data	

Table 3.2. Inputs variables for neural network training and modifications (cont'd)

Input variables	Rationale	Input source (year 2018)	Modification(s) for different scenarios
Built-environment (BE) information			
Walkability index	Incorporate characteristics of the built-environment based on residential density, number of junctions, sheltered pathways, and cycling paths (for bicycle index) per trip-stages' origin & destination	Calculated per O & D	S2: increased index rate due to extended shelter
Cycle-ability index		Calculated per trip-stage O & D	S2: increased index rate due to provision of cycling paths
Distance to public transport	Estimate travel distance to bus stops/MRT stations to determine current & future usage of public transport & how it relates to active mobility	Calculated per trip-stage O & D	S2: reduced travel distance to transport stations as per goals in master plan
Type of town	Compare differences between towns with full & minimal active mobility infrastructure	Survey data (based on household location)	S2: all towns considered as cycling towns
Land use type	Asses effect of different type of land use in overall active mobility rates	Calculated per TAZ	Remains same
Trip(-stage) (T) information			
Origin	Determine trip(-stage) origin & calculate travel time & distance. Main input for trip-production in trip generation stage	Survey data	Remains same
Destination	Determine trip(-stage) destination & calculate travel time & distance. Main input for trip attractions	Survey data	Remains same
Mode of transport	Understand current trends & forecast future demand. Main focus is on active modes of transport	Survey data (Targets)	Output
Perceived (reported) travel distance	Understand user's perception & compare it with calculated travel time & average travelling speed	Survey data	Remains same
Calculated travel distance	Ascertain actual distance (by different modes of transport) from origin to destination & explore possible active trips	Calculated	Remains same
Trip-stage purpose	STAR TRIP, CHANGE MODE, REACH DESTINATION	Survey data	Remains same
Trip purpose	Assess trip characteristics & usage of different modes of transport	Survey data	Remains same
Trip frequency		Survey data	Remains same
Willingness to shift (W)			
Willingness to shift to walking	Gain better understanding on user's willingness (or not) to use different active modes. Pin-point factors that are likely to increase active mobility rates	Survey data	S1: increased acceptance of active trips & thus willingness to shift (based on stage number & distance)
Willingness to shift to cycling		Survey data	
Willingness to shift to PMD		Survey data	

These inputs were selected using the PDMD framework as guideline and as they are deemed to capture factors related to travel behaviour as is explained in Section 6.3.

Distribution

After mode choice modelling, active trip-stages were distributed (3rd step). This allowed for a good visualisation of the generations and attractions for different trip-stages and usage of the active mobility network on the basis of observed data set. To determine how active trip-stages are distributed (3rd step) across the TAZs, an O-D matrix was created, while bearing in mind that, as the analysis is made at sample level (and not population), some TAZs would produce/attract zero (0) trips.

Nevertheless, the usage of O-D matrix, as per traditional approach, was selected to investigate the functionality of the method and search for suitable approaches to gross-up sample data to make it representative of the population (100%) at TAZ level. The Gravity model is the most commonly used method and was utilised in this thesis. The model has a functional form similar to that of the Newtonian law of gravity. Equation 3.7 was used in estimating trip-stages (T_{ij}) from one zone (i) to another zone (j). Distribution of trip-stages across TAZs was made taking into consideration the trip-stage rates by different modes of transport.

$$T_{ij} = \frac{P_i(A_j * K_{ij}/F_{ij})}{(\sum A_k K_{ik}/F_{ik})} \quad (3.7)$$

where

- T_{ij} = Total trip-stages from zone i to zone j;
- P_i = Total trip-stages produced in (or originated from) zone i;
- A_j = Total trip-stages attracted to (or with destination to) zone j;
- K_{ij} = Socio-economic adjustment factor, typically assumed to be unity;
- F_{ij} = C_{ij}^α , where α is calibrated for different scenarios; and
- C_{ij} = Distance between each zonal pair (from origin to destination).

For this thesis, daily observed O-D matrixes were constructed using household survey data and clustering active trip-stages into specific TAZs. Gravity model was used to calibrate alpha and friction factors for each town based on distance between each TAZ. Higher alpha values were calibrated for non-cycling towns (Hougang = 2.5, and Serangoon = 4), and lower for cycling towns (Sembawang = 1.12 and Yishun = 2).

Higher alpha values indicate higher sensitivity to distance, resulting in fewer long-distance trips. Thus, calibrated values are coherent considering that more cycling trips (which are of longer distance)

occurred at cycling towns. The socio-economic adjustment factor (K-factor) was assumed to be unity as per standard analysis procedure.

Assignment

Finally, to gain better understanding of the usage of the active mobility network, for the path choice or network assignment (4th and final) step, number of trip-stages on foot, by bicycle, and by PMDs were assigned to the existing formal off-road active mobility network. For practical reasons, and based on reported preference to commute off-road, cyclists and PMD riders were assumed to travel only on off-road pathways (Nguyen et al., 2015; Rojas López & Wong, 2018c).

The existing off-road active mobility network was first thoroughly tested for connectivity for accurate utilisation of shortest path analysis. Combinations of pathway selection of O-D pairs (for each trip/trip-stage) were tested in each town under study and optimal paths between each O-D pair was determined by selecting the one with lowest impedance. For a better representation of the density, the network was segmented, and the segment lengths are about 100 metres on average. In noting that some trip-stages do not make use of the whole segment, a threshold of 50% usage was selected. That is, for a trip-stage utilising 50% or more of a particular segment, this segment will be considered as being “used” for that trip/trip-stage; if less than 50% was utilised, then it would not be considered.

For this research study, impedance is solely related to travel distance (i.e. the shorter the travel distance, the lower the impedance). Instead of following the traditional approach of clustering trips at TAZ level, determining shortest travel distance between TAZs and analysing usage of the network based on number of trips from one TAZ to another, network assignment (in this thesis) is based on actual trip/trip-stage origin and destination locations. This procedure allows for a precise representation of shortest paths, which is most applicable for re-evaluation of a town’s existing infrastructure rather than development and planning of new areas/towns, and noting that, as the assignment is based on a sample of the population, findings might not be fully representative of the actual network usage nevertheless.

After the network was prepared and trip/trip-stage O-D points were geocoded, the NetworkRouting tool was utilised. The tool was developed for usage on ArcGIS V10.6.2 by the Urban Redevelopment Authority (URA), which was modified to account for the factors taken into consideration in this thesis. The tool serves to identify the shortest paths linking the O-D points. In cases of several O-D points within a trip (i.e. trips with more than one stage or a trip-chain), special consideration was taken to map the shortest path in the order that the trips/trip-stages were made. The tool provided information

on the specific segments of the transport network that were utilised in this shortest path by trip/trip-stage and this was used to calculate the number of active mobility users per path. The traffic flow was then mapped by density using different colours as presented in Section 6.4. Moreover, in recognising that other factors besides shortest distance can affect road choice decision, options to improve the tool has been mentioned in Section 7.4.

3.4. Chapter summary

This chapter first introduces survey techniques and characteristics (of survey procedures and questionnaires) to collect data to determine and understand pedestrians' and cyclists' travel quality needs. For this, three studies were formulated and conducted. Due to the different nature of the issues being studied, data for these studies was collected using different methodologies (unobtrusive observation, intercept surveys – for qualitative and quantitative data collection, focus group sessions, one-to-one in-depth interview, etc.) and data was analysed accordingly. Specific research questions being considered and the methodology for data collection and analysis utilised for these three studies is presented in Section 3.1.

Then, taken into consideration active mobility users quality needs in Singapore (i.e. findings from the three studies mentioned previously), procedures to develop and establish the PDMD framework is explained. The PDMD framework was developed based on a comprehensive review of 27 previously posted theories related to (active) travel behaviour as well as characteristics of the local context. The PDMD framework introduces a comprehensive overview of factors that affect mobility – decision to make trips – and those that influence the selection of different modes of transport (with main consideration for active modes). While innovative, the PDMD framework is a continuity of previous research, and conclusions and finding can be compared and contrasted across different studies. Using the PDMD framework, a comprehensive data collection instrument was developed. Methodology for the development of the PDMD framework is presented in Section 3.2.

Finally, the technique utilised for household travel data collection and travel demand analysis was specified. Changes in demand based on different scenarios was considered at the mode choice step of a modified 4SM (instead of at generation step as per traditional approach). In the modified 4SM the order of the steps is modified considering generation → mode choice → distribution → network assignment. Travel demand in the mode choice step was analysed using the PDMD framework as a guidance for selection of inputs variables for a computer-intelligence model, in the form of neural network.

A neural network model was calibrated using travel survey data and capabilities of the method to predict changes in demand was tested introducing changes in the built-environment as well as changes based on policies and programmes. These changes were considered individually (using two different scenarios) and combined (third and final scenario). Characteristics of the modified 4SM, as well as rationale for the modification, and the procedure utilised for each of the steps are presented in Section 3.3. Noticing that main focus was placed in the mode choice step.

Chapter 4. Understanding and meeting quality needs

In this Chapter, findings related to active mobility users' fundamental travel characteristics and travel quality needs based on empirical (quantitative and qualitative) research are presented. Three studies were conducted by the author in this thesis to gain a deeper understanding on pedestrians' and cyclists' quality needs, and many of the findings are qualitative in nature. For each study, different methods were selected due to the different nature of the issues studied.

Firstly (1st study), active travelling characteristics and behaviour in the local context is summarised in Section 4.1. An early version of this study has been presented in the *Velo-City Conference 2017* (Rojas López & Wong, 2017b). Then (2nd study), overall usage of the transport network by active mobility users is described in Section 4.2., and some of the findings from this study have been presented, for consideration for publication, in *International Journal of Sustainable Transportation* journal for which a manuscript is currently under review (Rojas López & Wong, 2018c). Afterwards (3rd study), attitudes towards walking and cycling in Singapore, based on a qualitative survey, are explained in Section 4.3. A version of this study has been published in the *Case Studies on Transport Policy* journal (Rojas López & Wong, 2017a).

These findings form the basis for the development of the PDMD framework to be presented in the subsequent chapter and providing ground truth information to complement the available theoretical knowledge. In each of the sections, the applications of the findings for the development of the PDMD framework are indicated. A summary and discussion regarding key active travelling quality needs in Singapore is given in Section 4.4.

4.1. Active travelling characteristics

Arising from the first study, it can be observed that many cyclists park their bicycles away from designated parking areas, especially bicycles from the bicycle-sharing schemes. The number of active mobility users (pedestrians, cyclists, and riders of PMDs) was found to be higher at sheltered pathways, which is attributed to weather and comfort factors. Also, as sheltered pathways are commonly close to public transport stations, a higher number of active mobility users is expected. At PM non-peak periods, many "recreational" cyclists were observed (assumed to be recreational as they were cycling at parks, off-peak periods, and at a relatively slow pace). Data provided by 202 residents or frequent visitors of the cycling towns under study (i.e. Sembawang and Yishun), at 61% and 39% respectively, who participated in the survey, was analysed. Participants were interviewed

at different locations over the cycling towns while commuting as pedestrians (73%) or cyclists (27%). Slightly more males (57%) participated of the survey and most participants were young adults (20-29 years old – 24%) and adults (30-39 years old – 32%) – with approximately 10% of the participants pertaining to the remaining age groups (i.e. 10-19 years old, 40-49 years old, 50-59 years old, and ≥ 60 years old). About 2 in 3 or 66% of the participants were employed, 17% students and 17% others (housewives, unemployed or retired). Almost all survey participants (91%) have lived in Singapore for at least 5 years, and they reported to have generally good knowledge about the local transport system. Demographic and transport characteristics of the respondents are summarised in Table 4.1.

Table 4.1. Sample characteristics – Active travelling characteristics study

General characteristics	Sample n=202	National proportion ◆	Cycling frequency	Sample n=202
Cycling town residents	61%	NA	Regularly (≥ 1 per week)	26%
Cycling town frequent visitors	39%	NA	Occasionally (< 1 per week)	20%
Males	57%	49%	I cycle outside [cycling town]	7%
Pedestrians*	73%	NA	I don't cycle but I plan to start	8%
Cyclists*	27%	NA	I don't cycle & I don't plan to start	39%
Age distribution			Bicycle & PMD availability <i>Households with 1 or more:</i>	
10-19 years old	11%	22% (0-19 yrs.)	Adult bicycle	63%
20-29 years old	24%	71%	Child bicycle	9%
30-39 years old	32%		Electric bicycle	1%
40-49 years old	12%		PMDs	3%
50-59 years old	11%			
≥ 60 years old	10%	7%		
Employment			Motorised vehicle availability <i>Households with 1 or more:</i>	
Employed	66%	61%	Car	36%
Students	17%	20%	Motorcycle	3%
Others	17%	19%		
*At the point of interview		◆(SINGSTATS , 2011a)		

More than half of the participants reported to cycle in Singapore and 8% reported intentions to start cycling in the future. The remaining participants reported not to cycle and no intentions to become cyclists. Interestingly, 3 in 4 households of the surveyed participants owned some types of bicycle

(adult bicycle, children bicycle, and/or electric bicycle). The elevated rate of bicycle ownership is attributed to the fact that cycling activities are quite prominent at residential cycling towns. The average number of bicycles at those households equals to 1.7 (SD=1.3; Max 6 – Min 1).

Survey participants were asked to select their most commonly-used mode of transport among MRT, public bus, private transport, walking, cycling and other modes (e.g. PMDs, taxi, etc.). Public transport was the main mode of transport used by most of the respondents (54%) (34% MRT and 20% public buses), 13% mostly use private transport, 21% mostly commute as pedestrians, 10% mainly cycle, and a small 2% use other modes of transport as shown in Figure 4.1. In addition, as previously mentioned, almost half of the participants reported to cycle at the towns under study (as main or secondary mode of transport). The elevated bicycle usage indicates that indeed cycling is more popular at these towns as compared to the average 1-2% cycling (as main mode) at the national level. As compared with national rates it can be seen that more cycling takes place at these towns and private transport is less commonly used, indicating positive influence of active transport facilities in increasing active mobility.

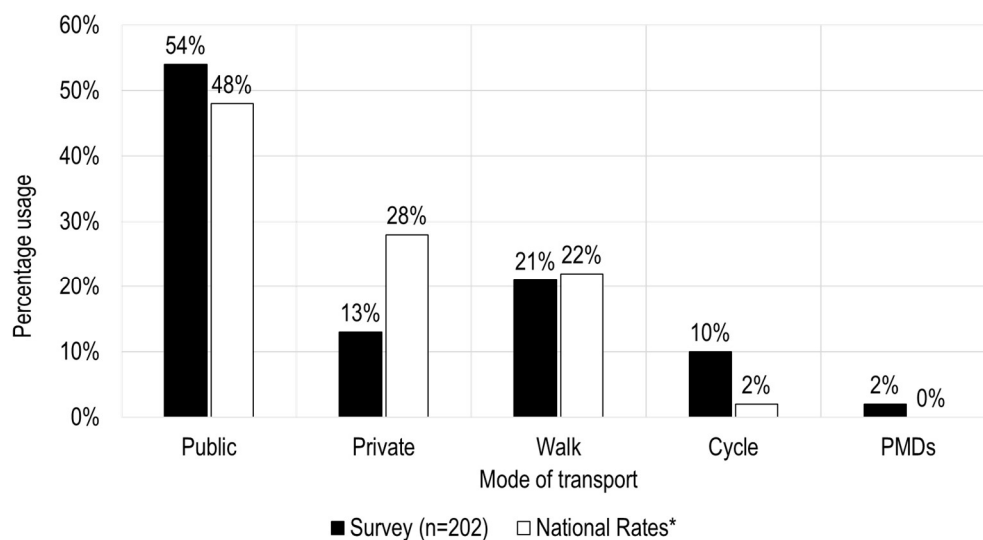


Figure 4.1. Most commonly-used mode of transport – Active travelling characteristics study

*Source: LTA Statistics in Brief 2015

Designated cycling paths and other cycling facilities were implemented in Sembawang and Yishun in 2013 and 2015, respectively (LTA, 2015d). Of the 202 survey participants, 111 or 55% reported to be aware of these demarcated cycling paths. Interestingly, many (33) of them do not cycle, indicating that besides cyclists who obtain most benefits from the paths, pedestrians also enjoy the comfort of having demarcated cycling paths in the towns. More specifically, 7 in 10 residents (n=123) reported

being aware of the demarcated cycling paths. However, this is not true for frequent visitors as only 1 in 7 answered positively about awareness of the cycling network. Thus, although many reported to be aware of the cycling paths, more can be done to increase awareness, especially among those do not live, but frequently visit the town as these are potential active mobility users. Authorities could focus further in advertising about path locations and characteristics. Alternatively, paths can be modified so that they become more obvious to everyone. For instance, these can be painted in different colours (currently most of them are of the same colour as normal pathways) or be equipped with clearer signage for specific users.

Moreover, a section of the questionnaire was intended to assess travel behaviour changes and its relationship with provision of shared facilities, thus those who reported being aware of cycling paths were further interviewed about their travelling characteristics. The responses are shown in Figure 4.2. Based on answers of those who reported being aware of the demarcated cycling paths ($n=111$), 7 in 10 reported to use motorised modes, walking, and PMDs the same as before the implementation. Interestingly, a change in cycling usage was reported. Respondents who reported to cycle at Sembawang/Yishun ($n=93$) were asked to state the year they started cycling. Using these dates and the implementation of cycling network dates, it was found that one third started cycling after the implementation of the cycling network, suggesting that provision of infrastructure increased cycling demand. This can be considered at the planning level in estimating possible increase in active trips based of type of infrastructure provided.

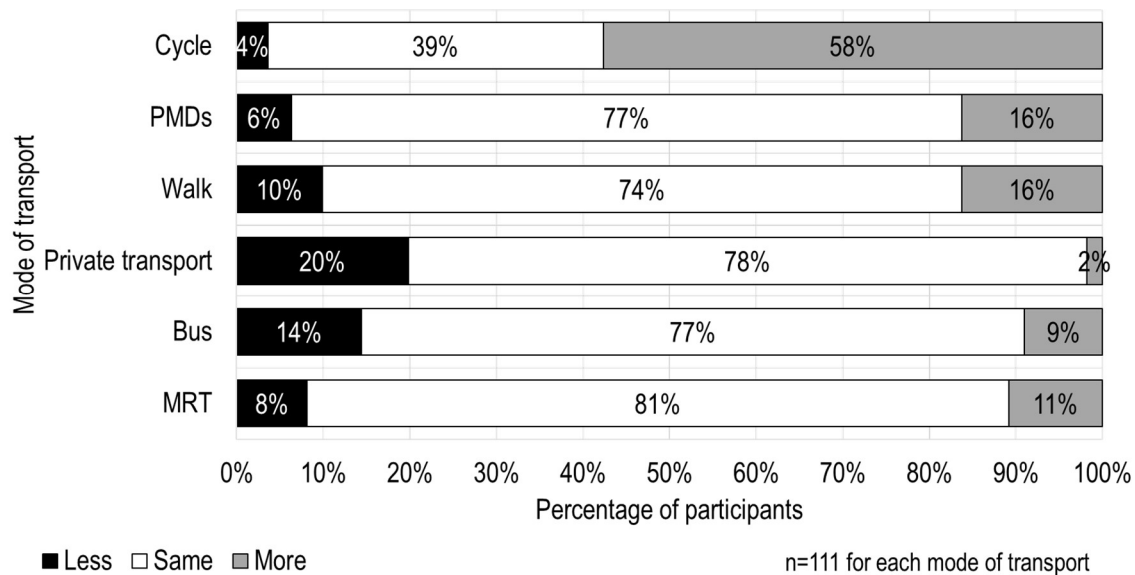


Figure 4.2. Modes usage after network enhancement – Active travelling characteristics study

Of the total survey of 202 participants, 26% cycle regularly (once a week or more), 20% cycle occasionally (less than once a week) and 109 or 54% respondents do not cycle at the cycling towns under study, of whom 13 reported to cycle (and stayed) elsewhere. Cyclists' participants were inquired about their cycling frequency at the cycling towns, and non-cyclists (who were commuting as pedestrians at the time of the interview) about their willingness to undertake more cycling trips. They provided from one to maximum 3 reasons for doing so. Of the 96 non-cyclists who currently do not cycle at all, around one in five (or 17 non-cyclists) reported willingness to start cycling in the near future. Contrastingly, the remaining four in five (or 79 non-cyclists) reported being unwilling to start cycling – "I do not cycle and have no plans to start cycling in the near future". Of the non-cyclists unwilling to start cycling, only 2 of them reported being aware of the dedicated paths available for cyclists in the towns under study and of the non-cyclists willing to start cycling, around 40% reported to be aware of the demarcated paths in the towns. Thus, as mentioned, if more advertising campaigns were available and/or if path characteristics were more prominent, demand, not only for cycling but also for other active modes of transport, is likely to increase.

Reported top 3 motivations for willingness to start cycling are: [1] because it is convenient – 26%; [2] for health or recreation – 21%; and [3] because it saves time and money – 21%. Enhanced safety was the next mentioned motivation. Surprisingly, very few participants reported willingness to start cycling due to better cycling infrastructure – 5% (Figure 4.3a – non-cyclists). Top reasons for not being willing to start cycling included: [1] distance (I go to places too far or within walking distance) – 19%; [2] feeling of insecurity related to traffic safety and convenience of public transport – 14% each; and [3] weather factors (too hot/too rainy) – 12% (Figure 4.3b – non-cyclist).

Among the 93 cyclists' respondents who reported reasons to cycle more, same, or less after the enhancement/provision of off-road cycling paths in the towns under study, 70% or 65 cyclists, reported to cycle more frequently as compared to before implementation of the paths. Interestingly, top 3 reasons for cycling more frequently are the same as the reported motivations to undertake cycling in the future, but with slightly different percentages. The top reasons for cyclists to cycle more are: [1] because it is convenient – 32%; [2] because it saves time/money – 21%; and [3] for health/recreational reasons – 19% (Figure 4.3a – cyclists). On the other hand, the reasons for not cycling more were asked to the 28 cyclists who reported to cycle same or even less after the cycling paths implementation. The cyclists were given the same set of possible reasons for not to cycle more as non-cyclists who reported not to have plans to start cycling in the near future. The most common reasons for cyclists not cycling more are: [1] because they did not recognise the improvement – 27%;

[2] lack of parking and/or end of the trip facilities – 16%; and [3] too long or too short travel distance – 13% (Figure 4.3b – cyclists).

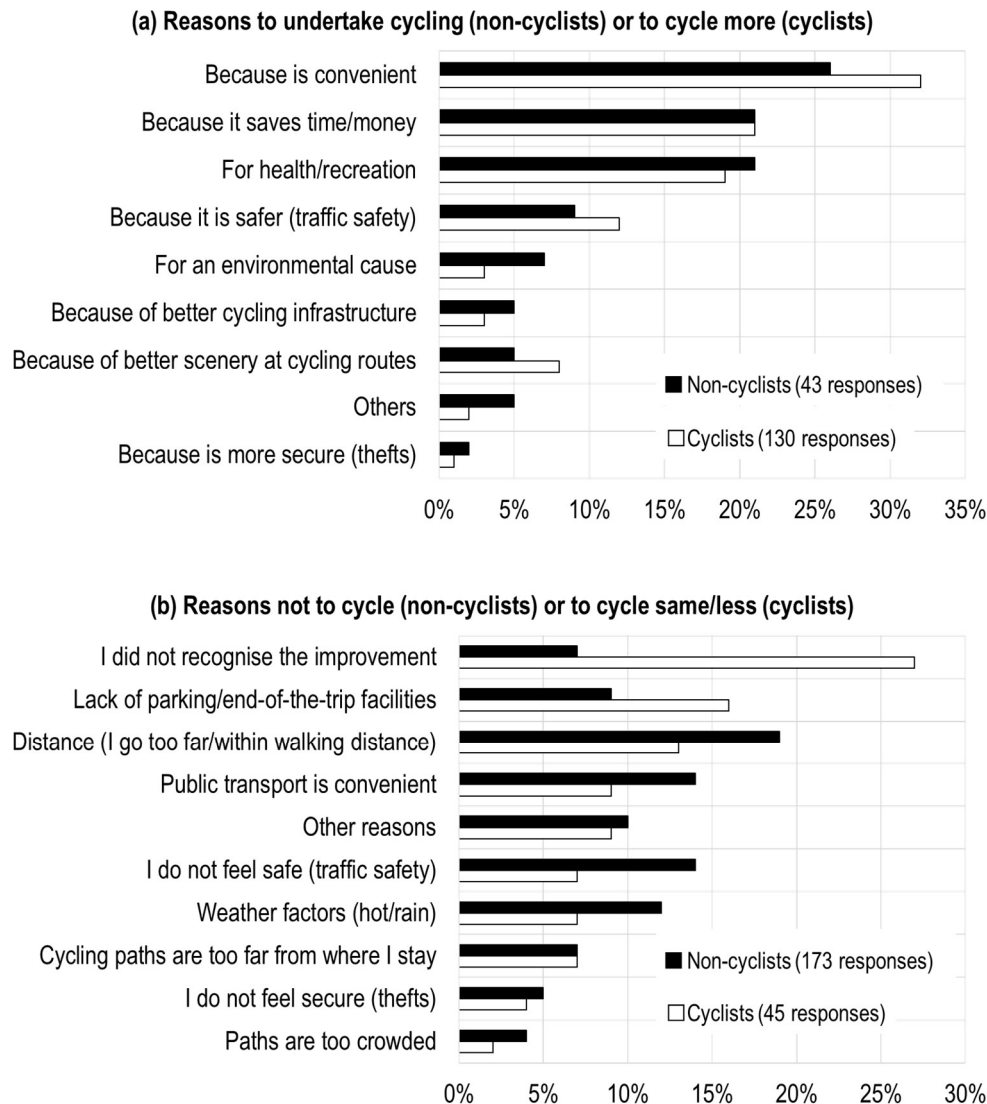


Figure 4.3. Reasons to cycle or undertake cycling – Active travelling characteristics study

Interestingly, the stated reasons for current non-cyclists to cycle in the future and the reason for current cyclists to increasing cycling trips are not very different. The greatest differences noted are “Because is convenient”, and “For an environmental cause”. Cyclists tend to give more weightage to convenience while non-cyclists who are willing to start cycling are more likely to do so because of shifts to sustainable and “green” or active modes of transport. For non-cyclists who are unwilling to start cycling or those who are unwilling to cycle more than before, two interesting points can be highlighted. None of the respondents (non-cyclists nor cyclists) reported sharing issues as deterrents for cycling. Although traffic safety concerns were mentioned, this was mostly related to high speed

traffic at adjacent roads and concerns at crossings. Second, very few cyclists and non-cyclists mentioned improvement of the network (better cycling infrastructure) as main reason to cycle more or to take-up cycling. Moreover, many respondents said not to recognise the improvement and lack of end-of-the-trip facilities as reasons for not cycling more or willingness to take-up cycling.

Finally, cyclists who reported increased cycling trips were asked to recall all their cycling trips performed in a given week day, similar to a small-scale travel diary but only concerned about cycling trips. Then, they were enquired how these trips were made before the enhancement/provision of off-road cycling paths in the towns under study. Although participants were asked to report ALL their cycling trips in a given day, most respondents only reported one and maximum two trips, presumably their most common cycling trip(s). After filtering for abnormal data, a total of 100 cycling trips were analysed. Almost all these trips were home-based two-way trips, with origin and destination at one of the two towns under study. Most common trip purposes are: [1] to commute to work/school – 32%, [2] leisure/exercise – 22%, and [3] as first/last mile trips to reach other modes of transport – 19%.

Of the 100 analysed cycling trips, 78 of them were shifted from other modes and 77 were new cycling trips. The majority shifted from walking mode (37 trips). This is interesting given that participants mostly indicated to walk same as before the implementation of the paths. Thus, it is assumed that, as some cycling trips shifted from walking, new walking trips arise elevating the overall active mobility rate in the towns. Regarding shifts from motorised modes, most people shifted from the bus mode (28 trips). Only few trips shifted from MRT or private transport, 4 and 3 trips, respectively. To estimate the shift-rate from motorised modes of transport, the methodology used by Nguyen et al. (2015) was used. Their study analysed shift rate to cycling at Tampines residential cycling town in Singapore at different time periods. Following Nguyen et al.'s methodology, first the proportion of cycling trips shifted from different modes is calculated as shown in Equations 4.1 to 4.3.

$$b = \frac{\text{No. of reported cycling trips shifted from bus}}{\text{Total no.of reported cycling trips}} = \frac{28}{100} = 0.28 \quad (4.1)$$

$$\text{mrt} = \frac{\text{No. of reported cycling trips shifted from MRT}}{\text{Total no.of reported cycling trips}} = 0.04 \quad (4.2)$$

$$c = \frac{\text{No. of reported cycling trips shifted from private vehicles}}{\text{Total no.of reported cycling trips}} = 0.03 \quad (4.3)$$

Then, these proportions and the average number of daily trips can be used to estimate the shift rate to cycling due to infrastructure enhancement/provision by way of Equations 4.4 to 4.6.

$$\text{Shift rate from bus to cycling} = \frac{b \times \text{Cycle}}{\text{Bus}} \quad (4.4)$$

$$\text{Shift rate from MRT to cycling} = \frac{\text{mrt} \times \text{Cycle}}{\text{MRT}} \quad (4.5)$$

$$\text{Shift rate from private transport to cycling} = \frac{c \times \text{Cycle}}{\text{private_transport}} \quad (4.6)$$

where Cycle, Bus, MRT and private_transport represent the average number of daily trips by each of these modes of transport in a specific town. These shift rates can be applied using the overall town (or country) statistics such as those obtained from Household Interview Survey. In this thesis, the cycling shift rates due to infrastructure enhancement are utilised as input in the demand forecast model for the future scenario. The average number of trips by each mode of transport is estimated using data collected from the sampled 1,119 households as described in Section 6.1. Usage of each mode of transport is projected to the overall population in each town and then shift rates are calculated accordingly and then shift from other modes to cycling are estimated. A similar approach can be utilised at most residential towns in Singapore as most of them have similar land use, similar transport network features (especially in future scenario when all towns in Singapore are provided with cycling network), and similar socio-economic characteristics.

Study discussion

This study is focussed on two cycling towns in Singapore, Sembawang and Yishun. Active travel characteristics and the influence of providing dedicated cycling paths as affecting travel behaviour were studied. Data from 202 cyclists and non-cyclists was analysed. Interestingly, 7 in 10 town residents reported a positive awareness about the infrastructure provision but only 2 in 7 frequent visitors did so, cyclists and non-cyclists alike. This lead to recommendations to further advertise the characteristics and locations of the paths and/or provide the paths with more striking characteristics so that these are clearly noticed by everyone. This is not only applicable in these areas, but also in other areas of Singapore and even overseas cities as is important that most people recognise the investment in active mobility infrastructure and thus recognise the convenience of these modes.

Moreover, the reported usage of public transport, and walking in the two cycling towns was found to be quite similar to the national rates. However, a lower usage of private transport and an increased usage of bicycles was found. Almost 6 in 10 cycling participants reported to cycle more after the enhancement/ provision of off-road cycling facilities. The current study also sheds light into PMD usage, which are yet to be reported in national surveys. Around 2% of the participants mostly travel by PMDs. Indeed, when asked specifically about modifications of their travel behaviour after the

implementation of the dedicated paths and other active mobility infrastructure, majority of respondents reported increased cycling trips (cycle more), and although minimal, some reported increased trips as pedestrians and PMD riders, and reduced usage of motorised modes.

Cyclists participants recalled cycling trips and mode of transport of such cycling trip before enhancement/provision of off-road cycling facilities was enquired. From the 100 cycling trips analysed, almost 8 in 10 cycling trips were shifted from other modes of transport after the provision/enhancement of off-road cycling paths, mainly walking. Thus, it is concluded that provision/enhancement of off-road cycling facilities, as in Sembawang and Yishun cycling towns, has a positive effect in increasing overall active mobility rates. The reported before and after usage levels were used to calculate cycling shift rate due to infrastructure enhancement. The rates will be used to estimate overall cycling shift rate for future demand analysis using household survey data.

Finally, interviewed non-cyclists (mostly pedestrians) were asked to report their willingness or not to take more cycling trips in the future. Of these, 1 in 5 reported willingness to start cycling in the future. Reasons were compared with those of cyclists who reported to cycle more or cycle less after the enhancement/provision of paths. Interestingly, non-cyclists who are considering cycling in the future and current cyclist who reported to cycle more, mentioned similar reasons for doing. Yet, some differences were found among non-cyclists who are not willing to start cycling and cyclists who reported to cycle the same or less as they did before the enhancement/provision of paths.

Reasons are qualitative in nature and those related to willingness to start cycling or increased cycling are: because cycling is convenient, because it saves time and money, and for health or recreation. Although not many directly mentioned infrastructure enhancement/provision as reasons to start or increase cycling, convenience can be associated with the enhancement of the off-road cycling facilities, which most likely made trips more comfortable and accessible. Consequently, although users might not perceive enhancement/provision as the underlying reason to increase cycling, this positively affects active mobility resulting in increased cycling rates and willingness to start cycling.

Reasons for not being willing to start cycling include: distance limitations, convenience of public transport, and safety concerns. Distance was also mentioned as a reason not to cycle more by current cyclists, but lesser effect than “I did not recognise the improvement”, and lack of parking/end-of-the-trip facilities. Perceived distance limitations could be eased by advertising how provision of cycling paths makes cycling more accessible and different locations are easier to reach by using bicycles, some even easier than by public transport modes. Increased advertising can also help to increase

awareness of the paths and thus increases cycling demand. Regarding safety, further research should be focused on understanding users' interaction and actual type of conflicts so that path characteristics can be modified and/or to incorporate devices, such as traffic calming (e.g. features that cause cyclists to slow down) and off-road traffic signals, to increase safety levels.

4.2. Usage of the (formal) active transport network

To understand usage of active transport network, data was collected using intercept survey interview, which was conducted around Singapore. A total of 277 respondents, 47% male and 53% female, participated in this study. A general description of participants' characteristics is given in Table 4.2.

Table 4.2. Sample characteristics – Usage of active transport network study

	n=277	Non-cyclists n=82	Cyclists n=195		n=277	Non-cyclists n=82	Cyclists n=195
				Gender			
Age distribution				Male	47%	46%	47%
15-19 years	8%	6%	9%	Female	53%	54%	53%
20-24 years	63%	59%	64%				
25-29 years	17%	18%	16%	Occupation			
30-34 years	3%	4%	2%	Employed	29%	34%	27%
35-39 years	5%	5%	6%	Student	65%	61%	67%
40-44 years	5%	8%	3%	Housewife	3%	3%	2%
				Unemployed	3%	2%	3%
Motorised vehicle availability-				Bicycle & PMD availability			
Car/van	55%	56%	53%	Adult bicycle	59%	38%	67%
Motorcycle	9%	9%	10%	Child bicycle	7%	10%	8%
				Electric bicycle	3%	4%	3%
■ Percentages are mutually exclusive				PMDs	11%	11%	10%

As targeted, most of the participants belonged to the young adult age groups (20-24 years old), the youngest participant being between 15-19 years old and the oldest just above 40 years old. About two in three (65%) respondents were full-time students, 29% were employed full time, and the remaining respondents (6%) were housewives or unemployed. In every other household (55%), there was at least one motorised vehicle (car, van), and in 59% of the households, there was at least one adult (pedal) bicycle. Some households (22%) do not own any motorised vehicle nor a bicycle/PMD. The 11% household ownership rate of PMDs indicates the escalating popularity of these devices in Singapore.

Participants were asked to state their most commonly-used mode(s) of mobility, designated here as “most-common” transport mode(s). As shown in Figure 4.4, the majority (71%) selected public transport (either as a single mode or in combination with others), with the most frequent combination being ‘MRT & Bus’ at 41%. Regarding usage of active modes of transport, close to one in three (29%) participants reported using some types of active mode as most-common mode(s) of transport, of which 19% selected combination of active mode with public transport, which is to be expected given the high public transport ridership in Singapore and that public transport does not provide a “door-to-door” service. Thus, FLM trip-stages in public transport trips are performed by either walking or cycling. A total of 9% of the participants selected active modes only as their most-common mode(s) of transport. No significant gender difference ($p=0.466$) was found regarding commonly-used mode(s) of transport. However, slightly more males selected cycle only and private transport only as their most-common mode(s) of transport. From a separate question, a large proportion of participants indicated that usage of active modes of transport has increased their familiarity with (some recently upgraded) active mobility network which thus synergistically provided experiential exposure to (recently improved) cycling /walking infrastructure.

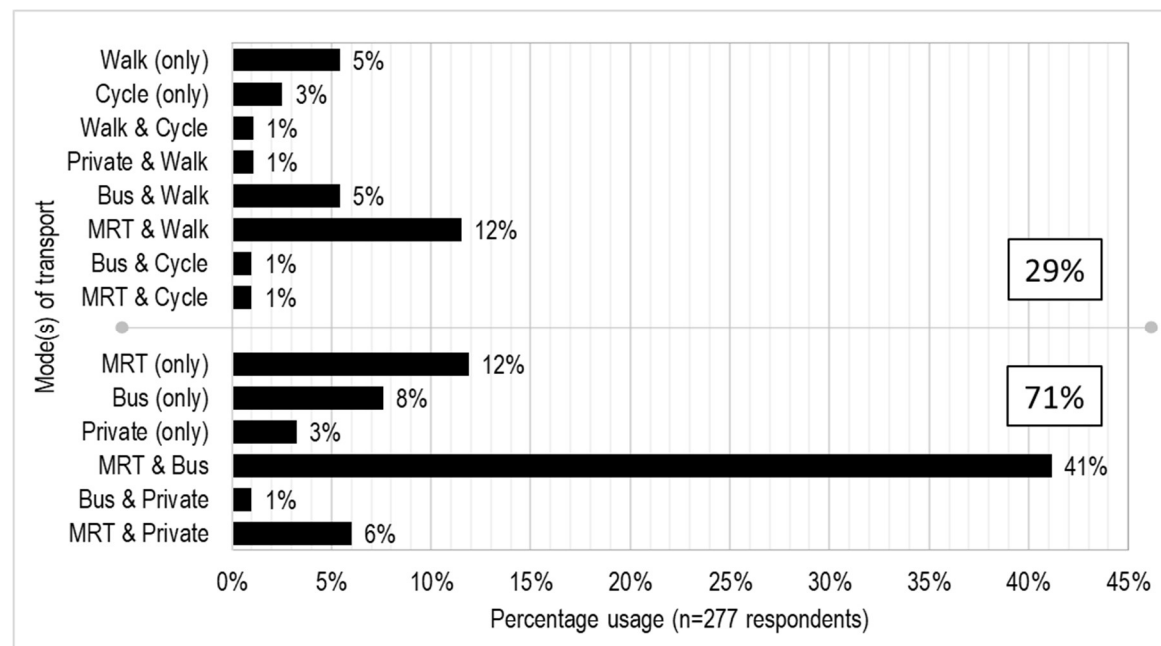


Figure 4.4. Commonly-used modes of transport – Usage of active transport network study

Six types of active mobility facilities were considered in this study, 4 of which are off-road (footpaths, widened paths, delineated paths, and segregated paths) and 2 are on-road (on-road bicycle lane, and on road without bicycle lane) as has been presented in Figure 2.3. PCNs were not included as many PCN segments do not provide direct route to activity centres and are rarely used for everyday

commuting. Participants who reported to cycle (cyclists, n=195) were asked to rate all 6 facilities according to usage preference for cycling, while those who do not cycle (non-cyclists, n=82) were asked to rate usage preference of off-road facilities, essentially from perspective of a pedestrian amidst other users like cyclist and PMD rider. Similar preferences for travelling facilities were reported by cyclists and non-cyclists. The 2 most preferred travelling facilities, for both cyclists and non-cyclists, were delineated paths and segregated paths as it can be seen in Figure 4.5. Interestingly, most participants ranked the delineated paths as their top-choice travelling facility, while on-road cycling facilities were accorded very low preferences.

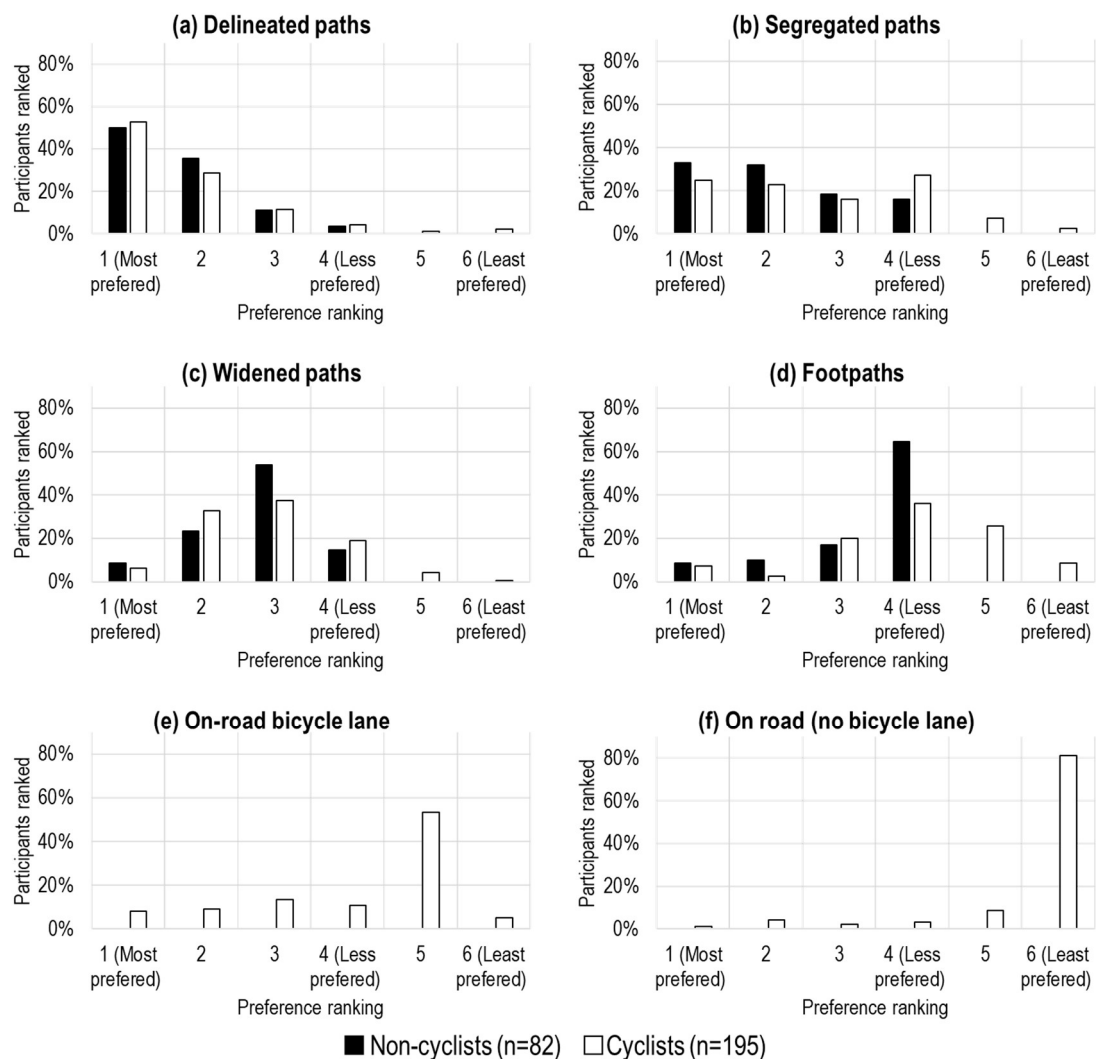


Figure 4.5. Preferred travelling facility – Usage of active transport network study

For participants who rated delineated paths as top preferred facility, a good demographic representation was found, with close to 50-50 male-female ratio and age distribution similar to the overall sample size. Moreover, both utilitarian and recreational cyclists selected delineated path as

their preferred travelling facility. Survey participants also shared the reasons for ranking a specific facility as their top choice. Common themes such as right-of-way, perception of increased safety, convenience and accessibility, and **dynamic use of space**, were identified using the GT approach. For delineated paths (as well as widened paths), the majority of participants (both cyclists and non-cyclists) discussed it is best to move along these facilities due the “dynamic use of space” as the proportions of user groups vary spatially and temporally, with dominantly more pedestrians during certain times and vice versa. As mentioned by respondents, at some periods, paths get rather crowded with pedestrians and having wider areas to move around (even if encroaching upon cycling space) improves navigation. Also, it was highlighted that often times, users do not keep to their designated paths (i.e. pedestrians encroach onto cycling paths and vice versa). Hence, having paths contiguously adjacent to each other makes it easier to manoeuvre, as articulated in the following sample comments.

“These [pointing at widened & delineated paths illustrations] are better. Sometimes there are a lot of people and can make use of the space. This one [delineated path] even better as if there is a cyclist he knows which side to go” (pedestrian, female, 20-24 years old)

“Having both paths [pedestrian’s and cyclist’s] together but well delineated is better. You know your way but there is space to manoeuvre if a pedestrian blocks you” (cyclist, male, 25-29 years old)

Also, delineated paths were preferred as these usually have a good signage scheme, highlighting the rights-of-way of respective users. A few participants did mention that segregated paths also have good signage scheme, yet it is not easy to change from one path to another when situation demands. The most common reason for selecting segregated paths as the top facility to move about was the physical separation from other types of road users which increases the perceived levels of safety, as revealed in the following sample comments.

“Sometimes I get confused and go into the cycling way, but segregated is better as all the modes of transport are separated from each other and it is safer” (pedestrian, female, 40-44 years old)

“As long as there are no pedestrians using it, this [segregated path] is best. Separated space and no need to worry about other users” (cyclists, male, 20-24 years old)

As for on-road facilities, not surprisingly, most cyclists selected on-road bicycle lane as their top facility (whereas only 2 participants – one male and one female – selected on-road cycling without bicycle lane). Participants who selected on-road facilities were cyclists who have been cycling for

more than 10 years (i.e. are more confident cyclists) and the top reason was travelling convenience. Based on observations by the authors, people who cycle on the roads in Singapore are the “professional cyclists”, who tend to travel at a faster speed, have better equipped bicycles, and commonly wear safety gears (helmets, knee pads, glasses) and flashy cycling outfits.

Moreover, a group of 50 cyclists from the sample reported that the implementation and/or improvement of (off-road) cycling paths had positively impacted their walking trips. These participants were further queried (using open-ended questions for interview) to understand the extent of such impacts. Improved convenience (46%) and safety (36%) were the most commonly-mentioned factors, while improved accessibility and better interaction among users were also proffered as value-add improvements accrued from cycling path implementation. Participants have associated improved safety and convenience with the dedication of facilities and the greater space that provides pedestrians and cyclists with the required rights-of-way to travel.

In addition to the provision of infrastructure, other developments such as the provision of bicycle-sharing, also have influences on active trips. As these are mainly focused on cycling, cyclist respondents were asked additional questions regarding their cycling behaviour. Most participants (39%) reported to have cycled regularly for more than 10 years. On the other hand, a high proportion took up cycling recently, with 8% of them cycling since less than 6 months ago, and 5% less than one year ago as presented in Figure 4.6. It can be seen that more young and mature adults took up cycling recently reflecting that the developments have positive effects in several age groups.

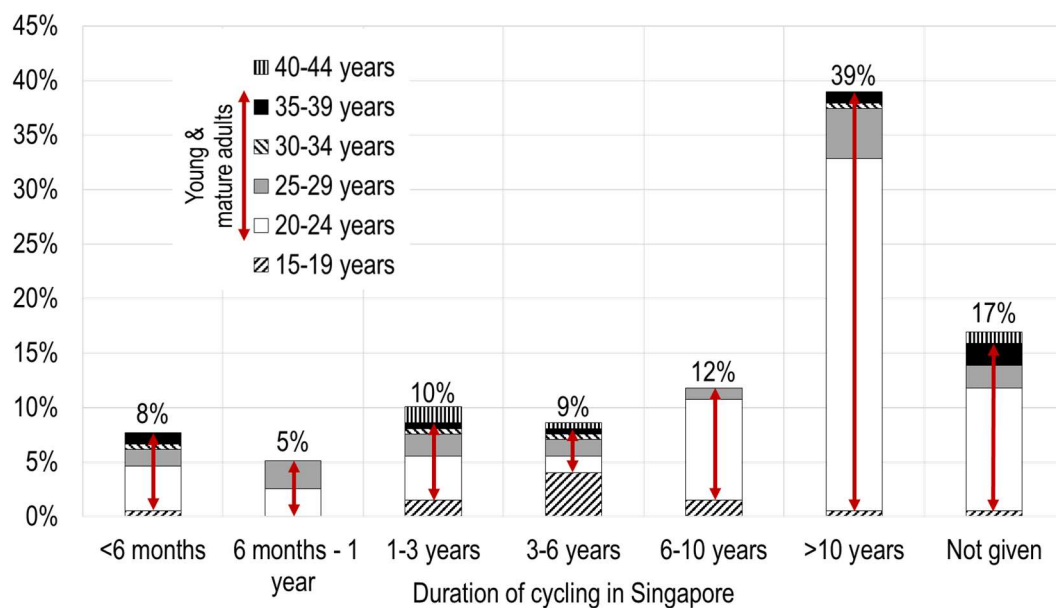


Figure 4.6. Duration cycling in Singapore (n=195) – Usage of active transport network study

Participants were engaged in discussion regarding their reasons to take-up cycling regularly. Almost all cyclists (79% out of the 195) provided in-depth discussion. Main reasons were classified within the “because is a good form of recreation/exercise” category. Other factors were mentioned, and these are grouped as: improved convenience, availability of bicycle-sharing scheme, and parents/peer influence. Improved convenience is commonly associated with improved safety perception provided by the infrastructure and due to dedicated right-of-way, which improves overall cycling perception which encourages users to undertake cycling. Looking at reasons based on period (duration) of cycling in Singapore, as presented in Table 4.3, most “new” cyclists reported to take-up cycling due to availability of bicycles from the advent of bicycle-sharing schemes, thereby highlighting the importance of such programmes in increasing cycling mode share among young and mature adults. It is also interesting that most of those who did not report when they took up cycling did indicate being influenced by improved infrastructure to take-up cycling.

Table 4.3. Reasons to take-up cycling – Usage of active transport network study

Cycling period	<1 year	1-3 years	3-6 years	6-10 years	>10 years	Period not given
n=	26	20	17	23	77	32
Improved convenience	7 (30%)	3 (18%)	5 (30%)	1 (5%)	7 (9%)	6 (20%)
Bicycle-sharing	14 (54%)	0	0	0	0	10 (30%)
Recreation/exercise	4 (17%)	13 (65%)	7 (41%)	15 (67%)	40 (52%)	13 (40%)
Must know skill	0	2 (12%)	3 (18%)	4 (19%)	12 (16%)	3 (10%)
Parents/peer influence	0	1 (6%)	2 (12%)	2 (10%)	14 (19%)	0
Others	0	0	0	0	4 (5%)	0

Moreover, regardless the reasons to take-up cycling, cyclists' participants were queried about their most common cycling purpose. Almost 2 in 3 of those who have cycled for less than a year (66%; n=26) reported to most commonly do it for transport (utilitarian cycling), while 3 in 4 of those who cycled for more than one year (74%; n=169) reported to do it mostly for recreation and health purposes. Facility usage and cycling frequency were compared between respondents who cycle for utilitarian transport versus those who cycle for recreation. No significant difference ($p=0.441$) was found regarding cycling facility and almost all of the cyclists (84%; n=195) reported to cycle off-road. For cycling frequency, a significant difference ($p<0.001$) was found for those who cycle for utilitarian transport than those who cycle for recreation, with 11% utilitarian cyclists (n=57) cycling almost every day, 28% cycling a few days a week, 40% a few days a month, and 21% at least once a month, compared with respectively, 2%, 10%, 15% and 74% doing it for recreation (n=138).

Study discussion

To understand usage of the active mobility network in Singapore, four main interrogates were considered and these are discussed using vélomobility politics. The study was mainly concerned with the usage of the formal active mobility network, while usage of void decks and/or green spaces as part of the informal mobility network was not analysed. As mentioned, vélomobility politics refers to factors that affect cycling planning and its related policies. In Singapore, ample attention is placed on transport planning, with pedestrians and motorised modes always receiving much attention. Herein, cycling planning can be improved by considering users' preferences and attendant travel behaviour, particularly by better understanding the quality needs of adults, especially young adults who are the "mover-and-shaker group" in relation to usage of active modes of transport and related systems/services. Locally and in other countries where pedestrians and cyclists share off-road mobility facilities, planning for pedestrians and cyclists should be integrated. Mixed-stream traffic of pedestrians and cyclists poses major challenges to planners in providing well-fitting infrastructure, policies, and services that can concurrently enhance quality of walking and cycling trips while maximising available resources, especially under constrained land space.

Vélomobility politics as posited by Koglin and Rye (2014) highlighted that obstacle-free cycling space should be provided, which for active mobility is addressed by providing dedicated facilities for pedestrians and cyclists. While the literature has discussed cyclists' infrastructure preferences, herein mixed-stream human traffic and travel demand variability are considered. In the local context, off-road facilities are preferred over on-road paths for travelling. At first purview, (off-road) segregated paths are seen as the most suitable infrastructure in that physical separation between different user groups shall demarcate "obstacle-free cycling". However, as found in this study, most active mobility users, around 1 in 2 cyclists and non-cyclists alike, prefer to travel along delineated paths (contiguous walking and cycling channels delineated by pavement marking or colouration).

Using GT approach, main reasons for such preference were audited (covered during the survey and reviewed based on answer) and the principal reason of "dynamic use of space along such facility" was identified. That is, the ability of users to shift to/from pedestrians'/cyclists' paths in accordance to the traffic at certain periods of the day. Participants proffered that, in delineated paths, the "wider" and adjacent facilities (with no physical separation) allow users to easily avoid obstacles and easily navigate crowds by shifting to adjacent channel. It was mentioned that delineated paths are most suitable in cases when the proportions of different groups of travellers (pedestrians versus cyclists) differ across the day. Such "dynamic" adaption of available space according to demands maximises

usage of space and increases trip efficiency, and comfort. It must be noted that the dynamic adaptation might have impacts in safety by increasing interaction among users. However, the provision of dedicated right-of-way improves safety. In this regard, clear policies and/or regulations are required to ensure safety of more vulnerable road users and these shall take into consideration demographic characteristics of active mobility users in the country.

Interestingly, the GT did not reveal factors associated with users' interaction as not many participants discussed about this issue despite this being explored during the interview as explained in Sections 3.1.2 and 3.1.3. This could be explained due to many respondents focusing on infrastructural usage and preferences about different modes. There were several mentions of pedestrians blocking the way of cyclists by encroaching onto cycling path and vice versa. Participants did report that improvements of the mobility infrastructure or provision of cycling facilities has improved their walking trip safety, this being ascribed to reduced number of conflicts between pedestrians and cyclists. The relatively few mention about conflicts with other users could also be an indication of increased acceptance of "facilities sharing" which again, could be because of the implementation of the cycling mobility regulation that reinforces "safe sharing" (Active Mobility Advisory Panel, 2016). This indicates that infrastructural planning must be coupled with such policies and programmes aimed to encourage safe and inclusive travel behaviour. It should be noted that the more vulnerable users (e.g. elders or children) might be more susceptible to adverse interactions with other road users.

Another factor considered by the vélomobility politics is the positive representation of cycling as a mode of transport. In this study, cycling rates have been reported to be positively affected by the provision of bicycle-sharing scheme, and the scheme has increased public "acceptance of cycling" by heightening its competitiveness as a mode of transport. A major behaviour change can be seen as many of participants (of various age ranges) reported they had recently taken up cycling and had been motivated by the availability of bicycle-sharing scheme. Planners shall always consider the positive impact that such schemes might have in active mobility, which directly affects usage of the formal and informal active mobility network as well as travel demand. Further promotion policies should be made to encourage other user groups to make use of these services, perhaps motivated by the example of young adult users.

Illegal parking issues as related to bicycle-sharing scheme was not duly covered in the surveys. Yet, based on site observations illegal parking is causing limitations to mobility and even blocking the way. As previously mentioned, authorities and service providers are already investigating various ways to manage illegal parking issues, such as virtual bicycle parking stations that are demarcated by geo-

fenced perimeters (Hong, 2017). This could be coupled with policies encouraging users to properly park self-owned and/or shared bicycles. The positive acceptance of this scheme as well as parking issues are to be considered in the demand analysis. Bicycle-sharing schemes are likely to (positively) affect demand for active modes of transport.

Regarding cyclists of different characteristics having different travel behaviour and preferences, a significant difference ($p < 0.001$) was found between newer and older cyclists as newer cyclists are cycling more for transport than for recreation. Again, this might be due to the current representation of cycling as a viable and competitive mode of transport and not just as means of recreation as in the past. In addition, those cycling for transport were found to cycle much more frequently than those who cycled for recreation. Motivated by these changes, authorities and planners could focus on efforts to promote usage of active modes of transport and its related developments across all user groups. For example, cycling shall be promoted as a viable form of commuting to school among children, and/or to nearby amenities for elders (which also engenders greater social interaction).

4.3. **Attitudes towards active mobility**

As mentioned in Section 3.1.3., 20 adults and 26 elders participated in focus group sessions and one-to-one interviews (total of 46 participants). The gender split for focus group sessions was evenly-matched and more males (65%) participated in one-to-one interviews. The youngest participant was 20 yrs old and the oldest 70 (mean=49 yrs old; Std. Dev.=14.7). The average household size was 3.5 members (average population = 3.4 members/household (Lee, 2016)). In 39% of participants' households, there was at least one car available (22% of the participants were regular drivers or car passengers) and in 80% of them there was at least one bicycle (adult bicycle, children bicycle, or electric bicycle). Two in five (41%) were full time employed or students, 22% part-time employed, and 37% housewives or retired workers. Respondents' characteristics are shown in Table 4.4.

The most common reasons for walking and cycling were reported by respondents. As in previous studies, among adults, walking was reported to be most commonly used to connect with motorised modes of transport, as in FLM trip-stages in multi-modal trips, and for work/school-related purposes. Cycling was mostly used for recreation or exercise. Among elders, walking was also used mostly for FLM travel, and the second most common reason was for shopping or to run errands. Elders cycled mostly for FLM travel, social purposes, and for shopping. Reasons for walking and cycling among elders and adults are shown in Figure 4.7. These are of relevance to mobility decisions and included into the PDMD framework accordingly as described in Section 5.1.2.

Table 4.4. Sample characteristics – Attitudes towards active mobility study

	Sample		Sample n=46
Adults	n=20	Motorised vehicle availability (households with 1 or more)	39%
20-30 years	7		
31-40 years	6	Bicycle availability (households with 1 or more)	
41-50 years	7	Adult bicycle	72%
Male	50%	Child bicycle	30%
With children	55%	Electric bicycle	22%
Elders	n=26	Occupation	
51-60 years	12	Full-time employed	28%
61-70 years	14	Full-time student	13%
Male	65%	Part-time employed	22%
With children	77%	Housewife/retired	37%

All the participants reported to walk, at least for short trip-stages, so all of them have at some points acted as pedestrians, and almost all (74%) reported to have cycled. Cyclists and non-cyclists were asked to report their perceptions about active mobility. Responses from non-cyclists are of special interest to determine possible factors to motivate them to undertake cycling in future.

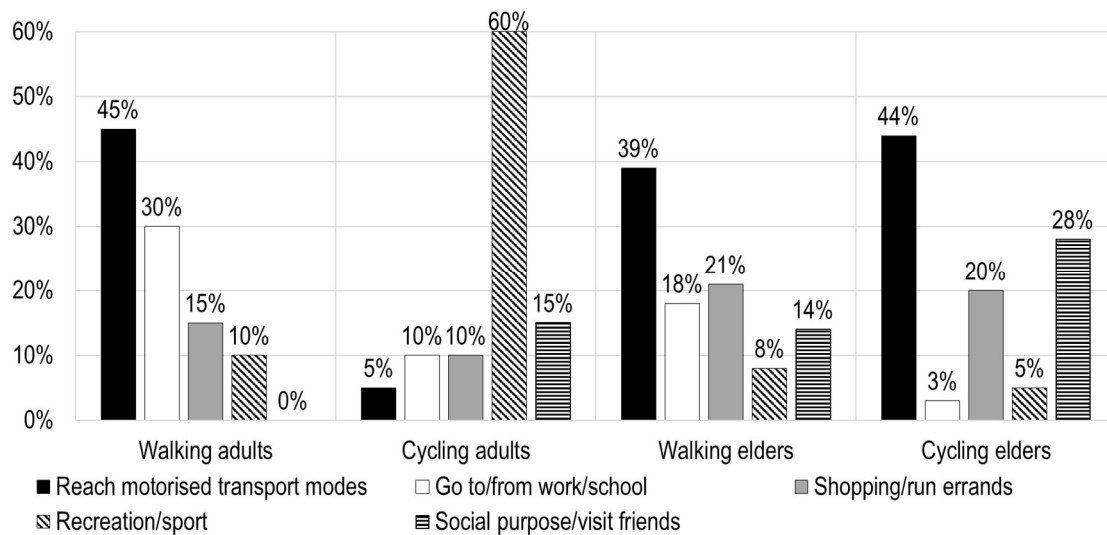


Figure 4.7. Reported reasons for walking and cycling – Attitudes towards active mobility study

Adults and elders were asked to report their agreement with safety and convenience of walking and cycling. A scale from 0 (strongly agree) to 4 (strongly disagree) was used. Most participants agreed that walking is safe and convenient for all users. In addition, cycling is considered safe and convenient for adults, but the same is not 100% true to elders and especially children. Special zones, such as

areas near schools and those with provision for elders, were perceived to encourage active mobility. Responses of elders and adults can be seen in Figure 4.8. It was agreed that in Singapore the transport environment is conducive for walking. Elders, who mostly do short trips around their neighbourhood, reported that the network is quite walkable. For cycling, many participants expressed that although cycling safety levels are good, cycling infrastructure level-of-service can be improved.

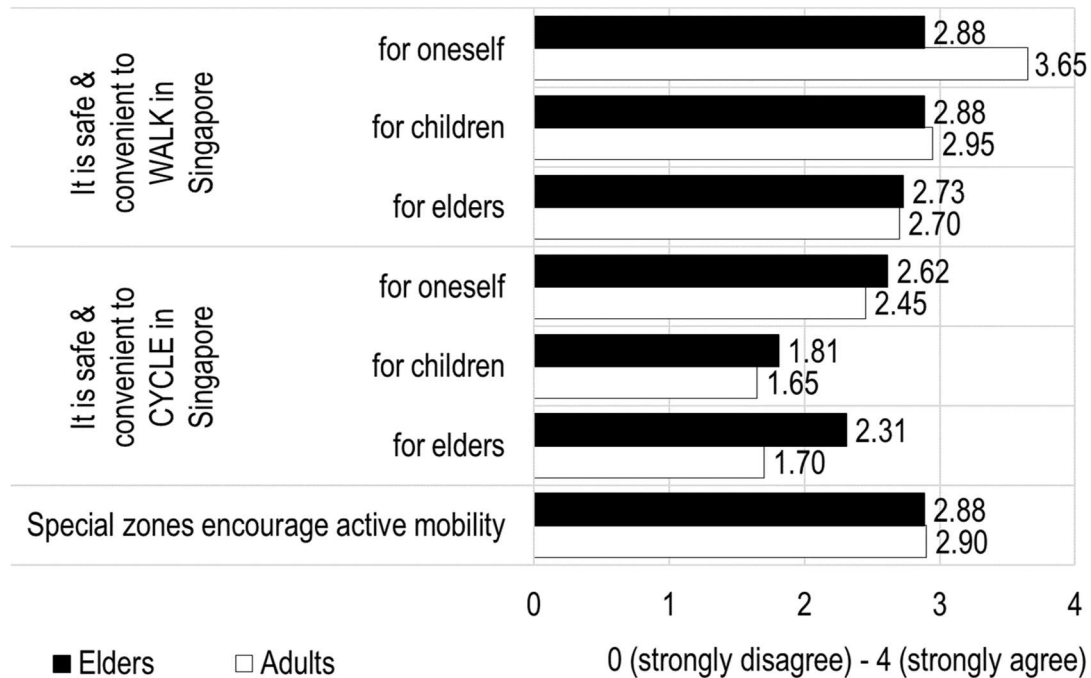


Figure 4.8. General perception of active mobility – Attitudes towards active mobility study

Most participants reported to choose to travel by walking or cycling based on travel time (or trip distance) and availability of other modes of transport. Active modes were most commonly used for short travel of maximum 30 minutes duration. Around 40% of the participants reported willingness-to-shift from motorised modes of transport to active modes for FLM travel if improvements to the transport network were made (particularly provision of sheltered footpath and cycling paths) and several participants discussed the likelihood of undertaking “new” walking or cycling trips. Several of the participants with children reported that they might be willing to allow active trips to school (for their children) if better infrastructure was available.

4.3.1. Attitudes towards walking

Adults and elders reported several strengths, weaknesses, threats, and opportunities about walking in Singapore. These are summarised in a SWOT matrix as presented in Table 4.5.

Table 4.5. Walking SWOT matrix – Attitudes towards active mobility study

Strengths	Weaknesses
Convenience Independence (can be done alone) Reliability Health and environmental benefits Good and safe infrastructure Cost (free)	Limited to short distance Hot and rainy weather Slow travelling speed Sweat and tiredness Crowds and congestions
Opportunities	Threats
Way-finding features and signals More shelters and shades Places to rest Able to compete with bus system Highlight benefits and convenience Education to all road users Incentives to those who walk	High speed of personal mobility devices (PMDs) Motorised vehicles high speed High amount of motorised vehicles Sharing footpaths with other users

Walking convenience

In Singapore, footpaths (mostly with shelters in high-activity locations) provide on-foot access to most locations within a neighbourhood. Thus, walking was viewed as a convenient mode of transport by most participants. It was also considered a mode that can be used independently, without requiring too much effort or much help from others. Independence of the mode was particularly praised by elders. By not having to depend on transport schedules or on other people, walking was also seen as a reliable mode of transport. An example of respondent's comment goes as follows:

"I would rather walk 15 mins, knowing for sure that I will arrive in 15 mins, than wait for the bus 2 minutes and riding from 10 to 20 minutes based on congestion" (male, 22 years-old).

However, it was mentioned that, currently, the convenience of walking is almost matched by convenience of the bus system, even for very short trips. With bus stops available every 100-200 metres and the distance-based fare, it was reported that riding the bus for a few minutes rather than walking for a few blocks to reach the destination is a common travelling characteristic in Singapore.

Benefits of walking

Most participants were aware of the health benefits of travelling on-foot. Some reported walking to work or walking their children to school as a form of exercise. Several elders mentioned that walking was recommended by their doctors. Interestingly, some of the participants, who mostly commute by motorised modes (public or private), took walks as a form of exercise (and not to go to an activity

destination). This group mentioned that they would like to combine commuting and exercise, however this is rather impractical due to time constraints or “perspiration and tiredness”, for example:

“I would like to walk, but I need to drop the kids at school and need to arrive to work 20 minutes later, walking will take me longer than that. I cannot be late!” (female, 50 years-old)

“Why not cycle to work? It might even take less time. But then, where do I shower and what do I do with my sweaty clothes?” (male, 34 years-old)

Several mentions were made about environment-friendliness of walking, and many said that travelling on-foot is a good way to socialise with the neighbours. Parents reported that they allow their children to walk so that they get to know the people who live around the area. Being a “free mode of transport” was acknowledged as a big positive feature about walking. However, this was not reported to be a key factor for choosing this mode over others. This was affirmed by participants with comments such as:

“Walking is free, but taking the bus only cost a few cents! Is not that much what one can save by walking” (male, 70 years-old)

Limitations for walking

Distance limitation, slow travelling speed, and hot-rainy weather in Singapore were the most discussed limitations for walking. Also, the fact of having to lug many things (especially students) was also discussed. Users reported that they need to travel long distance to commute to work or school. Thus, walking trips were in many cases not even considered. Some reported that they need to carry several things to commute to work (e.g. notebook, lunch, documents, etc.), a task that becomes challenging after walking more than a few blocks. Parents also reported that their children need to carry many things to school, thus walking is not appealing to them.

Weather in Singapore was reported as an influential factor of active mobility. Adults stated that in case of rain they are not likely to commute by walking. Elders stated that very high temperature or rain, most of the times, cause them to avoid the active trip or to shift timing. As mentioned previously, perspiration of the trip and not having a place to refresh after arriving at the destination is a reason to avoid walking trips, especially among the working population. Only one participant mentioned that:

“That [weather] is actually just an excuse, people in other countries walk and cycle in the snow! Now, to shower afterwards will be necessary” (male, 40 years-old)

Safety concerns

Safety concerns were reported to increase with the number of users on footpaths and/or vehicles, i.e. under crowding and/or congestion. As footpaths are not only used by pedestrians, but rather shared among pedestrians, cyclists, and personal mobility device (PMD) users, the footpath wide was perceived as being too narrow. Most of the participants affirmed that if wider footpaths were available, sharing shall not post any danger, thus safety concerns will be reduced. The principal concern was the speed differential when pedestrians cross path with cyclists/PMD riders, for example:

“They [PMD riders] just go ‘ffuuuppp’ and don’t even look around [to check for presence of] for other users” (female, 28 years-old)

Public transport stations (e.g. bus stops), waiting areas of road crossings, and other locations where many users congregate were of special concern. It was explained that high number of users, moving in a relatively free-pattern, cause confusion, and increased concerns of pedestrians about being involved in conflicts or even accidents with other users, including other pedestrians. In addition, it was explained that as most crowdedness occurs during peak periods, users are “just in a hurry” to reach their destinations and tend not to be respectful of other road users.

About the on-road vehicles, adult and elder pedestrians explained that they do not feel very safe walking when there is heavy traffic on the roads adjacent to the footpaths, which is very common during peak periods. They expressed their perception of vulnerable users like pedestrians to be more likely involved in a traffic accident when there are many vehicles, especially bigger vehicles such as goods vehicles and buses.

Schemes to promote walking

To further increase the number of walking trips, participants mentioned several infrastructural provisions and policies/programmes such as education and promotion. Shelter provision was expressed to be very important to promote walking trips. The rain-cover and shade provided by these infrastructures were considered as an incentive to undertake more and longer walking trips. In addition to the shelters, several mentioned that these can be complemented with greenery not only to reduce the weather temperature but also to have better scenic views.

Signage was associated with convenience of walking. Most of the adult participants were comfortable with currently available signs. Yet, many suggested that these could be relocated as some of the signs are blocked by tree branches or are located at “estranged locations”. On the other hand, elders

suggested road control signals to be made bigger so that they can be easily spotted. Adults and elders agreed that legend with limited or no wording was best for signals given the multi-racial population. Majority agreed that signals would not be necessary if users respect each other. Thus, participants affirmed that educational campaigns and publicity should be available for all users. Techniques were suggested, such as:

“Just like they [people in the street] give flyers about shops or even public transport service, they should also give flyers for good behaviour on footpaths and towards pedestrians” (male, 54 years-old)

Most elders and some adults said that having places to rest and water dispensers on the streets should be an approach to increase walking trips. These ancillaries may not be necessary for commuting to work or to school (due to time schedule), but certainly useful for social or shopping trips. This led to the discussion about incentives for those who walk to work. Some of the incentives included “If you walk to work you can arrive half/an hour later”; “if you walk to work you can enter and exit later”; and “If you do it [walk or cycle to work] you can get an extra day-off”. Interestingly, none of the parents ever considered the idea of “flexible school time”.

Another well-discussed approach was to promote benefits and convenience of walking, as well as to highlight that walking can compete with bus services for short distance trips, which was seen as especially true during peak periods. Participants said that promotion of the benefits derived from walking should be made as part of a holistic approach of transport, health, and social development authorities.

4.3.2. Attitudes towards cycling

As in walking, positive and negative aspects about cycling were examined. These were classified accordingly, and a cycling SWOT matrix was constructed considering specific features of cycling trips as shown in Table 4.6.

Cycling activity or trip?

First of all, it is worth mentioning that participants in general discussed about cycling with much more enthusiasm than when they discussed about walking. During the interviews, cycling was regarded by adults as a “very enjoyable and fun activity”. This was related to the fact that until recently, cycling was not widely-used as a mode of transport, but more commonly-used as an activity in itself among these user groups.

Table 4.6. Cycling SWOT matrix – Attitudes towards active mobility study

Strengths	Weaknesses
Health and environment benefits Enjoyable activity Avoid congestion Fast travelling speed Long travelling distances Cost (accessible as compared to cars)	Lack of infrastructure and parking No access to bicycles Hot and rainy weather Unclear cycling rules Sharing spaces (with cars/pedestrians) Bicycle weight
Opportunities	Threats
Cycling paths (on- or off- roads) Bicycle-sharing systems End-of-the-trip facilities Signals for cyclists Education and training Cycling activities/events Allow bicycles on MRT Incentives for cyclists	Not designated cycling space High speed of PMDs Motorised vehicles high speed Absence of safety gears among cyclists Crossings

Although adult participants mentioned that cycling is much faster and can be used for a longer distance than walking, they agreed that the travel distance is nevertheless limited as well. Many adults reported to make several long trips, for which motorised modes were selected over cycling. Elders, however, did use cycling for social and utilitarian trips. They reported that some of their trips are “far” to walk, but just nice for cycling.

Benefits of cycling

As for walking, health and environmental benefits of cycling were mentioned. Yet, interestingly more environmental aspects than health benefits were discussed. Cycling was seen as a green mode of transport that could help to reduce CO₂ emission. In addition, it was seen as a way “to connect with nature”. For the health benefits, both user groups, i.e. adults and elders, mentioned that this is a good way to exercise as well as to relax.

Cycling for medium-length trips was also seen as a way to avoid traffic congestion and save money. Many mentioned that during peak periods, one can either cycle for 10 minutes or take “the very crowded bus that stops every 2 min” for a 20 minutes ride. Many said that after a number of rides, instead of taking bus or MRT, the bicycle is ‘paid’ and thence transport money can be saved for other expenses. Some adults and most elders also mentioned that bicycles are much more accessible as compared to cars. Thus, this is a very good option for personal mobility in case one cannot or does not want to use public transport. Some participants affirmed that:

“I might never be able to afford a car here [In Singapore], but a bicycle yes. With it [a bicycle] I can go to buy diapers at any time, even 2 or 3am” (female, 31 years-old)

Limitations for cycling

The main limitation and concern mentioned by current and potential cyclists is the perceived lack of infrastructure and parking. Majority mentioned that absence of cycling paths (on- or off-roads) deter them from cycling. Bicycle parking was also mentioned as a “big deal”. Many mentioned that while there are parking spaces at many MRT stations and HDB void decks, these parking facilities are not in good conditions and most of the time occupied by abandoned bicycles (e.g. rusty bicycles with missing parts).

Another very important limitation discussed was not having access to bicycles. Although it was mentioned that users do not perceive bicycles as an expensive thing, many consider “illogical” to buy a bicycle to ride it only twice a day. Parents also mentioned that they would allow their children to cycle to school or other locations if they could rent a bicycle near the home and return it near the destination, which eliminates parking concerns.

The hot and rainy weather in Singapore (or more commonly the perspiration produced when cycling) was mentioned as a limitation. Not for the temperature per-se, but for not having trip-end facility to refresh/change after reaching the destination. Lastly, the weight of the bicycle was also mentioned. For the majority of elders, bicycles are quite heavy if they need to push them upslope (at crossings or side-slope), and the “weight can feel even heavier under hot weather”. Thus, other modes were selected by elders if they were aware of having to negotiate hilly topography on the way.

Safety concerns

The same concerns of the pedestrians are shared by cyclists. While on footpaths, cyclists reported to be very worried of hitting some pedestrians or hitting some road furniture when trying to get out of pedestrians’ and/or PMD riders’ way. Serious concern was reported when there are children around, such as:

“You [as cyclist] never know in what direction they’ll jump, and parents don’t teach them to be aware or respectful either. Very few times parents tell their kids to move out of the way, they prefer to give a bad look to the cyclist” (female 59, years-old)

In addition to concerns on footpaths, cyclists also reported concerns when cycling on the roads. Several mentioned that riding on roads alongside big vehicles driving at high speed was very worrying. In many cases, adults and elders reported that users, either pedestrians (on footpaths) or drivers (on the roads), do not respect them at any location, which increases the safety concerns. This was reported to occur, especially at crossings “where everyone thinks they have more rights than cyclists”.

Absence of safety gears was mentioned as a safety concern as well. Many reported that cyclists can be difficult to spot, thus increasing possible conflicts and accidents. These conflicts and their severity could be reduced if bicycles had lights and riders wore bright-colour clothes and if cyclists wore helmets.

Schemes to promote cycling

Not surprisingly, the provision of bicycle paths (on- or off-roads) was considered a major way to promote more cycling trips. Participants affirmed that such facilities are likely to increase safety levels and making cycling a more attractive mode of transport. Other infrastructural modifications such as improving crossings to a more bicycle-friendly layout and provision of signals specifically designed for cyclists (“easy to be understood with just a glance”) and signals/signage being placed at cyclists’ eye-sight level in conspicuous locations can further increase safety. One participant, for example, affirmed that:

“There are 100+ signals for pedestrians and for motorists, but for cyclists there are very few. Also, many of them are at places where no one really looks” (male, 60 years-old)

Based on responses, provision and/or improvement of bicycle parking are a must so that potential users will go from being merely potential cyclist to become an actual cyclist. Adults and elders also discussed that if there were bicycle for rent (which still were not available by the time of interview), i.e. bicycle-sharing schemes – though such specific terminology was rarely used as yet, bicycle-sharing was commonly referred as “bicycles for rent, public bicycles, etc.” – more people will cycle on a daily basis. Interestingly, some mentioned that bicycles of different sizes should be available, so children can also have access to them.

With the many complaints about the weather, provisions of showers or similar facilities at destination or even at work locations were recommended by participants. These facilities, known in the literature as “end-of-the-trip-facilities” are seen as encouragement to use cycling as a mode of transport and these are currently being implemented in Singapore (Chew, 2017). Moreover, participants,

particularly the workers, mentioned that they are likely to shift from bus to bicycle for their FLM travel from home to work if they were allowed to carry bicycles onto the MRT at all times (instead of presently being restricted to off-peak periods).

Education for all road users to respect cyclists, cycling training to improve cycling skills, law enforcement (mainly for speeding vehicles and cyclists on footpaths), incentives to people who commute to work by bicycle, and local activities/events that promote cycling and its related health and environmental benefits were recommended to further increase the cycling rate in Singapore. Many said that local authorities should collaborate, so they can all “get the benefits of cycling” leading to a better transport, healthier and more educated citizens, and an eco-friendly and social country.

Study discussion

The current study was aimed at gaining deeper understanding about adults’ and elders’ attitudes towards active mobility in Singapore. To offer a satisfactory walking and cycling transport-network-service and attract people to use it, it is important that the infrastructure matches current and potential users’ expectations (Susilo & Cats, 2014; Susilo et al., 2015). It was found that in general, adults and elders provided similar responses and discussed similar topics that encourage or discourage walking and/or cycling. However, it should be noted that in general, more adults as compared to elders, perceive Singapore to present a safe travelling environment and convenient network to walk.

Moreover, regarding comfort with provided facilities, it was found that, overall, users are comfortable with the level-of-service of walking facilities but not with the cycling facilities. For walking, provision of more covered walkways, with some “green” features (plants), was mentioned as one key attribute to encourage more users to travel on-foot. On the other hand, most participants mentioned infrastructure improvement for cycling being: wider paths; crossing enhancement; more and improved cycling facilities; and signal modifications. Interestingly, wish-list (or required) improvements for cycling are much related to safety concerns of pedestrians.

In the same line, there are more “opportunities” to promote cycling trips as compared to “threats”. Interestingly, there were much more positive attitudes and greater willingness-to-shift to cycling as compared to walking and this is demonstrated in the SWOT analysis. At current stage of development, users see cycling as a highly interesting mode of transport, and one that could surpass other modes of transport. This “novelty factor” should be taken advantage of and cycling should be promoted as “an ideal mode of transport”. Publicity and campaigns are a key factor to ensure the success of this

mode (Assaker et al., 2011; Markou & Singh, 2003). It must be noted that currently, a competition might exist regarding cycling and usage of PMDs (which were not considered in the interview).

Participants understood that transport network improvements alone are not enough to promote active mobility (Cervero et al., 2009; Pucher & Buehler, 2008). Other “complementary” services should be provided. These include bicycle-sharing schemes and end-of-the-trip facilities, which are currently being implemented in Singapore (Cheong, 2017; Chew, 2017). The cost of providing these services should be carefully reviewed. The overall cycling cost should be able to compete with public transport services. Finally, potential users (who could shift from motorised modes) were identified to be those users that are currently using public transport for short trips. Many participants highlighted that the public transport service is so convenient and accessible in Singapore that it is considered superior to active trips even for short distances. The efficiency of the MRT and bus service in Singapore is a feature that needs to be carefully factored into local transport research. A balance between enhancing public transport improvement and encouraging active mobility needs to be found (Ogilvie, 2004; Zuniga, 2012).

Moreover, among incentives to attract more people to walk and cycle to their destinations, most reported incentives are associated with flexible working hours or other work-related incentives. Such incentives have been shown to be efficient in several countries (He & Giuliano, 2017; Kitamura et al., 2000). Users’ perceived attractiveness of such incentives can provide motivation for local authorities to enhance the current “Travel Smart” scheme so that it is equally focused on public transport and active modes of transport usage. School hours need to be considered in such scheme, even though while flexible working hours were mentioned, flexible school hours were not (yet) considered by parents. The current restriction to only allow foldable bicycles onto the MRT needs to be reviewed since several participants mentioned that being able to carry their bicycles onto public transport will encourage them to cycle for their FLM travel.

In addition to all the mentioned options, education for all road users was constantly mentioned as a way to increase the number of walking and cycling trips. Participants mentioned that it is essential for all to learn to share spaces and be respectful to each other. Cyclists in particular mentioned that users need to “accept” them on roads or on footpaths so that sharing can be done in a more comfortable and safe way. Education campaigns have shown its efficiency in improving overall transport safety (Davis, 1998; LTA, 2015c; Pucher & Buehler, 2010). At the same time, increased safety was mentioned as a factor that encourages the usage of active mode of transport. Thus, more

educated users will lead to higher safety levels, which will increase the attractiveness of walking and cycling in Singapore.

4.4. **Chapter summary**

This chapter presented findings of three main studies conducted by the author to gain deeper understanding on pedestrians' and cyclists' quality needs. While the overall objective was to understand and search for schemes to meet those needs, each study had its respective research questions and methodology, and these were discussed accordingly. From the three studies, active travelling characteristics in Singapore were first studied using observational studies and intercept survey. Then, usage of the active transport network was investigated using a mix-research method which combined quantitative and qualitative questionnaires. Finally, to gauge attitudes regarding active mobility, an in-depth qualitative study was conducted. In all three studies, off-road mixed-stream active travelling was taken into consideration, which is quite unique of the local (Singapore) context. Herein, applications of these findings to other areas/cities are presented as well as how these studies are utilised in the development of the PDMD framework.

As it has been mentioned, Singapore's public transport is very convenient, especially due to the distance-based fare. Thus, not surprisingly, MRT and especially buses are the most commonly used modes of transport and are sometimes in competition with active modes for short-range trips. Authorities should consider the benefits of each mode usage and review the distance-based fare to further increase active mobility demand. It should be noted that in areas/cities where public transport is not so convenient and/or widely used, the competition between these modes and active modes might not be present. Also, characteristics of active trips might differ as fewer FLM trip-stages are likely to occur. In such cases, authorities could either consider prioritising infrastructure provision for active trips at other areas frequented by pedestrians and cyclists or enhancing active mobility accessibility to public transport to increase public transport usage while enhancing active travelling.

For the 1st study – Active travelling characteristics, qualifying responses of 202 participants were analysed. A positive awareness about the infrastructure provision was found among town residents and frequent visitors are commonly not aware of such facilities. In addition, as compared to national rates, usage of active modes at cycling towns in Singapore was found to be much higher. This indicates the positive impact of infrastructure provision in increasing active mobility rates. Interestingly, people who reported to make new cycling (after infrastructure enhancement) trips reported these to have shifted from walking, yet overall walking rate remained the same. This is an

indication that, new walking trips are undertaken as an indirect result of cycling infrastructure enhancement. Finally, some current cyclists and possible future cyclists mentioned the same motivating reasons for using this mode of transport, with increased **convenience** and to **save time/money** being the principal reasons.

Regarding awareness, local and international authorities can consider these findings to develop campaigns to promote enhancement of infrastructure not only among residents but also for visitors as these are also potential active mobility users. This is true regardless the demographics of the area. At infrastructural level, it is acknowledged that different traffic settings (e.g. off-road active mobility provisions in Singapore as compared to on-road cycling in other countries) do affect level of service of the facilities. These features are further affected by perception of users, whereby it is important that pedestrians, cyclists, and PMD riders are aware of the different improvements and how these affect their travelling characteristics (as found in this study). Moreover, results indicated that with the provision of cycling infrastructure, not only cycling but also walking and PMD ridership rates increased. Thus, locally and internationally, authorities should consider impact of provision for one mode is likely to affect decisions related to usage of other modes in general, and thereby develop parallel schemes to enhance interaction between users and levels of safety.

Findings from this 1st study, including the different factors that encourage cycling and the use of other active modes, have been taken into consideration in the development of the PDMD framework to ensure that interrelations between different modes and impacts of infrastructure are taken into consideration. These are then included in the demand analysis by utilising the PDMD framework to select variables within the neural network model.

For the 2nd study – Usage of the (formal) active transport network, a total of 277 participants were interviewed using mixed-method approach. A quantitative questionnaire was followed with qualitative questions to increase the usefulness of findings and to affirm answers provided by qualitative responses. Participants selected (off-road) delineated paths to be their preferred mobility facility as cyclists and/or pedestrians, mainly due to **dynamic use of space** along this type of facility. Relatively, few conflicts with other users were mentioned in the survey, which could be due to increased acceptance of “sharing” of off-road mobility facilities, yet these are still present and are cause of safety concerns. The provision of **bicycle-sharing scheme**, in combination with infrastructural improvements, is associated with a rapid increase in cycling demand in the recent year.

Taking into consideration the main finding from this 2nd study, local and international developers and planners can consider the dynamic use of space when providing infrastructure, especially off-road ones. Commonly, segregation between different types of users is desired, yet this study pointed out that wider shared channels are preferred as these allow for more room to manoeuvre between users. That being said, safety considerations should be taken into consideration as this type of provision also increase interaction among users. This could be tackled by “right of way” signages that are suitable for each location (area/city). In addition, delineated paths (rather than segregated paths) are valuable to countries like Singapore with limited land as type of facility maximises usage of space. While these findings are of special interest to areas/cities with off-road travelling settings and features similar to Singapore, these are also valuable to other countries. For instance, a similar concept of dynamic use of space can be considered regarding cyclists and vehicles sharing on-road spaces. Similar interactions (at higher level) might occur, and related safety considerations should be taken into account.

Moreover, survey results indicated that bicycle-sharing greatly contributed to the increase in active mobility rates. This could be used as a good-practice example from Singapore to cities that are looking to increase active mobility rates. Yet, other externalities of bicycle-sharing (e.g. indiscriminate parking) should be considered and planned accordingly. Findings from this study were considered for analysing the actual limitations/requirements of trips that affect mobility decisions as presented in the PDMD framework.

There are some limitations to the study, the notable one being the skewed demographics of the sample. Most respondents were young and mature adults. While these groups are the main users of active modes, their responses might be different from those of elders or children. To address this issue, further research can aim to expand the present study to encompass all user groups in order to compare and contrast their travel behaviour. In addition, longitudinal studies will be of interest to understand how current (young) adult generation behave into their elder-hood in the realm of active mobility. Moreover, this study was focussed on cyclists and non-cyclists only. The inclusion of PMD riders as a group of its own can provide interesting views regarding their preferences for travelling spaces as well as interaction with other users. The quality needs of PMD riders would also have some effect on planning for active modes of transport.

Finally, for the 3rd study – Attitudes towards active mobility in Singapore, the study presents findings from two qualitative techniques (focus groups and one-to-one interviews), with a total of 46 adults and elder participants. Strengths, weaknesses, opportunities (to promote) and threats (safety

concerns) of walking and cycling as modes of transport were highlighted. Adults and elders current travel behaviour, perceptions, and opinions were considered. Using Grounded Theory, findings were used to gain a deeper understanding of pedestrians' and cyclists' travelling characteristics and identify factors that limit or encourage active mobility. These findings form a strong basis to develop quantitative studies to measure the efficiency of several transport policies and schemes currently being developed in Singapore.

Results show that attitudes towards walking and cycling are different. Walking was described as a **safe** and **somehow** convenient "mode of transport" but the **distance limitations** reduce its attractiveness. Cycling, on the other hand, was perceived as an enjoyable "activity" and most of the limitations can be addressed with the **provision of infrastructures, facilities, or policies**. Users expressed their willingness-to-shift from motorised modes to active modes of transport given certain infrastructural and/or policies modification. Potential-shift to cycling was more commonly reported than potential-shift to walking. Moreover, it was understood that pedestrians and cyclists share similar safety concerns, with the most commonly mentioned ones being **conflicts** and perceived lack of respect from other users at facilities shared between pedestrians and cyclists. Participants agreed that most of these conflicts can be reduced with wider and demarcated walking and cycling spaces, clearer signals, and intensive education and courtesy campaigns.

One of the main issues that should be considered locally and internationally is to "level up" perception about walking and cycling. In Singapore, cycling is perceived as an activity rather than a mode of transport. This is also true in other areas/cities and in some cases, cycling is even regarded as an "inferior" mode/activity. By conducting a SWOT analysis as in this study, opportunities can be identified to develop schemes to enhance perception of cycling as a convenient mode of transport. In this regard, local characteristics should be taken into account as opportunities might differ in different cities. Nevertheless, the approach used in this study serves to provide background information on attitudes towards active modes. Findings from this study were utilised in two areas of the PDMD framework, some of the reported attitudes were used to guide the "process" area of the framework that considers factors that affect trip making behaviour, and some were utilised to identify the psychological and actual limitations/requirements of the trips that affect mobility decisions.

Moreover, findings from these studies can be utilised by policy makers and practitioners to make better informed transport-centric decision, thereby contributing towards healthy and vibrant lifestyle through greater walking and cycling activities. several schemes that are currently being implemented overseas can facilitate to increase the usage of walking and cycling as strong modes of transport. As

mentioned by the participants, these schemes should not only come from transportation authorities, but it should rather be collaboration between all authorities and stakeholders. It is also important to understand that different users have different travel behaviour and needs. Future planning for active mobility, in Singapore and internationally, shall consider the mixed-traffic scheme and dynamic sharing of facilities as a suitable design approach to enhance active travelling experience. Policies shall not only focus on desirable usage of specific facilities but also in quality features that can enhance sharing of facilities and thus increase trip safety. In this thesis, studies are focussed on understanding of pedestrians and cyclists' quality needs in Singapore and programmes and policies recommendations are only presented in line with the identified trends. If findings from these studies were to be used for development of robust policies recommendations, the possibility of increasing the sample size and conducting multivariate analysis should be considered and this could indeed be explored as part of future work.

Chapter 5. Unifying mobility framework and survey instruments

In this Chapter the PDMD framework is introduced. The PDMD is a travel behaviour framework that presents a holistic overview of factors that affect mobility decisions and that can be dynamically modified and scaled to different contexts. First, findings from a scientific review of previously posted theories and frameworks related to travel behaviour is given in Section 5.1.1. This is followed by the framework build-up in Section 5.1.2, where different factors that affect travel behaviour are highlighted and their relationship is established and discussed.

The PDMD framework is then utilised as a guideline to develop a refined household survey questionnaire as presented in Section 5.2. The questionnaire is developed to capture overall travelling characteristics in Singapore with main interest being in short-range active trips within residential towns in Singapore. Characteristics of the developed survey instrument are presented and related methodologies discussed. The questionnaire is used for data collection and collected data is used for demand analysis as previously described in Section 3.3. Across following sections, the manner that the framework contributes to the academic knowledge and could be utilised in local and overseas practices has been discussed.

5.1. “Process and determinants of mobility decisions (PDMD)” framework

This section presents detailed characteristics of the developed PDMD framework, conceptualises framework built-up, and discusses its possible applications. A version of this study has been submitted for consideration for publication to *Travel Behaviour and Society* journal and it is currently under review (Rojas López & Wong, 2018b).

5.1.1. Review of posted theories/frameworks and the local context

A total of 27 theories and conceptual frameworks were scientifically reviewed as summarised in Table 5.1 and these are presented by year of publication. Specific features of each theory/framework were included to the PDMD framework accordingly. Some theories are of general characteristics, some are focused on certain population and/or travel context (e.g. children trip to school or elderly travel behaviour) and some are concerned with specific travel modes (e.g. active mobility). As mentioned, two key frameworks (the theory of travel decision-making, and the PASTA framework) were considered as main guidelines for the development of the PDMD framework. A quick overview of the reviewed theories/frameworks are described next, followed by in-depth description (and critiques where necessary) of the two main frameworks and how different aspects are addressed in the PDMD framework.

Table 5.1. Characteristics of theories/frameworks used for developing the PDMD framework

Theory/framework	Main reference	Field (s) of study	*General(G) vs Travel-related(T) decision	*Special focus on active mobility (Y/N)	*Determinants(D) vs Impacts of mobility(I)	*Discussed applications for survey instruments(S) vs demand analysis (D)	*Scales utilised		
							Trip(T) vs Activity(A)	Individual(I) vs Household(H)	Built(B) vs Social(S) Environment
Theory of Human Motivation (THM) or Hierarchy of Needs	Maslow 1943	Psychology	G	N	D/I	S	A	I	B/S
Activity Pattern Model	Love & Chapin 1976	Geography	T	Y	D/I	D	A	H	B/S
Theory of Planned Behaviour (TPB)	Ajzen 1991	Psychology	G	N	D/I	-	A	I/H	-
Theory of Repeated Behaviour (TRB)	Ronis et al., 1989	Transport	G	N	D/I	S	A	I	-
Theory of Reasoned Action (TRA)	Ajzen et al., 1980	Psychology	G	N	D/I	-	A	I	-
Social Cognitive Theory (SCT)	Bandura 1991	Psychology	G	N	D/I	-	A	H	B/S
Activity-travel patterns	Wen & Koppelman 2000	Transport	T	N	D	-	T/A	I/H	B
Random Utility Maximisation (RUM) Theory	McFadden 2001	Economics	G/T	N	D	D	A	I	-
Social ecological model of influences on physical activity	Pikora et al., 2003	Health	G	Y	D/I	-	-	I/H	B
Ecological model of neighbourhood environment influence on walking & cycling	Saelens et al., 2003	Psychology	T	Y	D	S/D	T/A	I	B
The hierarchy of walking needs	Alfonzo 2005	Transport	T	Y	D	S/D	T/A	I	B
McMillan framework	McMillan 2005	Transport	G	Y	D	S	T	I/H	B
Theory of Interpersonal Behaviour (TIB)	Egmond & Bruel 2007	Psychology	G	N	D	-	A	I	-
Integrated Behavioural Model (IMB)	Montaño & Kasprzyk 2008	Psychology	T	N	D	-	A	I	S
Environmental determinants of active travel in children	Panther et al., 2008	Geography	T	Y	D	S/D	T	I/H	S
Ecological and Cognitive Active Commuting (ECAC) framework	Sirard & Slater 2008	Transport	T	Y	D/I	S/D	T	H	B/S
Conceptual Model of Active Travel Behaviour	Burbidge & Goulias 2009	Transport	T	N	D	S/D	A	I/H	B/S
Comprehensive Action Determination Model (CADM)	Klöckner & Blöbaum 2010	Psychology	G	Y	D	-	A	I	S
A conceptual model of travel behaviour	van Acker et al., 2010	Psychology / Transport	T	Y	D	S	T/A	I/H	B
Model of Children Active Travel (M-CAT)	Pont et al., 2011	Health/	T	Y	D/I	S/D	A	I/H	B
Behavioural Model of School Transportation (BMST)	Mitra 2012	Transport	T	Y	D	D	T	H	B/S
Framework for structuring modal choice determinants	De Witte et al., 2013	Transport	T	Y	D	S/D	T	-	S
Theory of Routine Mode Choice Decisions	Schneider 2013	Psychology / Transport	T	Y	D	D	T	I	-
Theory of travel decision-making	Singleton 2013	Psychology	T	Y	D	S/D	A	I	-
Well-being & Mobility	Nordbakke & Schwanen 2014	Transport	G	N	D/I	S	T	I	B/S
PASTA framework	Götschi et al. 2017	Transport	G	Y	D/I	S	A	I/H	B/S
Unmet travel needs	Luiu et al. 2018	Health	G	N	D/I	-	A	I	B/S

* Based on most common factors covered/conceptualised in respective theory/framework.

Regarding the terminologies utilised in different studies, some remain fairly standardised across disciplines while others can be quite different. In the efforts to merge the knowledge from the different scientific disciplines and possibly harmonise usage, a lexicon of terms commonly utilised is presented in Table 5.2. The terms do not form an exhaustive list of all those utilised within each framework/field of study, nevertheless it summarises most relevant ones in an attempt to unify definition and improve communication among different scientific disciplines.

Table 5.2. Common terms utilised in travel behaviour theories/frameworks

Term(s)		Definition
Accessibility		Feasibility of performing an action; selecting a choice
Action		Carry out something; state of performing and activity
Activity	Activity participation	To be part of something; often considered as the reason for travel demand
	Physical activity	Bodily movement produced by skeletal muscles that requires energy expenditure
Behaviour		Mode of acting/reacting that varies from one person to another
Choice		Decision made towards something when there are more than one options
Decision		Analysis and steps to eliminate possible choices and select one possible outcome
Environment	Built	Physical transport or urban infrastructure available in a city/county
	Natural	Non-artificial non-manmade things; e.g. weather, terrain
	Social	Social setting where an individual live/work/play
Feasibility		Viability of performing an action; selecting a choice
Mode		Often refers to the available modes of transport that individuals can select
Outcome		Effect of performing an action; selecting a choice

In general, it was found that theories “grew on” each other, with psychological theories being the roots for most of them. From the economic theories, the most common technique utilised to explain transport-related decisions is the utility maximisation theory, which argues that individuals select the alternative that yields the highest utility (McFadden, 2001). Psychological theories have also been utilised for explaining travel behaviour and the common factors include attitudes and preferences, suggesting that these have strong effect in the decision-making processes (Montaño and Kasprzyk 2008; Ajzen 1991; Ronis et al., 1989; Bandura 1991; Love and Chapin 1976; Alfonzo 2005). Not surprisingly, it is from the field of psychology that most theories and frameworks dedicated to travel behaviour emerged (Alfonzo, 2005; Burbidge & Goulias, 2009; Pikora et al., 2003; Pont et al., 2011). geography theories have been introduced aimed at explaining specific decisions to delineate activity-patterns, such as time-space prism (Hägerstrand, 1970) and activity pattern model (Love & Chapin, 1976) which have triggered the development of activity-based planning (Castiglione et al., 2015).

Tints of a socio-ecological system are found in majority of the reviewed theories. The majority considers that factors related to individual/household (socio) and the built-environment (ecological) have effect on travel-related decisions. In addition, many theories combined components of the theory of planned behaviour or theory of reasoned action to explain relationship between moderating factors, mediators, and decisions (Alfonzo, 2005; Götschi et al., 2017; Klöckner & Blöbaum, 2010; McMillan, 2005; Panter & Jones, 2010; Pikora et al., 2003; Pont et al., 2011; Sirard & Slater, 2008). Furthermore, some of the reviewed frameworks are aimed at explaining responses to environmental or policy changes/incentives (Singleton 2013; van Acker et al., 2010; Gärling et al., 1998; Oliver et al. 2014).

Typically, cascading layouts are utilised to explain temporality of effect of each factor and in some cases feedback loops are introduced (Götschi et al., 2017) and relationship among factors are indicated using different types of arrows. Most commonly, the reviewed frameworks are dedicated to adult travel behaviour and consider factors based on individual perspective, being the possible outcome of self-selection of mode of transport, travel route, travel time, etc. (Singleton, 2013). Reviewed frameworks that are specifically related to children travel behaviour are also developed based on adults' perspectives and how these affect children travelling characteristics and their decision to allow children to perform different types of travel (Pont et al. 2011; Mitra 2012; McMillan 2005; Panter et al., 2008).

Interestingly, while many of the reviewed scientific and social theories acknowledge that age affects travel behaviour, a limited number are specifically concerned with elders' travel behaviour. Some studies have been done on the theory/frameworks in improving facilities and built-environment to enhance travelling quality among elders (Luiu et al. 2018; Nordbakke & Schwanen 2014). These studies highlight the effect of different factors (e.g. built-environment, policies, household demographics, etc.) on travelling among the elders, and key factors have been included in the PDMD framework accordingly. To the extent possible, the PDMD framework discusses differences among users of different age groups.

The "theory of travel decision-making" (Singleton, 2013), was developed in an attempt to suggest various techniques travel behaviour for demand analysis. Seven components have been presented in Singleton's theory, highlighting their relationship backed up by different empirical and theoretical studies. The first component is the [1] **activity** component, where the demand for travel as arising from demand for activities among individuals is explained. Then, [2] **the hierarchy of travel needs** is introduced. This component borrows generously from theories introduced by Alfonzo (2005) and

Maslow (1943) – Theory of walking needs and Theory of human motivation, respectively – and presents 5 factors that influence travel decision in a pyramidal way where basic needs are presented as supporting base as shown in Figure 3.2. Then, the [3] **moderation** components are introduced as those related to personal characteristics such as demographics, socio-economic level, etc. and the [4] **mediation** components as those related to perceptions, and the reaction(s) towards the perceived object (i.e. attitude(s)) towards different travel decisions. The [5] **decision rule** component explains the different rules that people might consider in making travel decisions, and the [6] **decision-context-outcome** component describes the possible scenarios that can be affected by different travel decision without specifying to which context(s) it is applied. Finally, the [7] **feedback** component, explains how past travel experience influences current decisions.

Each of these components is reviewed, and these are compared with ground situation knowledge (e.g. quality needs of active mobility users in Singapore), and an updated perspective is presented in the PDMD framework. Only those deemed more relevant and applicable components are presented. This helps to provide concise, yet accurate, representation of factors that affect travel related decisions.

Götschi et al. (2017) subsequently developed a framework specifically related to active travel behaviour, known as PASTA – derived from the name of the project Physical Activity through Sustainable Transport Approaches – framework. The PASTA framework was developed based on an audit of previously existing ones and it conceptualises 3 main components, comprising the behavioural decision, the structural scales (social, physical, and individual context) and relationships, and the contents and topical domains. Overall, as similar to other frameworks, the PASTA framework considers behaviour to be dictated by demand for activity participation which generates travel demand. This triggers a choice process for a desired outcome. A nested view between theory of reasoned action and utility maximisation is proposed, highlighting the differences between considered choices and actual selection.

Behaviours that are non-reasoned such as habit or exploration are also kept in the framework. The framework is one of the few that captures temporal scales, and layers of different resolutions are introduced where a higher resolution indicates short-term decision and a lower resolution is linked to longer-term phenomena. Interestingly, the number of arrows utilised in the framework is kept to minimal, and relationship among different factors is presented by clustering and proximity. In this thesis, these components are re-reviewed yet also considering the local characteristics and traffic settings (mainly for active modes of transport), and findings are summarised in the PDMD framework.

In general, the reviewed theories/frameworks have indicated that factors vary from one travel context to another. However, they have not specifically explained to what extent and what are the specific factors that are affected by the localised context. Thus, regardless how comprehensive are the theories/frameworks, they are very hard to be well generalised. This is especially true in cities/countries with very unique urban layout and/or setting for different modes of transport such as the case of Singapore. While it is understood that the main objective of the frameworks/theories is to understand/investigate the phenomenon, it is also important for these to be flexible, so they could be implemented internationally for the development of a unifying concept – which could allow for practical comparison of findings and academic break-throughs.

Hence, it is timely to develop a framework that can be dynamically modified and scaled to different context(s), while considering different transport users' quality needs. Building such a framework as a continuation of previous research allows for synergies and similarities to be easily identified. Moreover, there are no specific travel behaviour frameworks developed or applicable for the localised (Singapore) context. Indeed, while most of the frameworks acknowledge environmental and weather influences in travel behaviour decision, none has specifically considered shared facilities environment and tropical (hot and humid) weather, which are characteristics of Singapore.

In the local context, Koh and Wong (2013) introduced a spider web diagram indicating the importance of 12 factors that affect the decision to walk while considering different land uses – residential, industrial, mixed – as well as a comprehensive list of reasons to use (or not) walking or cycling as modes of transport in the residential areas. Most of the factors presented in the spider web diagram are related to the built-environment (e.g. shelters, slopes, signage, etc.) and some are related to perception (e.g. trip comfort, crowdedness level, distance, etc.). Then, based on the factors that were reported to affect willingness to walk and/or cycle (or not), Koh and Wong (2013) developed a mode choice model considering travel distance (actual and perceived), personal, and built-environment factors. Meng et al. (2015) also developed a local mode choice model specifically focused on FLM home-bound trips. The model also considered distance, personal, and built-environment factors and in addition, included socio-cultural factors and availability of different modes of transport. Both models provide an overall view of the factors that affect mode choice decision. Yet, these do not explain the relationship between different factors, nor their effect on other transport-related decisions.

5.1.2. Framework build-up and applications

The PDMD framework presents two major divisions which are: (1) the process, which illustrates what generates demand for a trip, and (2) the determinants, which conceptualise different factors that

affect travel behaviour and their relationship with each other, finally leading to transport/travel -related decisions. There are countless variables and trade-offs to be considered when taking a travel-related or mobility decision (De Witte et al., 2013; Klöckner & Blöbaum, 2010; Schneider, 2013) and many of them are so complex as to be presented in a single framework.

In contrast with some theories and frameworks that have conceptualised an immense number of factors – making them too complex and sometimes hard to be understood, the current proposed framework only presents key topics and factors. An overall view of the PDMD framework is presented in Figure 5.1. where dashed delineations (---) indicate factors that are highly influenced by the local environment and factors noted with an asterisk (*) are those that are influenced by socio-demographic characteristics. Different sub-factors considered in each dimension are discussed in detail afterwards.

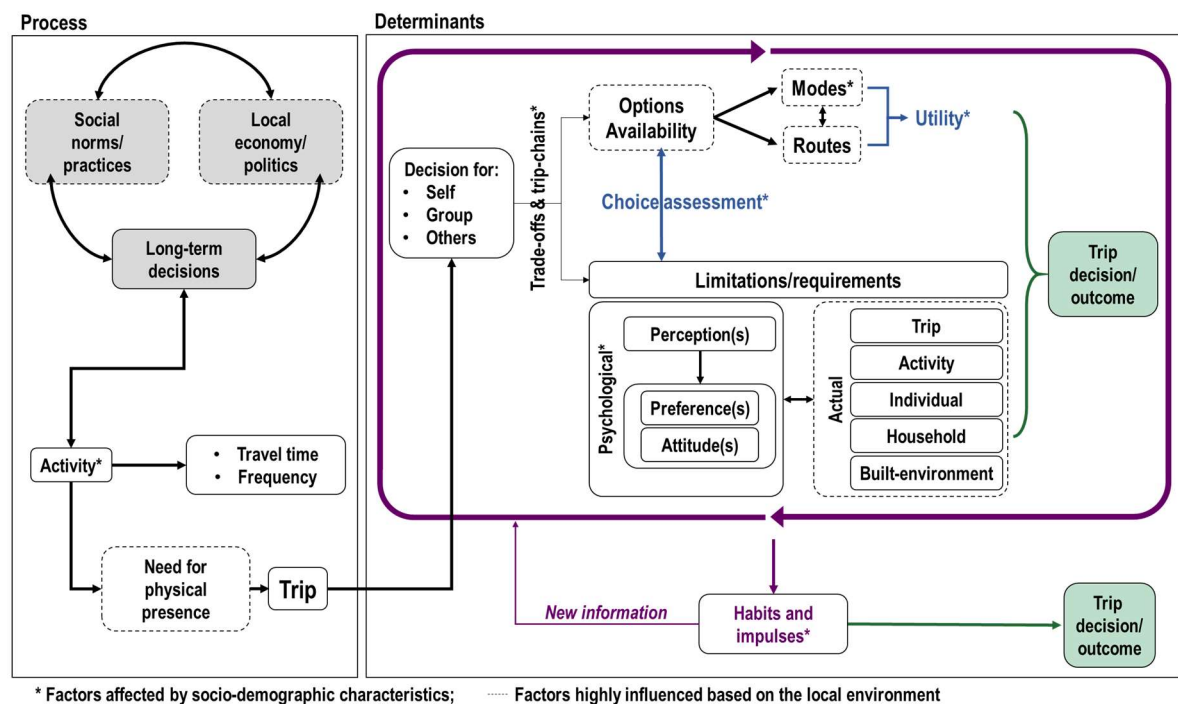


Figure 5.1. “Process and determinants of mobility decisions” framework

In the “**process**” stage, certain external factors related to the local context and long-term decisions are first indicated. External factors are mutually dependent as social norms/practices are affected by economic and social politics, which affect long term decisions (e.g. housing location), and these again play an important role in shaping the social context. Research has shown that these external factors, especially long term decisions, exert influence on activity participation and thus travel demand (Singleton, 2013; Zuniga, 2012; Nordbakke and Schwanen 2014).

Local contexts play important roles in shaping these factors. For instance, countries such as Singapore and Japan have good transport and urban planning to ensure decentralisation of activities and to invest in public transport and active mobility infrastructure (Koh and Wong 2015; Yamaguchi et al. 2008). Provision for facilities are coupled with a safe and secure environment. These factors help to distribute trips and encourage people to engage in more activities of different types. However, the same is not true in developing countries' cities such as Asunción (Paraguay) or Guatemala (Guatemala), where different types of locations are still clustered to specific areas and urban sprawl is common, thus, encouraging longer and motorised trips (Castillo Cabrera & Haase, 2018).

Instead of affirming that activity generates a travel or trip demand, as has been suggested by several theories/frameworks (Götschi et al., 2017; Love & Chapin, 1976; Singleton, 2013), a new sub-component by way of the "need for physical presence" is introduced in the PDMD framework. In modern days, it is no longer merely an activity that dictates the need to travel. Some activities that previously required travelling can now be done digitally or even while travelling (Golob 1998; Transport Analysis 2016; van Acker et al., 2010). This calls for a review of factors considered in the activity-based modelling to consider the change in temporal-spatial characteristics of activity-making and thus demand for trips.

Thus, even if demand for activities is greater in developed countries, the number of trips made by citizens is not that high. This is because in the island-nation of Singapore, online banking and shopping (among other activities) are strongly established. In this sense, it is the need for physical presence that generates demand for a trip. This is because online banking and shopping (among other activities) are convenient and widely used. This calls for a review of factors considered in the activity-based modelling to take into account the change in temporal-spatial characteristics of activity-making and thus demand for trips. In addition, it is suggested that factors such as travel time and frequency (scheduling) are in fact dictated by the type of activity and not a trip-related decision (Alfonzo, 2005; Burbidge & Goulias, 2009; De Witte et al., 2013).

For empirical measure of the determinants, the PDMD framework can be utilised as a guideline to develop survey questionnaires. Researchers/planners should first identify the norms/practices (related to the social and work environment) and economics/politics (related to built-environment and related programmes/policies/law enforcement) characteristics of the area/context under study and establish the influence of long-term decisions made by individuals. Characteristics of these long-term decisions can then be used to verify/falsify the relation between activity participation and need for physical presence. Based on findings, alternatives to reduce travel need can be explored.

The “**determinants**” stage encompasses the main factors that affect mobility decisions. In general, it is suggested in the PDMD framework that the first thing to be considered by individuals is whether the trip-related decision is taken for one-self, for a group trip including one-self (e.g. escorted trip to school), or for others (e.g. children, elder). Factors and preferences are likely to vary according to the type of trip and at this stage, the individual considers possible trade-offs. For instance, trip decisions made for one-self individuals are likely to select the fastest travel mode without so much consideration of safety. Safety and accessibility plays a much bigger role when taking decision for others (McMillan, 2005; Mitra, 2012; Pont et al., 2011; Saelens et al., 2003).

This stage might not be affected as much by local context as different individuals and groups gauge possible options differently. The PDMD framework proposes that afterwards, alternatives to fulfil the greatest number of activities (that requires travelling) while minimising number of trips are considered. Herein, individuals analyse possible trip-chains, and these affect the trade-offs between limitations/requirements of the trips/trip-stages and available transport options. Trip-changing behaviour is commonly affected by the local context as the provision of infrastructure and available modes, affect possible chains.

Then, the individual considers the available options/choices available regarding the two most common transport-related decisions, which are mode and route choice (Pikora et al. 2003; Panter et al., 2008). Provision of infrastructure and transport modes affect the availability of options. Possible choices are assessed based on an amalgam of psychological and actual limitations and/or requirements on each of them (van Acker et al., 2010). Commonly, the selected choice is the one that the individual assumes has the best utility, while noting that the selected option might not always be the preferred one. A good example would be when a user considers driving or taking taxi but due to economic considerations decides to take public transport or walk instead. This can be said to be true in Singapore’s context where public transport is in general affordable to majority of the population, but car ownership is not. In Asunción and other developing countries/cities however, private transport is the main mode, even for short trips (that could have been made by active modes) as users perceive the trip unfit for walking or cycling.

Until recently, low monetary cost and short travel time were the main points of consideration to measure utility of a trip (McFadden, 2001). This however has changed in recent years. Factors such as positive health impact and environmental impact are considered as a positive utility (Bandura, 1991; Hägerstrand, 1970; Maslow, 1943; McFadden, 2001). In many developing countries/cities, including Asunción, condition of the roadways plays an important role, while noting that the shortest route might not always be one in best shape resulting in users taking longer but safer/more

comfortable routes. In addition, a positive utility for travel time has been identified for some modes of transport (especially for active mobility) (Singleton, 2017).

The most common psychological factors that affect the selection of a certain choice are perception(s), which plays an important role in shaping preference(s) and determining attitude(s). These are affected by demographic characteristics and many have argued that these factors play a much bigger role in shaping mobility decision as compared to the actual factors (Maslow 1943; Love and Chapin 1976; Ajzen et al. 1980b; Schwartz, & Howard 1981; Ronis et al., 1989; Ajzen 1991). Psychological limitations/requirements are greatly influenced by locally available programmes and/or policies to encourage or deter the use of certain modes of transport. As Singapore is tirelessly promoting usage of active modes and advertising the convenience of public transport, mode share of these modes is high or continues to rise. Many developing countries however are still investing most of its efforts in advertising routes and indirectly encouraging people to acquire private vehicles at very low prices.

The actual limitations/requirements are divided into 5 categories: trip limitations/requirements (e.g. trip duration, trip distance); activity limitations/requirements (e.g. requires specific outfit, need to carry things); individuals' limitations/requirements (e.g. need for mobility aid, physical activity requirement, psychological requirements); households' limitations/requirements (e.g. presence of adult at home); built-environment's limitations/requirements (e.g. safety, accessibility, connectivity). These, especially those related to the built-environment, are greatly influenced by different local contexts (Pikora et al. 2003; Saelens, Sallis, and Frank 2003; Singleton 2013; Mitra et al., 2010).

To verify/falsify these relations proposed in the PDMD framework, different factors as indicated can be utilised in the development of empirical studies. Comprehensive questionnaires can be developed that include the factors as questions or possible answers' options. It is suggested (when/if possible) to utilise activity-based questionnaire and record related trips as well as activities performed while travelling. This can help to identify characteristics of activities that entail travelling and to further measure travel utility based on activities performed during the trip. Similar (or same) questionnaires can be used in different contexts (countries) to capture variations, and individuals of different demographics in each context can be targeted to identify variations in different life stages as well as based on socio-economic characteristics.

Alternatively, individuals (could) act out of habit and select the mode/route they are already used to, or out of impulse and thereby select the deemed most attractive option without considering the actual limitations/requirements. In many cases, habits and impulses are also shaped based on whether the trip-related decision is taken for one-self, for a group trip including one-self, or for others. Habits could

have been formulated based on repetitive trip making and after sometimes, available options are no longer re-assessed (although utility of the option might have changed, or a better option be available).

In many cases, people do consider less or inaccurate information regarding other choices. For example, it has been found that frequent drivers commonly overestimate the effort required to commute by active modes (Schneider 2013; Ronis et al., 1989; Ajzen 1991). On the other hand, new information (e.g. advertising regarding a certain mode of transport), new choices (e.g. new public transport line, new vehicle model availability), and/or significant events (e.g. marriage, child birth, new home, new job), can cause people to act out of impulse or even cause modification of a habit (Schneider, 2013; Yang, 2015). Change of habit or decisions based on impulse due to new information might be more common in developed countries as Singapore with specific transport and plans (as compared to developing countries) as it is likely that projects which affect transport decisions are better developed and often implemented in shorter time.

5.2. **Refined household travel survey**

The refined questionnaire is developed as a combination of findings from the PDMD framework and redesigns of locally developed survey (conducted in the past). A style similar to local surveys is maintained so that, if required, data from the different surveys can be compared and contrasted. In addition, by redesigning surveys (rather than introducing a whole new approach), local practitioners can easily gauge pros and cons of the refined survey questionnaire and incorporate valuable questions/answer options in future surveys. Yet, the survey remains comprehensive and easy to be modified so it could be applied in different contexts, e.g. to record travel behaviour characteristics in a developing country/city, such as Asunción.

There are three main survey sections – household level section, individual or respondent level section (i.e. concerning each member of a household), and trip level section – and questions were designed accordingly. The trip level section is again divided whole-trip information and trip-stage information. Overall, the questionnaire has close to 50 survey questions. Some of the questions were filled up in the pre-survey stage and some were observable (i.e. participants did not have to answer them directly). Using logic jumps, most participants had to answer only questions related to the individuals and thereby reducing overall survey burden.

Logic of the questionnaire was also designed taking into consideration findings from the PDMD framework, with most attention paid to questions aimed at capturing trip characteristics and willingness to shift to active modes of transport. Information regarding travelling was captured at trip-stage level taking special attention to record FLM trip-stages as well as short-range single-stage trips,

most of which are (or could be) performed by active modes of transport. Each section of the survey is described next and key questions utilised are presented in subsequent sections and in Tables 5.3. to 5.5., while noting that information presented in the tables are not an extensive overview of the whole questionnaire but rather a representation of key questions.

5.2.1. Household level

This section of the questionnaire aims to collect information that can affect travel behaviour at household level. There is a total of 12 questions at household level of which 6 are required to be replied by the head of household, and 6 are pre-survey or observable questions as shown in Table 5.3.

Table 5.3. Household level questions

ID	Question	Question type	Question aim
H1	Township	Multiple option - Selected by surveyor based on household selected	Differentiate households based on their location (cycling towns vs non-cycling towns)
H2	May I know your housing type?	Multiple option	Determine type of dwelling unit
H3	Address for Landed Property	Open-ended - Completed by surveyor	Specific household location
	Address for Condominium		
	Address for HDB		
H4	Household ID	Computer generated	Identify unique households
H5	How many members, (including yourself and full-time maids/domestic helpers), are staying in this household?	Numerical	Determine household size
H6	You mentioned that there are ??? members staying in this household. Can you please let us know how many of them are 6 years old and above?	Numerical	Determine number of survey qualified respondents
H7	You mentioned that there are ??? members, who are 6 years old and above, in this household. Can you please let us know how many of them are aged between 6 to 14 years?	Numerical	Determine number of children in the household
H8	What is your household's monthly income?	Multiple option	Determine income at household level
H9	Which of the following types of vehicle does your household own?	Multiple option (different type of bicycles and PMDs are included)	Determine motorised and non-motorised vehicle ownership in Singapore
H10	How many of H9 does your household own?	Numerical	Assess exact rate of vehicle ownership

Questions to the head of household include questions about household composition and vehicle ownership. The household composition will probe into the total number of people who live in the household, their age and gender. The refined questionnaire also aims to record ownership as well as the different types of bicycles and PMDs available in the household. Upon completing this “Household” section, the head of household is invited to first respond to the “individuals” and “trips” sections for themselves, and then provide answers on behalf of household members aged between 6 and 14 years old. If children are present during the interview, interviewer shall also take note (with adult’s consent) of any comments provided by them about the questions in the questionnaire and responses provided by their caregiver.

The household level questions would require some modification if/when the questionnaire is to be applied to different contexts. The extent of the survey shall also be considered. For instance, township location might be shifted to city level for bigger scale surveys or eliminated if the survey is to be conducted at only one location. In addition, the available options regarding type of housing will need to be refined accordingly to those available in the country. In Singapore, housing types are quite standard and thus the given options can be defined beforehand. In other countries however, there are countless house designs. In such cases, the question could be modified to an open-ended question or only include some differentiations, e.g. landed house vs residential building.

Moreover, for the income level question, possible options shall also be refined according to the local context and income per capita. Researchers and practitioners could refer to public records to determinate most suitable answer options. Similarly, the different types of vehicles, bicycles and PMDs options shall be modified based on those that are most commonly used in the country/city under study. In general, it is recommended to first conduct a smaller scale study of the characteristics of the country/city under study to ensure survey design is most suitable.

5.2.2. Respondent or individual level

A total of 12 questions were set aimed at collecting information at individual level, 11 of which are to be asked to participants, 4 are asked only in given cases (e.g. if participant is over 18 years old, then question about driving licence is asked), and 5 are observables or pre-survey questions as shown in Table 5.4. The questions in this section are concerned with personal, social, and demographic characteristics of individuals. In addition, some of the questions are regarding travel behaviour, such as usage of active modes of transport and willingness to utilise (and reasons) in bicycle-sharing system. These questions serve to analyse data according to specific social, economic, and

demographic characteristics as well as based on perception of different factors. These can also allow for the creation of sample clusters of those users of specific characteristics.

Table 5.4. Respondent level questions

ID	Question	Question type	Question aim
R1	Is the respondent aged 6 - 14 years old?	Observational	Determine if questions shall be directed to participant or to an adult guardian
R2	Gender of the respondent	Observational	Determine gender
R3	May I know your/your child exact age, please?	Numerical	Determine participants' exact age
R4	Age range	Computer generated	Aggregate age responses
R5	What is your current marital status?	Multiple option	Determine marital status
R6	What is the highest level of education that you have attained?	Multiple option	Determine level of education
R7	Which of the following best describes your current occupation?	Multiple option	Determine occupation
R8	Which option best describes your working hours?	Multiple option	Determine working arrangements
R9	Do you have a driving licence?	Multiple option (respondents above 18 years old only)	Assess ability of driving licence in Singapore
R10	Do you require any mobility aid when travelling outside?	Multiple option	Determine movement constraints
R11	Which of the following types of mobility aid do you require?	Numerical	
R12	You mentioned that you R12 mobility aids. Please rank them in terms of importance	Rank	
R13	How often do you cycle in Singapore?	Multiple option	Determine cycling frequency in Singapore
R14	How often do you use personal mobility device in Singapore?	Multiple option	Determine PMD usage frequency in Singapore
R15	How likely are you to participate in a bicycle-sharing scheme?	Multiple option	Willingness to use bicycle-sharing scheme
R16	(Would participate) May I know the reason why?	Multiple option	
R17	(Would not participate) May I know the reason why not?	Multiple option	
R18	How much are you willing to pay for a public bicycle-sharing scheme?	Multiple option	

The respondent level questions that would require some modifications are mostly those concerned with working hours, driving licence, and willingness to use a new service (bicycle-sharing scheme).

Options for the working hours shall be selected based on the local average or entering/leaving work and taking into consideration traffic peak periods of the country/city where the survey is being conducted. The age limit of obtaining a driving licence shall be considered and question R10 shall be directed to all those that could possess one. Finally, questions R16 to R19 shall be modified to assess willingness to use any new scheme or service being implemented in the country, such as: development/enhancement of public transport, or implementation of infrastructure to promote a specific mode of transport

5.2.3. Trip (and trip-stages) level

The questionnaire comprised a total of 12 questions to be asked at trip or trip-stage level. Of these, 10 are asked to all participants of the survey and 2 are computer generated as presented in Table 5.5. These questions are concerned with recording trip details such as starting and ending locations, trip purpose, trip frequency, and mode(s) of transport. Questions in this section are repeated for each trip and some are repeated for each trip-stage. After collecting general household information, interviewers immediately proceed to collect trip information. This section is placed at the beginning of the questionnaire to ensure respondent is still “fresh” and provides most detail and accurate information. In addition, respondent is reminded that he/she can provide any additional trip information though the course of the survey.

The trip-stages questions that would require modification are those concerned with the mode of transport as well as those related to willingness to shift from motorised modes to active modes. First, the given transport options shall be in line with those available in the country/city under study, e.g. train option shall not be provided at countries/cities with no train service, and these shall also be modified according to respondents’ characteristics, e.g. if a respondent reported not having a driving licence, option of driving a car shall not be made available. Moreover, the willingness to shift questions and available options shall be modified based on the aim of the survey. If more interest is placed towards usage of a specific public transport mode, the question can be changed to be focused on that mode instead of active mobility as is the case in Singapore.

It must be noted that origin and destination points of each trip-stage are of crucial interest for accurate transport demand analysis. In many cases, respondent may not know the exact address of the destination, especially for trip-stages when bus station address or carpark address is not known. In the case of Singapore, the author could extrapolate exact location using the technique explained in Section 3.3.2., which is possible due to the outstanding mapping and routing system. For other

locations, researchers/practitioners shall search for alternatives to clearly pin-point origin and destination of each trip-stage for efficient and accurate demand analysis.

Table 5.5. Trips/trip-stages level questions

ID	Question	Question type	Question aim
T1	Day of record	Computer generated	Determine day of the trip
T2	Number of trips recorded	Computer generated	Determine average number of trips per person, per day
T3	Number of trip-stages recorded	Computer generated	Determine average number of trip-stages
T4	Trip Starting Point	Open-ended	Determine trip & trip-stage origin
T5	Trip Ending Point	Open-ended	Determine trip & trip-stage destination
T6 /S1	At what time did you depart from <u>ORIGIN (T4)</u> ?	Open-ended	Determine (perceived) travel time
T7 /S2	At what time did you arrive at <u>DESTINATION (T5)</u> ?	Open-ended	
T8	How often do you take this trip?	Multiple option	Determine trip frequency
T9	What was the purpose of this trip?	Multiple option	Determine trip purpose
S3	What is the mode of transport utilised between origin and destination?	Multiple option	Determine trip-stage mode of transport
S4	From <u>TRIP-STAGE ORIGIN (S1)</u> to <u>TRIP-STAGE DESTINATION (S2)</u> , would you consider switching to active mobility?	Multiple option	Willingness to shift to walking, cycling or PMD
S5	May I know why you would consider switching to active mobility?	Multiple option	
S6	May I know why you would not consider switching to active mobility?	Multiple option	

5.3. Chapter summary

In this chapter, the features of the developed PDMD framework are introduced followed by characteristics of the refined survey instrument developed utilising inputs from the framework. Possible modifications to the framework and the survey instrument are introduced by introducing contrasting local contexts.

Prior to the PDMD framework, In the efforts to merge the knowledge from the different scientific disciplines a lexicon of terms commonly used in explaining travel behaviour is provided. This aims to improve the communication between scientists of different fields thereby strengthening the knowledge regarding travel behaviour. The proposed definition of terms could also help to

standardise research approaches and make findings comparable across different fields that study travel behaviour.

The framework has been developed considering findings from the 3 studies that investigated active mobility users' quality needs and based on a comprehensive review of 27 scientific theories/frameworks that have been/can be related to travel behaviour. The PDMD framework can be utilised (locally and internationally) to develop studies that are aimed at determining the importance of service improvement from users' perception. As indicated by its name, the proposed "process and determinants of mobility decisions" framework presents two (2) major divisions: the process, and the determinants.

The process conceptualises what generates activity and trip demand, introducing the "need for physical presence" as the key factor for demand generation. Then, the determinants division describes what factors affect different travel-decisions and how individuals assess different options. Different factors are considered based on for whom the trip decisions are made. The individuals assess possible choices based on psychological and actual limitations and/or requirements, with psychological factors having the greater influence in majority of the cases.

Rather than focusing in one particular location or group of people, the authors indicated in the framework description which factors change from one context to another, giving contrasting examples whenever possible, thereby providing considerations on how different aspects of the framework could be considered in different contexts. The PDMD framework can be used as a guide for the development of empirical studies in different contexts, thereby unifying the methodology and enhancing interdisciplinary collaboration and international understanding regarding mobility decisions. In addition, it can also be used by authorities and planners to make informed decisions regarding different transport interventions, either for built-environment improvement or policy development.

Moreover, characteristics of the survey instrument are presented in three main sections comprising approximately 50 questions. The survey aims to capture in detail the household, personal/individual, and trips' characteristics/information. For the trips' characteristics, key interest is placed in recording active and short-range (active or motorised) trips. The fact that the survey is focused on recording detailed characteristics of each stage of the trip differentiates it from other surveys previously conducted in Singapore where attention is placed on whole trip rather than at each trip-stage. As for the PDMD framework, features of the survey that should/could be modified to apply to another country/city are highlighted and discussed.

In different contexts, plans and policies exist to encourage the use of certain modes of transport. The proposed framework can be used to: (1) estimate the importance of service improvement from users' perception; and (2) develop transport schemes, infrastructures, and policies, aimed to increase the usage of green and sustainable modes of transport such as active modes. Practitioners can also utilise the framework to audit existing schemes and determine if currently implemented ones fully consider most (if not all) factors affecting mobility decisions for different group of users. These can then be modified accordingly to enhance its efficiency. The survey questionnaire can be used in different context to examine and record users' travel characteristics and develop transport models and plans accordingly and assess how people respond and change travel behaviour based in the local environment and/or introduced programmes or policies.

Chapter 6. Travel demand analysis

In this chapter, the findings related to demand analysis are presented. To analyse demand for different modes of transport and changes in demand based in different scenarios, collected household data was utilised and the developed PDMD framework was utilised as guideline for selection of input components. Modifications to the traditional 4SM were introduced by modifying the order of the steps and by employing computer-intelligent methods in the form of neural networks in the mode choice step. Besides current scenario (survey data), 3 different scenarios were considered and changes in demand for different mode of transport was estimated. The main analysis and related discussion are focused on the mode choice step while other steps are considered only to gain an overview of the transport network usage. As in previous chapters, in this chapter, number of bicycles and PMDs are presented separately and in no case, bicycles are classified as a type of PMD.

First, the overall sample characteristics of the interviewed households are introduced. Then, following the modified 4SM, outcomes from trips/trip-stages generation step, are presented and is followed by neural network mode choice modelling results – for current scenario and 3 modified scenarios. This is followed by the findings obtained from the trips/trip-stages distribution step. Then, the active trips are assigned to the off-road active mobility transport network. Finally, a discussion of specific impact of different factors (as considered in the different scenarios) in travel demand and usage of the network is presented. A version of this study, with main interest on demand analysis, is in preparation for submission for consideration for publication to *Transportation Planning and Technology* journal and it is currently under review (Rojas López et al., 2018) and some issues regarding trip distribution are discussed in a study published at Proceedings of the Institution of Civil Engineers – Transport (Poyil, Rojas López, & Wong, 2017).

6.1. General sample characteristics

Data from 1,119 households, interviewed at cycling (Sembawang and Yishun) and non-cycling (Serangoon and Hougang) towns, was utilised which corresponds to approximately 0.8% of the HDB household population in the towns under study. A description of the 4 towns under study is provided in Table 6.1. Both types of towns are alike, the majority (around 48%) of the interviewed households were 4-room HDB apartments, which is not surprising as this type of apartment is the most common in HDB building-blocks (HDB, 2018b; SINGSTATS, 2017).

Table 6.1. General description of towns under study for demand analysis

Region		Sembawang ✓ 	Yishun ✓ 	Serangoon ✗ 	Hougang ✗ 	References
		North	North	North-East	North-East	
Area	Total	12.34 km ²	21.24 km ²	10.1 km ²	13.93 km ²	(SINGSTATS, 2011b)
	Residential	3.31 km ² (27%)	3.98 km ² (19%)	1.63 km ² (16%)	3.67 km ² (26%)	
Population	Total	76,530	201,970	120,670	222,310	
	Density	6,200/km ²	9,500/km ²	12,000/km ²	16,000/km ²	
Total No. of HDB flats		77,351 (53%)		68,016 (47%)		(HDB, 2014, 2018a)
No. of HDB flats per type	1-Room	601 (3%)	1,038 (2%)	272 (1%)	532 (1%)	
	2-Room	1,184 (6%)	1,414 (2%)	324 (2%)	1,066 (2%)	
	3-Room	504 (3%)	15,403 (27%)	4,541 (24%)	10,610 (22%)	
	4-Room	9,441 (47%)	29,657 (52%)	10,231 (54%)	25,842 (53%)	
	5-Room	8,272 (41%)	9,837 (17%)	3,754 (20%)	10,844 (22%)	
Cycling network	PCN	Sembawang PCN (2km); Canberra PCN (1.3km)	Yishun PCN (3 km)	Serangoon PCN (4.2km)	Hougang Ave 3 PCN (4.4km)	(NParks, 2016c)
	Intra Town Cycling Network	10.7km	15.5km	--	--	(LTA, 2016b)
MRT station(s)		Sembawang; (Canberra)	Yishun; Khatib	Lorong Chuan; Serangoon; Bartley	Tai Seng; Hougang; Kovan	(LTA, 2015b)
No. of bicycle parking at MRT		722	821; 195	63; 79; 54	80; 156; 61	(MyTransport, 2016)

Household socio-demographic characteristics and vehicle ownership are presented in Table 6.2. Regarding monthly household income, most (16%) of the households reported their household average monthly income to be between 7,000SGD and 7,999SGD per month, which is consistent with the national average monthly income of 7,900SGD for HDB households (DATA.Sg, 2017; SINGSTATS, 2017). Around 3 every 10 households reported to have a motorised vehicle available in the household, and around 3 in 10 households reported to have a bicycle, while slightly over 1 in 10 households reported to have a PMD (excluding bicycle). Interestingly, the proportion of motorised vehicles was found to be lower as compared to the national rate. The lower proportion vehicles could be due the households being HDB households where vehicle ownership is in general lower (as

compared to households in condominiums and landed properties), as well as Singapore's ownership policies and elevated costs on acquiring a COE plate (Goh, 2017; Mahmud, 2018). In the households that owned at least one motorised vehicle, bicycle, or PMD the average number of these vehicles equals 2.1 (SD= ± 0.65 ; Max=5), 1.6 (SD= ± 0.88 ; Max=6), and 1.4 (SD= ± 0.54 ; Max=5), respectively.

Table 6.2. Households' characteristics –Household interview travel survey

Characteristics	Sample (n=1,119)	National rates
Type of HDB household		
1-Room	1%	3%
2-Room	1%	4%
3-Room	24%	26%
4-Room	48%	42%
5-Room	26%	25%
HDB household size (Average)		
Average size of interviewed households*	3.4 people	3.4 people
Adults who made trips (average)	1.5 adults	NA
Children 6 to 18 years old who made trips	0.4 children	
Individuals >6 years old who did not made trips	1 adult/child	
Children <6 years old who did not need to report trips	0.5 children	
HDB household average monthly income*		
Below 1000 SGD	13%	13%
Between 1000-1999 SGD	9%	5%
Between 2000-2999 SGD	10%	5%
Between 3000-3999 SGD	11%	5%
Between 4000-4999 SGD	11%	5%
Between 5000-5999 SGD	10%	6%
Between 6000-6999 SGD	7%	6%
Between 7000-7999 SGD	16%	5%
Between 8000-8999 SGD	4%	5%
Between 9000-9999 SGD	2%	5%
Between 10000-14999 SGD	5%	18%
15000 SGD or more	2%	22%
Vehicle ownership (Households with one or more) *		
Rented/ company owned motorised vehicle	2%	8%
Self-owned motorised vehicle	28%	55%
Bicycle	29%	25%
PMD	13%	NA
References for national rates: SINGSTATS, 2017.		
*National rates include households in HDBs, condominiums, and landed properties.		

Households were reported to have 3.4 (SD= ± 1.42) members on average, which equals the average household size in Singapore (Lee, 2016). A total of 2,115 household members made trips, which constitutes an average of 1.9 (SD= ± 0.8) trip-making members or respondents per household, of whom 81% were adults of more than 18 years of age. Respondents from whom demographic and

travelling information was recorded were on average 41.5 (SD=±21) years old, the youngest member from whom information was reported was 6 years old and the oldest member who reported information was 97 years old. The age distribution of respondents was considered a good representation of the overall national statistics. A similar split between male and female household members was observed on the final respondents' sample, with 46% males and 54% females, which is also comparable with Singapore's gender split. General characteristics of individuals who reported trips are shown in Table 6.3.

Table 6.3. Household members' characteristics – Household interview travel survey

	Sample (n=2,115)	National rates		Sample (n=2,115)	National rates
Age*			Occupation		
Average respondent age	41.5 yrs.	NA	Full-time employed	43%	61%
Adult average age	48.9 yrs.		Part-time employed	4%	
Child average age	10.9 yrs.		Self-employed/voluntary worker	3%	
0 - 6 years	NA	4%	Full-time student	22%	20%
6 - 9 years	7%	7%	Housewife, domestic worker, retired, unemployed	28%	19%
10 - 14 years	8%	6%			
15 - 17 years	3%	13%			
18 - 24 years	5%				
25 - 29 years	7%	7%	Cycling frequency		
30 - 34 years	9%	8%	At least once a week	13%	NA
35 - 39 years	9%	9%	At least once every 2 -3 weeks	5%	
40 - 44 years	8%	8%	At least once a month	4%	
45 - 49 years	6%	8%	Less than once a month	10%	
50 - 54 years	7%	8%	Don't cycle & not willing to try	39%	
55 - 59 years	7%	6%			
60 - 64 years	9%	5%	Don't cycle, but willing to try	7%	
65 - 69 years	6%	3%			
70 - 74 years	4%	3%	Used to cycle, but not anymore	22%	
75 - 79 years	2%	2%			
80 years & above	3%	3%			
Gender*			PMD usage frequency		
Male	46%	49%	At least once a week	14%	NA
Female	54%	51%	At least once every 2 -3 weeks	5%	
Level of education* •			At least once a month	5%	
None	1%	NA	Less than once a month	12%	
Preschool	9%	29%	Don't use & not willing to try	51%	
Primary	24%				
Secondary	48%	27%	Don't use them, but willing to try	13%	
Tertiary (non-university)	2%	15%			
University & over	16%	29%			
References for national rates: SINGSTATS, 2017.					
*National rates comprise Singapore citizens and permanent residents.					
• National rates for level of education are for resident population aged 25 years and above.					

Household members who reported trips were also asked to report their occupation at the time of the survey. The largest group (43%) reported as being full-time employed, followed by 28% housewives, domestic workers and retired, 22% reported as being full-time students, and the remaining 7% part-time employed or voluntary workers. Regarding usage of bicycles and/or PMDs, a total of 265 (13%) of the individuals reported to ride a bicycle at least once a week and 287 (14%) reported to ride a PMD with the same frequency. More specifically, 32% of the members reported to cycle in Singapore, 7% reported not to cycle but being willing to start, 22% reported used to cycle but not anymore, and 39% reported not cycling at all and not being willing to start. On the other hand, 36% reported to use PMDs in Singapore, 51% reported not to use them but being willing to try, and 13% reported not to use them and not being willing to start.

From the 1,119 households, a total of 2,115 members reported trips. There reported on average 2.4 trips, which constituted a total of 5,065 trips, and each trip was on average comprised of 1.8 stages. Thus, a total of 9,316 trip-stages were recorded and these were utilised for travel demand analysis. An overview of the total trip and trip-stage characteristics, as well as by type of town, are given in Table 6.4. Of the total number of trips, 77% (or 3,894 trips) involved at least one active mode for some of the stages (mostly first or last mile trip-stage), of which 47% (or 1,822 trips) were fully made by an active mode of transport (single-stage trip from origin to destination). Thus, the sample had a good representation of active trips and trip-stages.

Comparing cycling and non-cycling towns, significantly more ($p < 0.001$) active trips/trip-stages were reported at cycling towns. There were 70% active trip-stages reported in cycling towns as compared to 55% active trip-stages at non-cycling towns. In addition, more full-active-mode trip (single-stage trips) were reported at cycling towns as compared to non-cycling towns – 79% compared to 68%. This is expected due to the provision of cycling infrastructure which has been highlighted that also affects other modes of transport positively.

Participants were asked to report the approximate starting and ending times of their trips and this information was utilised to calculate the (reported) travel time. On average, reported full-trip travel time (taking total of 5,065 trips into consideration) was found to be around 31mins ($SD = \pm 24$ min) and trip distance approximately 12 km ($SD = \pm 14$ km). More specifically for trip stages (taking total of 9,316 trips-stages into consideration), single-stage motorised trips were found to be around 38mins and 15km on average, single-stage active trips around 11mins and 2.8km on average, and for multimodal motorised and active trip-stages these were found to be around 25mins and 9.2km, and 8mins and 0.6km, respectively. In general, full-trips (active and motorised) were found to be of similar average

distance for cycling and non-cycling towns, however, active trip stages were found to be slightly longer in cycling towns (10mins on average) as compared to non-cycling towns (7mins on average). No great difference was found for motorised trip stages.

Table 6.4. Characteristics of reported trips on household travel survey (for 1,119 households)

Characteristics	Total	Cycling towns	Non-cycling towns
Total number of reported trips	5,065	1,959	3,106
<i>Trips with at least 1 active trip-stage</i>	77%	79%	68%
<i>Full-active-mode trips (single-stage trip)</i>	36%	41%	35%
Total number of reported trip-stages	9,316	3,473	5,843
<i>Active trip-stages</i>	56%	70%	55%
<i>Motorised trip-stages</i>	44%	30%	45%
Type of trips	n=5,065	n=1,959	n=3,106
<i>Home-based work (HBW)</i>	21%	22%	22%
<i>Home-based education (HBE)</i>	8%	9%	8%
<i>Home-based maintenance (HBM)</i>	55%	53%	57%
<i>Home-based recreation (HBR)</i>	4%	3%	4%
<i>Home-based others (HBO)</i>	5%	5%	5%
<i>Non-home-based (NHB)</i>	7%	8%	4%
Frequency of trips	n=5,065	n=1,959	n=3,106
<i>Daily</i>	9%	4%	9%
<i>5 days per week</i>	56%	57%	63%
<i>At least once a week</i>	22%	26%	16%
<i>At least once a month</i>	4%	5%	3%
<i>Less than once a month</i>	3%	3%	2%
<i>Only for this time</i>	6%	5%	7%

Moreover, trips were classified by purpose, and 6 classifications were applied. These are defined as:

- Home-based work (HBW): work purpose trip between individual's home and workplace;
- Home-based education (HBE): education purpose trip between individual's home and school/university;
- Home-based maintenance (HBM): maintenance purpose trip (grocery shopping, eating, personal errands, medical, etc.) between individual's home and maintenance activity location;
- Home-based recreation (HBR): recreation purpose trip (social visit/gathering, recreation, exercise) between individual's home and recreational activity location;
- Home-based others (HBO): trip with purposes other than work, education, maintenance, or recreation between individual's home and activity location; and
- Non-home-based (NHB): trips with any purpose that do not begin or end at individual's home.

Interestingly, from the total number of trips, most of them (55%) were HBM. This is not surprising as participants were asked to report each and every trip, including short range ones that are commonly

under-reported. Following HBM, HBW (21%) and HBE (8%) trips were the most common trips. Although small differences were found regarding reported trip purposes for the two types of towns under study, the difference was found to be statistically significant ($p < 0.001$), with more HBM trips and fewer NHB trips being made at non-cycling towns. Moreover, regarding trips frequency, most (56%) of the trips were reported to be made 5 days a week. A significant difference ($p < 0.000$) was also found for the trip frequency, where many trips were reported to be made with less frequency at cycling towns, which are likely to be recreational/exercise trips. The main difference was found for trips made at least once a week, with 26% at cycling towns compared to 16% at non-cycling towns.

From the 4,054 motorised trip-stages reported at both type of towns, respondents reported willingness to shift from motorised modes to active modes (either walking, cycling, or riding PMDs) for 8% of them. The reasons for being willing or unwilling to shift to walking, cycling, or riding PMDs were recorded in the survey. The most common reason for being willing to shift was found to be “to save travel time”; on the other hand, “weather is too hot” and “afraid of being involved in an accident” were reported as the most common reasons for not being willing to shift. The reported factors that affect willingness to shift are taken into consideration for the modification of input variables for the different scenarios considered in the travel demand analysis as presented in Section 6.3.

6.2. Trip-stage generation

To gain an overview of the travel characteristics, reported trip-stages' origins and destinations were assigned to corresponding TAZs to compute the number of productions and attractions per TAZ. An overall view of all trips was considered. For visualisation, heat maps were created in ArcGIS. Figure 6.1 and 6.2 show the overall view of trip-stages distribution based on current scenario. The heat maps are presented for each town under study noting that scale for the heat maps varies across towns due to variations in the total number of trip-stages produced and attracted at each town. Same procedure can be followed to map the trip-(stages) by trips purpose (HBW, HBE, HBM, HBR, HBO, and NHB) or by time of the trip (peak, non-peak) should a more in-depth analysis be needed.

As expected, larger TAZs attract and produce more trips and the number of trip-stages was found to be higher at TAZs closer to MRT stations. Also, the production and attraction rates for each TAZ are quite similar, which is due to the nature of the survey. In using travel diaries over a 24-hour period for household interview travel survey (as in the current research study), almost every trip shall have a return trip, thus origins and destinations are “repeated inversely”. The small variation in productions and attractions can be explained by some trip chaining behaviour. It should be noted that in the scales

utilised for the different towns, different colours represent different number of trips, with many more trips being recorded in Sembawang town as compared to other towns.

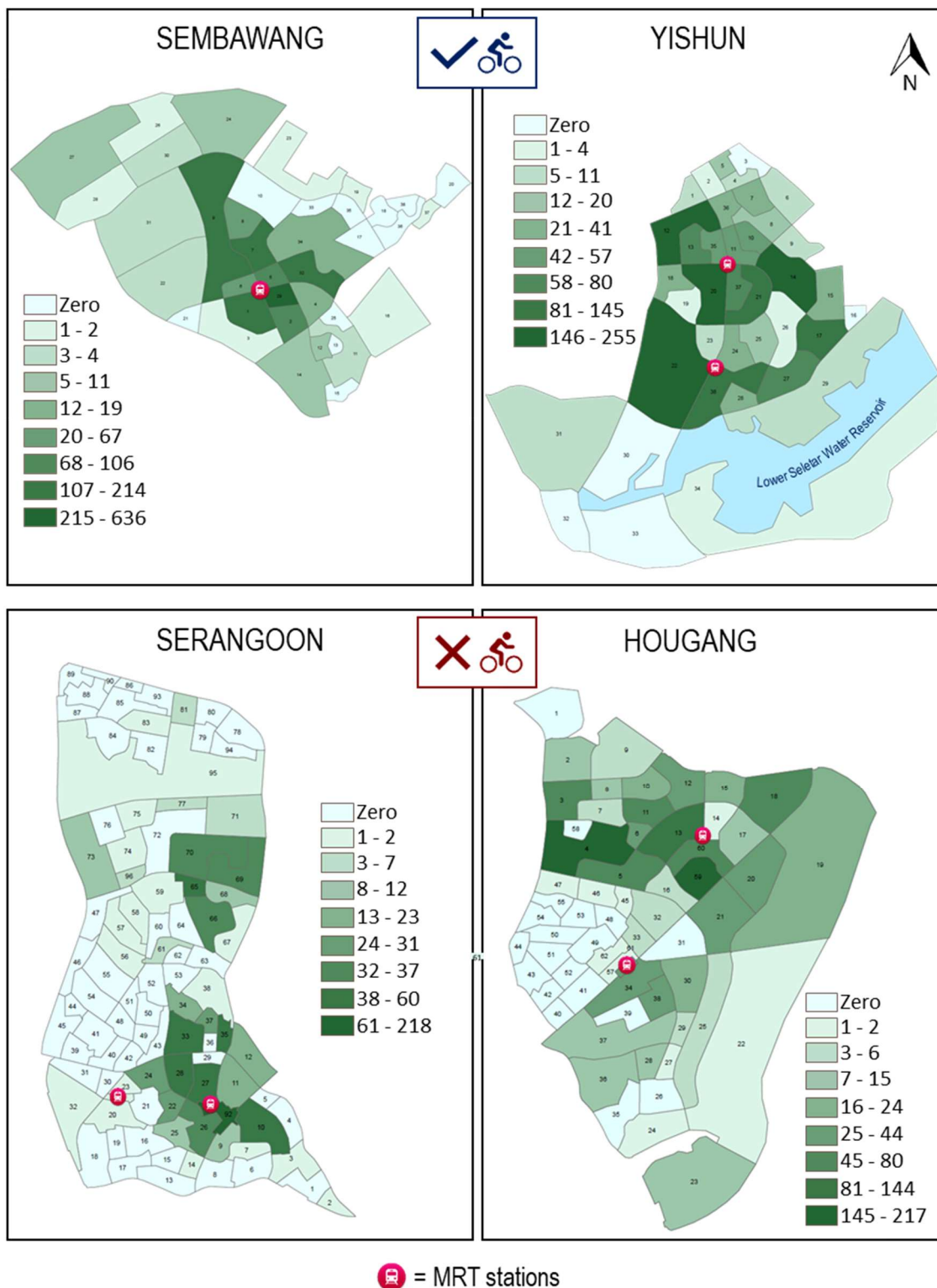


Figure 6.1. Trip production heat maps per town under study (for 1,119 households)

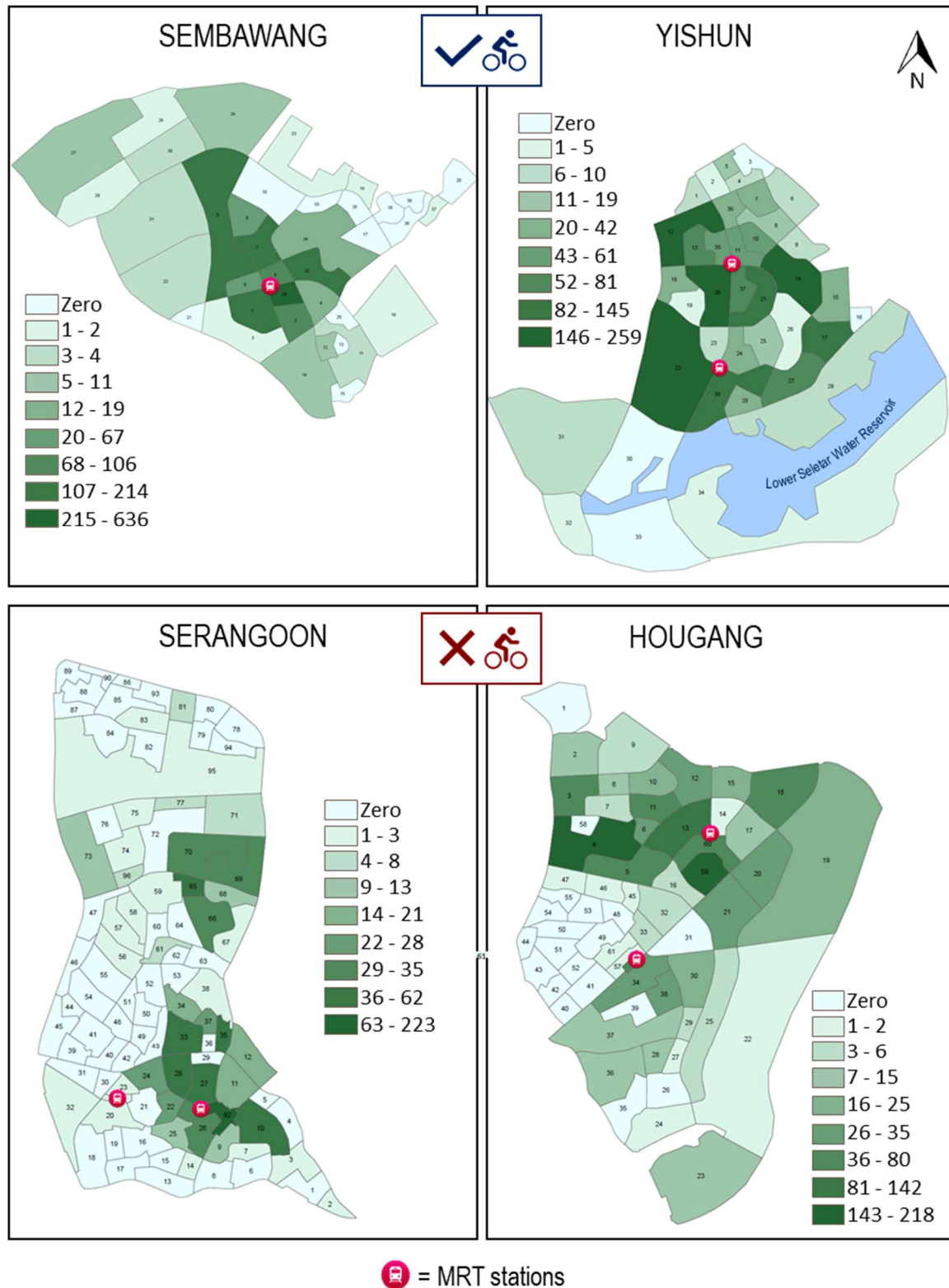


Figure 6.2. Trip attraction heat maps per town under study (for 1,119 households)

Land use type was considered for each TAZ and the impact of land use type on the number of trips generated and attracted was estimated. Although residential land use generated slightly more trips as compared to other land uses, no significant difference ($p=0.832$) was found on the land use types

and the number of generated trips. This could be explained by the fact that, in Singapore, land uses are planned to ensure a good mix and distribution of land uses so there is no clustering of activities in a specific zone.

6.3. Mode choice analysis using neural network model

As previously explained, a neural network model with 28 input components, 3 hidden layers, and 28 nodes or neurones per layer was utilised for travel demand analysis based on changes for 3 hypothetical future scenarios. For the selection of number of hidden layers and training function, several combinations were tested as shown in Figure 6.3.

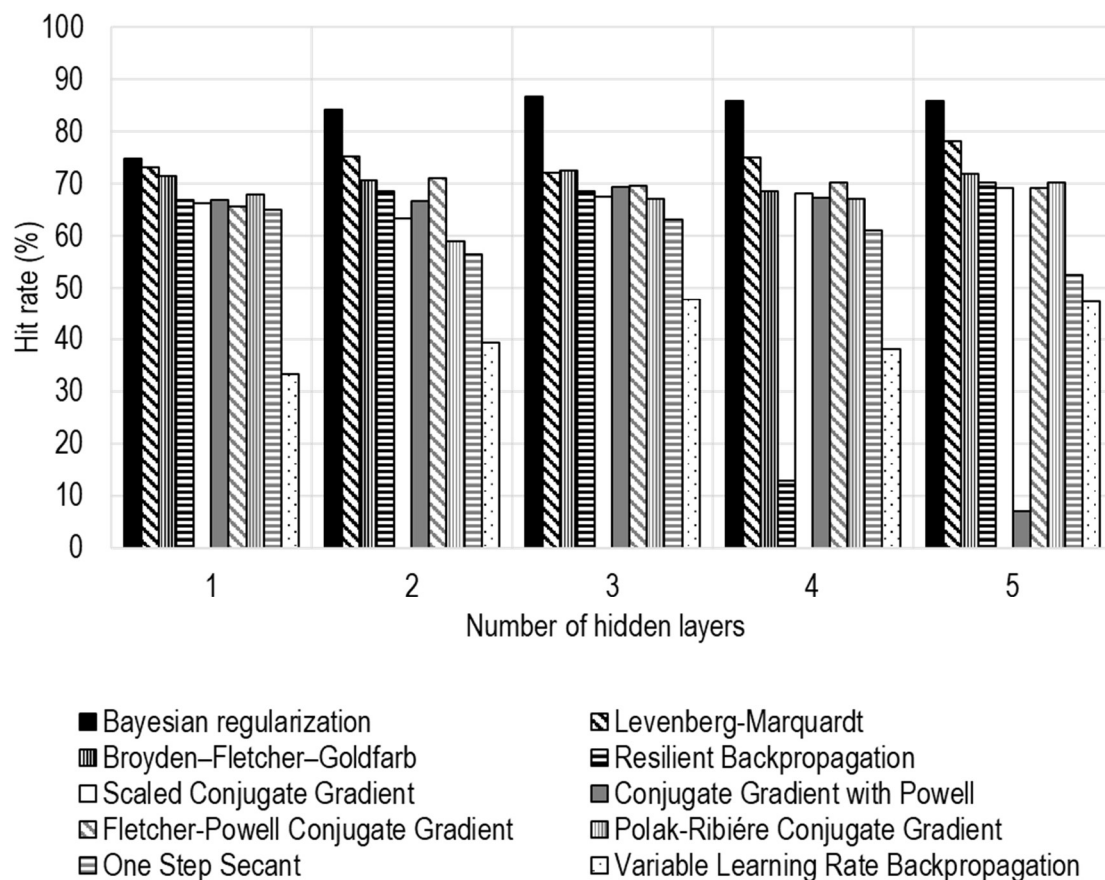


Figure 6.3. Output (mode of transport) hit rate for different training functions and number of hidden layers (for 9,316 trip stages)

Bayesian regularisation was found to be the training function that yielded the highest hit rate (thus, lower number of miss rate) and thus was selected. Bayesian regularisation is a back-propagation training function where values of the input components are “fed forward” to the following hidden layers and neurones, and error value is “propagated back” to previous layer for consideration within the neurones and increase accuracy. The literature has suggested that Bayesian regularisation is one of

the most robust and practical approaches as it obviates the need for cross-validation, and rarely allows for over-training (otherwise much time is spent in learning from inputs which may negatively affect predictive ability) and over-fitting (exceed an optimal size – number of hidden layers) (Burden & Winkler, 2008) of the model. Due to not having the need to perform cross validation, the final sample size was divided into training set (80%) and evaluation set (20%).

To select the final input components from the survey data, the PDMD framework was taken into consideration and only those components that were applicable at household level and those that affect or can affect all household members were considered. Thus, the “driving licence” (which does not apply to household members of less than 18 years of age) variable was removed from the initial list of input variables presented in Section 3.3.3. The 28 inputs components (classified as household socio-demographics, individuals socio-demographics, built-environment information, and trip-stage information) were selected as they present high level of correlation with selected mode choice for each trip-stage.

To train the neural network model, values for each of the selected input variables were presented as specific numeric values for continuous variables (e.g. age, travel distance, distance to public transport station, vehicle ownership, etc.) or as ranks/scales for discrete variables (e.g. type of household, cycling frequency, etc.). Some of these variables were modified for demand analysis for different scenarios, for which a summary of the modifications is presented in Table 6.5 and expanded in Section 6.3.1 (related to S1) and Section 6.3.2 (related to S2). To modify the variables, the numerical scales were modified for each of the individuals and their respective households and trips/trip-stages. These were then introduced into the trained neural network model for travel demand estimation.

The input components are related to the target output of **transport mode choice**, between private motorised vehicles, taxis, other-buses (e.g. school bus and shuttle bus), public buses, MRT, PMDs, cycling, and walking mode of transport as reported by survey respondents. The neural network model was trained to learn relationship between inputs and target output and estimate factors that lead to the specific output. These values were stored as weights and the weights were modified through each hidden layer as it has been explained in Section 3.3.3. A general good fit of the model was found as observed from the good degree of learning and high coefficient of correlation between the target outputs and predicted outcomes (R – as shown in Figure 6.4) and small error span (-2 to 2 – as shown in Figure 6.5) being normally distributed around the mean for the training and evaluation data sets.

Table 6.5. Modifications of input variables for different scenarios

	Modification of input components	
Input	Scenario 1	Scenario 2
	Policies and programmes	Changes in the built-environment
Number of motorised vehicles in the household	Reduced vehicle ownership by 60% or lower	No change
Number of bicycles in the household	Increased access to bicycles by 90% based on access to shared bicycles	No change
Number of PMDs in the household	Increased access to PMD by 50% based on possible provision of PMD sharing system	No change
Cycling frequency	Increased cycling and PMD riding frequency among for current users as well as for non-users	No change
PMD usage frequency		
Work schedule	Increased flexible arriving and leave work hours for those who currently have fixed hours, access to telecommuting for those who have flexible working hours	No change
Distance to public transport stop	No change	Set distance from HOME to BUS STOP within 400 metres & to MRT stations to 850 metres
Walkability index	No change	Increased walkability & cycle-ability index based on full provision of cycling paths and provision of sheltered for 400 metres surrounding transport stations
Cycle-ability index	No change	
Willingness to shift to active modes	Increased willingness to walk for trip-stages within 800 metres Increased willingness to cycle for trip-stages within 1500 metres Increased willingness to use PMDs for trip-stages within 1800 metres	
Note:	Scenario 3 is a combination of S1 and S2	

The good fit of the model indicates that the provided information (data from input components) was robust and sufficient to train a network in predicting the target output (mode choice) and thus can provide strong predictions for different/future scenarios. This was possible due to the big sample size utilised for this research, noticing that the model is applicable to the areas under study and findings cannot be simply transferred to other areas. Other training performance parameters and related facts are presented in Appendix E.

ID	Reference
1	Private vehicles
2	Taxi
3	Other buses (not public)
4	MRT
5	Public bus
6	PMD
7	Cycle
8	Walk

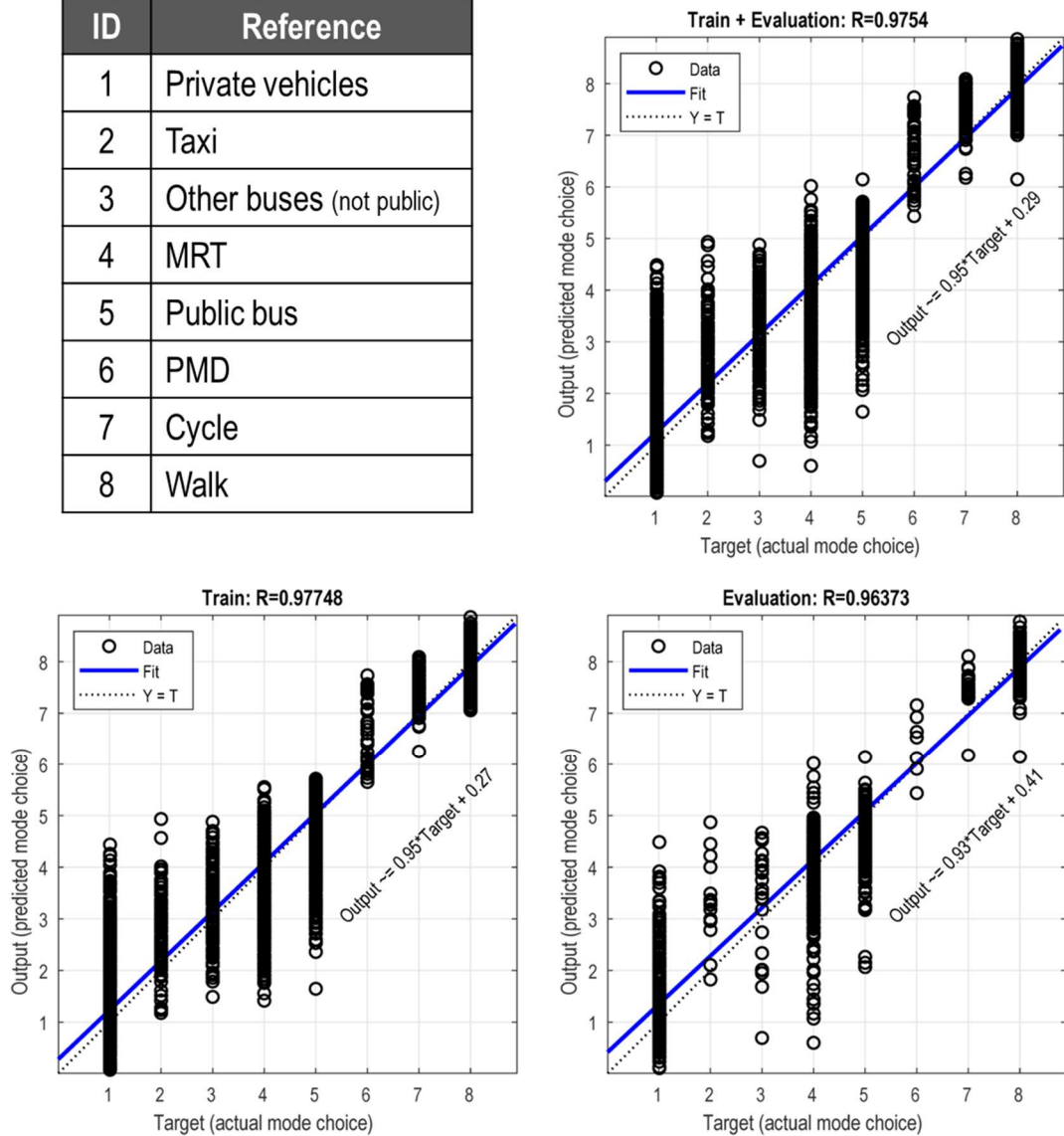


Figure 6.4. Fit of the neural network model based on regression (for 9,316 trip stages)

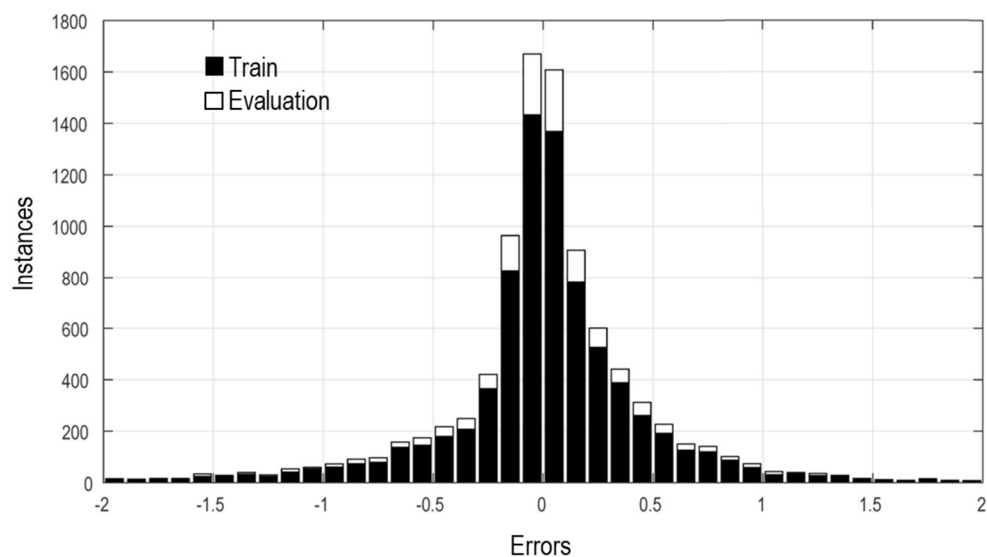


Figure 6.5. Histogram of error terms for neural network model training and evaluation

To further measure the accuracy of the trained model, information regarding target output was removed from the survey data and same input values were introduced to the neural network as “simulated data”. The trained model used stored relationships and weights to predict mode choice for the simulated data. Comparing actual survey data and trained output for trips made in cycling and non-cycling towns, as shown in Figure 6.6, it can be seen that the model yields fairly good estimations in regard to mode choice, specially walking, cycling, and riding PMDs. Interestingly, slightly lower rates for usage of private motorised vehicles and slightly higher predictions are found for taxis and usage of other-buses. This could be due to characteristics of taxis and other-buses being similar to those of private motorised modes in respect of travel distance, and almost door-to-door service, for which very few would have an active mode as first trip-stage.

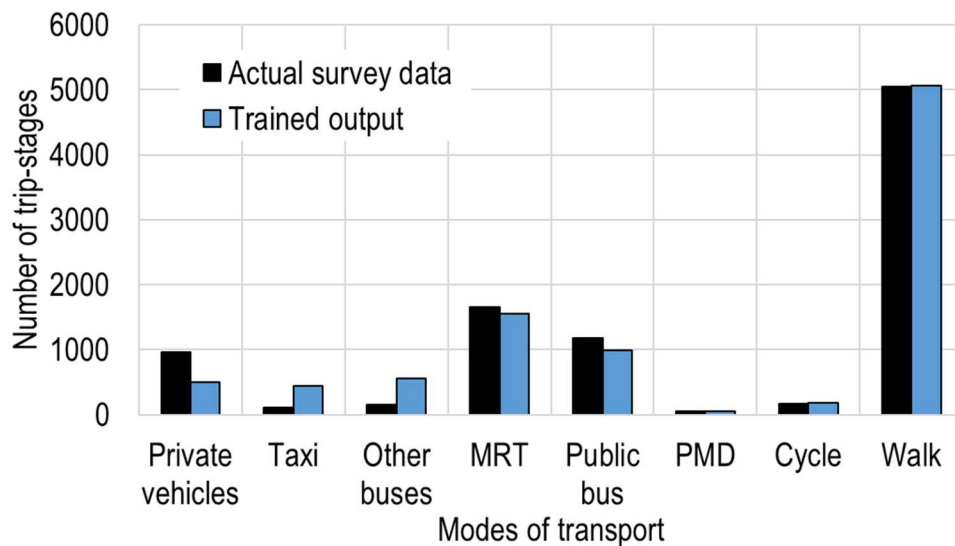


Figure 6.6. Mode choice for different trip-stages – Survey data vs simulated data

After neural network model was trained and validated, changes in travel demand (based on changes in mode choice) was estimated considering 3 different scenarios as described in Section 3.3.3. Modified inputs were used to re-run the trained neural network model using previously stored relationships and weights to predict usage of different modes of transport for each scenario. As the main goal was to understand what factors would increase active mobility, only the trip-stages made by motorised modes (public or private) of transport were considered. This is to understand the changes in demand from motorised modes to active modes in different/future scenarios.

This work pertains to re-evaluation of existent network, in brown-field developments which are common in Singapore. For green-field developments (e.g. development of new towns), certain information might not be available requiring re-training and validation of a neural network model based on available data. Taking into consideration travel distance, which greatly affects active

mobility, only first and second stages of the trips were considered. This is assuming that after second trip-stage, the travel distance would be too far and not comfortable/feasible to be covered by active modes of transport. Different scenarios and estimated travel demand are presented in subsequent sections. An overview of all the scenarios is given in subsequent sections, followed by a comparison of all scenarios and discussion of changes in travel demand in Section 6.3.4.

6.3.1. Scenario 1 – Policies and programmes

For this scenario 1, impact of several policies and programmes were considered. Five main changes were considered. First, is a reduction on motorised vehicle ownership of 60% at household level. While it is recognised that this is a big reduction on car population and unlikely to happen at a fast pace, the estimated demand serves to estimate changes as the number of motorised vehicles in household decreases in line with a car-lite society goal.

Also, increased availability of bicycles and PMDs was considered, as well as the frequency of cycling and/or riding PMDs among users. For the modifications, the number of bicycles available was increased by 90%. This is expected to occur as the number of shared bicycles continues to increase and so does the riding frequency. On the other hand, the number of PMDs was considered to increase by 50% assuming future provision of PMD-sharing schemes. Regarding the frequency of using these modes, for those who reported to cycle and or use PMD, their usage frequency was increased by one factor and for those who reported being willing to start were considered as occasional cyclists. More specifically, changes were made as follows:

- At least once a week → (increased to) daily
- At least once every 2 -3 weeks → (increased to) at least once a week
- At least once a month → (increased to) at least once every 2-3 weeks
- Less than once a month → (increased to) at least once a month
- Don't cycle/use PMDs, but willing to try → (increased to) less than once a month

Possible changes in (more) flexible working hours and working schemes were also considered. These changes are likely to occur with more companies/industries (locally and internationally) pledging to further enhancing programmes that allow for telecommuting and flexible working hours. For this scenario, features in the trained NN model were modified considering flexible working hours for employees who reported (currently) having fixed working hours and considering the possibility of telecommuting for those who reported already having flexible working hours.

Finally, for S1 as well as S2, an increased willingness to shift from motorised modes to active modes was considered, due to assumed increased acceptability of these, as well as increased likelihood to participate in bicycle-sharing programmes. Willingness to walk was set to be positive for all trip-stages within 900 metres, willingness to cycle was set to be positive for trip-stages within 1,500 metres, and willingness to use PMDs was set to be positive for trip-stages within 1,800 metres. Distance threshold for walking and cycling trips was set using previous studies in Singapore as reference (Koh et al., 2011). The study defines catchments of up to 950 metres and 1,500 metres for comfortable walking and cycling distances respectively (based on 85th percentile). As no actual data exists regarding PMDs, the research team assumed an estimated distance of 300 metres more than cycling due to the reduced physical activity required while using PMDs as compared to cycling. Estimated changes in demand based on the modified variables considered in this scenario are presented in Figure 6.7.

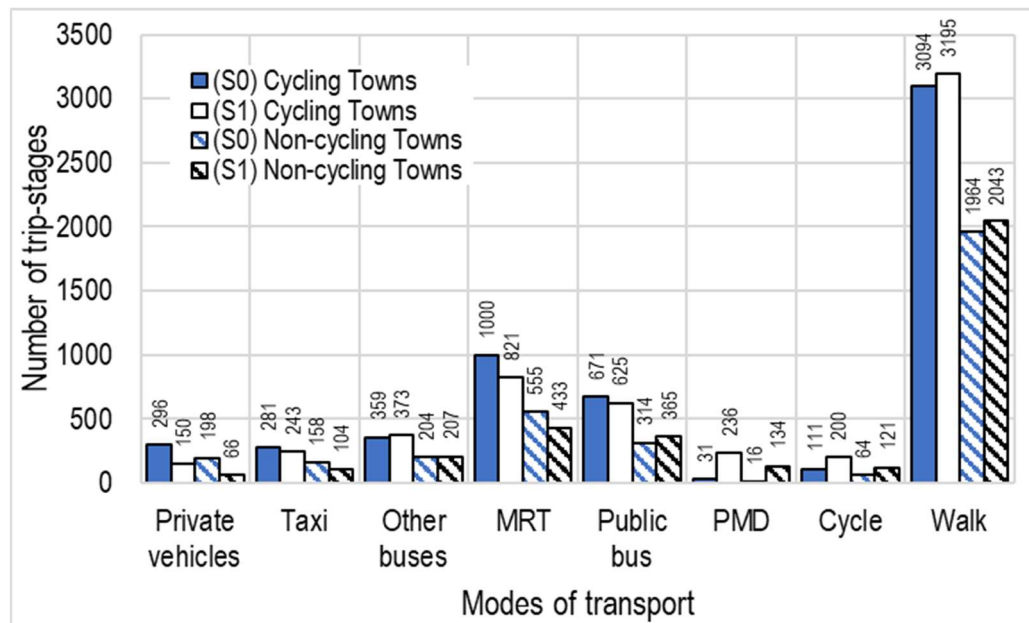


Figure 6.7. Mode choice selection – current situation and predicted Scenario 1 (S1)

In general, it can be seen that demand for all active modes of transport is predicted to increase and the opposite is true for motorised modes, except for other buses where predicted rates are slightly higher than those on the base scenario (S0). The highest increase in active modes is expected to occur for PMDs at cycling towns. Interestingly, while changes in demand are similar in cycling and non-cycling towns, the increase rate at cycling towns is predicted to be slightly higher. This could be due to the additional influence of available infrastructure in cycling towns that can cause to increase active mobility rates, especially in combination with dedicated policies and programmes.

6.3.2. Scenario 2 – Changes in the built-environment

In this scenario, hypothetical changes in the built-environment are introduced and how these affect travel demand is estimated. Two main changes were considered where the distance to public transport stations was reduced. More specifically, distances were set from HOME to BUS STOP to be 400 metres or less and to MRT STATIONS at 850 metres or less. The changes applied in the scenario related to accessibility to public transport are applicable for both types of towns.

Furthermore, an increased in pedestrians and cyclists walkability and cycle-ability index was considered based on full provision of cycling paths and provision of sheltered for 400 metres surrounding transport stations. Also, built-environment features of non-cycling towns were modified so that they match those of cycling towns. Using pathways (footpaths and cycling paths) database provided by LTA, the total length of cycling paths versus the total length of footpaths in cycling towns was calculated. Then, the same ratio was set for non-cycling towns to estimate changes in demand. It was found that on cycling towns there is 1 metre of cycling path for every 7 metres of footpath. For the scenario modification, non-cycling towns were set with the same 1-to-7 ratio. Modification was introduced at general town level rather than at location specific levels.

As mentioned, the increased willingness to shift to active modes is also considered as presented in Section 6.3.1. Impacts of these changes in travel demand is presented in Figure 6.8.

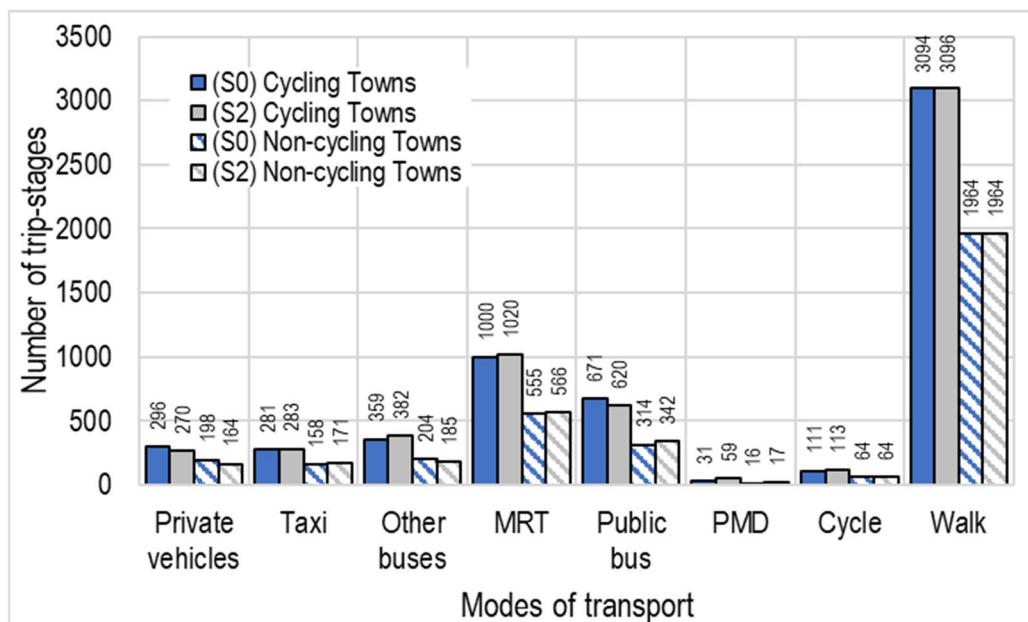


Figure 6.8. Mode choice selection – current situation and predicted Scenario 2 (S2)

While still and increase in active modes is predicted, it can be seen that by considering changes in the built-environment alone, the increase in demand for active modes of transport is less notorious.

Not surprisingly, a slight increase in MRT ridership demand was also predicted. This is not surprising as improvements to the built-environment to improve active travelling conditions also increases accessibility to public transport due to reduced travel distance as well as provision of shelters.

6.3.3. Scenario 3 – Combination of Scenarios 1 and 2

In this final scenario, all the variables described, and modifications considered, on S1 and S2 were combined. The trained neural network model was re-run to estimate changes in travel demand. As expected, this scenario presents the best outcome about increasing usage of active modes of transport, with most of these shifted from private motorised vehicles as shown in Figure 6.9. The highest increase in demand is predicted for the usage of PMDs in cycling towns.

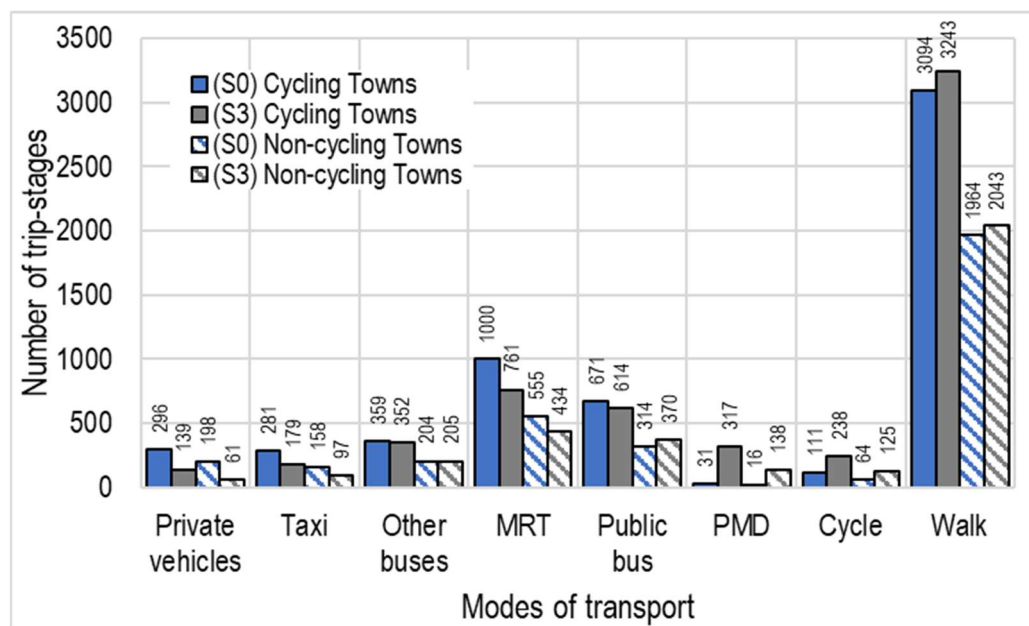


Figure 6.9. Mode choice selection – current situation and predicted Scenario 3 (S3)

An interesting point to note is the predicted difference in demand for public buses for cycling and non-cycling towns. At cycling towns, the predicted demand for public buses is predicted to decrease while the opposite is true for non-cycling towns. This could be explained due to first and second stages being considered for estimation in demand change. In cycling towns, FLM trip-stages are commonly performed by active modes connecting directly to MRT stations for the second stage of the trip (skipping the bus to MRT-station trip-stage). Herein, with provision of policies/programmes and infrastructures as introduced this hypothetical scenario, is likely that people in cycling towns shift from public transport to active trips for the full trip. For non-cycling towns, the shift towards active mobility is still at a smaller scale (for shorter distances) whereby people are predicted to walk, cycle, or ride a PMD for their FLM trips, consequently shortening the distance of remaining trip-stage(s), which could be covered by public buses, rather than by MRT.

6.3.4. Comparison of different scenarios

Comparing all the considered scenarios, clearly considering the combination of all the modified parameters, as presented in S3, the model predicts most positive outcomes regarding increase in overall active mobility rates as well as reducing trip-stages by private modes of transport. An overview of the estimated changes in demand for different modes of transport, represented by the mode choice selection, for each scenario is presented in Figure 6.10.

In general, it can be seen that policies/programmes alone (S1) have a more positive influence in increasing active modes of transport as compared to modifications to the built-environment alone (S2). In addition, S1 presents a big reduction in the number of trip-stages by private vehicles. On the other hand, S2 involving modifications for the built-environment (at macro-level as considered in this report) have a positive influence in reducing number of trip-stages by private motorised vehicles, yet most of these are then made by public transport modes (mostly by MRT) and only few of them by active modes. This can be related to the fact that the considered modifications to the built-environment, while enhancing active trip experience, also improves accessibility to public transport.

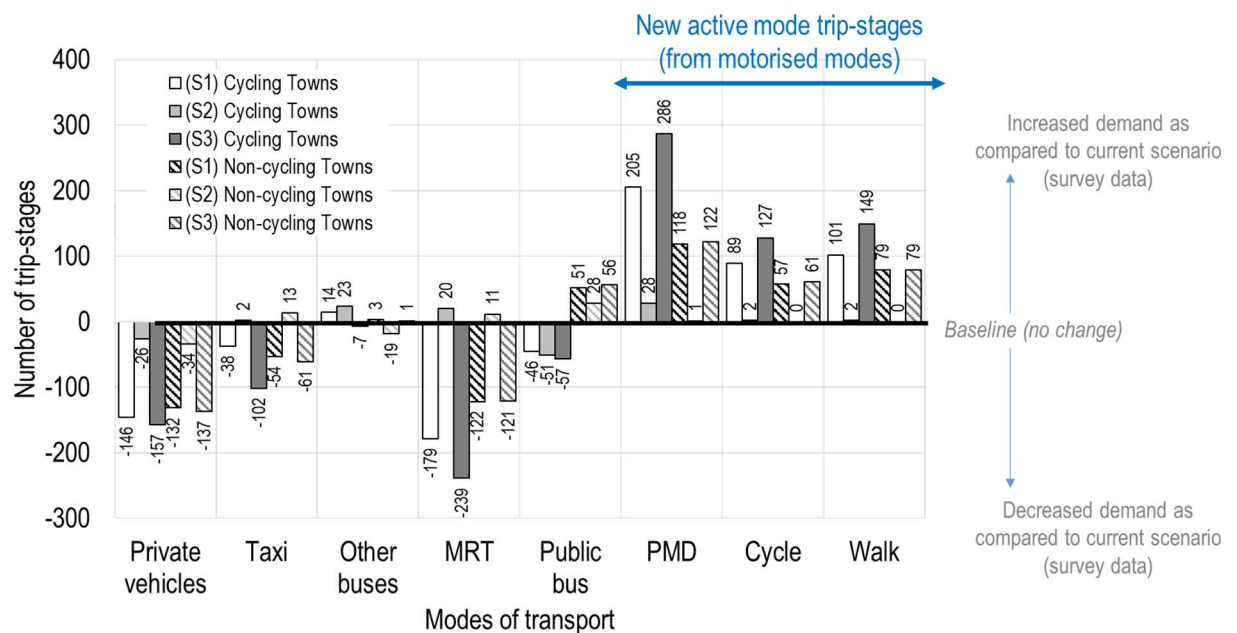


Figure 6.10. Changes in travel demand for different scenarios

When looking at the effect of the scenarios in cycling and non-cycling towns separately, it can be seen that the increased demand for active trip-stages, based on changes from S1 and S3, is more prominent in non-cycling towns as compared to cycling towns and modifications considered in S2 have the most influence in increasing demand for PMD ridership at non-cycling towns. Interestingly,

the demand for public buses increased at non-cycling towns and decreased at non-cycling towns for all the scenarios. Rationale for these differences has been discussed in Section 6.3.3.

The comparison between cycling and non-cycling towns considering the different scenarios, indicates that the model provides generally sound estimations of changes in demand. It should be noted that a comparison between estimated demand and actual demand (in the future) can provide interesting results and help to strengthen the model. This was not conducted in this thesis as changes from the considered scenarios are not yet implemented and due to household data being available only for the two areas under study and for one-time period

Moreover, in Table 6.6, the current number of trip-stages and the corresponding percentage of the overall sample are given. In addition, the estimated changes in demand for all the considered scenarios is given. Positive percentages indicate demand increase and negative percentages indicate demand decrease. The table confirms that S3 yields the highest demand increase for active modes of transport, presenting a potential increase in walking rates of 5%, cycling rates of 107%, and PMD rates of over 800%, with most of these shifts being from private modes of transport.

Table 6.6. Projected changes in demand by mode of transport for the different scenarios

Modes of transport	Current number of trip-stages	Projected changes in demand		
		S1	S2	S3
Walk	5058 (54%)	4%	0%	5%
Cycle	175 (2%)	83%	1%	107%
PMD	47 (1%)	687%	62%	868%
Public bus	985 (11%)	1%	-2%	0%
MRT	1555 (17%)	-19%	2%	-23%
Other buses	563 (6%)	3%	1%	-1%
Taxi	439 (5%)	-21%	3%	-37%
Private vehicles	494 (5%)	-56%	-12%	-60%

It must be noted that while several motorised trip-stages did shift to walking (as previously mentioned), the percentage of increased demand is low. This is due to the high initial number of walking trips in the current data. However, for trip-stages by PMD an opposite trend can be observed as the increase in demand is very high for all scenarios. This is explained due to the low number of PMD trips in the current data, hence, even a small increase translates to a high percentage.

6.4. Trip-stage distribution and path choice

As in previous steps, for distribution and network assignment steps, analyses were made for each trip-stage instead of the traditional full-trip, yet these were only concerned with walking, cycling and riding PMDs. In this research, the distribution step was developed using a gravity model as described in Section 3.3.3. Although behavioural factors were directly included in the step, this was done to gain a better understanding of how the reported active trip-stages were distributed through the different TAZs and estimate active trips attractiveness of each TAZ. Outcomes of trip-stage distribution are O-D matrices presenting the active trip-stage rates from one TAZ to another. Due to the large number of TAZs, the full distribution matrices present an extensive number of O-D pairs making them hard to be presented in full. A sample O-D matrix is presented in Table 6.7 for general illustrations purposes.

Table 6.7. Sample O-D matrix for active trips for Yishun town

		Destinations						
		TAZ1	TAZ2	TAZ3	TAZ4	TAZ5	...	TAZ38
Origins	TAZ1	0	5	0	5	8	...	18
	TAZ2	3	0	0	5	8	...	10
	TAZ3	0	0	0	0	0	...	0
	TAZ4	6	11	0	0	100	...	46
	TAZ5	9	17	0	106	0	...	105
	...	...	...	...	...	...	0	18
	TAZ38	14	14	0	32	69	...	0

Traditional approach of grossing-up number of trips is based on percentage of population being sampled to account for 100% of the population. The approach is selected as the aim of this step (in the current research) is to understand travelling characteristics of the current (interviewed) data sample and not to derive conclusions for planning, network assignment or demand estimation based on findings from this step.

More specifically, the proportion of sampled HDB households was close to 0.8% of the overall HDB household population in the study towns, thus, the numbers of trip-stages generated (with origin and/or destination within the towns) were also assumed to be about 0.8%. Simplest alternative to have an estimation of the overall trips/trip-stages (with origin and/or destination within the towns) made by the population would be to scale trips/trip-stages rates by a factor of 125. Indeed, this is the most common approach utilised by researchers and the grossing-up procedure usually occurs at the trip generation step for demand analysis. While the procedure is suitable when working at overall

town level, once the town is divided into TAZs, grossing up trips/trip-stages rates in different TAZs by the same factor can lead to inaccurate results.

Using data from the 0.8% of the HDB household population in the towns, no trips/trip-stages were recorded for some of the TAZs, thus, resulting in zero (0) production/attraction rates for the current scenario (survey data), such as TAZ3 in Table 6.6. TAZs with zero rates will remain zero in the future. Although “zero-rate-TAZs” were aimed to be avoided, with the delineation of TAZs (at initial stages of the 4SM development) considering a good representation of developments that are considered generators and attractors, this is a common issue when dealing with sample data rather than overall population data (Ortúzar & Willumsen, 2011; Rasouli, 2013). As an option to predicting trips/trip-stages generation rates, the zero cells can be “seeded” with a value (e.g. trip rates) based on rates of similar zones (distribution of trips/trip-stages as a function of the trips/trip-stages from a TAZ similar to the “zero-rate-TAZ” to and from every other TAZ – similar to category analysis). Herein, the resulting matrix would be dependent on the input assumptions (Ortúzar & Willumsen, 2011). Alternatively, sampling rates of each TAZ can be analysed and the gross-up factor be dynamically modified so that trips/trip-stages rates at each TAZ are normalised to the overall population level.

Information from O-D matrices are of most interest for planning the transport network system. For instance, using trip rates for one TAZ to another, practitioners can judge suitability of implementing new paths/roads in certain areas based. The information can also be used to prioritise development or enhancement of paths/roads closer to TAZs with higher trip-rates. Trip rates can be included into spatial intelligent models to determine areas of the transport network that need prioritisation (Poyil et al., 2017). Traditionally, information from trip distribution is also utilised for the development of mode choice and as guidelines for network assignment considering the number of trips/trip-stages generated and attracted from different TAZs, however, as in the current 4SM actual trips O-D locations, rather than information obtained from TAZs’ O-D matrices, are utilised.

Finally, regarding the network assignment step, trip-stages made by walking, cycling, and PMDs were assigned to the off-road (formal) pathway network. As mentioned, the existing active mobility network was thoroughly tested for connectivity for accurate utilisation of shortest path analysis. Different paths between origins and destinations were identified and shortest path was selected through optimisation of various combinations of distances between nodes or inter-links within the path network using a customised Network Routing tool in ArcGIS. Number of trips in each path was then computed to estimate usage of the network as shown in Figure 6.11 and 6.12.

For visualisation purposes, traffic flow was mapped utilising different colours, where:

- Lowest active mobility flow is presented in dark green;
- Low active mobility flow is presented in light green;
- Medium active mobility flow is presented in yellow;
- Medium-high active mobility flow is presented in orange; and
- Highest active mobility flow is presented in red.

Actual number of trip-stages (i.e. pedestrians or cyclists making use of each segment – rather than percentiles) was utilised for better representation of the usage. Each of the network assignment maps presented in the Figures has the related legend regarding the traffic per colour code. It can be seen that active mobility flow gets higher near to MRT stations and decreases as distance from MRT increases. This is to be expected due to high number trip-stages walking, cycling, and riding PMDs that have MRT stations as origin/destination. Paths with highest active mobility flow are likely to be those connecting to food-courts, markets, or other shopping locations in the neighbourhood.

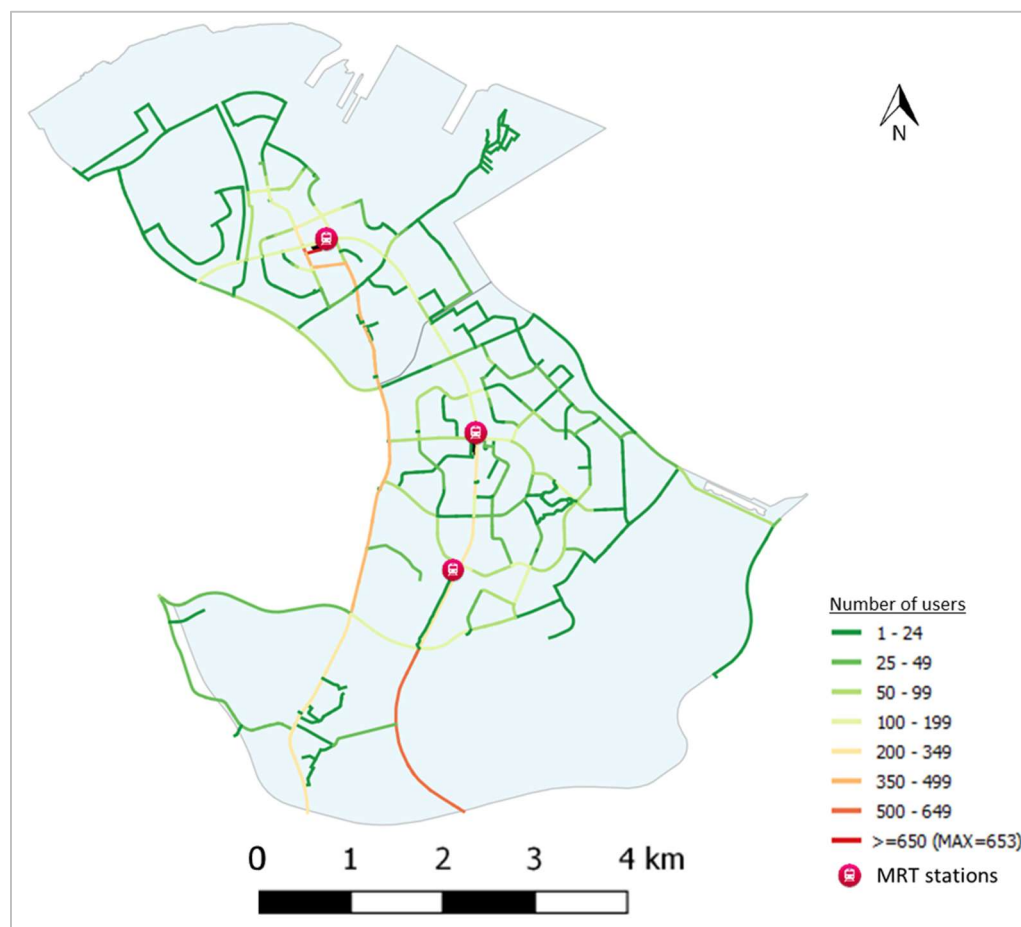


Figure 6.11. Usage of the active mobility network for current scenario – Cycling towns

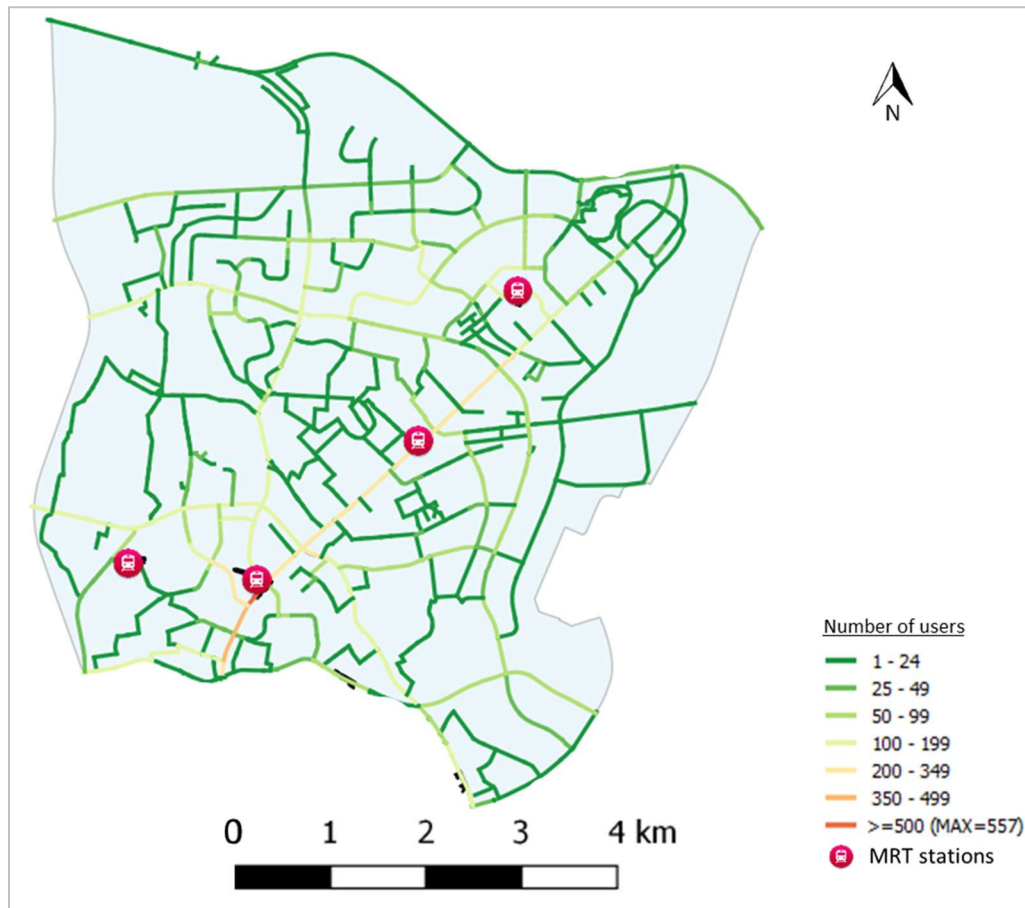


Figure 6.12. Usage of the active mobility network for current scenario – Non-cycling towns

It must be noted that the utilised approach will yield most precise results when working on population level (e.g. Census that collects travel data, electronic travel diaries collecting data at population level, mapping big-data, etc.), either of an area or the whole country. When working at population level, the usage of the network will be properly reflected, and planners can directly use the outcome for enhancement of the network or development of programmes/policies. For this thesis, data collected represents close to 1% of the population, while the trip rates have been grossed up to reach the 100% level, and it is expected that usage of the network varies as people can choose different origins/destinations for their trips.

Scheme recommendations to enhance trip comfort and level of safety for active trips/trip-stages should be mainly focused on areas with high active mobility flow. Based on traffic flow, capacity of the network can be tested to estimate if paths are acceptable under current operating conditions, require upgrade (i.e. widening), or even if provision of additional lane is required. Same network assignment procedure can be repeated for trips for different scenarios, by mode of transport, and/or by time of the day. This allows planners and practitioners to audit (current/future) usage of the network and estimate possible enhancements or modifications.

6.5. **Chapter summary**

This chapter presented findings that are related to travel demand analysis. First, characteristics of the sample (1,119 HDB households – 0.8% of population, 2,115 household members who reported trips/from whom trips were reported, 5,065 trips, and 9,316 trip-stages) are introduced and characteristics of the households/members are compared with Singapore's overall population whenever applicable. Following this, usage and development of the modified 4SM was presented, in which the main interest of this research study was placed on demand analysis at mode choice step while the remaining steps of the model were considered to gain an overall view of the trip-stages distribution and the usage of the network.

Modifications were introduced to the 4SM by analysing mode choice as the second step (instead of as a third as in the traditional procedure), this allowed for a more accurate inclusion of behavioural factors to estimate demand for the different modes of transport, mainly for active modes as is the main interest in this thesis. For the mode choice analysis, the author developed a neural network model to estimate demand based on current scenario (survey data) and for three other scenarios (based on modified input components). For training the network, Bayesian regularisation training approach was utilised, with 28 input variables, 3 hidden layers, and 28 nodes per layer. The model training yielded a good fit as observed from the good coefficient of correlation between the outputs and targets ($R < 0.96$ – for all scenarios) and small error span (-2 to 2 – being normally distributed around the mean for training and evaluation scenarios).

The use of neural network model in the mode choice allowed consideration of different (hypothetical) future scenarios and estimate changes in demand for active modes based on them. This is useful for re-evaluation of existent network, in brown-field developments which are common in Singapore. While still possible, these have been difficult and/or less accurate if trips were clustered into different TAZs as commonly done in the traditional 4SM. The same procedure could be extended for applications to different contexts by simple modification of variables.

Besides current scenario, three other scenarios were considered, and travel demand changes were estimated. Regarding modifications of scenarios, the thesis provides an overview of the many capabilities of neural network models. In the international context, after the neural network model has been calibrated accordingly, the context and future plans should be audited to determine possible future changes. These changes can then be incorporated as different scenarios into the model by simple modification of variables. Predictions of the developed model suggests that soft approaches

such as policies implementations have higher positive impacts in increasing usage of active modes of transport. Locally, this can be considered for prioritising invested in such schemes prior to investment on changes in the built-environment. International practitioners can take this into consideration for comparison with other countries, effects of similar policies (as those considered in this thesis) can be modelled into the local (international) context to compare/contrast findings and predicted changes in demand.

The procedure also affirms the usefulness of neural network model in predicting demand for different modes of transport. As the usage of this technique is quickly gaining popularity in several fields (G. Hinton & Salakhutdinov, 2006), it is important to incorporate such technique in the transport field with focus on active travelling. It can be incorporated by researchers and planners to test multivariable modifications for different (future) scenarios. In addition, the effect of each modification can be weighted to identify the ones with the most impact and thereby maximise resources for implementation of key/crucial modifications. It must be noted that the neural network model utilised in this research was trained fairly accurately due to a relatively high sample size. The accuracy of predictions can be further improved by further increasing number of reported trip-stages (9,316 trip-stages) (Hinton et al., 2006). Thus, the initial investment in collection of quality data shall be considered. Alternatively, the usage of big data or other alternatives to collect data from a relatively big sample size should be considered.

Furthermore, to give a complete picture of the distribution of active trips/trip-stages and usage of the active mobility network, O-D matrixes were constructed based on the trip-stages originated and attracted to each TAZ within the towns under study. The trip-stages origin and destination geo-coding technique utilised in this thesis is also of added value as it automatically analyses respondents information (which can be varied) to provide accurate geographic location and information on accessibility to nearby transport stations. It could be considered to include this tool into surveys to automate (and increase accuracy of) data recording from trips origins and destination.

Finally, the network assignment was performed using each trip stage origin and destination locations rather than clustering the trips at TAZ level. Benefits and limitations of such approach are discussed accordingly. The routing tool utilised in the thesis (for representation of usage of the transport network by active mobility users) is also interesting and of easy application. The tool can be utilised in different contexts in Singapore and the network layer (i.e. available paths for commuting) can be easily modified for including new paths and completely changed for other countries geocoded networks.

Chapter 7. Conclusions

In this concluding Chapter, the main points are highlighted and discussed. First, the key points of the research, including objectives and significance, are summarised. Then the utilised methodology is reviewed highlighting novelty approaches, this is followed by articulation of principal findings of each of the studies conducted.

Academic novelty of findings or “knowledge creation” is elaborated. Furthermore, real applications of the methods and findings utilised in this thesis are discussed. In the same line, limitations of the studies and how these can be addressed are presented. Measures to overcome limitations and the consideration of other techniques are discussed as part of the future work that concludes the thesis.

7.1. About the research

In Singapore, travelling characteristics and travel behaviour are changing rapidly in the quest for sustainable lifestyles. People are shifting to active modes of transport and modifying their trip characteristics. This calls for a review of currently established “quality needs”, frameworks describing travel behaviour, and travel demand analysis methods. These issues are reviewed in this thesis and innovative techniques to address/improve on them are suggested. The main interest is placed in the burgeoning population of pedestrians and cyclists, while PMD riders are included only to some extent, in the country and the unique active traffic setting in Singapore, where pedestrians and cyclists commonly share off-road travelling facilities.

Based on travel quality needs and literature review, factors that affect travel behaviour and related decisions are delineated. The relationship among different factors are presented conceptually as a set of models that delineates travel behaviour and travel-related decisions. This is encompassed under the “process and determinants of mobility decisions” or PDMD framework for short. This is then utilised for innovative demand analysis using neural network models and empirical travel data.

7.2. Research methodology

The thesis findings are presented in three main chapters, Chapters 4, 5 and 6 and the methodology for each is presented in Chapter 3 which are summarised in this section. Each study was specially designed for obtaining quality data/information regarding travel characteristics, travel behaviour and travel demand analysis. Techniques undertaken include intercept surveys (using qualitative and

quantitative methods), observational studies, household survey interviews, and statistical as well as computational intelligence – neural network models.

For understanding and meeting travel quality needs of different mobility users in Singapore, three studies were conducted. For each study, different methods were selected (due to the different nature of the issues studied) as follow:

- The first study, which was concerned with examining active travelling characteristics in Singapore, utilised observational studies and street intercept surveys. The study was conducted in two cycling towns in Singapore, Sembawang and Yishun, and a sample of 202 participants was analysed.
- The second study, concerned with understanding usage of the active transport network in Singapore, utilised data collected using intercept survey interview from a total of 277 respondents. The survey questionnaire comprised quantitative and qualitative questions. For quantitative data, descriptive statistics analysis was conducted and, where applicable, T-tests were run to test different characteristics of subgroups within the sample. Qualitative data was analysed using grounded theory (GT) approach.
- The third study reviewed attitudes towards active mobility in Singapore using in-depth qualitative interviews. Focus-groups and one-to-one interviews were conducted and data from 46 participants was analysed. GT approach was also used and SWOT tables regarding walking and cycling were compiled.

For developing a unifying mobility framework – presented as the PDMD framework, findings regarding quality needs from previous stages were combined with a comprehensive review of the available theories (mostly in English language domain, with some in Spanish) that describe and/or can be applied to travel behaviour. Different factors that affect travelling were highlighted and their relationship presented in a holistic framework that can be applied for different modes of transport and travel-related decisions. The developed framework was constructed based on an extensive search and audit of published literature regarding travel behaviour. Those that are related or can be closely applied to travel decision-making were selected.

The theory of travel decision-making presented by Singleton (2013), and the PASTA framework by Götschi et al. (2017), were utilised as main guidelines for building the PDMD framework. Herein, the potential of value-add areas was highlighted, and components of previously posted theories/frameworks were adjusted to capture variations across different/contrasting contexts (e.g.

considering different/contrasting contexts and giving descriptive examples when possible). Then, the PDMD framework was utilised to develop a refined household travel survey questionnaire with specific questions to capture characteristics of active trips. The questionnaire was utilised to collect travel data for the demand analysis study.

To model travel demand, first characteristics of the household travel survey sample are investigated, and comparison between households from cycling and non-cycling towns are made. The traditional 4SM was modified by mode choice analysis being developed right after generation step, and not after distribution step as in the traditional approach. Furthermore, for a more accurate modelling of trips/trip-stages characteristics, the origin and destination for each trip-stage were considered (over full-trips only). This modification also allowed for a good representation of active trip-stages through the study towns and the transport network. Main interest of this research is on travel demand analysis concerning active modes of transport under different scenarios (i.e. to understand changes in demand based on factors that would increase active mobility). Thus, most discussion and analysis were focused on the 2nd step (mode choice) of the modified 4SM while remaining steps were also considered to gain an overview of the transport network usage.

For the mode choice, computer intelligent neural networks were utilised, instead of traditional statistical methods, which can include partial relationship among explanatory variables, and account for non-linear relationship. Neural network models also allow for easy modification of variables for testing of possible future scenarios. This was tested in this thesis using 3 different scenarios and demand for different modes of transport per scenario was estimated and compared. Findings from the model can be used for re-evaluation of existent network, in brown-field developments which are common in Singapore. For green-field developments (e.g. development of new towns), certain information might not be available requiring re-training and validation of a neural network model based on available data.

For training the neural network model, Bayesian regularisation training approach was utilised, with 28 input components (variables), 3 hidden layers, and 28 nodes or neurones per layer. Network was trained based on current scenario (survey data). Travel data from 1,119 households comprising 5,065 trips and 9,316 trip-stages, evenly distributed in 4 residential towns in Singapore (Sembawang, Yishun, Serangoon and Hougang) was utilised, which was collected using the developed survey questionnaire and comprehensive household selection approach to ensure randomisation and representation of the overall population.

Input variables of the neural network model were modified, and trained model was re-run yielding the changes in travel demand for different scenarios. The main interest in model development was placed on active trips/trip-stages. After mode choice step, trip-stage were distributed across different TAZs in the study towns and the usage of the network was analysed.

7.3. Findings and discussion

Each study presented a small discussion related to all findings in the study and how these affects active travelling, travel behaviour and/or demand analysis. In this section, only the most relevant findings are presented and discussed. These are selected as being deemed of most interest and application to local and international academics and transport planners/decision-makers.

7.3.1. Understanding and meeting travel quality needs

As mentioned, three studies were conducted to understand quality needs. In general, the 1st study found that infrastructure provision has a positive influence in increasing active trips and that perception of the infrastructure as well as other personal factors influence decision to walk and cycle. Interestingly, while safety was mentioned by some participants, this was not described as main reason to walk and cycle (or not). More specifically, residents of cycling town reported to be aware of the infrastructure provision for active mobility users however the opposite was true for frequent visitors. This suggests that more can be done to promote these facilities. Some of the measures proposed by the author include enhancing pathway marking and provision of traffic signals that indicate provision of facilities and convenience of walking and cycling.

Moreover, although participants of the survey in the 1st study reported not to have changed their usage of public transport and walking, a lower usage of private transport and an increased usage of bicycles was reported, and majority were shifted from walking, which did not experience a usage rate drop. This could be an indication that new walking trips have also being generated. Based on these findings, it is suggested to develop programmes and policies aimed to promote walking and cycling trips/trip-stages and highlighting benefits and convenience of each of these modes of transport. The study also found that pedestrians who were considering cycling in the future and cyclists who reported to cycle more after the implementation of segregated paths, mentioned the same reasons for doing so (i.e. convenience, save money and health/social benefits). This further strengthen the author's recommendation to develop programmes that are specifically dedicated to each type of active mobility user.

Findings from this 1st study, including the different factors that encourage cycling and the use of other active modes, have been taken into consideration in the development of the PDMD framework to ensure that interrelations between different modes and impacts of infrastructure are taken into consideration.

As part of the 2nd study, preferences towards 6 travel facilities that form part of the formal transport network in Singapore, were studied. Overall, participants prefer off-road commuting spaces for walking and cycling alike and, interestingly, it was found that participants prefer (off-road) delineated paths for mobility, even over segregated cycling and walking paths. This type of path was selected due to dynamic use of space that allows users to easily encroach on adjacent paths, especially as the proportions of user groups vary spatially and temporally, with dominantly more pedestrians during certain times and vice versa. Participants also highlighted that these paths are commonly provided with good marking thereby ensuring that right of way is properly defined. This indicated markings and signals are appreciated (well received) by active mobility users and shall be considered by planners as a suitable scheme to improve overall trip experience and safety, and yet maximising land space. This finding, and its possible application, is interesting for countries/cities such as Singapore that are very densely developed and has limited land space.

Moreover, relatively few conflicts with other users were mentioned in the survey, which could be due to increased acceptance of “sharing” of off-road mobility facilities. Also, the provision of bicycle-sharing scheme, in combination with infrastructural improvements, is associated with a rapid increase in cycling demand in the recent year. Interestingly, many of these “new cyclists” reported to cycle for transport and not only for recreation. Planners shall thus consider the elevated active travel demand to ensure a high level of service in active mobility facilities. In general, male and female respondents presented similar responses and preferences; however, it should be noted that most respondents were young and mature adults. While these groups are the main users of active modes, their responses might be different from those of elders or children. Longitudinal studies will be of interest to understand how current (young) adult generation behave into their elder-hood in the realm of active mobility.

Finally, based on data analysis from the 3rd study, attitudes towards walking and cycling in Singapore were found to be different. While walking was described as a safe and somehow convenient “mode of transport” but the distance and travelling limitations reduce its attractiveness. Cycling was perceived as an enjoyable “activity” and most of the limitations can be addressed within the provision of infrastructures, facilities, or policies. Users expressed their willingness-to-shift from motorised

modes to active modes of transport given certain infrastructural and/or policies modification. Potential-shift to cycling was more commonly reported than potential-shift to walking. This again indicated the increasing acceptance of this mode of transport. Most of the safety concerns were shared among pedestrians and cyclists. The most common conflicts were perceived lack of respect from other users at facilities shared between pedestrians and cyclists. This was more commonly discussed by cyclists as in some cases they are still being “rejected by other users” from cycling on-road as well as off-roads. Participants agreed that most of these conflicts can be reduced with wider and demarcated walking and cycling spaces, clearer signals, and intensive education and courtesy campaigns.

Findings from these studies can be utilised by policy makers and practitioners to make better informed transport-centric decision, thereby contributing towards healthy and vibrant lifestyle through greater walking and cycling activities. Several schemes that are currently being implemented overseas can facilitate to increase the usage of walking and cycling as strong modes of transport. As mentioned by the participants, these schemes should not only come from transportation authorities, but it should rather be collaboration between all authorities and stakeholders. It is also important to understand that different users have different travel behaviour and needs. Future planning for active mobility, in Singapore and internationally, shall consider the mixed-traffic scheme and dynamic sharing of facilities as a suitable design option to enhance active travelling experience. Policies shall not only focus on desirable usage of specific facilities but also in quality features that can enhance sharing of facilities and thus increase trip safety.

7.3.2. Unifying mobility framework and survey instruments

A holistic and dynamic travel behaviour framework has been developed explaining process and determinants of mobility decisions. Understanding that travel behaviour cannot be simply explained by one area of expertise. The PDMD framework combines crucial points from psychology, geography and even economy disciplines, which use as well as descriptive models. In the same vein, a lexicon of terms was collated to enhance communication between the different disciplines. Then, using this framework as a guideline, a survey instrument aimed to record household, individual, and trips characteristics was developed. PDMD framework and survey characteristics, as well as modifications to implement them in different local contexts are duly presented and discussed.

For the framework development, a total of 27 previously published theories/frameworks from different disciplines were thoughtfully audited. Features of contrasting contexts were considered to include possible applications of the framework to different contexts, which was found to be lacking or not so

widely discussed in previously developed travel behaviour frameworks/theories. Two mayor divisions are presented in the framework: (1) the process, that conceptualises what generates activity and trip demand, introducing the “need for physical presence” as the key factor for demand generation, and (2) the determinants, that describes what factors affect different travel-decisions and how individuals assess and possibly choose different and available transport/travel options.

For the determinants, different options and possible limitations and/or requirements that are considered when taking travelling decisions are described, as well as how these vary if the travel decision is being taken for individuals, for others and/or for group travelling. Also, the PDMD framework proposes that individuals also considered to maximise their time and hence consider possible trip-chains. Psychological factors, instead of actual ones, exert greater influence in decisions. At some stages of the framework, contrasting examples of Singapore and a city of a developing country, i.e. Asunción, were given as means of highlighting possible applications of the framework and alternatives to testify validity of the PDMD framework components/sub-components.

The development of the survey questionnaire and its characteristics were described in detail, highlighting questions in each section and aims of each of them. The author also indicated uses and possible modifications of the survey for it to be applied in different contexts. The proposed PDMD framework can be used to: (1) estimate the importance of service improvement from users' perception; and (2) develop transport schemes, infrastructures, and policies, aimed to increase the usage of green and sustainable modes of transport such as active modes. The survey questionnaire can be used in different context to examine and record users' travel characteristics and develop transport models and plans accordingly.

7.3.3. Travel demand analysis

For travel demand analysis, data from 1,119 HDB households, 2,115 individuals, 5,065 trips and 9,316 trip-stages, was analysed. The proportion of sampled HDB households was close to 0.8% of the overall HDB household population in the study towns. Some differences were found between data from cycling and non-cycling towns. For instance, significantly more ($p < 0.001$) active trips/trip-stages were reported at cycling towns, active trip stages (of multi-modal trips) were found to be slightly longer in cycling towns (10mins on average) as compared to non-cycling towns (7mins on average). In addition, more HBM trips and less NHB trips being made at non-cycling towns and many trips were reported to be made with less frequency at cycling towns. These differences are expected due to the nature of the towns and the different infrastructure provision.

For the travel demand analysis, a modified version of the 4SM was utilised. Instead of the traditional approach of considering generation, followed by distribution, mode choice and network assignment, mode choice analysis was performed right after the generation step and changes in demand was measured at the mode choice step. In addition, instead of considering only full-trips' origins and destinations, the origin and destination for each trip-stage was considered for a better representation of active trip-stages. Main interest was placed in this step while the remaining steps of the model were considered to gain an overall view of the trip-stage distribution and the usage of the network. The modification of the procedure allowed the researcher to include features from the trip generation step as inputs for the mode choice model and have a clearer representation of active trip-stages across the TAZs and in the transport network, within each town.

Regarding trip generation, the number of trip-stages was found to be higher at TAZs closer to MRT stations. Also, the production and attraction rates for each TAZ were found to be quite similar, which is due to the nature of the survey. In using travel diaries over a 24-hour period for household interview travel survey (as in the current research study), almost every trip shall have a return trip, thus origins and destinations are "repeated inversely". The small variation in productions and attractions can be explained by some trip chaining behaviour.

For mode choice model, the author developed a neural network model to estimate demand based on current scenario (survey data) and for three other scenarios (based on modified input components). Variables that have effect in all members of the household were selected as the input components and taking into consideration the PDMD framework. The model training yielded a good fit as observed from the good coefficient of correlation between the output targets and predicted outcomes ($R=0.96$) and small error span (-2 to 2) being normally distributed around the mean. Besides the current scenario, three other scenarios were considered, and travel demand changes were estimated and compared.

The considered S1 (policies/programmes alone) presented more positive outcomes in increasing active modes of transport as compared to S2 (macro-level modifications to the built-environment alone), specially for non-cycling towns. Scenario 1 also presented a big reduction in the number of trip-stages by private vehicles. On the other hand, S2 showed a positive influence in reducing number of trip-stages by private motorised vehicles, yet most of these are then made by public transport modes (mainly MRT) and only few by active modes (mostly by riding PMDs). When combining S1 and S2 (i.e., S3), most positive findings were seen in respect to increasing usage of active modes of transport and reducing usage of private motorised vehicles for certain trip-stages.

This thesis provides an overview of the many capabilities of neural network models for scenarios modifications, and the usage of the neural network model allows to gain better understanding of the dynamics of mode choice (i.e. factors that would increase demand for active mobility and thus decrease demand for other modes). This information is of interest for re-evaluation of existent mobility network in the different towns. Re-evaluation and improvement of the network in brown-field developments are very common in Singapore in the quest for a “car-lite” nation. The same procedure could be extended for applications to different contexts by simple modification of variables. Yet, careful consideration must be given to transferability of the neural network mode choice model, whereby in cases of green-field development (e. g. planning and development of a new town) some of the variable considered might not be available. In such cases re-training and validation of a neural network model based on available data may be required.

Using this technique, researchers and planners can test multivariable modifications for different scenarios, which, while still possible would be of greater difficulty using traditional demand models. The effect of each modification can be weighted to identify the ones with the most impact and thereby maximise resources for implementation of key/crucial modifications. Using the appropriate grossing-up approach and in cases where sufficient data is available to train neural network models based on overall population, the modified 4SM could be scaled-up for re-evaluating the whole town existing transport network.

The trip-stage distribution step served to visualise how active trip-stages were distributed across the TAZs, and a set of O-D matrices was created and trip-stage rates from one TAZ to another was identified, within the towns under study. Traditional approach of grossing-up trips/trip-stages rates by the same gross-up factor – 0.8% sampled population was grossed up to 100% taking a factor of 125 – to estimate the trips/trip-stages rates from the overall population was utilised. This approach is selected since the goal of this step was to gain understanding of how trips/trip-stages made by the interviewed sampled are distributed (rather than to derive conclusions for planning, network assignment or demand estimation as per traditional approach). Noticing that this method has limitations, other approaches to modify gross-up factors (which might be more applicable when working at TAZ level) are discussed. The trip-stages origin and destination geo-coding technique utilised in this thesis is also of added value as it automatically analyses respondents information (which can be varied) to provide accurate geographic location and information on accessibility to nearby transport stations. It could be considered to include this tool into surveys to automate (and increase accuracy of) data recording from trips origins and destination.

Then in the network assignment or path choice step, trip-stages made by walking, cycling, and PMDs in the current and modified scenarios were assigned to the off-road (formal) pathway network using the shortest path algorithm. These were mapped for visualisation and different areas of the network were coded by percentile of active traffic flow. The routing tool utilised in the thesis is also interesting and of easy application. The tool can be utilised in different areas of Singapore and the network layer (i.e. available paths for commuting) can be easily modified for including new paths and/or completely changed for other countries networks.

7.4. **Limitations and recommendations for future work**

This thesis addresses several gaps identified in the literature and common practices for transport analysis. The research, that was assembled using information from exhaustive reviews, theory development, and empirical data (quantitative and qualitative) collected in the field, considers and analyses the overall situation and needs of different active trips as well as the trip makers. Mobility models were utilised in a novel way for demand analysis suggesting and testing modifications to the traditional transport tools. While these are of aid to researchers and planners to develop measures to cope with needs of populations and emerging modes of transport, there are some limitations to the study and the study can be further enhanced by future work (which will be continued to be explored by the author).

The author has introduced neural network models into traditional demand analysis and forecasting tools for demand analysis. Research can continue to explore capabilities and training methods of neural network models and these can be compared with statistical models with the ultimate goal being the development of outstanding measures to address transport planning and managing questions considering emerging modes of transport and intrinsic people travel behaviour, and optimising travel characteristics. A limitation regarding the selected approach is that the only feature being considered regarding trip-chains is the characteristics of the preceding and following trip(s). This aspect will continue to be explored to comprehensively incorporate not only trip-chains but also tours (sequence of linked trips starting and ending at the same point) into the demand analysis, which can further improve the accuracy of predicted demand. Also, as it has been mentioned, characteristics on the data limited the possibility of developing complex intra-household decision-making models. Instead, only some characteristics of the households were included as some of the neural network training inputs. This aspect will be explored by the author in the future to develop models that can account for the decision-making process so that these could be comprehensively incorporated into the demand analysis.

Another limitation is regarding the methodology utilised for network assignment, which is based only on shortest path. For network assignment or road choice, other factors besides shortest distance (e.g. path characteristics, pedestrian/cyclist density, derived positive utility, etc.) can also affect route choice selection and these can provide a deeper understanding of the network usage. These factors are modelled as means of route choice models. The development of robust road choice models requires a specific set of skills and data. Indeed, much international transport research is focusing on collecting and analysing big data regarding actual travel paths to develop route choice models. In route choice models, several factors are taken into consideration to understand and predict route choice selection. Given the multiple number of variables considered and the vast amounts of data required, computer intelligent algorithms are mainly utilised. Indeed, capabilities of neural networks for trip/trip-stage distribution by the means of destination choice models and for network assignment (road/path choice models) can be explored and established.

Finally, regarding the demand analysis, it should be noted that an in-depth comparison of travel demand at different areas of Singapore can yield very interesting findings and help to validate reliability of the model. For instance, similar methodology could be applied to other areas (locally or international) and the trends compared. This will also help to shed light into the differences among users in different contexts. In addition, the study could continue to compare estimated demand with actual demand (in the future) and this could then be used to review the current methodology and enhance the model so that future demand could be estimated with a higher degree of accuracy.

Moreover, future work can also focus on enhancing the “PDMD framework” related lexicon by incorporating terms utilised in different countries and studies. This can help to unify definitions regarding travel behaviour (across different fields) and establish patterns that are inherent to transport-related decision. In addition, the study on quality needs (which has been used for the PDMD framework development) should be constantly reviewed and updated as travel behaviour factors that are affected by policies, programmes and/or the built-environment are constantly changing based on changes in the individuals. In this regard, longitudinal studies could be conducted to capture changes in travel behaviour factors based on implemented policies, programmes and/or the built-environment as well as individual development (e.g. life stages).

There are some other aspects that are not covered by this research yet can provide interesting findings. For instance, usage of PMDs was included only in the general sense. This was due to the population of these users being not (yet) big enough to draw statistically sound conclusions for some of the studies. Yet, as the PMD usage trend is likely to keep increasing, inclusion of PMD riders as a

group of its own can provide interesting views regarding their preferences for travelling spaces as well as interaction with other users.

The quality needs of PMD riders would also have some effect on planning for active modes of transport. In addition, the present research is mainly focused on analysing mobility based on the formal transport network. However as more and more users are utilising informal spaces – especially in Singapore context, such as void decks and green areas to move/commute, it shall be interesting to study the spatial distribution of trips and how the informal network affect travel behaviour and demand for different modes of transport. Finally, different studies of the thesis, including demand analysis have (mostly) been performed considering normal weather conditions. To study changes in travel behaviour in accordance to changes in weather shall also provide interesting points for consideration for transport analysis and planning.

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Appendix A – Active mobility spaces in Singapore

This appendix presents an overview of different spaces, in Singapore's urban planning, that are utilised by active mobility users in Singapore. These are components of a manuscript under review for *Habitat International* journal platform (Rojas López & Wong, 2018a).

Active mobility users and types of mobility network/spaces

Pathways in Singapore are heavily used by pedestrians, and riders of bicycles and Personal Mobility Devices (PMDs – e.g. kick-scooter, hover-boards, unicycles), as depicted in Figure A1. Pedestrians walk for transport and to run errands, with Singapore being ranked multiple times as one the most walkable places in the world (CLC, 2018; Nguyen et al., 2015), with the walking mode share at 22% as a main mode of trip-making (LTA, 2011). Cyclists' characteristics are quite different as, after a phase of unpopularity and under usage (1970s to 2000s), cycling is now re-emerging vigorously (Koh & Wong, 2012, 2015). The cycling mode share equals 2% as a main mode of trip-making (Cheong, 2016), with some cycling for transport and to run errands (utilitarian cyclists), and others doing it for recreation (recreational cyclists). PMD riders can be said to be a new variable adding to the already complicated transport planning equation. Herein, the “new” PMD and attendant travel behaviour is an area yet to be much analysed.



Figure A1. Active mobility users travelling on off-road facility (formal network)

Several programmes and services are being implemented to enhance trip comfort and safety, so as to further increase walking and cycling rates (Active Mobility Advisory Panel, 2016). Examples are safe riding programme, walk-cycle-ride, and the introduction of dock-less bicycle-sharing systems since 2016. Today, several companies offer such services where bicycles are rented using mobile phone Apps, and these are available all over the country (Abdullah, 2017; Lim, 2017b). The number of rental bicycles is rising rapidly, and by early 2018, over 100,000 units are registered (Abdullah, 2018; Lim, 2018a). Although the high growth rates have a positive effect in elevating the usage of bicycles, development of cycling infrastructure is progressing at a slower pace. This can be seen in the way people leave the bicycles “parked” haphazardly at random locations and even obstructing pedestrians’ rights-of-way (Hong, 2017; Tan, 2017) which is partly due to under-provision of parking spaces. To tackle this situation, one scheme consists of virtual bicycle parking stations that are demarcated by geo-fenced perimeters (Hong, 2017). This scheme is being implemented nationwide by mid-2018 (Ng, 2018).

Facilities for active mobility users are being expanded taking into consideration the usage of the transport network as gleaned from public consultations and feedbacks by means of online surveys and other programmes (Lim, 2018b). An extensive network of pathways is being built up, and developers are required to provide facilities to enhance safety and provide accessibility to residences, shopping areas, and public transport stations (URA, 2013, 2016). Pathways, crossings and overhead bridges are common infrastructure. Shelters are also provided at areas with high levels of active mobility users (Chin & Menon, 2015). At recreational places, pathways are provided for active mobility user movement (NParks, 2016c; Tanuwidjaja, 2011). Moreover, pedestrians, cyclists, and PMD riders have been observed utilising the void decks under the public housing blocks as thoroughfare to reach nearby locations and/or public transport stations. The various facilities can be judiciously classified as formal mobility network, informal mobility network, and recreational mobility network, which are respectively described in the following sections.

Formal mobility network

Most active mobility activity takes place off-road, thus, pedestrians, cyclists, and PMD riders commonly share the mobility facilities. This was not always the setting in Singapore since previously (until late 2016), cyclists were only legally allowed on pathways at a few “cycling towns”, while elsewhere they were supposed to cycle on-road. However, considering the safety concerns in sharing space with motorised users and the ever-increasing number of cyclists and PMDs using off-road pathways, a review was convened to amend usage regulations and update urban plans. Today, a

set of rules and codes of conduct for usage of bicycles (including electric bicycles) and PMDs on pathways have been implemented. Bicycle and PMD riders can now travel alongside pedestrians at a maximum speed limit of 15km/h at shared footpaths, and 25km/h at active mobility device channel of dual-channel pathways (Active Mobility Advisory Panel, 2016). Other recommendations pertaining to the sharing of mobility spaces include rights-of-way, consideration for other users and movement direction (Active Mobility Advisory Panel, 2016). These rules and codes of conduct are aimed to increase safety and reduce conflicts among the mixed multimodal traffic.

As the number of active mobility users increases rapidly, authorities have started improving off-road facilities in earnest and reviewing future plans to ensure travel quality needs of active mobility users are fully covered. Footpaths, that have always been readily available along-side majority of the roads in Singapore, are being enhanced and are provided with markings and signage's to encourage safe sharing of paths. Moreover, at places with high active mobility usage, footpaths are being widened and, space permitting, delineated or segregated paths are provided, comprising a pedestrian path adjacent to a cycling path (LTA, 2017a; Rojas López & Wong, 2017b). These commuting facilities can be generically known as the "formal mobility network" utilised by active mobility users.

Table A1 depicts pathway characteristics of the formal transport network utilised by active mobility users. Facilities such as signalised and zebra crossings and overhead bridges are also available to enhance active travelling and form part of the formal transport network utilised by active mobility users (Chin & Menon, 2015; Rojas López & Wong, 2017a).

More and more residential towns are becoming cycling towns in Singapore. The current 11 cycling towns are provided with specific facilities to further increase active mobility rate and specifically cycling rates. These residential towns also contain other types of land uses (e.g. commercial, industrial, green spaces). The overall active mobility rates have been found to be higher at the cycling towns as compared to the national average. Thus, given that elevated number of pedestrians and cyclists increases social interaction and healthy living, implementation and improvement of active mobility facilities enhances overall liveability of towns (van Kamp, Leidelmeijer, Marsman, & de Hollander, 2003; Wolch, Byrne, & Newell, 2014).

Herein, the authorities plan to expand these facilities to all residential towns by 2030 (LTA, 2016a), which improves users' perception of the quality of life in their living environment.

Table A1. Off-road formal mobility network utilised by active mobility users

Facility	Picture	Description
Footpath		*Off-road pathways of 1.5 metres wide on average. Shared by all types of active mobility users except electric bicycles. Speed limit of 15km/h.
Widened path		*Off-road pathways of 2 to 3 metres wide. Shared by all types of active mobility users. Speed limit of 15km/h.
Demarcated path		*Off-road pathways of 1 to 2 metres wide per path with pedestrian & cycling path adjacent to each other delineated by pavement marking. Shared by all types of active mobility users. Speed limit of 25km/h.
Segregated path		*Off-road pathways of 1 to 2 metres wide per path with pedestrian & cycling path next to each other but with physical separation in between. Shared by all types of active mobility users. Speed limit of 25km/h.

* adapted from (GOV.Sg, 2016)

At the cycling towns, intra-town cycling networks, comprising demarcated cycling paths and stretches of off-road widened pathways, are available. In addition, more traffic signals that are oriented to active mobility users and designated pedestrians' and cyclists' crossings – which are also part of the formal network – are available at cycling towns. These infrastructures of at the cycling towns are shown in Figure A2.



Figure A2. Characteristics of the formal mobility network in cycling towns

Recreational mobility network

Recreational areas increase positive utility of the urban environment (Brown, 2003) and these are present in almost every city in the world. In many cases, such facilities are green spaces (Tolley, 1990). In Singapore, many such areas exist, and these are equipped with purposively-built facilities, dedicated to active mobility users for recreational purposes and sometimes as regular access ways. Some examples are presented in Figure A3. The main recreational mobility network is the Park Connector Networks (PCNs). PCNs can be said to be part of the pioneer cycling facilities in Singapore. They were planned and first developed in 1992 as a scheme to encourage recreational cycling. Today, pedestrians, cyclists and certain PMD riders can enjoy the paths, around 400 km length, located at parks, nature reserves and other green areas in the island (NParks, 2016b). PCNs are mostly used for recreational cycling, recreational walking, exercising and other recreational activities (Tanuwidjaja, 2011).

As of 2018, one on-road bicycle lane exists at a public maintained road (Lim, 2017a) and a rather short on-road bicycle lane exists in Sentosa recreational island (Cheong, 2015). These bicycle lanes are located alongside vehicle lanes and are provided with chevron-shaped markings or different pavement colour from motorised road lanes. They are considered recreational facilities as being most commonly frequented by sport cyclists. Sport cyclists are identified by faster cycling speeds and

distinctive cycling gears (cycling suits of flashing colours, helmets, knee/elbow protector, etc.) which are not common in utilitarian cyclists. Finally, mountain biking trails are available in Chestnut Nature Park and Pulau Ubing recreational islands (NParks, 2016a). Recreational off-shore islands are visited for recreational purposes and do not connect to main-land amenities thus are not used for transport and/or utilitarian purposes.



Figure A3. Recreational mobility network utilised by active mobility users

In addition, recreational cyclists have also been observed travelling at “remote” roads; these are roads with relatively low traffic, good scenic views, and/or challenges of tough terrains (e.g. hills). No bicycle lane is provided along these roads, meaning that cyclists travel alongside motorised vehicles. Such usage of roads can be considered opportunistic usage, in part due to the sparse recreational network. Likewise, more experienced cyclists – those who cycle for long distances on a regular basis – have also been observed cycling on roads that are not provided with bicycle lanes.

Informal mobility spaces

As mentioned, Singapore presents a unique open void decks concept. In everyday context, these spaces are utilised by various user groups. For instance, elderly users frequent these areas in the mornings for small talks or table games, and children can be found playing at void decks right after school before heading home. In some cases, these spaces are decorated and utilised for big social gatherings such as weddings. Thus, void decks play a value-add role in the social life in Singapore.

These spaces are well-illuminated and well-maintained, and residents do their part to keep this communal space vibrant. Moreover, the ubiquitous presence of open space void decks in residential areas has afforded a somehow unrestricted movement of active mobility users. Although originally designed to enhance social interaction among residents, the void-deck area readily permits active mobility users to traverse across residential blocks, instead of circumnavigating them, to connect with the formal network. Examples of informal mobility spaces utilised by active mobility users are shown in Figure A4.



Figure A4. Informal mobility spaces utilised by active mobility users

Void decks have become core informal mobility space utilised by active mobility users as thoroughfares. There is no formal regulation regarding the use of void decks (yet) and many pedestrians can be seen criss-crossing these facilities. The occasional presence of steps has however deterred some cyclists and PMD riders to use them. While void decks can provide an almost “straight line” trajectory, which is attractive to thoroughfare travellers, these areas are frequented by vulnerable road users such as elders and children. This is of special concern when considering the speed difference of pedestrians, cyclists, and PMD riders. Indeed, recent accidents involving active mobility users in void decks have been registered. Herein, it is in the public interest to develop policies or regulation to manage the use of void-deck facilities by bicycles and PMDs. Moreover, pedestrians, cyclists, and PMD riders have been observed cutting through green spaces – sometimes creating

man-made pathways – and playgrounds nearby housing blocks. All these mobility access ways are considered part of the informal mobility spaces.

Appendix B – International and local practices on interview surveys

This appendix presents a comprehensive review of different survey attributes pertaining to household travel surveys previously conducted in overseas cities/countries and Singapore.

International practices on household travel survey

This review summarises the different survey instruments/information pertaining to household travel surveys (with focus on cycling and walking) in overseas cities and countries, namely Sydney, London, Tokyo, Hong Kong, The Netherlands, Denmark, and Germany. For the reviewed city or country that has more than one type of travel survey, focus is placed onto the one that is deemed as a better reference for this study and of comparable features as those conducted in Singapore.

For example, Sydney has 2 types of survey that capture cycling, namely Sydney's Household Travel Survey (HTS) and Sydney Cycling Survey (SCS). In comparison with its Household Travel Survey, SCS is aimed to measure a mode share for cycling, out of all trip modes of up to 10 km in length for all modes of travel, using measures of non-cycling trip modes from Sydney annual Household Travel Survey (BTS, n.d.). With this consideration in mind, the literature review presented in the following section focuses more on the Sydney's HTS.

A similar choice is applied on The Netherlands' case as it has Dutch National Travel Survey (OVIN) and The Netherlands Mobility Panel (MPN). As the OViN sample is rather a personal survey (instead of a household survey) when compared to MPN's sample that comprised both household and personal samples, the literature review presented in the following section focuses more on the MPN. In addition, MPN survey is also more useful in shedding lights on the various methods of conducting surveys capturing active mobility.

Objectives of household travel surveys

The primary objective of conducting the household travel survey primarily is to gain a complete picture of all trip-making activities and how travel patterns change over time. The information is then used as input into transport and land use planning, as well as policy making.

The frequency of conducting household travel survey is observed to vary from annually (e.g. in Sydney, London, The Netherlands and Denmark) to once in a few years (e.g. once in around 6 years for Germany's example, once in around 9 years for Hong Kong's example, once in 10 years for

Tokyo's example). From the reviewed references, it is observed that the household travel survey was originally conducted once every few years. However, some cities/countries (such as Sydney, London, Sweden, and Denmark) then deemed that it is not frequent enough to capture, analyse and monitor the travel behaviour in relation with the development rate, as a city/country development progresses at a higher speed over time, hence the basis of conducting annual household travel surveys.

Targeted respondent

The targeted respondent for the household travel survey is found to vary from residents of the reviewed city/country (e.g. in Sydney, London, Hong Kong, and Tokyo), to only the natives residing in the reviewed city/country (e.g. in The Netherlands and Denmark).

Sampling and response rate

Most of the reviewed cities and countries surveys drew their samples from the public domain (i.e. representative randomised-selection from the city's/country's statistics bureau or population register) such as in Sydney, London, Tokyo, Hong Kong, and Denmark. In comparison, travel surveys in countries such The Netherlands and Germany drew their samples from an existing access panel. This is considering that while public domain sampling frame offers a true probability sample of households from a scientific perspective, the response rate is usually relatively low as depending on the data collection methodology (i.e. face-to-face interview usually helps the most to boost the response rate from randomised selected households drawn from the public domain).

Indeed, examples in Sydney, London, and Hong Kong which drew their samples from the public domain and employed face-to-face interview to collect their data had relatively higher response rate (i.e. 67%, 50%, and 71%, respectively) compared to Tokyo's (with a response rate of 24%) that employed a self-completion questionnaire distributed and collected via mails from the randomly selected households (TMATPC, n.d.). Danish National Travel Survey (TU) which drew their samples from the public domain and employed a combination of web interview and telephone interview had an average response rate of 60% until 2011, and 58% from 2012 onwards (DTU Transport, 2015).

For The Netherlands' case, it conducted its MPN household travel survey on the same panel for 5 years. This sampling method resulted in 64% response rate (for MPN 2013) albeit with application of self-reporting, self-completion, web-based place-based travel diary. In comparison, Germany opted for a rotating panel to counter between-wave data collection fatigue. Each of these Germany's household only participated for 3 consecutive years, and each year the sample was refreshed to

replace those households that had to quit after 3 years and the non-responsive households (Hoogendoorn-Lanser et al., 2015).

Data collection methodology

The methods used for household travel interview survey have become more diverse with the passage of time, from the conventional face-to-face interviews using pen and paper to the employment of digital strategy such as computer-assisted web interview (CAWI). Data collection methodology employed in the reviewed cities and countries varied from face-to-face interview by way of pen-and-paper interview (PAPI) only or with variations to a certain extent (e.g. show cards, maps) such as Sydney's HTS and London's, face-to-face with assistance of digital strategy or Web-based Computer-Assisted Interviewing (CAPI) such as in Hong Kong, questionnaire distribution and collection via mail such as in Tokyo, phone interview such as Sydney's Cycling Survey (SCS), Computer-Assisted Telephone Interview (CATI) such as in Sweden, Computer-Assisted Web Interview (CAWI), or combinations of them such as in Germany and Denmark. It is observed that when face-to-face is opted as the data collection methodology, high response rate as well as quality detailed data are obtained. On the other hand, employment of CATI and/or CAWI is observed when there is budget constraint.

The household travel surveys in Tokyo, Hong Kong, The Netherlands, Denmark and Germany are examples that implemented geo-coding digital strategy into either their data collection or data analysis, which reduce burden on the respondents. In the case of Hong Kong's, CAPI technology was employed in combination with face-to-face interview for data collection. During household visits, the interviewers brought with them a tablet PC and interviewed the respondents using web-based CAPI on an online platform. The CAPI platform enables real-time logic checks of answers provided by the respondents and also geo-coding of locational information through Google Map. This enables time allocated for data cleaning to be shortened. If necessary, respondents could also provide their data through self-completed electronic e-questionnaires via the web-based CAPI platform using a personal password to login (Transport Department, 2014).

In The Netherlands' MPN 2013 case, dedicated car, bicycle, and public transport trip planning tools were used to compute the travel distances and times for alternatives to the reported trips. Similarly, the travel survey in Denmark also computed several attributes such as variables with the closest train station and its distance which in other surveys may be asked as questions.

Questionnaire

The questionnaires used in the reviewed cities and countries are mostly divided into probing 3 aspects, namely: household, individual (household member), and trip details. In Hong Kong's and Germany's cases, topical data items (e.g. factors affecting walking and use of travellers, cycling, potential changes in and factors affecting trip-making patterns, impact of electric bicycles or innovative mobility services) that are deemed as useful for enhancing the understanding of the public's views and attitudes towards the transport system and their trip-making behaviour are incorporated into its travel survey as supplementary surveys imposed on sub-samples. This is done to moderate considerations such as the burden on respondents, and time and budgetary constraints of data collection.

Inclusion of cycling (and walking)

Most of the reviewed cities and countries are observed to be collecting active trip-stages (i.e. walking and cycling) as part of the recorded travel diary in their household travel surveys. The travel survey in Denmark is somewhat an exception as walking is disregarded when in combination with other modes (DTU Transport, 2015). From 2010/11, London Travel Demand Survey asked each respondent who had cycled in the previous 7 days to complete a cycling diary which collects information on all cycle stages the respondents had made on up to 2 different cycle travel days (TfL, 2015). Travels surveys in Hong Kong and Germany included investigation into cycling as one of the topical data items of their travel surveys that were imposed on a sub-sample (Schulz et al., 2017).

In the case of Sydney, in addition to its annual detailed Household Travel Survey that already enables calculation of walking and cycling mode share, it also implemented a separate annual survey to monitor the mode share of bicycle trips and cycling participation rates, named as Sydney Cycling Survey (SCS). In comparison with its Household Travel Survey, SCS is aimed to measure a mode share for cycling, out of all trip modes of up to 10 km in length for all modes of travel, using measures of non-cycling trip modes from Sydney's annual Household Travel Survey. Sydney's SCS 2012 was conducted using computer assisted telephone interview (CATI) (BTS, 2013). A total of 23,643 telephone numbers were used in the main fieldwork phase, of which 13,026 (55.1%) were in-scope for the survey (Table B1). A total of 4,227 interviews were completed (17.9% of numbers dialled, and 32.5% of in-scope numbers). About half (51.9%) of the in-scope numbers were to respondents who declined to participate in the survey. The survey covered both weekdays and weekends.

Data on individual and household demographics were obtained, as well as information on cycling participation. Participation is on voluntary basis, and the cycling travel diary records 1-day trips defined as 24 hours from midnight to midnight. There is a maximum total of 27 questions for the household representatives (i.e. other household members get fewer questions). While during the interview any cycling distances are considered as trips, only cycling trips with distance of $100\text{m} < x \leq 10\text{km}$ were included in the analysis.

Table B1. SCS 2012 completion rate— each count represents a phone number (BTS, 2013)

Outcome	In-scope contacts	% of dialled numbers	% of in-scope contacts
<i>In scope</i>			
Completed interviews	4,227	17.9%	32.5%
Appointment/no answer*	1,643	6.9%	12.6%
Declined to participate	6,765	28.6%	51.9%
Communication difficulties	391	1.7%	3.0%
<i>Total of in-scope numbers</i>	<i>13,026</i>	<i>55.1%</i>	<i>100.0%</i>
<i>Other contacts</i>			
Non-qualifying respondents	292	1.2%	
Over-quota	6	0.0%	
<i>Non-contacts</i>			
Dead' numbers (called 5 times)	4,317	18.3%	
Non-working number	6,002	25.4%	
<i>Total of all numbers</i>	<i>23,643</i>	<i>100.0%</i>	

Age qualifier for a household representative was 18 years or above, while survey age qualifier was 15 years or above. SCS allows for proxy reporting where a household member aged 15 years or above is unavailable and another person can provide the information, and for children under 15 years who had ridden the preceding day.

However, since SCS is aimed at monitoring the mode share of bicycle trips and cycling participation rates, the report on its results considers the annual change in isolation.

Data analysis methodology

Sampled data are grossed up by weighting to make them representative of the city's/country's population and/or travel characteristics. Most of the reviewed cities/countries weighted their data to their population, with incorporation of additional weights to other variables, as available (e.g. trip expansion based on independent transport statistics).

For Sydney's HTS, the annual estimates were based on 3 waves of data pooled and weighted to the latest estimated resident population (ERP) (BTS, n.d.).

Data for London travel survey were analysed according to the geographical level. Results from a single year are usually robust enough to analyse at the London-wide level and can be split by area for Inner and Outer London residents. When analysing results at a more spatially disaggregated level (typically borough of trip origin), three (3) years of data need to be combined, giving an average figure over the three years.

For Hong Kong's case, there are 2 stages of expansion involved for its HIS data: demographical/population expansion, followed by trip expansion. Demographical expansion is applied at household and person levels to match the corresponding population characteristics. These expanded results were then compared against independent observed data or transport statistics available and then adjusted accordingly. The trip expansion is aimed to counter under-reporting of trips. However, trip expansion is not feasible to be applied on walking and cycling data due to the unavailability of independently observed data for control.

Denmark weighted its data by calendar date and socio-geographic data (for population weighting, it is done such that a one-year sum is the number of Danish inhabitants aged 10-84 years).

Age qualifier

The age qualifier to participate in the survey varies from a certain age or older such as 12 years or older (e.g. in The Netherlands) or 15 years or older (e.g. in Sydney and Hong Kong), to a specific age range such as between 6-84 years old (e.g. in Sweden) (Transport Analysis, 2016) or 10-84 (e.g. in Denmark). In some cases, the minimum age to qualify as a participant differs from the minimum age for the trip to be recorded. For example, while Sydney's age qualifier is 15 years or older, trips made by household member aged 0-14 years old are still recorded via proxy interview with another adult. Similarly, while Hong Kong's age qualifier is 15 years or older, trips made by household member aged 2-14 years old are still recorded. Other reviewed cities/countries such as London, Tokyo, The Netherlands and Denmark use the same age qualifier to sort the participant and record the trip made.

Trip duration and days of coverage

Most of the household travel surveys in the reviewed cities and countries are found to record 1-day travel, except for The Netherlands' NMP survey of 3 days; in comparison, the Dutch National Travel Survey recorded trips for one day. However, the 24-hour duration definition varied from 03:00h to

03:00h (e.g. in Tokyo and Denmark), 04:00h to 04:00h (e.g. Sydney's HTS and in London), and midnight to midnight (e.g. Sydney's SCS).

The household travel surveys in Sydney, London, The Netherlands and Denmark are examples whose data collection covered both weekday and weekend, being aimed to study the day-to-day variation in travel behaviour. In comparison, both the travel surveys in Hong Kong and Tokyo collected only weekday data.

For Tokyo, survey date is more specifically defined as Tuesday, Wednesday and Thursday, excluding public holiday, the day before the public holiday and the day after the public holiday.

Trip recall vs travel diary

Most of the reviewed cities/countries are observed to employ travel diary (e.g. in Sydney, London, The Netherlands, and Denmark). Household travel surveys in Tokyo and Hong Kong used trip recall with reference made to the previous weekday which was not a public holiday before the day of interview.

Token of appreciation

Most participation on the household travel surveys in the reviewed cities and countries is found to be on voluntary basis (e.g. Sydney, Tokyo, Hong Kong and Denmark). The household travel survey in London made use of a good cause of giving back to community, by informing the potential respondents that charity donations will be made for each completed survey. As a result, thousands of pounds were raised in recent years for charities including Action for Blind People, BBC Children in Need, Cancer Research UK and the Royal Society for the Protection of Birds (TfL, n.d.).

The Netherlands' MPN 2013 survey gave incentives on a point revenue system that is translated into monetary value. Apart from earning individual points for completing the personal questionnaire and travel diary, each individual within the household receives additional points if whole household participate in the survey. In addition, lottery is also held, offering prizes that range from web-shop vouchers to an electrical scooter (Hoogendoorn-Lanser et al., 2015). Most relevant attributes reviewed and considered regarding household travel surveys in overseas cities and countries are summarised in Table B2.

Table B2. Attributes of household travel surveys in reviewed overseas cities and countries

Item	Overseas city	
	Sydney ^{1, 2, 3, 4}	London ^{5, 6, 7}
Density characteristics	Population: 4,605,992 (as per 2012) Area: 12,367.7 km ² Density: 372.4/km ²	Population: 8,673,713 (as per 2015) Area: 1,572 km ² Density: 5,518/km ²
Travel survey name	Household Travel Survey (HTS)	London Travel Demand Survey (LTDS)
Survey frequency	Annually - Conducted everyday (i.e. covers 365 days a year) from July-June of each financial year	Annually
Survey objective	To gain a complete picture of all trip making and how travel patterns change over time.	To collect relevant travel data as inputs for updating of transport policies and facilitating future transport planning.
Survey coverage area	Sydney Greater Metropolitan Area (i.e. Sydney, Lower Hunter, Central Coast, Blue Mountains, Illawarra)	Greater London area (i.e. all (32) London boroughs and the City of London)
Targeted respondents	Residents of Sydney Greater Metropolitan Area	Residents of Greater London Area
Sampling	(Approached) 5,000 households each year. Selected households are notified by mail that they have been chosen to participate & that an interviewer will visit the household to explain the survey.	(Approached) 8,000 households each year. The randomly selected samples are drawn from the Postcode Address File (PAF) for each survey year.
Response rate	67% (Based on 3 years of pooled data, from a combined gross sample of 14,636 GMA households of which 9,859 responded - 25,596 people were interviewed with 106,885 trip records.)	Generally a little over 50%.
Data collection methodology	F2F (PAPI); use showcards & maps	F2F
Use of geo-coding digital instrument	Unknown	Unknown
Data analysis methodology	The annual estimates are based on 3 waves of data pooled and weighted to the latest estimated resident population (ERP).	Results from a single year are usually robust enough to analyse at the London-wide level, and can be split down by area for Inner and Outer London residents. When analysing results at a more spatially disaggregated level (typically borough of residence of borough of trip origin), three (3) years of data need to be combined, giving an average figure over the three years.
Age qualifier	≥ 15 years old as participant; ≥ 0 years old for trip-recording (via proxy interview with another adult participant)	≥ 5 years old (for both as participant and trip-recording)
Trips recorded	1 day (defined as 24hrs from 04am to 04am)	1 day (defined as 24hrs from 04am to 04am)
Days coverage	Both weekdays and weekends	Both weekdays and weekends
Info on token of appreciation	None (on voluntary basis)	Charity donation is made for each completed survey (e.g. Action for Blind People, BBC Children in Need, Cancer Research in UK, the Royal Society for the Protection of Birds)
Questionnaires	3 sets, comprising: 1) Household characteristics form : 5 questions 2) Household members' interview form: 2a) Occupation: 23 questions 2b) Trip details: 6 introductory questions, 23 questions of different cases of trip details (repeated for each trip) and 6 questions on travel opinions. 2c) Demographic: 13 questions of different cases 3) Household members' interview form: 3a) Person details: 7 questions of different cases 3b) Trip details: 6 introductory questions and 12 questions of different cases of trip details (to be repeated for each trip made) 3c) Demographics: 4 questions	3 sets, consisting of: 1) Household (i.e. demographic information on household members, and household characteristics such as income, housing tenure, and vehicle ownership) 2) Individual (i.e. further demographic and travel-related information, e.g. working status, frequency of use of transport modes, and details of driving license and PT transport tickets held) 3) Trip sheets (i.e. captures data on all trips made on a designated travel day, e.g. trip purposes, modes used, trip start and end times, locations of trip origins and destinations)
Trip recall/Travel Diary	Travel diary. Interviewer outlines the survey procedure, take some household details and allocate a particular day to the household's "Travel Day", the day for which their travel details will be collected (fridge magnet as Memory Jogger). The interviewer returns at a prearranged time to record the details of each trip undertaken on that day by F2F interview.	Travel diary
Remarks	-	-

Table B2. Attributes of household travel surveys in reviewed overseas cities and countries (cont'd)

Item	Overseas city	
	Hong Kong ⁸	Tokyo ⁹
Density characteristics	Population: 6,881,900 (as per 2011) No. of households: 2,363,300 (as per 2011) Density: 6233.6/km ²	No. of households: about 16 millions
Travel survey name	Travel Characteristics Survey (TCS)	Person-Trip Survey
Survey frequency	9 years (for TCS 2011, survey fieldwork conducted between September 2011 and January 2012)	10 years (conducted from October-November 2008 for the 5th Tokyo Metropolitan Area Travel Survey)
Survey objective	To collect relevant up-to-date travel characteristics data and develop database for subsequent updating and enhancement of the government's transport models, and planning tools.	To collect travel characteristics data for inputs in transport and urban planning, as well as provide guidance for individual enterprises regarding person mobility
Survey coverage area	Hong Kong Special Administrative Region (HKSAR)	Tokyo Metropolitan Area (Tokyo, Kanagawa prefecture, Saitama prefecture, Chiba prefecture, Ibaraki prefecture south)
Targeted respondents	Hong Kong (HKSAR) residents.	Residents of Tokyo Metropolitan Area
Sampling	(Approached) 50,000 households (for TCS 2011). Random samples drawn from the Frame of Quarters maintained by the Census & Statistics Department (C&SD).	Targeted about 1.4 million households (for the 5th Tokyo Metropolitan Survey)
Response rate	71% (for TCS 2011, 35,401 households responded out of 50,000 households approached)	About 24% (for the 5th Person-Trip Survey, about 340,000 households are collected)
Data collection methodology	F2F CAPI; The interviewer brought a tablet PC and interviewed the respondents using the web-based CAPI on an online platform. This enables real-time logic checks of answers provided by the respondents and geo-coding of Locational information. If necessary, respondents could also provide their data through self-completed electronic e-questionnaires via the web-based CAPI.	Distribution of survey forms by mail to surveyed households, and collection of survey forms by mail.
Use of geo-coding digital instrument	√	√
Data analysis methodology	Demographical expansion is applied at household & person levels to match the corresponding population characteristics. These expanded results were then compared against independent observed data or transport statistics available and then adjusted accordingly. Trip expansion is aimed to counter under-reporting of trips. Trip expansion is not feasible to be applied on walking & cycling data due to the unavailability of such independent observed data for control.	Unknown
Age qualifier	≥ 15 years old as participants; ≥ 2 years old for trip-recording	≥ 5 years old (for both as participant and trip-recording)
Trips recorded	1 day (for HIS, defined as the previous weekday which was not a public holiday before the day of interview)	1 day (defined as 24hrs from 03am to 03am)
Days coverage	Weekday trips only	Weekday trips only
Info on token of appreciation	None (on voluntary basis)	None (on voluntary basis)
Questionnaires	TCS 2011 comprised 3 main surveys: Household Interview Survey (HIS), Stated Preference (SP) survey, and Hotel/Guesthouse Tourists Survey (TS). The survey collects household, personal and trip data, in addition to private vehicle usage and expenses; travel propensity, walking and use of travellers; cycling; effects of transport information system; and views of elderly on transport services.	2 sets, comprising: 1) Household information, and 2) Trip details
Trip recall/Travel Diary	Trip recall	Trip recall
Remarks	While TCS 2011 comprised 3 main surveys, summarised findings are assembled based on the overall TCS 2011 and HIS (mainstay of the transport model development).	-

Table B2. Attributes of household travel surveys in reviewed overseas cities and countries (cont'd)

S/No	Item	Overseas country	
		Netherlands ^{9, 10}	Denmark ^{11, 12}
1	Density characteristics	Population: 17,100,475 (2017 estimate) Area: 41,543 km ² Density: 412/km ²	Population: 5,707,251 (as per January 2016) Area: 42,925.46 km ² Density: 132.96/km ²
2	Travel survey name	MobiliteitsPanel Nederland (MPN) / The Netherlands Mobility Panel	Transportvaneundersøgelsen (TU) / Danish National Travel Survey
3	Survey frequency	Annually -- from September-November	Annually -- covers 365 days a year to provide a complete picture, and due some of the partners have particular interest in non-working days
4	Survey objective	To determine the short-run and long-run dynamics in the travel behaviour of Dutch individuals and households and to determine how changes in personal and household characteristics and in other travel-related factors correlate with changes in travel behaviour. To identify and explain day-to-day variations in mobility and the role of habits in travel behaviour.	To survey the transport behaviour of Danes residing in Denmark
5	Survey coverage area	The Netherlands	Denmark (excluding Greenland and the Faroe Islands)
6	Targeted respondents	Dutch citizens residing in the Netherlands who had the ability to read and write in the Dutch language	Danish resident (Danes residing in Denmark)
7	Sampling	Drawn from an existing access panel (MPN survey will be using the same panel 5 years)	(Approached) around 33,000 persons each year, sampled from the Danish Civil Registry (CPR).
8	Response rate	64% (for MPN 2013, the sample consists of 1,978 households and 3,996 individuals)	58% on average from 2012 onwards (this is a decline from 60% in TU 2006-2011)
9	Data collection methodology	CAWI or Self-reporting, self-completion web-based survey	Combination of telephone and internet interview (i.e. 20% web and 80% telephone interview)
10	Use of geo-coding digital instrument	Dedicated car, bike, and public transport trip planning tools were used to compute the travel distances and times for alternatives to the reported trips	Several variables are computed, which in other surveys are asked as questions. E.g. the variables with the closest railway station and the distance to this are based on coordinate data in TU
11	Data analysis methodology	Data collected via the questionnaires and diary is enriched with data from administrative registers (pertaining to additional spatial transport-related characteristics, socio-economic of recorded postal codes, etc). Dedicated car, bicycle and public transport trip planning tools were also used to compute the travel distances and times for alternatives to the reported trips.	Data is weighted by calendar date and socio-geographic data (for population weighting, it is done such that a one-year sum is the number of Danish inhabitants aged 10-84 years).
12	Age qualifier	≥ 12 years old (for both as participant and trip-recording)	10-84 years old (for both as participant and trip-recording)
13	Trips recorded	3 days (that runs from 00:00 to 23:59)	1 day (defined as 24hrs from 03am to 03am)
14	Days coverage	Both weekdays and weekends	Both weekdays and weekends
15	Info on token of appreciation	Incentives are given on a point revenue system that is translated into monetary value. Apart from earning individual points for completing the personal questionnaire and travel diary, each individual within the household receives additional points if all respondents aged 12 and older participate in the survey. In addition, lottery is also held, offering prizes that range from webshop vouchers to an electrical scooter.	None
16	Questionnaires	The MPN consists of 5 research instruments: 4 questionnaires and a travel diary. The screening and household questionnaires for each household are filled out by an adult household member, while the 2 individual questionnaires and the travel diary are filled out by each household member aged 12 and older.	The average duration of an interview is 10-12 minutes by telephone, and 20 minutes by web.
17	Trip recall/Travel Diary	Self-reporting, self-completion, computer-aided, web-based place-based travel diary	Travel diary
18	Remarks	-	Stated: TU is an individual survey, because most applications regard either individual behaviour or general statistics and because <u>the response rate is an issue</u> . However, the ordinary questionnaire contains background information on the composition of the HH, plus questions on co-participants in each trip. Walking is disregarded when in combination with other modes.

¹ (BTS, n.d.)

² (BTS, n.d.)

³ (BTS, 2014)

⁴ (City of Sydney, 2017)

⁵ (TfL, 2015)

⁶ (TfL, n.d.)

⁷ (Wikipedia, 2017b)

⁸ (Transport Department, 2014)

⁹ (TMATPC, n.d.)

¹⁰ (Hoogendoorn-Lanser et al., 2015)

¹¹ (Wikipedia, 2017a)

¹² (DTU Transport, 2015)

¹³ (Wikipedia, 2017c)

Discussions from overseas surveys

After a period of un-popularity and low usage as modes of transport, active modes particularly walking and cycling can be said to have “revived” with people’s search for sustainable lifestyles and government efforts to reduce motorised traffic (Koh & Wong, 2013a; Wright, 2005). Around 1970s, countries started to implement policies and develop sustainable infrastructure to facilitate the use of active mobility (Barter et al., 2003; Pucher & Buehler, 2010; Sagaris, 2015). Interestingly, these initial movements to increase active mobility took place at countries with high private vehicle ownership and usage. Today, high proportions of walking and walking trips have been well maintained in these countries as shown in Figure B1. This may be contributed by several factors such as environment (e.g. weather, built-environment), socio-economic (e.g. gender, age, income), and external (e.g. country’s policies and programmes) factors.

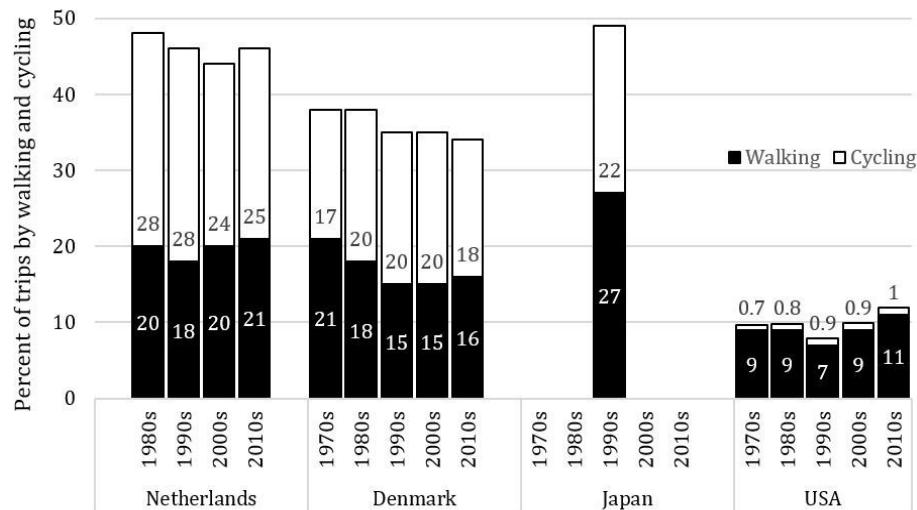


Figure B1. Trends in active mobility in countries with high vehicle ownership

In some cities, many active mode users are also motorists or people with access to private vehicles who use different modes for different types of trip. Motorists who are also pedestrians or cyclists hold a different mind-set towards active modes of transport. Such confounding findings cannot be readily generalised or be used as basis for developing policies and programmes across geographical or social contexts. Herein, local conditions and perceptions must always be considered. While the findings from the reviewed overseas cities and countries vary immensely, best practices can be combined and adapted for local implementation. As for the references within the Asian continent, Hong Kong is considered a better reference considering both the methodology used as well as similarity in population and car density with Singapore (see Figure B2).

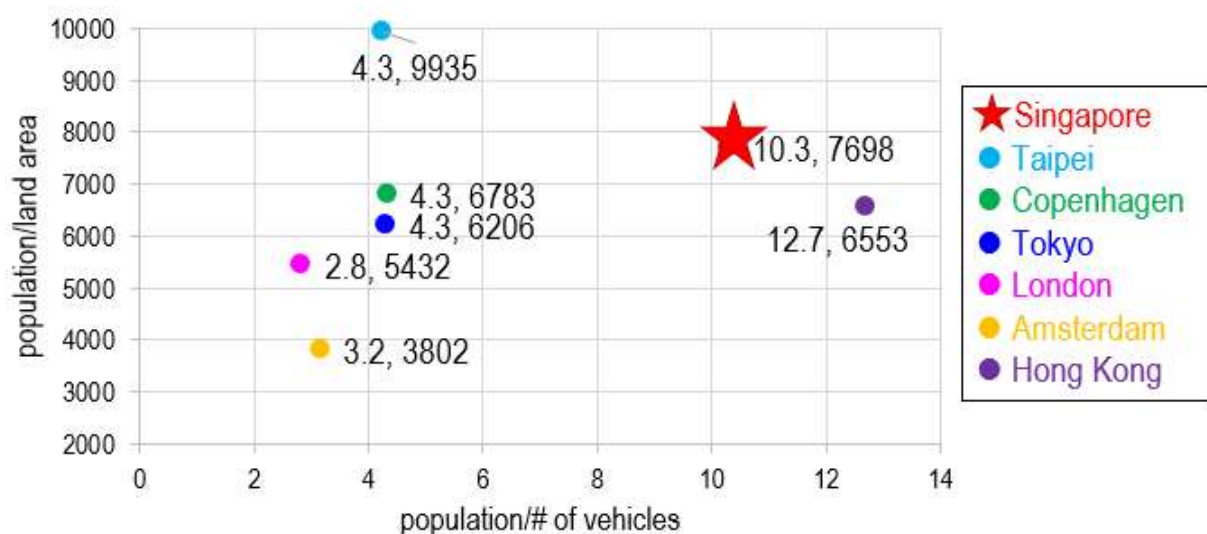


Figure B2. Vehicle ownership and land density at different countries

Local practices on household travel survey

In this section, survey questionnaires, survey interview manuals, glossaries and definitions, and available reports for Singapore's household travel surveys are analysed as shown in Table B3. Relevant findings are presented in the following sections.

Table B3. Reviewed survey materials of Singapore's past surveys

Year	Materials Reviewed	Notes
1981	Household Interview Survey – Report	Printed version
	Household Interview Survey – Procedures manual	
	Household Interview Survey – Definitions and glossary	
	Household Interview Survey – Final survey questionnaire	
1988	Home Interview Survey – Instructions for answering the questionnaire	Printed version
	Home Interview Survey – Final survey questionnaire	
1991	Singapore travel survey – Interviewer's Manual	Printed version
	Singapore travel survey – Final survey questionnaire	
1997	Singapore travel survey – Research report	Key questions only
	Singapore travel survey – Partial survey questionnaire	
2008	Press releases and online information	Survey questionnaire
2013	Press releases and online information	
2016	Household Interview Survey – Survey smartphone app	From a participant

Household interview surveys are travel surveys conducted in Singapore every four to five years. Currently, the survey samples approximately 1% of households in Singapore spread across different geographical areas of the country (Choi & Toh, 2010). Using this type of survey, travel behaviour data have been collected in Singapore since early years. The survey questionnaire collected variables (including options for multiple-option questions) and definitions have changed over the years. Survey materials (but not outcomes) for 7 past surveys were reviewed for this research.

Other various publications and press releases available in the public domain regarding travel surveys in Singapore were also reviewed to gather relevant pointers. Findings will be used as inputs to assemble the survey specifications (including key questions to fully collect active modes usage and travel pattern) and procedures for conducting the household survey interview for this study.

Survey questionnaires/questions overview

In general, a comprehensive paper-based questionnaire has been developed to collect travel behaviour information of every member aged 6 years old or older in the sampled household. Information regarding members who are between 6 and 14 years old has commonly been provided by the head of the household. Majority of the reviewed surveys has 2 main sections, namely one concerning travelling or trip characteristics and another regarding socio-economic characteristics of the household members. Some information regarding the household type is also collected over the years, most commonly before the surveys as based on sampling stratification.

In most of the surveys, travel or trip characteristics were collected by inquiring about all trips made by household members “yesterday” (the day before the interview was conducted) or for a typical weekday. Collected information included: transport mode, frequency of trips, travel purpose, time of travel, origin and destination. All the reviewed surveys collected data using recall method for 24-hour travel, except for 1991 survey that collected 2-day travel diary that was focused more on activities rather than trips. While being true that the amount of information collected in the 1991 survey was extensive and it can allow detailed modelling, the survey burden on respondents caused issues in completeness of data (e.g. tendency for lower reporting level for Day-2). Besides trip details, these surveys also captured common socio-economic information such as individuals’ income, education level, work schedule and location, vehicle ownership/availability, and possession of driving licence.

The collected information regarding walking and cycling trips for the 7 surveys varied substantially (see Table B4). In the earlier surveys, the conducted interview surveys focused mostly on recording trips by motorised transport modes. Thus, no information about walking or cycling trips was recorded. Subsequent years’ surveys included information on walking trips, with minimum walking trip duration being stipulated differently, for example with the 2013 survey the minimum walking time was set at 10 minutes or more.

Cycling trips appeared in 1991 survey onwards, while bicycle availability was collected from 2008 onwards, indicating that more attention was placed on this mode of transport. Interestingly, the 2013 survey only recorded trips that took place out of home for longer than thirty (30) minutes. Considering that active trips are mostly short trips that are less than 1 km (except for recreational active trips), setting 30 minutes as minimum trip duration to be recorded is likely to result in significant non-reporting of active trips.

Table B4. Characteristics of various travel surveys

Year	Trip	Bicycle		Walking		Cycling		Type
		ownership	type	full-trip	trip-stage	full-trip	trip-stage	
1981	By motorised modes of transport	✗	✗	✗		✗	✗	Paper based
1988	OD	✗	✗	>5 min	✓	✗	✗	
1991	Any			>2 min	>2 min	>2 min	>2 min	
1997	movement on public street >100 metres	✗		>2 min	>2 min	✓	✗	computer aided computer aided
2008	-	✓	exclude children bicycle	to work or school	✓	✓	✗	
2013	>30 min out of home	✓	✗	>10 min	✓	✓	✓	
2016	-	✓	✓	✓	-	✓		phone App

Trip purposes

Various definitions in the trip purposes were applied in the surveys. The most appropriate trip purpose (applicable for that origin-to-destination travel) was recorded as interpreted from the given response. Trip purposes, as well as some other socio-economic factors, are commonly selected from predefined lists. For the 2013 survey, 20 trip purposes were considered, namely:

- | | |
|--|---------------------------------|
| 1. Education | 11. Return home |
| 2. Entertainment | 12. Shopping groceries |
| 3. Go to work | 13. Shopping others |
| 4. Meal/eating break | 14. Social visit/gathering |
| 5. Medical/dental (self) | 15. Sports/exercise |
| 6. National Service | 16. To accompany someone |
| 7. Personal errand/task (pay bill/banking) | 17. To drop-off/pick-up someone |
| 8. Recreation | 18. Working for paid employment |
| 9. Religious related matters | 19. Work-related business |
| 10. Return another home | 20. Change mode |

Trip purposes are helpful not only to identify demand for specific trip purposes, but also determine some patterns about people and household travel behaviour. For the present survey, different trip purposes are defined following options in previous surveys as well as incorporating other crucial factors derived from the literature review.

Reports and interviewers' manuals - key findings

The reviewed local survey reports and interviewers' manuals provided important pointers to consider for the development of survey questionnaire (i.e. questions layout and multiple-answer options), training of interviewers and household sampling stratification.

Household sampling stratification

Sample size has remained constant across the various surveys (i.e. around 1% of households). However, the sampling method varied. The 1981 survey developed the sampling selection with representation of different levels in the number of vehicles per household. Census divisions (69 at the time) were divided into smaller reticulated units (RU – approximately 94 households each). RUs were randomly selected to avoid bias, and households were systematically chosen from each RU. A total of 60% no-vehicle household, 23% one car, 14% motorcycle only, and 3% multi-car were sampled (see Figure B3). Vehicle ownership data was obtained from Statistics Department's census summary.

59.5 percent	Non-vehicle owning
14.1 percent	Motorcycle only
23.4 percent	One Car
3.0 percent	Multi-Car

Figure B3. Year 1981 Household interview survey – households sampling

In the later years, sample households were selected based on National Database of Dwelling Units address and housing type maintained by the Singapore's Department of Statistics (DOS). Households were randomly selected at certain areas to accurately represent the general population in terms of the national house type (type of dwelling unit – see Figure B4) and good geographical spread across the island.

Type of dwelling
Landed Properties
Bungalows
Semi-Detached Bungalows
Terrace Houses
HDB flats
1- & 2-Room Flats
3-Room Flats
4-Room Flats
5-Room, 6-Room & Executive / Maisonette Flats
Others
Other Public Flats
Private Flats (include Condominiums)
Shophouses
Attap / Zinc-Roofed Houses
Others

Figure B4. Type of dwelling units sampled and sampling procedure – 1997

Similar to 1981 survey, subsequent surveys also applied a two-stage stratified sample design. For the 1991 and 1997 surveys, polling districts were first identified and stratified by predominant house types. Then, a fixed number of households was determined from each polling district. Households were systematically selected (with a random start) to ensure all types of dwelling unit were sampled. Probability of a household being selected was set to be proportional to the polling district size. For cases where initial contact was unsuccessful, several repeated attempts were made to interview the households. In case of unsuccessful contact, the initially selected household was replaced with another of similar characteristics (next in line in systematic selection) until the desired sample size was reached (see Figure B5).

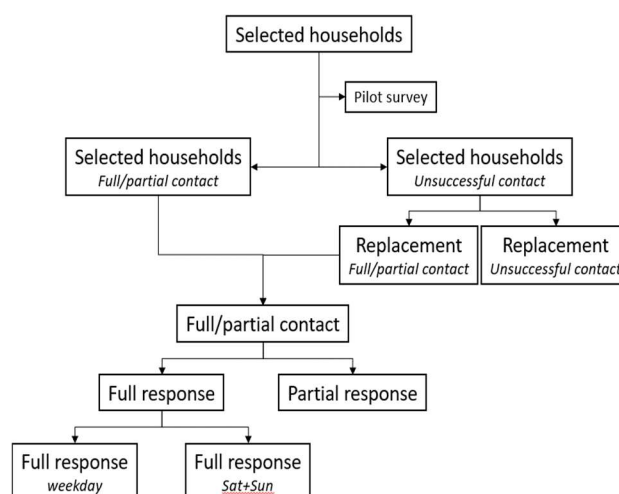


Figure B5. Household selection and replacement procedure – 1991 & 1997

Information was not available for the household sampling stratification for HITS 2012. Thus, this study shall take into consideration sampling stratification from earlier surveys.

Pilot survey

For most previous surveys, a pilot survey was conducted to test adequacy of the survey process with main focus on survey questionnaire. Main points of consideration included: clarity of the questions, layout and order of the questions, length of the survey questionnaire (time taken to complete), as well as testing of interview software (in cases when the survey used digital devices).

While the pilot survey is small in scope (i.e. no more than 500 households), it provides valuable information that can help improve overall survey success. Not only the questionnaire used can be further strengthened and clarified, a pilot survey is also useful for determining refusal rate (i.e. proportion of households that refuse to participate in the survey) and caters for better incentives and sample boosters, if necessary.

Training of interviewers

In all the surveys, interviewers received training prior to main survey (data collection). The most comprehensive information on training of interviewers was found in the 1991 travel survey. Training sessions were conducted two weeks before the main survey by the selected survey company. This was done in discussion with relevant authorities. Interviewers were given training notes and manual before the session and prompted to ask as many questions as possible regarding different aspects of the study and the survey. During the training, they were briefed on the background of the survey, information/data to be collected, meaning and definition of variables and any possible ambiguous terms as well as household contact and field work procedures (e.g. how to address different members, attitude in case of rejection, sensitivity towards delicate issues, etc.). Special attention was given to encourage interviewers to have a friendly attitude when conducting the survey to ensure participants remained motivated throughout the survey and provide complete answers.

In cases when digital devices were used to collect survey data, interviewers were given “hands-on” training or familiarisation period with the PC notebooks or other devices used to collect the data. Less skilled interviewers were offered additional training in the use of the devices. Interviewers were also encouraged to choose a few “trial” households (family, relatives, friends, etc.) for mock interviews.

Similar to HITS survey, this study also requires the selected survey company to have sufficient readily available pool of trained surveyors to carry out face-to-face interviews using structured

questionnaires. NTU participated in the training session to clarify any possible discrepancies and/or ambiguities regarding the background of the survey and survey questionnaire. Control measures to ensure that interviews have been carried out by field staff in a professional manner as well as data quality were required from the company.

Household travel survey 2016

The Land Transport Authority has commissioned Ascentic Pte Ltd to conduct household travel survey year 2016 of about 15,000 households in Singapore between July 2016 and May 2017. The survey targets to collect travel information from household members aged 6 years and above. This survey is found to be significantly handier (than the past survey) as it implements a smartphone app to automate and auto collect participants' travel data.

During the survey, an interviewer visits the randomly-selected household to ask about the household members' travelling pattern for a particular day. Household members may also be asked to install a smartphone app to assist in the data collection. A set of random username and password to install the app is generated by the survey platform/website upon completion of respondent's socio-demographic questionnaire. For travel to be recorded in the app's Activity Diary, respondents need to carry their smartphones with them and keep the Location Services (GPS) and Wi-Fi/Data turned on. A date must appear in dark green colour in the calendar section to be considered as validated. All black "Verify" buttons must become blue "Verified buttons in that day's Activity Diary for the date to be considered fully validated. In addition, only full-day validation is accepted, of which first day of download is not considered a full-day validation.

This way, respondents become the proxy for the system to auto-monitor all respondents' activities without surveyor having to return to conduct personal survey on trip details. This is also expected to provide a more accurate reading because respondents may not necessarily recall all the stop times and routes accurately. Respondents only need to validate their trip details at the end of the day. For this, respondents are required to keep the app running in the background of the smartphone for 7 full days and confirm 3 full-day activities within the 7 days when the app is running. Screenshots of the smartphone app (installed in iPhone) is given in Figure B6.

A room for improvement is identified in regards of the app sensor that seemed to be more sensitive in detecting movement and stops when the user is actively using the phone. This entails several issues, for example, since a participant may not be in the safest situations if s/he is actively using the phone while travelling. This also leads to another weakness as it is the trip-stages data that contains

abundant active trips data. Thus, while the app greatly helps data collection to a certain extent, the data collection in the present survey by way of face-to-face interview together with careful recall and probing can still provide the most detailed trip-stage data.

HTS 2016 is also found to combine the best practices on giving out token of appreciation to the respondents. Upon respondents' willingness to participate in the survey, respondents are given a special edition EZ-link card (of zero balance) as a token of appreciation. This serves as a pre-paid incentive before the respondents actually complete the survey on trip details. For completion of 1-day validated travel diary, respondents earn 1 point in a raffling held, offering prizes such as travel vouchers. Respondents who complete more than 1-day validated travel diary earn additional points for the raffling.

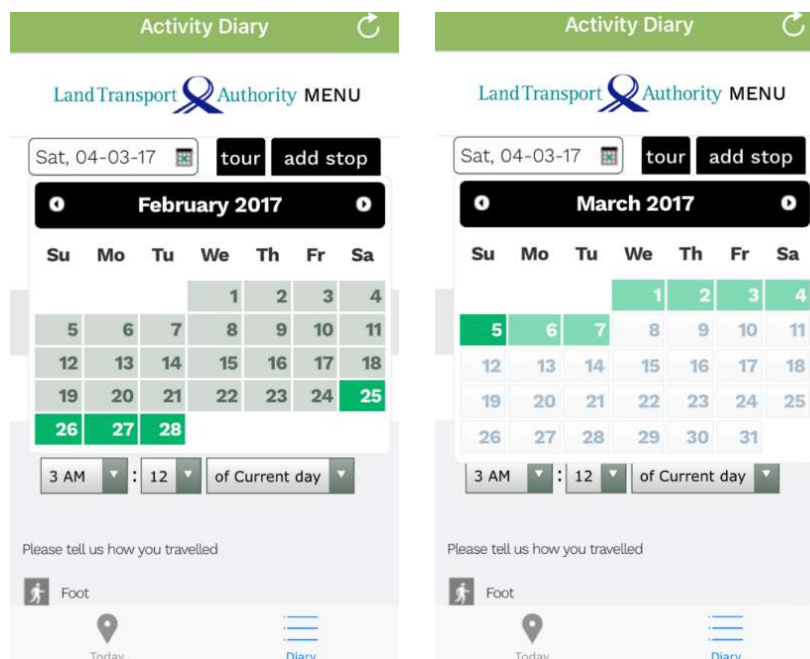


Figure B6. Screenshots of the smartphone app used for travel data collection in household travel survey 2016

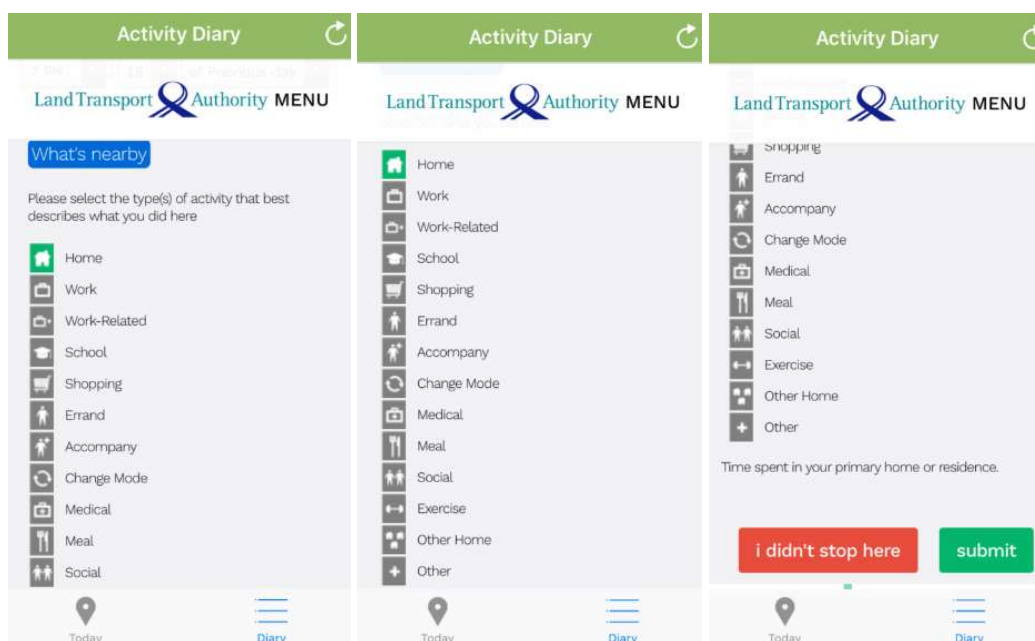


Figure B6. Screenshots of the smartphone app used for travel data collection in household travel survey 2016 (cont'd)

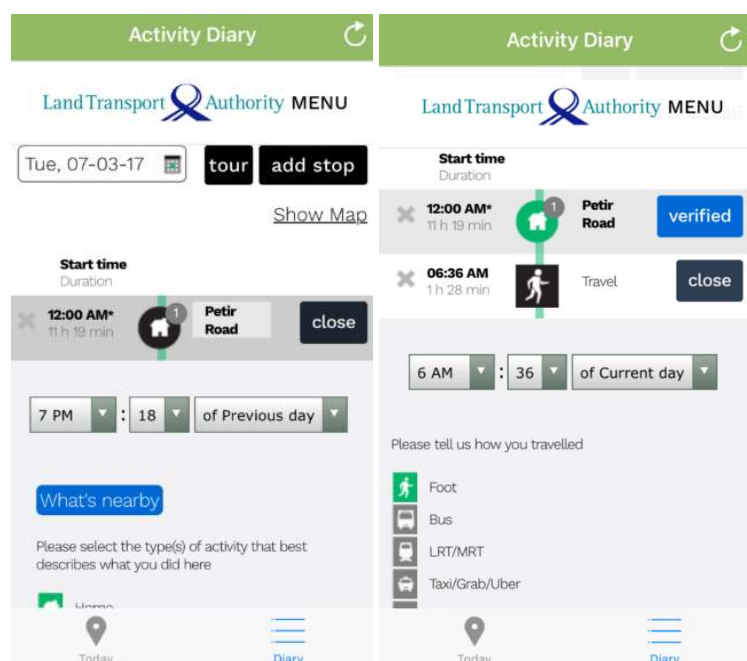


Figure B6. Screenshots of the smartphone app used for travel data collection in household travel survey 2016 (cont'd)

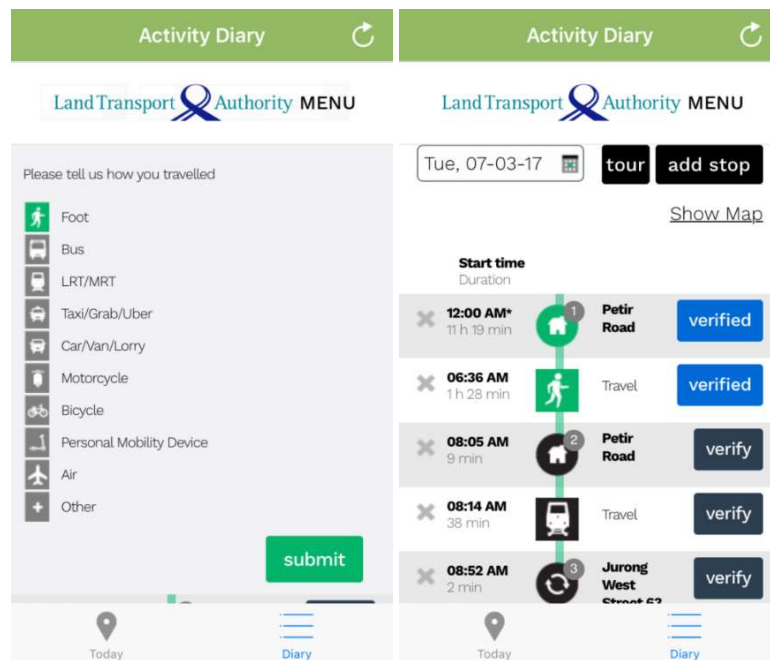


Figure B6. Screenshots of the smartphone app used for travel data collection in household travel survey 2016 (cont'd)

Appendix C – Forms and questionnaires for quality needs studies

This appendix presents the questionnaires utilised for the investigating pedestrians' and cyclists' quality needs. Methodology for each survey questionnaire is explained in Chapter 3 and findings are presented and discussed in Chapter 4. For each survey an official letter for data collection was issued by PhD supervisor and interviewers carried with them together with their NTU ID.

The official letter for data collection layout, survey questionnaires, and related tables/show-cards are presented as shown in Table C1. It should be noted that layout of the questionnaires was slightly modified for presentation within this thesis. Actual questionnaires had bigger fonts and more space for possible answers for more efficient data collection.

Table C1. Order of presentation of different forms, questionnaires, and show-cards

Study ID	Study name	Form type
		Template of official letter for data collection (Updated for each study)
I	ACTIVE TRAVELLING CHARACTERISTICS	Survey questionnaire – Cycling at the time of the survey
		Survey questionnaire – Walking at the time of the survey
		Tables related to survey questionnaire
II	USAGE OF THE (FORMAL) ACTIVE TRANSPORT NETWORK	Survey questionnaire
		Paths show-card
		Types of PMDs show-card
		Voucher issuance form
III	ATTITUDES TOWARDS ACTIVE MOBILITY	Focus group pre/post survey questionnaire
		Focus group activities & questions (power point slides)
		In-depth one-to-one interview survey questionnaire
		Focus group & one-to-one interview agreement of participation

Template of official letter for data collection (Updated for each study)



**NANYANG
TECHNOLOGICAL
UNIVERSITY**
SINGAPORE

School of Civil and Environmental Engineering

Reg. No. 200604393R

DD/MM/YYYY

Dear Neighbourhood Police Post/Centre

FIELD WORK IN THE NEIGHBOURHOOD

The Nanyang Technological University is researching about pedestrians' and cyclists' behaviour and interaction in Singapore. The purpose of this specific study is to **ADD PURPOSE OF THE STUDY**. The overall goal is to **ADD GOAL OF THE STUDY**.

The study involves survey data collection based on street intercept as well as unobtrusive video recording of pedestrians and cyclists commuting off-road (**MODIFIED PER STUDY**). In this regard, on-site data shall be collected **ADD STUDY DATA COLLECTION PERIOD STUDY**. Study is led by NTU's PhD Student; Maria Cecilia Rojas Lopez (G1304707W), and some student helpers (**ADD STUDENTS NAME AND ID**).

We greatly appreciate that you will allow us to do field data collection within the neighbourhood. Should you have further queries, please feel free to contact me.

Thanks and Regards

SUPERVISOR SIGNATURE AND DATE

WONG Yiik Diew
Associate Professor
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Internet: <http://www.ntu.edu.sg/cee>

A School of the College of Engineering

ACTIVE TRAVELLING CHARACTERISTICS STUDY

Survey for interviewees cycling at the time of the survey

To be completed by interviewer

1. Location: _____	2. Date: / / (dd/mm/yy)	3. Time: _____	4. Interviewer's name: _____	Interviewee's gender: ☐ Male ☐ Female
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*To be asked to interviewee*Q1. Do you stay in SEMBAWANG/YISHUN? ☐ Yes, postal code: _____ ☐ No

Q2. When did you start cycling in SEMBAWANG/YISHUN? Year: _____

Q3. Are you aware of the dedicated cycling paths in SEMBAWANG/YISHUN? ☐ Yes ☐ No

Q4. Do you cycle more after dedicated cycling paths were introduced (2013/2015)? Why? – See table

☐ Yes	☐ No
Because is safer	I did not recognize the improvement
Because it is more convenient	I do not feel safe
Because it saves time	Lack of parking/end-of-the-trip facilities
To exercise/for health	Weather factors (hot/rain)
Because of good scenery at cycling routes	Cycling paths are too far from where I stay
Others:	Others:

Q5. For your existing cycling trips, you used to walk/cycle/take bus/others: _____ before the implementation (2013/2015) – Complete in table

Cycle from (Building name/ no)	Cycle to (Building name/ no.)	Previous used mode	Purpose	1/2 ways	AM/P M
<i>E.g.: Home (Blk 881)</i>	<i>Sembawang primary sch</i>	<i>Bus</i>	<i>Pick up children</i>	<i>2</i>	<i>AM</i>

Demographics

QD1. How many bicycle(s) and PMDs in your household?

☐ Adult bicycle _____ ☐ Children bicycle _____ ☐ Motorised bicycle _____ ☐ PMDs _____

QD2. Age range?

☐ 10-14 yrs	☐ 25-29 yrs	☐ 10-44 yrs	☐ 55-59 yrs
☐ 15-19 yrs	☐ 30-34 yrs	☐ 45-49 yrs	☐ 60-64 yrs
☐ 20-24 yrs	☐ 35-39 yrs	☐ 50-54 yrs	☐ ≥65 yrs

QD3. Nationality? ☐ Singaporean ☐ PR ☐ Others: _____QD4. Occupation? ☐ Employed ☐ Student ☐ Housewife ☐ Retired ☐ Unemployed ☐ Others: _____

Survey for interviewees walking at the time of the survey

To be completed by interviewer

1. Location: _____	2. Date: / / (dd/mm/yy)	3. Time: _____	4. Interviewer's name: _____	Interviewee's gender: ☐ Male ☐ Female
-----------------------	----------------------------	-------------------	------------------------------------	--

*To be asked to interviewee*Q1. Do you stay in SEMBAWANG/YISHUN? ☐ Yes (1), postal code: _____ ☐ No(0)

Q3. Do you cycle in SEMBAWANG/YISHUN?

☐ Regularly (>1/week) – go to section A & demographics☐ Occasionally – go to section A & demographics☐ I don't cycle, but I plan to start cycling – go to section B & demographics☐ I don't cycle and I have no intention of becoming a cyclist – go to section B & demographics

<i>Section A (Cyclists)</i>	<i>Section B (Non-cyclists)</i>
Q.C1. When did you start cycling in SEMBAWANG/YISHUN? Year: _____	Q.NC1. What are the reasons for your change/no change in behaviour? Answer: _____
Q.C2. Are you aware of the dedicated cycling paths in SEMBAWANG/YISHUN? ☐ Yes ☐ No	Q.NC2. Are you aware of the dedicated cycling paths in SEMBAWANG/YISHUN? ☐ Yes ☐ No
Q.C3. Do you cycle more after dedicated cycling paths were introduced (2013/2015)? Why? – See table 1	Q.NC3. After the implementation of the cycling tracks, do you use Table 3 modes of transport more/less often? Why? – See table 3
Q.C4. For your existing cycling trips, you used to walk/cycle/take bus/others before the implementation (2013/2015) – Complete in table 2	

Demographics

QD1. How many bicycle(s) and PMDs in your household?

☐ Adult bicycle _____ ☐ Children bicycle _____ ☐ Motorised bicycle _____ ☐ PMDs _____

QD2. Age range?

☐ 10-14 yrs	☐ 25-29 yrs	☐ 10-44 yrs	☐ 55-59 yrs
☐ 15-19 yrs	☐ 30-34 yrs	☐ 45-49 yrs	☐ 60-64 yrs
☐ 20-24 yrs	☐ 35-39 yrs	☐ 50-54 yrs	☐ ≥65 yrs

QD3. Nationality? ☐ Singaporean ☐ PR ☐ Others: _____QD4. Occupation? ☐ Employed ☐ Student ☐ Housewife ☐ Retired ☐ Unemployed ☐ Others: _____

Tables related to survey for interviewees walking at the time of the survey

Table 1:

☐ Yes	☐ No
Because is safer	I did not recognize the improvement
Because it is more convenient	I do not feel safe
Because it saves time	Lack of parking/end-of-the-trip facilities
To exercise/for health	Weather factors (hot/rain)
Because of good scenery at cycling routes	Cycling paths are too far from where I stay
Others:	Others:

Table 2:

Cycle from (Building name/ no)	Cycle to (Building name/ no.)	Previous used mode	Purpose	1/2 ways	AM/P M
<i>E.g.: Home (Blk 881)</i>	<i>Sembawang primary sch</i>	<i>Bus</i>	<i>Pick up children</i>	<i>2</i>	<i>AM</i>

Table 3:

	Same	More	Less
MRT			
Public bus			
Private vehicle			
Walk			

USAGE OF THE (FORMAL) ACTIVE TRANSPORT NETWORK STUDY

Transport usage & infrastructure in Singapore



We are from NTU, doing a research study into transport usage with focus in active mobility. This survey will take you **less than 5 mins** to complete and you can get a **FREE GIFT** 😊

Q1. What is your most commonly used mode of transport? (*choose up to 2*)

☐ MRT ☐ Public bus ☐ Private transport ☐ Walk ☐ Cycle ☐ Others: _____

Q2. Do you stay in a cycling town? ☐ Yes ☐ No ☐ Unsure Postal code: _____

Q3. How often do you cycle in Singapore?

☐ Almost everyday ☐ Few days a week ☐ Few days a month
☐ Less than once a month ☐ Never (*skip Q4, Q5, Q6*)

Q4. Do you cycle more for transport or for recreation?

☐ For transport ☐ For recreation ☐ Both (T/R)

Q5. When did you start cycling and why? _____

Q6. Where do you usually cycle?

☐ On road ☐ Off road

Q7. Please rank accordingly where do/would you feel more comfortable commuting? Why (*for #1*)?
 1 (*more comfortable*) to 6 (*less comfortable*)

____ Pathways
 ____ Extended paths
 ____ Delineated paths
 ____ Segregated paths
 ____ On road cycling lane
 ____ On road cycling

Reasons for 1:

Q8. What do you most commonly (*choose up to 2*) do when you see a...

pedestrian on your way (for cyclists)	cyclist on your way (for pedestrians)
☐ I move to/keep to the left	☐ I move to/keep to the left
☐ I go opposite from the pedestrian	☐ I go opposite from the cyclist
☐ I slow down to allow the pedestrian to pass	☐ I stop to allow the cyclist to pass
☐ I ring the bell to alert the pedestrian	☐ I step off the path to let the cyclist pass
☐ Nothing, keep at the same direction & speed	☐ Nothing, keep at the same direction & speed
☐ Others:	☐ Others:

Q9. When sharing paths, **where...** (*choose up to 2*)

do you usually look? (for cyclists)	do cyclists usually look? (for pedestrians)
☐ The path (below)	☐ The path (below)
☐ To the front to look out for obstructions	☐ To the front to look out for obstructions
☐ To the front to look out for traffic signals	☐ To the front to look out for traffic signals
☐ At my mobile device	☐ At their mobile device
☐ To the sides (sightseeing)	☐ To the sides (sightseeing)
☐ Others:	☐ Others:

Q10. Do you agree with the following statements?

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
I feel comfortable sharing paths with pedestrians/cyclists					
I consider dangerous to share paths with pedestrians/cyclists					
I tend to avoid paths with high volume of pedestrians/cyclists					
I think more signals and marking are necessary to improve safety on shared paths					
I think paths should be wider for sharing					
(cyclists only) I prefer to share with pedestrians than to share with cars					
(cyclists only) I am willing to cycle directly on road					
(cyclists only) I am willing to cycle on road provided a cycle lane					

Q11. Does the provision of cycling infrastructure affect your walking/cycling trips?

- ☐ Yes, why and how? _____
- ☐ No

Demographics

QD1. How many bicycle(s) and PMDs in your household?

☐ Adult bicycle _____ ☐ Children bicycle _____ ☐ Motorised bicycle _____ ☐ PMDs _____

QD2. How many vehicles in your household?

☐ Car/Van _____ ☐ Motorcycle/Motorised scooter _____
QD3. Gender: ☐ Male ☐ Female

QD4. Age range:

☐ 10-14yrs	☐ 25-29 yrs	☐ 40-44 yrs	☐ 55-59 yrs
☐ 15-19 yrs	☐ 30-34 yrs	☐ 45-49 yrs	☐ 60-64 yrs
☐ 20-24 yrs	☐ 35-39yrs	☐ 50-54 yrs	☐ ≥65 yrs

QD5. How long have you lived in Singapore? _____ years

QD6. Occupation? ☐ Employed ☐ Student ☐ Housewife ☐ Retired ☐ Unemployed ☐ Others:

Interview Details

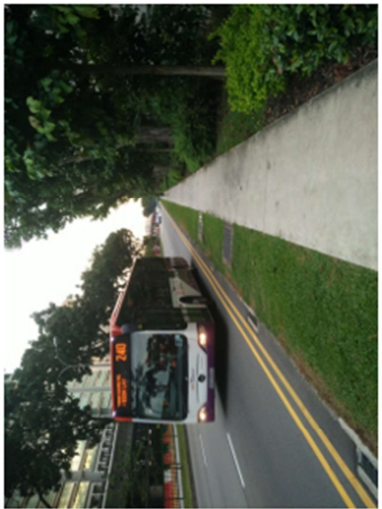
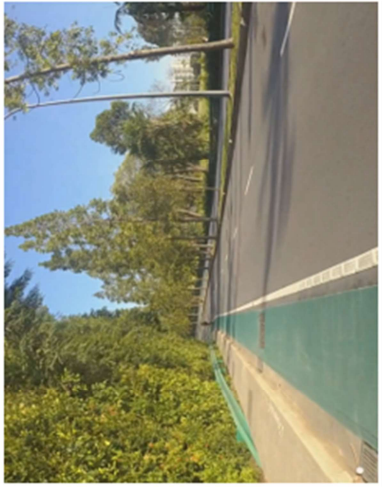
Location: _____

Type of path: Pathway/ Extended Paths/Segregated Paths/Delinated Paths

Type of user: Pedestrian/cyclist

Interviewer: _____ Date: _____ Time: _____

Pathways show-cards (related to Q7) — presented in different order per survey

<u>Pathway</u> 	<u>Extended Paths</u> 	<u>On Road Cycling Lane</u> 
<u>Delinated Paths</u> 	<u>Segregated Paths</u> 	<u>On Road Cycling (No Cycling Lane)</u> 

Types of PMDs show-cards (related to QD1)

Example of PMDs



Kick scooter



Electric scooter



Electric unicycles



Hoverboard



Roller skates



Skateboard

Voucher issuance form

(ADD LOCATION) _____

By signing below, I acknowledge that I've received a **5S\$** shopping voucher for participating in a Survey for research study. Conducted by NTU students at (ADD LOCATION) _____.

	Full Name	Voucher Amount	Contact	Signature	Additional remarks
1		5 S\$			NTUC
2		5 S\$			NTUC
3		5 S\$			NTUC
4		5 S\$			NTUC
5		5 S\$			NTUC
6		5 S\$			NTUC
7		5 S\$			NTUC
8		5 S\$			NTUC
9		5 S\$			NTUC
10		5 S\$			NTUC
11		5 S\$			NTUC
12		5 S\$			NTUC
13		5 S\$			NTUC
14		5 S\$			NTUC
15		5 S\$			NTUC

- Total number of vouchers: _____
- Total amount (in vouchers): _____
- Checked by: _____
- Date: _____

ATTITUDES TOWARDS ACTIVE MOBILITY STUDY

Pre or Post focus group session and one-to-one interview questionnaire

1. What is the most common reason of your walking trips in Singapore?

- ☐ Reach another transport mode ☐ Go to work/school ☐ Shopping/run errands
☐ Recreation/sport ☐ Social purpose/visit friends ☐ Other (please specify): _____

2. How often do you cycle in Singapore?

- ☐ Almost every week ☐ Once a month ☐ Less than once a month ☐ Never

3. What is the average length of your cycling trips?

- ☐ Less than 15 minutes ☐ 15 to 30 minutes ☐ 30 to 45 minutes ☐ More than 45 min

4. What is the most common reason for your cycling trips?

- ☐ Reach another transport mode ☐ Go to work/school ☐ Shopping/run errands
☐ Recreation/sport ☐ Social purpose/visit friends ☐ Other (please specify): _____

5. Do you agree with the following statements?

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
It is very safe and convenient for me to walk in Singapore					
It is very safe and convenient for children to walk in Singapore					
It is very safe and convenient for elders to walk in Singapore					
It is very safe and convenient for me to cycle in Singapore					
It is very safe and convenient for children to cycle in Singapore					
It is very safe and convenient for elders to cycle in Singapore					
Special zones (school and silver zones) encourage people to walk and cycle more					

6. Do you have children?

- ☐ Yes (Please indicate their ages): _____ ☐ No

7a. How many cars in your household? _____ 7b. How many members in your household? _____

8. How many bicycles in your household

- ☐ Children bicycle: _____ ☐ Adult bicycle: _____ ☐ Electric bicycle: _____

9. Occupation

- ☐ Full time employed ☐ Part-time employed ☐ Others (Student/housewife/retired)

Focus group activities and questions

To be completed by moderator: Participant Number: _____

Participant Gender: _____

At the beginning it will be made clear that we refer to walking and cycling as modes of transport.

Engagement questions/activity:

1. Write two advantages and two disadvantages of walking and cycling in Singapore. See Figure 1.

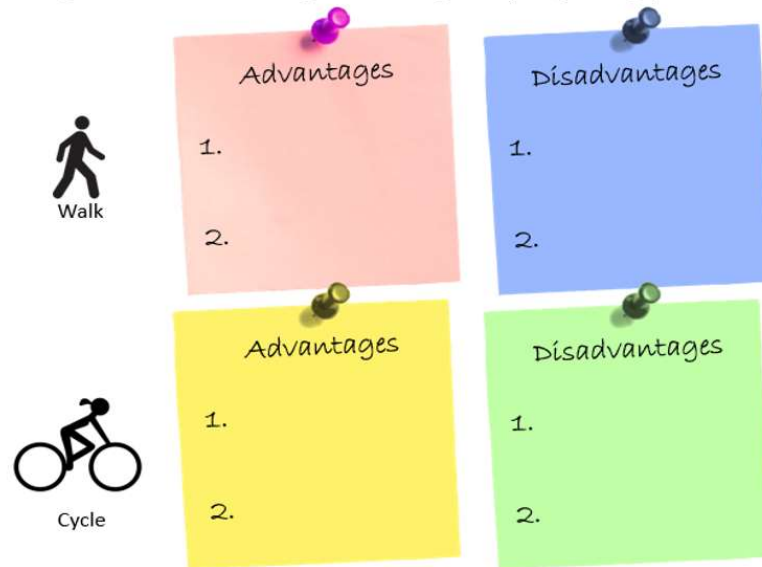


Figure C1. Example of cards given to participants for focus group activity

2. Please explain why these are advantages or disadvantages and how do you think they can be improved.

Exploration questions:

3. (general) How do you decide whether or not to use active modes (as modes of transport)?
4. (general) Who do you think is responsible for promoting active trips in Singapore?
5. (walk) Is the overall transport environment in Singapore conducive for walking trips?
6. (cycle) Do cycling facilities in Singapore meet your expectations? Why?
7. (walk) What could be done to promote more walking trips in Singapore?
8. (cycle) What could be done to promote more cycling trips in Singapore?

Exit question:

9. (general) Does someone have anything to add about reasons for walking or cycling in Singapore?

In-depth one-to-one interview questionnaire

One-to-one interview questions (Qualitative data)

To be completed by moderator: Participant Age: _____

Participant Gender: _____

At the beginning it will be made clear that we refer to walking and cycling as modes of transport.

Engagement questions:

1. Please cite two advantages of walking
2. Why do you think this is an advantage?
3. Please cite two disadvantages of walking
4. Why do you think this is a disadvantage?
5. Please cite two advantages of cycling
6. Why do you think this is an advantage?
7. Please cite two disadvantages of cycling
8. Why do you think this is a disadvantage?

Exploration questions:

1. (general) How do you decide whether or not to use active modes (as modes of transport)?
2. (general) Who do you think is responsible for promoting active trips in Singapore?
3. (walk) Is the overall transport environment in Singapore conducive for walking trips?
4. (cycle) Do cycling facilities in Singapore meet your expectations? Why?
5. (walk) What could be done to promote more walking trips in Singapore?
6. (cycle) What could be done to promote more cycling trips in Singapore?

Exit question:

1. (general) Does someone have anything to add about reasons for walking or cycling in Singapore?

Focus group and one-to-one interview agreement of participation

Participation Consent form and Incentive Receipt



Introduction:

We (PhD students from Nanyang Technological University, Singapore) are conducting active mobility perception and study. The main purpose of this study is to get a clearer picture of factors that affect active modes of transport (walking and cycling) mode choice.

For the study participant will be asked to complete a survey regarding his/her demographic data and overall opinion about active mobility then, during the focus group session, 8 to 9 open-ended questions to be asked allowing few minutes' discussion per question. The task requires you to answer simple and easy questions and discuss opinions. There are no direct risks related to your participation in the focus group session.

Participation is voluntary and one may choose to withdraw from the study at any time with no penalty. The recorded data will be used for academic research and publications. No personal information (Name, NIRC/FIN No, and contact information) will be disclosed.

##

Consent and receipt:

I Acknowledge that I decided to volunteer as a research participant for the above-mentioned study conducted by Nanyang Technological University, Singapore. For my participation I received _____ incentive.

Name: _____

Signature: _____

NIRC/FIN No.: _____

Contact No.: _____

E-mail: _____

Date: _____

Appendix D – Training of interviewers and pilot test

This appendix explains the methodology for the training of interviewers and the household survey pilot test using the developed household survey questionnaire.

Training of interviewers

Interviewers who shall be conducting the household surveys attended a training session (see Figure D1). The training session was conducted at The Nielsen's office (#13-00 Goldbell Towers, 47 Scotts Road at Newton) on 11 September 2017. Members of NTU researcher team attended the training session to gain the first-hand experience of the training methodology, to address any queries regarding the aim of the study, and to ensure the definitions of key terms were kept in accordance with the project's scope. During the training session, interviewers received inputs on four key points related to the project to understand the travel habits of Singapore residents. These included:

- (1) Research objectives → Key objectives are to understand the different trips made by various members of the households in Singapore in a typical day, to get a deeper understanding of travel behaviour among Singapore residents, to gauge opinion of their sentiments towards walking and cycling and to measure their willingness to switch to active mobility modes of transport for their daily commuting requirement.
- (2) Target groups and research methodology → 4 townships are covered in this study. Target groups include all household members aged 6 years and older and it also includes members who are sharing the house with the main tenant. Research methodology adopted is face-to-face interview using computer assistance at respondent's home for HDB and landed property and for condominium, street intercept method is adopted for initial household approach reasons.
- (3) Sampling methodology → Selection of blocks (PSU) is done by Nielsen Statistician using the list of the addresses provided by Department of Statistics (DoS), taking into consideration the 4 town boundaries. Each township will have around 50 PSU.
- (4) Survey methodology → Instructions given to interviewer on how to collect details such as household demographics, individual details, personal trip details, bicycle/PMD usage, bicycle-sharing information and addresses of locations travelled by the respondent. The importance of recording all trip-stages and specific geo-references origin and destination of each trip-stage was highlighted to the interviewers.

Interviewers were also given a detailed manual to refer back to it when necessary as shown in Figure D2



Figure D1. Interviewers' training session

SURVEY FLOW

- ☐ Household Demographics
 - Household Details (PAPI)
 - ☐ Individual Details
 - ☐ Personal Trip Details
 - Trip Entries Form (PAPI)
 - ☐ Bicycle/Personal Mobility Devices Usage
 - ☐ Bike Sharing Information
 - ☐ Township/Address

The following questions to be answered by head of household. If head of household is unavailable, speak to a senior member of the household instead.

INSTRUCTION TO INTERVIEWER:

Interviewer to approach head of household for the following questions. If head of the household is unavailable, seek another senior member of the household, who is aware of household conditions (E.g. number of members in the household, monthly household income)

INTERVIEWER TO TELL RESPONDENT (HEAD OF HOUSEHOLD OR OTHER SENIOR MEMBER):

Dear Respondent - We are from the Nielsen Company, a leading market research agency and are currently conducting a study on yours and your household member's travel habits.

Your inputs will be greatly appreciated.

Before we begin, we would like to inform you about the purpose of this study and our commitment to privacy and confidentiality:

1. We will only use the information provided to us for research purposes and not to market or sell anything to you.
2. We may process your information locally or abroad but whenever is processed we are committed to protecting it.

Thank You.

Figure D2. Interviewers' manual

SURVEY FLOW

- ☒ Household Demographics
 - Household Details (PAPI)
- ☐ Individual Details
 - ☐ Personal Trip Details
 - Trip Entries Form (PAPI)
 - ☐ Bicycle/Personal Mobility Devices Usage
 - ☐ Bike Sharing Information
 - ☐ Township/Address

In the following questions, there may be TEXT A or TEXT B. Text A is for respondent who are 15 YO and above, while Text B is for those who are answering on behalf of 6-14 YO.

INSTRUCTIONS TO INTERVIEWER:

Interviewer to explain survey details to current respondent. Following questions (Q15-Q48) will be asked for each household member above the age of 6 years old (including full time domestic help / maids). In the event of the household member being older than 6 years old, but younger than 14 years old, their information would be collected from their parents / guardian.

Subsequently, interviewer to commence the next section with the current respondent (who answered the above questions).

INTERVIEWER TO EXPLAIN TO RESPONDENT:

In this study, we will be interviewing all the household members who are 6 years old and above. For household members who are 6-14 years old, we will require their parents/guardian to answer on their behalf.

Now, we would like to understand more about yourself.

For household members who are 6-14 years old, parents/guardian to answer on behalf.

Q15 **INTERVIEWER TO CODE**

Is the respondent aged 6 - 14 years old? [SA]

Yes	1
No	2

NOTE: The FIRST RESPONDENT to key in their details and travel trips must be the one who just answered the household demographics.

Figure D2. Interviewers' manual (cont'd)

SURVEY FLOW

- ☒ Household Demographics
 - Household Details (PAPI)
- ☒ Individual Details
 - ☐ Personal Trip Details
 - Trip Entries Form (PAPI)
 - ☐ Bicycle/Personal Mobility Devices Usage
 - ☐ Bike Sharing Information
 - ☐ Household Details (PAPI)
 - Arrange for callback if needed

Trips to be captured for LASTWORK DAY only.

NOTE TO INTERVIEWER: To record all the trips on the "Trip Entries Form" and interview the qualified trips.

Text A: Now I would like to ask you about your travelling trips made yesterday. Note that a trip begins the moment you exit a place. For example, you walked to a friend's place from your house, you commute to work from home, taking a walk or a jog in the nearby park or you leave office for the nearby coffee shop for lunch. Can you take me through all the trips that you have made yesterday from morning to night in a chronological order.

Text B: Now I would like to ask you about your child's travelling trips made yesterday. Note that a trip begins the moment your child exit a place. For example, he/she walked to a friend's place from the house, he/she commute to school from home, taking a walk or a jog in the nearby park or he/she leave school for other curriculum. Can you take me through all the trips that your child has made yesterday from morning to night in a chronological order.

REFER TO THE NEXT SLIDE FOR "TRIP ENTRIES FORM" >>>

Figure D2. Interviewers' manual (cont'd)

HOUSEHOLD ID: YS760297/05-63

RESPONDENT NUMBER: 3

TRIP STARTING POINT	STARTING POINT WITHIN TOWNSHIP	TRIP ENDING POINT	TRIP ENDING POINT WITHIN TOWNSHIP	TRIP QUALIFIED FOR NEXT STAGE
HOME	YES	Chong Pang MKT	YES	YES
Chong Pang MKT	YES	Goldbell Towers	NO	YES
Goldbell Towers	NO	Far East Shopping Centre	NO	NO
Far East Shopping Centre	NO	Goldbell Towers	NO	NO
Goldbell Towers	NO	HOME	YES	YES

A trip qualifies if:

- Starting point is within the township and ending point is also within the township
- Starting point is outside the township but ending point is within the township
- Both starting point and ending points are within the township

A trip whose starting point as well as ending point is outside the township does not qualify.

LEGENDS

HG - Hougang	SW - Sembawang	SG - Serangoon	YS - Yishun
SCH - School	KG - Kindergarten	PRI - Primary	SEC - Secondary
MKT - Market	PK - Park/Garden	CC - Community Club	PG - Playground
PC - Polyclinic	HOS - Hospital	GP - Clinic	CS - Coffeeshop
C - Church	T - Temple	M - Mosque	HC - Hawker Centre
FC - Fitness Corner	BB - Basketball Court	FB - Football Court	SC - Swimming Complex

TRIP ENTRIES FORM

(GUIDELINES)

Trip starting point will most likely be "Home", unless respondent spent the night at other locations.

For Trip Starting Point and Trip Ending Point: Interviewer needs to record the location to the best of his/her ability. To probe if necessary. Needs to record the landmark and the region in brackets. For example: Sunshine Plaza (Dhoby Ghaut). If respondent mentions a landmark near their home (E.g. Kindergarten near my home), record it as "Kindergarten near (Respondent BLK Address)".

If trip points are not a landmark (E.g. Friends' house), probe for address if possible (BLK 123 Yishun).

All points of a trip needs to be recorded, once respondent stop over for any other purpose besides commuting. For example, a respondent picks up dinner at Newton MRT, 7-11 on the way back home. Instead of capturing it under 1 trip of "Goldbell Towers to Home", it will be 2 trips, "Goldbell Towers to 7-11 (Newton)" and "7-11 (Newton) to Home".

NOTE: A to and fro trip does not count as one trip. Also, do not confuse a child's trip details with the parents' trips. A child going to school and back home from school (2 trips) is different from a parent going to school to drop his/her child, and heading back home, after which going back to school to pick up his/her child back home (4 trips).

Examples

- SW PC (Sembawang Polyclinic)
- MKT near HG BLK 142 (Market near Hougang BLK 142)
- C near YS BLK 123 (Church near Yishun BLK 123)
- FC near SG BLK 22 (Fitness Corner near Serangoon BLK 22)

Figure D2. Interviewers' manual (cont'd)

TRIP ENTRIES FORM

(EXAMPLE 1)

HOUSEHOLD ID: YS760297/05-63

RESPONDENT NUMBER: 3

TRIP STARTING POINT	STARTING POINT WITHIN TOWNSHIP	TRIP ENDING POINT	TRIP ENDING POINT WITHIN TOWNSHIP	TRIP QUALIFIED FOR NEXT STAGE
HOME	YES	Chong Pang MKT	YES	YES
Chong Pang MKT	YES	Goldbell Towers	NO	YES
Goldbell Towers	NO	Far East Shopping Centre	NO	NO
Far East Shopping Centre	NO	Goldbell Towers	NO	NO
Goldbell Towers	NO	HOME	YES	YES

A trip qualifies if:

- Starting point is within the township and ending point is also within the township
- Starting point is outside the township but ending point is within the township
- Both starting point and ending points are within the township

A trip whose starting point as well as ending point is outside the township does not qualify.

*Interviewer questions about travelling trips made on previous work day.

R: I woke up in the morning and went to the nearby Hawker Centre – Chong Pang to have my breakfast. Once done, I went straight to office. Worked for 8 hours, before heading home. Didn't go out after that.

I: May I know roughly where is Chong Pang Hawker Centre?

R: Oh, it is in Yishun.

I: Also, may I know where is your office?

R: It is at Goldbell Towers in Newton.

I: During the 8 hours spent in Goldbell Towers, did you leave the office at all, perhaps for a visit to client or for meals?

R: Oh! I went Far East Shopping Centre for lunch.

I: That is the shopping centre in Orchard, right? Did you head anywhere else after lunch?

R: Right! No, I went back to office after lunch to continue working.

I: From after lunch to the end of work, did you leave the office?

R: No, I was at the office the entire time.

I: On the way back home from Goldbell Towers to your home, did you make a stopover at any other destinations, for example a convenience store to buy dinner?

R: No, I went directly back home.

Figure D2. Interviewers' manual (cont'd)

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TRIP STAGES (GUIDELINES)

You mentioned that you travel between <SHOW ANSWER FROM Q28> and <SHOW ANSWER FROM Q29> Can you share with me the details of the entire journey?

START	END	MODE OF TRANSPORT (DROPDOWN)
Chong Pang MKT	BS: Chong Pang MKT	Walk
BS: Chong Pang MKT	MRT: SW	Bus
MRT: SW	MRT: Newton	MRT
MRT: Newton	Goldbell Towers	Walk

LEGENDS

HG - Hougang	SW - Sembawang	SG - Serangoon	YS - Yishun
BI - Bus Interchange	BS - Bus Stop	CP - Carpark	TS - Taxi Stand

Do not confuse trip entries with trip stages. Trip stages is the details of the trip entries, where interviewer is supposed to capture the various modes of transport that the respondent used to get from point A to point B.

For Trip Stage Starting Point and Trip Stage Ending Point: Interviewer needs to record the location to the best of his/her ability.

Standardized Approach to capturing common destinations
 Bus Stop: XXXX
 MRT: XXXX
 Interchange: XXXX

Initial starting point = Answer from Q28
 Final ending point = Answer from Q29

Mode of transport will be a drop down list.

Examples

- TS: Novena Square (Taxi Stand: Novena Square)
- Bishan BI (Bishan Bus Interchange)
- BS near HG Blk 142 (Bus Stop near Hougang Blk 142)

Figure D2. Interviewers' manual (cont'd)

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TRIP STAGES (EXAMPLE #1)

You mentioned that you travel between <SHOW ANSWER FROM Q28> and <SHOW ANSWER FROM Q29> Can you share with me the details of the entire journey?

START	END	MODE OF TRANSPORT (DROPDOWN)
Home	Chong Pang MKT	Walk

*Interviewer questions about details of entire journey (Home to Chong Pang Food Centre)

R: Oh, Chong Pang Food Centre is quite some distance from my house. I walked there, it takes me about 15 minutes normally.

Figure D2. Interviewers' manual (cont'd)

TRIP STAGES (EXAMPLE #2)

You mentioned that you travel between <SHOW ANSWER FROM Q28> and <SHOW ANSWER FROM Q29> Can you share with me the details of the entire journey?

START	END	MODE OF TRANSPORT (DROPDOWN)
Chong Pang MKT	BS: Chong Pang MKT	Walk
BS: Chong Pang MKT	MRT: Sembawang	Bus
MRT: Sembawang	MRT: Newton	MRT
MRT: Newton	Goldbell Towers	Walk

*Interviewer questions about details of entire journey (Chong Pang Food Centre to Goldbell Towers)

R: Oh, its quite inconvenient at Chong Pang Food Centre. No nearby MRT. So I'm forced to take a feeder bus and switch to the MRT.

I: Sorry to interrupt, may I know from which bus stop do you take the feeder bus service? Also, kindly share the method which you used to travel to this bus stop from Chong Pang Food Centre.

R: I take the feeder bus service from the bus stop that is just down the road, a short walk away only.

I: Which MRT station do you take the bus to?

R: I take the bus to Sembawang MRT, then I take the MRT all the way to my office at Goldbell towers.

I: Just to confirm, it is a direct bus service from Chong Pang Food Centre bus stop to Sembawang MRT? Is there a transfer at any point in time?

R: Yes.

I: Which MRT station do you alight to head to Goldbell Towers? Also, once again what is the method used to travel from the MRT station to your office?

R: I alight at Newton MRT. My office is just a short walk away.

Figure D2. Interviewers' manual (cont'd)

1ST RESPONDENT
TRIP ENTRIES VS TRIP STAGES
HOUSEHOLD ID

TRIP STARTING POINT	STARTING POINT WITHIN TOWNSHIP	TRIP ENDING POINT	TRIP ENDING POINT WITHIN TOWNSHIP	TRIP QUALIFIED FOR NEXT STAGE
HOME	YES	KG NEAR BLK 142 HG	YES	YES
KG NEAR BLK 142 HG	YES	HOME	YES	YES
HOME	YES	KG NEAR BLK 142 HG	YES	YES
KG NEAR BLK 142 HG	YES	PG NEAR BLK 142 HG	YES	YES
PG NEAR BLK 142 HG	YES	HOME	YES	YES

TRIP ENTRIES:
Consists of details about the trips made for the entire day. Interviewer to fill up on PAPI form first. Subsequently, to choose **QUALIFIED** trips and key in CAPI device.

Trip Starting Point [SA]

☐ Within the township, please specify:

☐ Outside the township, please specify:

Trip Ending Point [SA]

☐ Within the township, please specify:

☐ Outside the township, please specify:

START	END	MODE OF TRANSPORT (DROPDOWN)
Chong Pang MKT	BS: Chong Pang MKT	Walk
BS: Chong Pang MKT	MRT: Sembawang	Bus
MRT: Sembawang	MRT: Newton	MRT
MRT: Newton	Goldbell Towers	Walk

TRIP STAGES:
Consists of the journey for QUALIFIED trip entries, where interviewer captures the various modes of transport that the respondent used to get from point A to point B. To key in directly into CAPI device, without PAPI.

	Trip Stages - Start	Trip Stages - End	Mode of Transport
Q1			Please select
Q2			Please select
Q3			Please select
Q4			Please select
Q5			Please select
Q6			Please select

Figure D2. Interviewers' manual (cont'd)

1ST RESPONDENT
TRIP ENTRIES VS TRIP STAGES
HOUSEHOLD ID

TRIP STARTING POINT	STARTING POINT WITHIN TOWNSHIP	TRIP ENDING POINT	TRIP ENDING POINT WITHIN TOWNSHIP	TRIP QUALIFIED FOR NEXT STAGE
HOME	YES	HG NEAR BLK 142 HG	YES	YES
HG NEAR BLK 142 HG	YES	HOME	YES	YES
HOME	YES	HG NEAR BLK 142 HG	YES	YES
HG NEAR BLK 142 HG	YES	PG NEAR BLK 142 HG	YES	YES
PG NEAR BLK 142 HG	YES	HOME	YES	YES

Trip Starting Point [SA]
☐ Within the township, please specify:
☐ Outside the township, please specify:

Trip Ending Point [SA]
☐ Within the township, please specify:
☐ Outside the township, please specify:

LEGENDS

HG - Hougang	SH - Sembawang	SG - Serangoon	YS - Yishun
SCH - School	KG - Kindergarten	PD - Primary	SEC - Secondary
MKT - Market	PK - Park/Garden	CC - Community Club	PG - Playground
PC - Polyclinic	HOS - Hospital	GP - Clinic	CS - Cafeteria
C - Church	T - Temple	M - Mosque	
FC - Fitness Center	BB - Basketball Court	FB - Football Court	SC - Swimming Complex

- Always ensure that whatever you keyed in can be identified on the map. ("KG" vs KG near HG BLK 142)
 - Refer to legend to replace certain words if needed.

START	END	MODE OF TRANSPORT (DROPDOWN)
Chong Pang MKT	BS: Chong Pang MKT	Walk
BS: Chong Pang MKT	MRT: Sembawang	Bus
MRT: Sembawang	MRT: Newton	MRT
MRT: Newton	Goldbell Towers	Walk

Trip Stages - Start	Trip Stages - End	Mode of Transport
R1		Please select
R2		Please select
R3		Please select
R4		Please select
R5		Please select
R6		Please select

LEGENDS

HG - Hougang	SH - Sembawang	SG - Serangoon	YS - Yishun
BI - Bus Interchange	BS - Bus Stop	CP - Carpark	TS - Taxi Stand

- Not to be confused with trip entries. Trip stages is associated with mode of transport, to understand how respondent gets from one point to another.
 - Refer to legend to replace certain words if needed.

Figure D2. Interviewers' manual (cont'd)

1ST RESPONDENT
TRIP ENTRIES VS TRIP STAGES
HOUSEHOLD ID

Household ID: SW750341/11-132

SW750341/11-132

Address

Block

Street Name

Unit Number

Postal Code

Household ID is generated by the link from the interviewers' inputs for township/address details.

When keying in address details, kindly ensure that no additional spaces, as well as no '#' is keyed in.

Project Saver 2017

Household ID:	Day of Trip Recorded:	Phone Screen Allowed: ☐
Reference ID:	Date for Trip Recorded:	6-14 yrs old, language barrier & disabilities: ☐

NAME OF RESPONDENT	AGE OF RESPONDENT	CONTACT DETAILS	Head of Household	Completed

Project Saver 2017

Household ID:	Day of Trip Recorded:
Respondent Name:	Date for Trip Recorded:

TRIP STARTING POINT	STARTING POINT WITHIN TOWNSHIP	TRIP ENDING POINT	ENDING POINT WITHIN TOWNSHIP	TRIP QUALIFIED FOR NEXT STAGE

A Trip qualifies if:
 • Starting point is ending point is within the township.
 • Both starting point and ending point are within the township.
 A trip whose starting point as well as ending point is OUTSIDE the township does NOT qualify.
 Please refer to the [Trip Recorder](#) if you are unsure reach out to Barry / Jacky.

Figure D2. Interviewers' manual (cont'd)

SURVEY FLOW

- ☐ Township/Address
- ☐ Individual Details
- ☐ Personal Trip Details
 - Trip Entries Form (PAPI)
- ☐ Bicycle/Personal Mobility Devices Usage
- ☐ Bike Sharing Information

The flow of the re-contact survey is similar to the main survey.

Differences between main survey and re-contact survey:

- We moved the "Township/Address" section to the top and have included 2 new questions (shown on the right).
- We have removed the "Household Details" section, since we have recorded in the main link.

RECONTACT SURVEY LINK

Q50 Household ID: _____

When keying in household ID, please ensure accuracy. No additional spaces, nor '#' to be keyed in.

Project Number 2017				
Household ID	Respondent Name	Day of Trip Recorded	Date for Trip Recorded	
TRIP STARTING POINT	STARTING POINT WITHIN TOWNSHIP	TRIP ENDING POINT	ENDING POINT WITHIN TOWNSHIP	TRIP QUALIFIER FOR NEXT STAGE?

Q51 [INTERVIEWER TO CODE](#)

Number of Respondent for Re-Contact? [SA]

Code (163)

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Figure D2. Interviewers' manual (cont'd)

Pilot survey

A pilot survey was conducted at HDB blocks in one of the selected towns (Hougang). The interviewers were trained survey personnel from The Nielsen's project team. The author participated in the pilot survey as an observer so as to get the first-hand experience of the field activities. The overall sampling technique and survey questionnaire were tested using the face-to-face approach with aid of electronic tablets for survey administration. The duration of the interview was measured as well as "friendliness" of the questionnaire. Special attention was placed in recording trip details and prompting respondents to report ALL trips made the day before, and also about trip chaining. The pilot test started at 2:30 pm. The timing was selected so that there would be some "incomplete" households and re-visit was to be made at a later time.

Appendix E – Other characteristics regarding neural network training performance

This appendix first presents information related to neural network training and performance for current scenario (survey data).

