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**INTERACTION BEHAVIOUR OF ACTIVE MOBILITY
USERS IN SHARED SPACE**

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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

2021

INTERACTION BEHAVIOUR OF ACTIVE MOBILITY USERS IN SHARED SPACE

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School of Civil and Environmental Engineering

A thesis submitted to the Nanyang Technological University in
partial fulfilment of the requirement for the degree of
Doctor of Philosophy

STATEMENT OF ORIGINALITY

I hereby certify that the work embodied in this thesis is the result of original research, is free of plagiarised materials, and has not been submitted for a higher degree to any other University or Institution.

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AUTHORSHIP ATTRIBUTION STATEMENT

This thesis contains material from one paper published in the following peer-reviewed journal in which I am listed as an author. The thesis also contains material from paper submitted to peer-reviewed journals and now under review.

Chapter 4 is published as **Che, M.**, Lum, K.M., Wong, Y.D. (2020) “Users’ attitudes on electric scooter riding speed on shared footpath: A virtual reality study”, *International Journal of Sustainable Transportation*, 1-10. doi:10.1080/15568318.2020.1718252.

The contributions of the co-authors are as follows:

- I proposed the initial project direction.
- I prepared the manuscript draft. The manuscript was revised by Prof Wong and Dr Lum.
- I designed the experiment and finished data collection.
- Prof Wong and Dr Lum helped with the interpretation of experiment’s results.

Chapters 5 and 6 combined are submitted as **Che, M.**, Wong, Y.D., Lum, K.M., Wang, X. (2020) “Interaction behaviour of active mobility users in shared space”, *Transportation Research Part A: Policy and Practice* (under review).

The contributions of the co-authors are as follows:

- I proposed the initial project direction.
- I proposed the conceptual framework. Dr Wang helped to refine it.
- I designed the survey and finished data collection.
- I completed the data analysis. Prof Wong, Dr Lum and Dr Wang helped to refine the data analysis.
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The contributions of the co-authors are as follows:

- I proposed the initial project direction.
- I prepared the manuscript draft. The manuscript was revised by Prof Wong, Dr Lum and Dr Rojas Lopez.
- I designed the experiment and finished data collection.
- Prof Wong, Dr Lum and Dr Rojas Lopez helped with the interpretation of experiment’s results.

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SUMMARY

The first Singapore Active Mobility Bill was enacted in 2017, which allowed pedestrians, bicycles and personal mobility devices (PMDs) to share rights-of-way along the generally narrow off-road footpaths which, hitherto, have been the exclusive domain of the pedestrians. The number of crashes has increased since the space sharing scheme started. The authority regulated travelling speed from 15km/h to 10km/h on the footpaths, which did not yield an effective result in improving safety performance. This calls for research into shared footpath user behaviour. Reviewing past literature, a knowledge gap is evident regarding theorisation of interactive user behaviour in shared space. In this research, the following steps are taken to establish a framework for modelling interactive shared space behaviour:

1. A virtual reality (VR) experiment was conducted to assess footpath users' (pedestrians and electric scooter riders) speed perception and attitudes.
2. With the findings from VR experiment and coupled with reviews on relevant social behaviour theories, critical constructs that influence users' behavioural intention were identified. Seven hypotheses were proposed. A conceptual space sharing behavioural framework was formed.
3. An online perception survey was conducted on pedestrians and cyclists to evaluate the proposed hypotheses and hence validate the developed space sharing behavioural framework.
4. The developed space sharing framework models people's behavioural intention. To examine how behavioural intention is translated to action (actual behaviour), a before-and-after field experiment regarding "keep left" on the footpaths was conducted.

The findings of the VR experiment suggest that speed regulation would not be effective in improving footpath user behaviour. Instead, perceptual factors such as perceived control and perceived priority have effects on users' behavioural intention. Built on these findings, a space sharing behavioural framework was developed which asserts that users' perceived control, perceived risk level and

perceived priority influence their attitudes. Their attitudes, in turn, determine how they intend to behave on the shared footpaths. The framework was validated by a perception survey which further suggests that different user groups form their behavioural intentions differently. Pedestrians tend to compensate for their own risks but take advantage of cyclists' risks, indicating a competitive way of space sharing. Cyclists tend to compensate for pedestrians' risks, thereby indicating a more cooperative way of space sharing.

The space sharing framework provides a model of behavioural intention. However, the "keep left" experiment shows that the relationship between behavioural intention and action could be weakened by the existence of habit. Travelling on footpath is an everyday recurring action, which becomes a habit. Habit is context dependent such that once formed, context cues such as physical location, environment and time of day trigger the action without any conscious rationalisation. In modelling such repetitive actions, behavioural intention alone is incomplete in influencing the behaviour pattern. Influence from habit should also be taken into consideration. The construct of habit is thus augmented into the framework to complete the modelling of shared space behaviour.

LIST OF PUBLICATIONS

Journals

Che, M., Lum, K.M., Wong, Y.D. (2020) “Users’ attitudes on electric scooter riding speed on shared footpath: A virtual reality study”, *International Journal of Sustainable Transportation*, 1-10. doi:10.1080/15568318.2020.1718252

Zhou, Q., **Che, M.**, Koh, P.P., Wong, Y.D. (2020) “Effects of improvements in non-motorised transport facilities on active mobility demand in a residential township”, *Journal of Transport & Health*, Volume 16. doi:10.1016/j.jth.2020.100835

Oehl, M., Becker, T., **Che, M.**, Brandenburg, S. (2020) “Validation of the cycling anger scale in Singapore”, *Traffic Injury Prevention*. doi: 10.1080/15389588.2020.1843161

Che, M., Wong, Y.D., Lum, K.M., Rojas-Lopez, M.C. (2020) “Users’ behavioural intention and their behaviour: Before-and-after study of “keep left” markings on shared footpaths”, *International Journal of Sustainable Transportation* (under review)

Che, M., Wong, Y.D., Lum, K.M., Wang, X. (2020) “Interaction behaviour of active mobility users in shared space”, *Transportation Research Part A: Policy and Practice* (under second revision)

Che, M., Upahita D.P., Secadiningrat, J.R., Wong, Y.D., Lum, K.M., (2019) “Cyclists’ preference study in using four types of cycling facilities in Singapore”, *Case Studies on Transport Policy* (under review)

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GLOSSARY

Active mobility	Pedestrians and cyclists including personal mobility device (PMD) users
Active Mobility Bill	An Act for the establishment of public paths for walking, cycling or other similar purposes, to regulate the use of these public paths, and to make consequential and related amendments to certain other Acts
Action	An individual's actual behaviour
Behavioural intention	The degree to which an individual has formed a conscious plan to perform a specified action
Electric bicycle	Bicycle equipped with battery-powered motor
Head-mounted display (HMD)	A head-mounted display is a display device, worn on the head or as part of a helmet, that has a small display optic in front of one or each eye.
Omnidirectional (360-degree) camera	A camera having a field of view that covers approximately the entire sphere or at least a full circle in the horizontal plane
Park connectors	Greenways that connect major parks and other places of interest, and providing off-road bicycle path for cycling and jogging
Personal mobility device (PMD)	Any assistive device that facilitates individual human transportation, including skateboards, kick-scooters, electric scooters, hoverboards and so on, but excluding bicycles and wheelchairs
Pedal bicycle	Bicycle that relies on human pedalling to travel

Personal space (PS)	Individual's preferred distance from others
Right-of-way	The legal right, established by usage or grant, to pass along a specific route through grounds or property belonging to another
Shared footpath	A length of path (whether or not contiguous with another path or a road) provided for pedestrians to use, or individuals to ride a bicycle or personal mobility device on, and ending at the nearest of the following: (a) a pedestrian-only path sign or pedestrian-only path marking; (b) a shared path sign or shared path marking; (c) a road; or (d) the natural end of the path (which may be a dead end)
Virtual reality	Simulation in which a person can interact within an artificial three-dimensional environment using electronic devices, such as special goggles with a screen or gloves fitted with sensors.

CHAPTER 1 INTRODUCTION

1.1 Background of space sharing in Singapore's context

Active mobility refers to any mode of individual transportation that actively engages the human activity, including walking, running, cycling, skating, riding electric scooters (ES) and so on. Space sharing among constituent modes of active mobility is developed in a unique pattern along the footpaths in Singapore in the recent years (see Figure 1-1). By far, pedestrians and cyclists form the two main user groups of active mobility, while users of personal mobility devices (PMDs) such as ES, skateboards, kick-scooters, hoverboards (but excluding bicycles and wheelchairs) briefly appeared as another major players but the PMDs faded away due to policy changes.

Bicycle usage was common in Asia since 1930s and had its first peak in Singapore in the 1960's, with dedicated bicycle tracks along several major roads at that time (Koh & Wong, 2012). Later, with the booming of motorised transport, road infrastructure development shifted away from bicycle transport, and bicycle usage also declined rapidly (Rojas López & Wong, 2017a). The revival of bicycle transport came in early 1990s (Meng et al., 2014), with implementation of more and more infrastructure (park connectors, intra-town cycling networks and etc.) since then. However, due to space restrictions, on most roads where there are no dedicated bicycle paths, most bicycles choose to share, albeit illegally, mobility space with pedestrians along the off-road footpaths, which are generally confined 1.5m-wide concrete channels alongside the roadway.

Alongside the revival of bicycles, various types of electric PMDs also quickly gained popularity since the early 2010's (Che et al., 2020). Among all types of PMD, electric scooter (ES) was particularly popular. However, more bicycles and ES on footpaths increases exposure which can lead to increasing rates of crashes and injuries. To cope with these changes, Singapore enacted the first Active Mobility Bill in 2017 (Land Transport Authority, 2017a) that officially allows space sharing among pedestrians, bicycles and PMDs on the footpaths, provided that the maximum speed of bicycles and all types of PMDs is limited to 15km/h.

Figure 1-1 Active mobility development in Singapore

As the conflicts on shared footpaths continued with high crash rates in ES-pedestrian and bicycle-pedestrian interactions (Toh, 2019), tighter bicycle and PMD speed limit (at 10km/h) was implemented in 2019 (Land Transport Authority, 2018a). When the remedy of tighter speed regulation was found not to be effective, those devices associated with more crashes, namely ES and other types of PMDs, were progressively banned from the shared footpaths (Land Transport Authority, 2020c).

Regulating operating speed seems to have little effect in improving the safety level of bicycle-pedestrian and ES-pedestrian interactions in shared space. Even after banning PMDs on the footpaths, conflicts between cyclists and pedestrians are still common (Alkhatib, 2020). In the most recent revision of Active Mobility Bill in 2020, all shared footpath users (pedestrians, bicycles etc.) are encouraged to navigate on the left side of shared footpaths (Land Transport Authority, 2020a). Despite recent legislations and banning of ES on the shared footpaths, active mobility users' mindsets and behaviour on space sharing are not well understood.

1.2 Problem statement

Questions regarding how active mobility users using the shared space perceive different operating speeds, and why there has been little impact on resolving the interaction conflicts, remain to be addressed. To develop effective remedies to safe utilisation of shared space, specifically shared footpaths, a theoretical approach that models user behaviour patterns is highly worthy of development, which forms the research focus of this thesis.

1.3 Research aims, objectives and scopes

The aim of this research is to examine the mutual co-existence of mixed-stream active mobility users by assessing their attitudes and behaviour. The objectives include a) gain a basic understanding of the critical factors into interaction behaviour of active mobility users; b) building on existing human behaviour theories, propose an integrated conceptual framework that serves to model users' behavioural intention; c) validate the proposed framework; and d) extend

the framework to real-world action. The main scopes of work in this research are as follows.

1. Literature review into active mobility, shared space and behaviour theories
 - a. Review the development of bicycles and PMDs both overseas and locally in Singapore
 - b. Review local policies regarding shared footpaths
 - c. Review studies and guidelines regarding shared space
 - d. Review theories regarding human interactive behaviour
2. Understand users' speed perception and attitude toward shared footpaths
 - a. Conduct a virtual reality (VR) experiment to investigate users' perception towards different PMD operating speeds
 - b. Investigate why the speed regulation had little effect on reducing conflict level
 - c. Identify perceptual factors that influence user behaviour
3. Formulate a conceptual framework that models users' behavioural intention on shared footpaths
 - a. Identify contributing social behaviour theories to form the framework
 - b. Propose hypotheses that are related to behavioural intention
 - c. Assemble proposed hypotheses to form the conceptual framework
4. Validate the framework using perception survey on shared footpath users
 - a. Conduct a perception survey to validate the formed framework
 - b. Test the proposed hypotheses
 - c. Test the framework's effectiveness in modelling users' behavioural intention
5. Apply the framework using a field experiment
 - a. Propose hypotheses regarding the relationship between behavioural intention (as modelled in the framework) and action (shared footpath users' actual behaviour)
 - b. Conduct a before-and-after "keep left" experiment to validate the proposed hypotheses

- c. Conclude on the experiment's findings' impact on the developed conceptual framework

1.4 Report outline

The current Chapter briefly introduces the background to the study. The problem statement is established. The research aims and scopes are accordingly identified. The afore-mentioned research objectives are covered in the following Chapters.

Chapter 2 covers the first part of the literature reviews regarding the development of active mobility both overseas and locally in Singapore. The history and past studies on space sharing were also reviewed to identify the research gaps and to contextualise the working process in Chapter 4 on the VR experiment. Subsequent literature reviews on social behaviour theories are built into Chapter 5 as covering the conceptual framework formulation process, as well as in Chapter 7 when forming hypotheses for the “keep left” field experiment.

Chapter 3 reports on the research methodology. It explains the broad methodological issues and how each of the research activities is achieved.

Chapter 4 presents the case study of users' attitudes towards ES speed regulations on shared footpaths in Singapore. This Chapter also discusses why there was little effect in remediating the conflicts. Herein, with a deeper understanding of users' attitudes, the conceptual framework of the current study could be built.

Chapter 5 builds the conceptual framework for modelling users' behavioural intention based on the findings of VR experiment and literature scan into the theories of user behaviour. The space sharing behavioural framework was then validated by user perception surveys in Chapter 6.

Chapter 7 completes the user behaviour study by assessing the relationship between behavioural intention and action through a before-and-after “keep left” field experiment.

Chapter 8 summarises the studies and makes conclusions and recommendations on the developed framework and attendant findings.

CHAPTER 2 LITERATURE REVIEW ON ACTIVE MOBILITY DEVELOPMENTS

2.1 Journey on the bicycle

The bicycle is one of the oldest forms of active mobility devices given that it was invented in 1817 by Baron von Drais (Woods, 2016). In the first phase of bicycle development in the 1860s to 1880s, the high-wheel bicycles were designed and used as thrill-seeking devices mostly by young single males (Jones, 1979). By around 1890, bicycles were becoming similar to the modern form, with designs such as inflated tyres, drive chains, and equal-sized wheels for a safer and more stable ride. This so-called “safety bicycle” gradually gained popularity among urban middle-class women and older men for easier and faster short-distance travels in daily commuting. Subsequently, in the early 1900s, bicycles started to dominate the streets of many European cities, and by mid-1930s, the ownership of bicycles had reached 15 million in Germany and 9 million in Britain (Oldenziel & de la Bruhèze, 2011). However, in the same period, starting from the US and spreading to many European cities, the middle classes were shifting from cycling to promoting motor vehicle touring, and commuting by bicycles started to become the symbol of the working class. Accommodating bicycles on the streets then became a problem-solving process, rather than embracing a good solution to urban mobility.

Fast-forwarding to recent decades, the focuses of urban mobility are rapidly evolving. Europe, USA and Australia are becoming more and more health and environment conscious. Cycling starts to gain increasing attention again for its advantages for society, economy and environment (Koh & Wong, 2012). Aside from health and environmental benefits, many countries are promoting cycling as a convenient and fast short-distance means of travelling that bridges first-last mile of public transit trips (Flamm & Rivasplata, 2014; Kumar et al., 2016; Liu et al., 2012).

In response to the increasing demand of cycling in recent years, a series of cycling facilities have been implemented as schemes in promoting cycling activities, which include bicycle boulevards, raised cycling lanes, bicycle parking and locking

and so on (Hunter et al., 2000; Larsen, 2017). Furthermore, governments and urban transport planners are making efforts to encourage innovative cycling schemes such as bicycle-sharing to enhance bicycle-transit integration (Flamm & Rivasplata, 2014; Martin & Shaheen, 2014).

2.1.1 Cycling in Singapore

The first booming stage of bicycles in Asia came a few decades later than European cities. It was until the 1930s when Japan formed its own bicycle productions that bicycles started to become common in Asia. By 1960, several major roads in Singapore already had dedicated bicycle tracks catering for 268,000 registered bicycles according to Singapore Land Transport Authority (Koh & Wong, 2012). However, the motorisation trend that occurred worldwide previously occurred in Singapore as well. Starting from 1970s, private motor vehicles became the preferred choices of commuting, while bicycles and public transport were treated as lower class forms of travelling. The bicycle tracks were then scraped and the road networks in Singapore were then fully catering for increasing demand of motorised transportation (Rojas López & Wong, 2017a). However, a reverse change occurred in the 1990s. Singapore government and society started to recognise the health and environmental benefits of cycling and its potential to complement public transit systems (Koh & Wong, 2012; Meng et al., 2014). Overall, cycling fits Singapore's vision of "Car-Lite" society to create a liveable and sustainable environment (Center for Liveable Cities & Urban Land Institute, 2016), where urban mobility shifts away its reliance from cars and enable greener mobility options. Indeed, in recent years, an increasing number of cyclists can be observed commuting from their homes to mass transit stations and bus interchanges.

While pedal bicycles are getting more and more popular, electric bicycles also started to draw users' attention. With battery-powered motor, electric bicycle allows riders to travel effortlessly and further in distance. It was once well-accepted in Singapore and the estimated ownership as of 2016 reached 12,000 units. However, its fast-travelling speed and heavy-sized frames can easily lead

to severe crashes when crashing into pedestrians. Singapore government started to ban the use of electric bicycle on footpaths and made it mandatory to have licence registration from Jan 2018 (TODAYonline, 2017). As a result, the ownership declined rapidly, and electric bicycles have more or less disappeared from Singapore streets.

To cope with the rapidly increasing cycling demand in Singapore, efforts have been made to build cycling infrastructure such as demarcated bicycle paths and widened footpaths in and around selected transit hubs. The proposal of a cross-island park connector network was approved by the Garden City Action Committee on 4th December 1991. Here in Singapore, “park connectors” are defined as greenways that connect major parks and other places of interest, and providing off-road dedicated paths for cycling and jogging (Newman, 2014). While the main purpose of park connectors is to generate social and recreational activities in the neighbourhood under Greening and Recreational Strategy (Tanuwidjaja, 2011), it also improves the infrastructure level for cycling. Starting from 2013, intra-town cycling networks are implemented in several townships in Singapore, linking some important urban rail stations and bus interchanges (Land Transport Authority, 2017b). There are currently 440km of cycling paths on the entire Singapore island, and they are expected to be expanded to 1,000km by 2025, and triple the current path length by 2030 with a budget of over 1 billion Singapore dollars (Land Transport Authority, 2020b). Another example of providing cycling space is the on-road bicycle lane in Sentosa island and Tanah Merah Coastal Road. From the year of 2015, Singapore started to build on-road bicycle lane, which is aimed at improving the safety of cycling by allocating cyclists their own space. Notwithstanding, there are only very limited on-road dedicated cycling facilities in Singapore.

2.1.2 Land scarcity and limited active mobility infrastructure

Singapore is well devoted to developing cycling infrastructure. However, being a small island nation with a land area of 719.8km² and a population of 5.70 million (Department of Statistics Singapore, 2019), Singapore is preserving as much

green field as possible for future development, which consequently limits the space for current development of cycling facilities. To date, the most common street layout in Singapore consists of roadway with pedestrian footpaths (see Figure 2-1) adjacent to the road carriageway (Land Transport Authority, 2016). Riding bicycles on the road carriageways is viewed by cyclists themselves as being dangerous (Lawson et al., 2013; Nguyen et al., 2015). It is pertinent to note that these ubiquitous footpaths, being as originally designed solely for pedestrians, tend to be rather narrow (most are 1.5m wide) and confined.

Figure 2-1 Singapore footpath (Land Transport Authority, 2016)

An Active Mobility Advisory Panel (AMAP) was established in July 2015, to deliberate on the rules and regulations that govern the use of bicycles and other active mobility devices. The AMAP conducted the first public consultation that involved more than 5,000 respondents in an online survey and 200 participants in focus group discussions. The AMAP made its first recommendation to the Ministry of Transport (MOT) in March 2016, which was subsequently accepted in April 2016 (Land Transport Authority, 2016) that footpaths shall be allowed to be shared (see Table 2-1) and be provided with a speed limit of 15km/h and a clear code of conduct, which were incorporated into the Singapore's Active Mobility bill. This bill was passed on 10-January-2017 (Land Transport Authority, 2017a).

Table 2-1 Where devices are allowed in Singapore (Land Transport Authority, 2017a)

Mode/Type of Devices	Cycling/Shared Paths (including Park Connector Networks) [Speed Limit – 25 km/h]	Footpaths [Speed Limit – 15 km/h]	Roads	Locations with ‘No Riding’ signs (e.g. pedestrian overhead bridges)
Personal Mobility Aid <i>e.g. motorised wheelchairs, mobility scooters</i>	✓	✓	✗	✓
Conventional Bicycle	✓	✓	✓	✗
Personal Mobility Device <i>e.g. skateboard, kick-scooter, electric scooters, hoverboards, e-wheels</i>	✓	✓	✗	✗
LTA-approved Power-assisted Bicycle	✓	✗	✓	✗

The 15km/h was later revised to 10km/h in 2019 due to increasing crashes on the footpaths (Land Transport Authority, 2018a). In the bill and its annexes, the order of right-of-way is not specified between riders and pedestrians (Singapore Statutes Online, 2017), but the general code of conduct for riders includes slowing down while approaching pedestrians, giving way to pedestrians etc. (Attorney-General's Chambers, 2017). Herein, many cyclists choose to ride on narrow channels of the off-road footpaths that are prevalent alongside local streets, which would unavoidably involve closer interactions with pedestrians (Rojas López & Wong, 2017b). However, with bicycles and pedestrians being very different in respective size, required physical strength, operating speed and manner of movement, it is important to ensure that off-road space is shared harmoniously to reduce any conflicts and crashes.

Although there are no exact statistics regarding cyclist-pedestrian crashes on shared space in Singapore, crashes are reported in the media from time to time. Two fatal cyclist-pedestrian crashes were reported in the 4th quarter of 2019 alone (Alkhatib, 2019; Chan, 2019), highlighting the conflicting situations on

shared footpaths. As mentioned in Chapter 1, besides cyclists, electric PMDs (mostly in forms of ES) were gaining popularity on shared footpaths.

2.2 Personal mobility device (PMD)

Personal mobility device by its name is referring to any assistive device that facilitates individual human transportation. In local Singapore's context, the definition of PMD excludes bicycles and wheelchairs, and refers to skateboards, kick-scooters, electric scooters, hoverboards and so on. The latter definition is used throughout the current thesis. Traditional PMDs such as skateboards or kick-scooters have mostly been used by children or young adults in recreational travelling. Recently, with the advances of technology and decrease in manufacturing cost, PMDs equipped with small-sized electric motors are becoming more and more popular. Such electric-powered PMDs provide alternative means of independent motorised mobility to the current transport system (Hiekata, 2019). PMDs allow individual travellers to quickly travel a short distance without inputting any physical effort as compared to riding a bicycle. PMD's compact size makes it possible to be carried and transferred easily across various modes of transport (Dowling et al., 2015). Furthermore, with a low energy consumption and low emission rate, PMD can potentially be a sustainable mode of mobility in supporting the first-last mile of public transit. Although some efforts have been put into studying this relatively new mode of commuting (Lieswyn et al., 2017), to date, there are not many well-established guidelines and codes of conduct regarding how to accommodate PMDs to the prevailing infrastructures (Dowling et al., 2015; Shaheen & Finson, 2003).

2.2.1 Growth and decline of PMD usage in Singapore

In recent years, among all electric-powered PMDs, ES' in particular are well-accepted and used by more and more people in Singapore. Their battery-powered motors enable commuters to conduct short-distance trips effortlessly and their small size allows them to be transferred conveniently, which make them a very popular mode of transport in tropical urban areas. As a relatively

new mode in the transport system (King et al., 2019), infrastructure and space that specifically cater for ES are currently not well fitting in Singapore.

Furthermore, unlike conventional bicycles that have been around for nearly 200 years, people's perceptions and behaviour are not yet fully adapted to embrace the increasing usage of newly emerging electric PMDs, which has experienced high crash rate. In the first half of 2017, electric bicycles and PMDs have been involved in around 90 crashes, which resulted in about 90 injuries and 4 deaths (Tan, 2018). Factoring the 2016's estimated population of 12,000 electric bicycles and 24,000 PMDs, the annual rate of casualty is around 0.52 per cent per active mobility device. Comparatively, for cars, the annual rate of casualty is only 0.41 for cars in 2017 (Singapore Department of Statistics, 2019). With such a high injury rate, Singapore is taking actions to reduce PMD crashes to ensure a safe and gracious active mobility culture for all users.

Singapore is very unique as compared to other cities worldwide. In the US, PMDs are allowed to travel on the road in most cities. In European cities, PMDs are not allowed to travel on road and should stick to sidewalks only, which is similar to Singapore. However, the speed limit for PMDs is walking-speed-level at 6km/h in European cities, which is nowhere as high as 15km/h in Singapore (Litman & Blair, 2017). For the more serious and problematic electric bicycles, they are no longer allowed to use the shared footpaths and must be licensed by Jan 2018 (TODAYonline, 2017), which minimises the chance of them encountering pedestrians and other active mobility riders. In the beginning of 2018, the government decided to take one step further to regulate the usage of PMDs on public paths. As announced at the Committee of Supply (CoS) Debate, the recommendation from AMAP has been accepted, which mandates the registration of PMDs in the second half of 2018 (Land Transport Authority, 2018b). The mandatory registration is expected to deter reckless riding, foster greater responsibility of riders, and serves to track down errant ES users.

Later on, in dealing with the many reported incidents, AMAP called for a second round of nation-wide public consultation in April/May 2018 that entailed

questionnaire responses from over 6,000 online respondents, travel diaries from close to 100 participants who rode bicycles or PMDs under prescribed set of parameters, and about 100 focus group discussion participants (Active Mobility Advisory Panel, 2018). Through online stated preference survey, it was found that over 70% of the path users (pedestrians and riders) preferred a speed limit below 15km/h for safety reasons. It was also pointed out that since the kinetic energy of a PMD is proportional to the square of its velocity, the severity of collision would be effectively reduced more than half by lowering riding speed from 15km/h to 10km/h (Ng & Lau, 2018), and 20 to 50 per cent reduction in the likelihood to sustain a serious head injury, as reported in a simulation study (Lim, 2018). As safety is the top priority, AMAP's recommendation in August 2018 (Active Mobility Advisory Panel, 2018) to lower the speed limit from 15km/h to 10km/h was accepted by MOT in September 2018, and subsequently implemented on 01-February-2019 (Land Transport Authority, 2018b). This speed limit would apply to both ES and bicycles on footpaths. However, in the same report, it was also noted that 10km/h riding speed might be too slow for some riders and might even result in instability in handling the mobility device, thereby discouraging daily riding commute.

Later in the fourth quarter of 2019, as the series of measures did not result in satisfactory improvements, ES has since been banned from usage on shared footpaths and can only be used on dedicated bicycle paths (Land Transport Authority, 2019), with reasons attributed to ES riders not being "gracious and responsible" in "co-sharing of footpaths" (Abdullah, 2019). Furthermore, in February 2020, the ban was extended to other types of PMD such as hoverboards and electric unicycles (Land Transport Authority, 2020c) that took effect in April 2020. A theory test is also applied to qualify PMD riders for riding PMDs. The growth and decline of ES usage have been accompanied by underlying conflicting situations on the shared footpaths. Mitigation measures such as reducing bicycle and ES operating speed seemed to have little effects. In addition, although the

more problematic ES have been banned from being used on the footpaths but problems of incompatible interactions between cyclists and pedestrians remain.

2.3 Existing studies on shared space

2.3.1 From traditional traffic segregation to shared space concept

The traditional design of the urban street has been very closely dependent on the safety aspects. Safety concerns on roads have emerged since the introduction of motorised vehicles to the streets, and grown into a major pillar in transport planning with mass urban motorisation since the mid-1900s. In 19th century, on US and European urban streets, the transportation of human and goods were dominated by animal-powered vehicles such as horse carriages, which were comparatively slow and shared the same street space with pedestrians. With the introduction and mass production of combustion engine vehicles in early 20th century, the street traffic flow became more rapid and effective, at the cost of more frequent and severe crashes (Luckin & Sheen, 2009). For example, the road crash data in Manchester UK in early 1900s confirmed that anyone above the age of 50 years was more likely to die in road crashes than any other fatality categories (Manchester City Council, 1942). The diffusion of new modes of transport followed the creation of a new set of socio-technical regime. With the high demand in motorised traffic and the serious safety concerns, the paramount task was the protection of pedestrians, who were the more vulnerable user group on the streets. Educational campaigns were conducted to teach drivers and pedestrians how to use the road safely (Geels, 2005). The more important means was the separation of vehicular traffic and pedestrian flow at the infrastructure level (Kaparias et al., 2015). From 1930s, city designs consisted of implementing pedestrian underground passes and overhead bridges and road side barriers that separate pedestrian footpath from the road (Corbusier, 1987), with the latter already considered to be reserved for cars. A clearer concept of infrastructure segregation was set out in Buchanan's "Traffic in Towns" report (Buchanan, 1963), which describes the functional roles of different types of transport modes and defines a clear hierarchy of roads from

expressway to local access, serving as a street design manual for decades in the UK.

In recent decades, there has been a somewhat reverse trend in moving away from traffic segregation. The focus of street designs has been shifted slightly from vehicles to pedestrians and other active mobility modes. The objective is to create a better public realm by redefining the main function of urban streets as places rather than arteries (Kaparias et al., 2015). It was argued that traditional street design approaches that regulate street activities by implementing precise rules, enforcements and infrastructure would negatively affect dynamic street users' interactions, especially considering that human users are complex and adaptative (Hamilton-Baillie, 2008).

2.3.2 Early concepts of shared space in forms of shared streets

The early focus of space-sharing studies is the integration of vehicular flow with pedestrian traffic on the streets (Ben-Joseph, 1995) to create a “liveable street” without causing any major conflicts in residential areas (Avery & Avery, 1982). It is also described as the Woonerf concept and is subsequently extended to the design of non-residential/mixed-use streets (Appleyard, 1980; Quimby & Castle, 2006; Turoń et al., 2017). This concept of shared space integrates all road users onto one shared surface. It provides a relatively safe shared space by physically altering the prevailing street layout, dimensions and even types of pavement. Coupled with other restrictive approaches such as natural obstacles and visual cues, the shared space physically forces vehicle flow to slow down and naturally orients the right-of-way towards pedestrians. Such practices are often used in re-designing shopping streets (Kaparias et al., 2015) and street intersections (Duncan, 2016; Smith, 2017) in many European cities and New Zealand.

2.3.3 Mathematical simulation approach to shared space

The Woonerf concept applies engineering measures that physically restrict vehicle movements for the safety of pedestrians (Ewing, 2017). Mixed-traffic modelling and simulating techniques were also developed to evaluate and validate such engineering schemes in shared space. Rules-based models, such as

cellular automata (CA), have been widely used in modelling mixed-traffic interactions, either between pedestrians and vehicles or between bicycles and vehicles (Chen & Wang, 2016; Zhang & Chang, 2011). CA models divide the shared space into discrete cells and define rules for each road user's motion and simulate the interactive movements (Lu et al., 2016). Another widely used microscopic modelling is social force model (SFM). Based on Newton's second law of dynamics, SFM tries to replicate road users' interactions (Dias et al., 2018; Rinke et al., 2017) in an effort to model conflicts among different types of users in shared space. However, the complex nature of mixed-traffic interactions are difficult to be adequately explained and modelled by currently available mathematical models (Anvari et al., 2015).

2.3.4 Active mobility shared space field studies

Instead of modelling user behaviour in shared space using complex models, some studies also focused on relationships between individual aspects of shared space interactive behaviour. A study employed the concept of personal space (PS) to examine the movement of a Segway (a type of electric PMD, referred as personal mobility vehicle – PMV in the study) in pedestrian flows, where personal space is defined as an individual's preferred distance from others (Burgoon, 1978). In Burgoon's (1978) study, it is also mentioned that as the speed of PMD increases, the personal space for pedestrian also increases. A study carried out in Japan (Iryo et al., 2016) plotted the detailed trajectories for a Segway and a Robstep (two types of electric PMDs) in avoiding standing pedestrians at an average approaching speed of around 10km/h. The average passing distances obtained from the trajectories are 0.81m and 1m for Segway and Robstep, respectively.

Such findings are also utilised in shared space design guidelines. The road design guideline in Australia specifies a few conditions where cyclists and pedestrians can share the same path (see Figure 2-2). Figure 2-2 shows that if the demand flow for bicycles and pedestrians is low (fewer than 10 users per hour for both cyclists and pedestrians) or demand for pedestrians is low, and bicycles are travelling under 20km/h, it is possible for them to share the same path.

1 The level of demand can be assessed generally on the basis of the peak periods of a typical day as follows:

a. Low volume: Infrequent use of path (say less than 10 users per hour)

b. High volume: Regular use in both directions of travel (say more than 50 users per hour).

2 These path volumes are suggested in order to limit the incidence of conflict between users, and are significantly lower than the capacity of the principal path types.

Figure 2-2 Guide to the choice of path treatment for cyclists (Austroads, 2017)

The above findings give an engineering basis for the possibility of accommodating bicycles and ES among pedestrians along shared footpaths. However, there is a huge gap in policy implementation of operational practices. As mentioned, the speed regulations did not seem to resolve the conflicts in Singapore's space sharing schemes. Herein, human-centric theories shall be well relevant towards bridging the gap.

2.3.5 Notion to theorise user behaviour

A systematic human-centric perception-behaviour framework is needed to advance knowledge about users' interactions in shared space. However, currently there seems to be little focus on how to establish a framework that can model shared space user behaviour. An established structure dedicated to user behaviour modelling is needed. In this regard, many research studies have adopted the concept from theory of reasoned action (TRA) (Fishbein & Ajzen,

1977; Madden et al., 1992) and theory of planned behaviour (TPB, as modified from TRA) (Madden et al., 1992). The two theories propose that human behaviour can be modelled as a psychological process and establish a robust belief-attitude-behavioural intention linkage for behavioural intention modelling (Ajzen, 1991).

With a general model from TRA and TPB, specific belief and attitude aspects dedicated to shared space interactions are still needed. For this, a better understanding towards users' attitudes is needed to identify perceptual factors that influence behaviour. A VR experiment was therefore conducted, which is discussed in Chapter 4.

With identified factors, pertinent behaviour theories shall be reviewed, and hypotheses specific to modelling interactive behaviour in shared space shall be proposed. Combined with the belief-attitude-behavioural intention structure from TRA and TPB, they form the building blocks to a conceptual framework that models interactive behavioural intention in shared space. The detailed hypotheses and framework formulation process is discussed in Chapters 5 and 6.

It should also be noted that TRA and TPB provide a robust basic framework to model behaviour. However, in many of such studies, the modelling process ends at behavioural intention. Behavioural intention is defined as the degree to which an individual has formed a conscious plan to perform a specified action (Fishbein & Ajzen, 1977). It is often assumed that behavioural intention is the direct antecedent to actual human action (Sheeran & Webb, 2016). Based on such assumption, studies could make interpretations based on their findings as referenced to real-world actions. However, some studies also suggest that such strong behavioural intention-action relationship may not always be true (Gourlan et al., 2019; Rhodes & Dickau, 2012), as dependent on the intention formation process and behaviour type (van den Broek et al., 2019). This calls for a further examination of the behavioural intention-action relationship through real-world experiment, for which the reviews of relevant detailed literature and an experiment are covered in Chapter 7.

2.4 Research gaps

By accommodating pedestrian and bicycle (and ES for a brief period) on the same space, it represents a new form of mixed traffic of active mobility users. It is timely and necessary to investigate the nature and characteristics of the new space-sharing schemes. Reviewing past literature on active mobility development and space sharing inspires the notion to theorise interactive active mobility user behaviour. To achieve this, several research gaps have been identified.

2.4.1 Lack of understanding in users' attitudes and behaviour in space-sharing

To theorise behaviour, users' attitudes need to be studied and understood. As mentioned earlier, Singapore's policies regarding ES on footpaths have kept on tightening, with focus on speed regulations. However, with little tangible effect on improving the safety level and rule violations, ES was eventually banned from the footpaths. Tightened speed limits are found not to be effective enough to reinforce positive and safe behaviour of ES riders. There is lack of understanding on how footpath users perceive ES speeds and how ES speeds subsequently impact their behaviour. This provides the motivation to conduct a critical case study. Various perceptual factors that model interactive behaviour in shared space need to be identified and integrated, which is lacking in the current literature on shared space. These gaps are addressed in Chapter 4 using a virtual reality experiment.

2.4.2 Lack of established framework to model shared space users' behavioural intentions

Understanding of users' attitudes and behaviour is a critical step to reinforce positive user behaviour. Interactions in shared space are observed among different types of users. Not only does the speed potentially affect user behaviour, other perceptual factors that depict the nature of interactions, users' priority and so on might also interactively influence user behaviour. After identifying the key factors, relevant theories regarding interactive behaviour need to be reviewed from an integrated framework for modelling users'

behavioural intention in shared space for mobility. To develop such a framework, the following gaps need to be addressed:

- Existing concepts and theories in modelling behavioural intention need to be modified and integrated to suit the planning of interactive shared space; and
- A study is needed to validate the developed space sharing behavioural framework.

Combined with the findings from Chapter 4, the modification and integration are discussed in Chapter 5. Subsequently, a study involving perception survey of shared footpath users is presented in Chapter 6, serving as validation of the integrated space sharing behavioural framework.

2.4.3 Lack of validated relationship between behavioural intention and action in shared space interaction

As mentioned, the developed space sharing behavioural framework based on various behavioural theories serves to model users' behavioural intention but not on action. An actual assessment of shared space users' interactions is needed to bridge the gap. For this, relevant studies were reviewed to form two hypotheses for testing. A before-and-after field experiment was conducted. They are presented in Chapter 7.

2.5 Chapter summary

This Chapter reviews on the development of bicycles and personal mobility devices and how they are adopted locally in Singapore. The government's regulations on active mobility have allowed the space sharing schemes among pedestrians, bicycles and PMDs. Along the development of regulations, it is revealed that the safety of shared path users has been compromised due to behavioural conflicts among different types of users, which consequently led to the ban of PMD on shared footpath. This Chapter also introduces past literature on shared space behavioural research, ranging from empirical studies to mathematical modelling. Finally, the research gaps are identified, including lack of understanding in users' attitudes and behaviour, lack of established

framework for behavioural intention modelling and lack of validated behavioural intention-action relationship. The next chapter reports on methodology regarding how each of the gaps is addressed.

CHAPTER 3 RESEARCH METHODOLOGY

The current Chapter presents the methods used to achieve the research scopes as mentioned in Chapter 1. The research tasks involved in the research are discussed and rationalised. The attendant research tasks entail the following activities (see Figure 3-1).

Figure 3-1 Research activities

3.1 Literature review

The literature review was built progressively in this research. A systematic search of literatures using Google Scholar and Scopus with different combination of keywords was conducted. In selecting literatures, heavier weightage was given

to the latest articles published in highly regarded journals with high citation numbers. The first part of the review has been covered in Chapter 2 in which published literature covering how active mobility evolves world-wide and locally in Singapore was reviewed. It established a basic understanding of the current situations regarding active mobility adaption. Further reviews on past studies regarding shared space and human interactions served to identify the research gaps for theorising shared space interactive behaviour. What factors contribute to users' attitudes and how they may influence behaviour are not well understood. It inspired a shared space experiment using virtual reality (VR). The experiment's findings identified a few key factors that influence users' behavioural intention.

Building on the VR experiment's findings, the literature reviews focused on related social behaviour theories. Several theories including theory of reasoned action / planned behaviour, risk compensation theory, and dyadic power theory were adopted for conceptual framework formulation, which models shared space users' behavioural intention. This part of the literature review was integrated into Chapter 5 on conceptual framework formation.

Literature review on behavioural intention-action gap and habitual behaviour also revealed that behavioural intention might not always translate to action (actual behaviour). It called for a before-and-after field study to examine the intention-action relationship regarding space sharing.

3.2 VR experiment to understand users' attitudes in space sharing

The first part of the literature reviews identified a gap in theorising shared space behaviour. The rise and decline of ES in Singapore provided motivation for a case study. Understanding why speed regulations seem to have little impacts on safer interactions in space sharing provided a critical understanding on users' attitude. A multitude of attitudes could lead to differentiated behaviour of road users that governs how interaction takes place. Understanding users' attitudes and behaviour is the key premise to constructively create safe environments for the conduct of active mobility. As such, the ES speed experiment was designed and

conducted in an VR environment to assess shared footpath users' attitudes. Comparing to traditional studies on speed, adopting VR offers a few advantages. Virtual reality (VR) could safely assess complex human behaviour and emotions by creating a controlled virtual environment (Suhaimi et al., 2018). Such three-dimensional (3D) virtual content is streamed by head-mounted displays (HMDs). By receiving sensory information including 3D vision and stereo audio, HMD users establish their presence in the created scenes with high fidelity (Garzotto et al., 2017).

VR also has some other crucial advantages besides being highly immersive. The current case study focused on pedestrian-ES interactions with varying ES operating speed conditions. If they were to be experimented in the real world, it would potentially introduce high risks to the participants. Adopting VR could eliminate such risks by avoiding actual physical interactions. Furthermore, VR contents are under complete control and can be identically replicated for every participant (Jensen & Konradsen, 2018).

For the afore-mentioned advantages, VR was adopted for assessing users' speed perception. Pedestrian-ES rider interacting scenarios with various ES operating speeds were designed and recorded using 360-degree camera. The video footages were streamed into HMDs for experiment's participants (pedestrians and ES riders) to experience. Such experimental setup isolates the effects of speed without considering possible operational errors, distance and location of each interaction between ES and pedestrian in each run. The detailed experimental design and experiment's findings are discussed in Chapter 4.

3.3 Form and validate conceptual framework in modelling behavioural intention

A space sharing behavioural framework that utilises users' attitudes was built to model users' behavioural intention as based on the VR experiment's findings, and findings from literature scan into existing social behaviour theories regarding space sharing and human interaction. Theory of reasoned action / planned behaviour, risk compensation theory and dyadic power theory were

identified. Seven hypotheses were proposed as depicted by the theories and their relevant studies. The hypotheses form the conceptual framework that models users' behavioural intention. The detailed formation process is discussed in Chapter 5.

The proposed framework was validated in Chapter 6. As the framework consists of seven pairs of causal relationship from the hypotheses, path analysis technique was adopted as the validation tool. Path analysis is used to examine causal relationships between multiple variables (Jeon, 2015). It is a subset of Structural Equation Modelling (SEM), which is a multivariate procedure to examine a group of relationships between multiple independent variables (Ullman, 1996). SEM has been widely used in transport studies with questionnaire items, which include pedestrian safety study (Sheykhfard et al., 2021), risky road user behaviour research (Sullman et al., 2012) and travel behaviour studies (Golob, 2003; Ikeda et al., 2019). Path analysis is unique from other SEM methods as it analyses the mediated effects in a defined pathway (the effect of X on Z in a " $X \rightarrow Y \rightarrow Z$ " pathway) (Hayes et al., 2017). As the framework proposes both direct and mediated relationships, path analysis suits very well for validation purpose.

It is also noted that the framework consists of latent variables such as perceived control, perceived risks, perceived priority etc., which cannot be directly measured by single items. Studies on active mobility user behaviour were reviewed to identify at least three measurable items for each latent variable in the framework. The measurable items form a questionnaire survey towards shared footpath users. The survey was administered online due to the difficulty in conducting face-to-face survey under COVID-19 pandemic. At the time of the survey, PMDs were already banned from the shared footpaths. Therefore, the survey mainly focused on the interactive behaviour between pedestrians and cyclists, which are the major footpath user group.

3.4 Illustration of space sharing framework by “keep left” experiment

The conceptual space sharing framework serves to model users’ behavioural intention. The manner that shared space users realise their intentions to action was examined in order to complete the space sharing behaviour modelling framework. This was illustrated by a before-and-after “keep left” experiment on a selected stretch of shared footpath.

The “keep left” treatment was applied to the experiment’s site. Intercept perception surveys were conducted on passing pedestrians and cyclists before-and-after the treatment. This assesses shared footpath users’ change in intention toward keeping left. To assess users’ actions (actual behaviour) of keeping left, naturalistic observations using video footages were also adopted before-and-after the treatment. The detailed experimental design and findings are discussed in Chapter 7.

3.5 Chapter summary

This Chapter covers the research methodology for all the research activities. VR technique was adopted to assess shared footpath users’ speed perception and attitudes. Based on the findings, the conceptual framework was developed and validated by an online perception survey. A before-and-after “keep left” experiment was adopted to examine the behavioural intention-action relationship as an illustration of the framework. The next chapter employs a case study of ES speeds, and provides more understanding into users’ attitudes towards various interaction characteristics in shared space.

CHAPTER 4 SHARED FOOTPATH USERS' ATTITUDES ON ELECTRIC SCOOTER SPEEDS

In Chapter 2, it was identified that there was lack of understanding in user behaviour in space sharing. Particularly, understanding why previous speed regulations did not work and what perceptual factors could contribute to determine users' attitudes and behaviour would be the first step to build a conceptual framework. As such, the present study in this Chapter aims to assess, using an immersive virtual reality (VR) experiment, the users' attitudes toward electric scooter (ES) operating speed during pedestrian-ES interaction on shared footpaths, from both the pedestrians' and ES riders' points of view. The experiment's subjects were also probed on their experience of crashes and near-misses on shared footpaths, and crash contributory factors involving ES. The practical implications accrued from this study are discussed regarding Singapore's ES speed regulations and the eventual ban of ES on footpath. This provides a better understanding of shared space users' attitudes.

4.1 Study procedures

The study incorporated VR to directly examine pedestrian and ES rider participants' attitudes. One-to-one pedestrian-ES rider interactions were created as immersive VR scenarios to elicit participants' safety concerns, potential presence of anger as well as perceived influence of the celerity of movement.

4.1.1 Experimental design

A straight stretch of shared footpath (1.5m in width) was selected as the VR environment. In each scenario, an ES rider and a pedestrian traversing on the footpath was recorded using a 360-degree video camera. In total, twelve VR scenarios were created, including six scenes (camera acting as pedestrian's vision) to assess pedestrians' interactive experience, and another six scenes (camera acting as ES rider's vision) to assess ES riders' interactive experience. The recorded twelve scenarios were streamed to participants (act as a pedestrian or

an ES rider) using HMDs. After experiencing each scene, participants' ratings and opinions were recorded for further analysis.

4.1.2 Participants

For the VR experiment, a total of sixty participants were recruited via social media advertisement. Vouchers worth 15 Singapore dollars were given to each participant as incentivisation. Written consent forms were obtained from all participants prior to the experiment. Thirty (30) participants took part in the experiment as pedestrians, comprising 13 females and 17 males, with an average age of 29.9 years. They have no experience with riding ES. Another 30 participants acted as ES riders, comprising 6 females and 24 males, with an average age of 30.0 years. They have regular ES riding experience of at least once a week. The age and gender ratio of the recruited riders match the user profile of Singapore ES riders that young male riders are more common. Figure 4-1 shows the age range of recruited participants.

Figure 4-1 Participants' age ranges

4.1.3 Creating VR scenarios

Table 4-1 shows the 12 scenarios prepared for pedestrian (Scenarios P1-6) and ES rider (Scenarios R1-6), respectively.

Table 4-1 Summary of creating scenarios using 360-degree camera

Preparation steps		10km/h ES speed	15km/h ES speed	20km/h ES speed
Face-to-face	Camera on the tripod, recording the ES riding toward the tripod	Scenario P1	Scenario P2	Scenario P3
	Camera on the ES, recording the ES riding toward a pedestrian	Scenario R1	Scenario R2	Scenario R3
Overtaking	Camera on the tripod, recording the ES overtaking the tripod	Scenario P4	Scenario P5	Scenario P6
	Camera on the ES, recording the ES overtaking a pedestrian	Scenario R4	Scenario R5	Scenario R6

Figure 4-2 Virtual reality scenario preparations

4.1.4 Virtual reality experiment procedures

The 12 recorded VR scenarios were administered to participants in random orders using an HMD (see Figure 4-3). Examples of pedestrian's and ES rider's views are shown in Figure 4-3 as well. After streaming each scene, participants rated their experience on a 5-point Likert-scale questionnaire. The rated items included: "As a pedestrian/ES rider, I feel safe travelling on the footpath" [options: strongly disagree (1), to strongly agree (5)]; "As a pedestrian, when approached by the ES rider, I felt ___" (rated by pedestrians) [options: very angry (1), to pleasant (5)], and "As a ES rider, the speed that I am travelling at is ___" (rated by ES riders) [options: too slow (1), to too fast (5)].

To assess participants' unbiased opinion about the speed conditions, they were not informed about the actual ES operating speed in each scene during the experiment. After experiencing each scene, they were also asked to estimate the ES operating speed (options: 5km/h, 10km/h, 15km/h, 20km/h or 25 km/h). After finishing all the scenes, participants were asked to briefly write down the ES/pedestrian incidents they had personally experienced, if any.

Figure 4-3 Virtual reality experiments

The study was conducted over the period from June 2018 to September 2018. It was before implementation of the new speed limit (10km/h), which was in February 2019. However, the announcements of AMAP's recommendation and MOT's acceptance of 10km/h speed limit were in August 2018 and September

2018, respectively. Four ES rider participants and seven pedestrian participants had their sessions shortly after the announcements. It was confirmed after their VR sessions, that they did not know about the announcements at that time. Hence, no attitudinal changes as induced by the announcements are expected.

4.2 Results and discussion

This section discusses the ratings from VR experiment's participants. Their safety concerns, anger levels, and celerity of the ES operating speeds are presented. ES/pedestrian incidents that the participants actually experienced are also categorised and discussed.

4.2.1 Safety ratings in face-to-face interactions

Figure 4-4 shows participants' (both pedestrians and ES riders) perceived safety ratings of face-to-face interaction with ES at different speed levels. Comparing to 20km/h and 10km/h, more pedestrian participants agreed with the statement "I feel safe" when the ES presented in the VR scenario was operating at 15km/h (two-tailed Wilcoxon signed rank test with $\alpha = 0.05$: 20km/h to 15km/h – $V = 66$, $p = 0.02$, effect size = 0.42; 15 km/h to 10 km/h – $V = 114$, $p = 0.07$, effect size = 0.33). The slowest ES operating speed of 10km/h was not rated as the safest for pedestrians.

It is possible that at a slow speed, the overall exposure time of interaction is longer. Too much time over the interaction could negatively impact pedestrians' perceived safety well-being, as pedestrians have more time observing the situation and reacting accordingly. Furthermore, an ES travelling as slow as 10km/h may waver more often, thus, inducing unsafe feelings for pedestrians. On the other hand, as the ES speed decreased, ES rider participants' perceived safety level increased (two-tailed Wilcoxon signed rank test with $\alpha = 0.05$: 20km/h to 15km/h – $V = 30$, $p = 0.26$, effect size = 0.21; 15km/h to 10km/h – $V = 97.5$, $p = 0.02$, effect size = 0.42).

Figure 4-4 Participants' safety ratings of face-to-face interactions (30 pedestrians and 30 ES riders)

Comparing the perceived safety ratings across different speed conditions between pedestrian and ES rider groups, ES rider participants generally felt safer in all operating speed conditions. (two-tailed Wilcoxon rank sum test with $\alpha = 0.05$: $W = 5484$, $p < 0.01$, effect size = 0.47). This may be due to the vulnerability differences between the two groups. In the event of collisions, pedestrians with less speed and physical power would be more easily injured as compared to ES riders.

4.2.2 Safety ratings in overtaking interactions

Figure 4-5 shows participants' perceived safety ratings for overtaking scenarios (ES overtaking pedestrian from behind). Both pedestrian and ES rider participants perceived lower ES operating speeds to be safer (two-tailed Wilcoxon signed rank test with $\alpha = 0.05$: 20km/h to 15km/h – $V = 77.5$, $p = 0.09$, effect size = 0.22; 15km/h to 10km/h – $V = 538$, $p < 0.01$, effect size = 0.56). Similar to face-to-face scenarios, ES rider participants felt safer as compared to pedestrian participants at all speed conditions (two-tailed Wilcoxon rank sum test with $\alpha = 0.05$: $W = 5885$, $p < 0.01$, effect size = 0.55).

Figure 4-5 Participants' safety ratings of overtaking scenarios (30 pedestrians and 30 riders)

Comparing between Figure 4-4 (face-to-face) and Figure 4-5 (overtaking), participants (especially pedestrians) generally perceived face-to-face interactions to be safer (two-tailed Wilcoxon signed rank test with $\alpha = 0.05$: pedestrian – $V = 1123$, $p < 0.01$, effect size = 0.33; rider – $V = 464$, $p = 0.15$, effect size = 0.15). In face-to-face scenarios, both pedestrians and ES riders could detect the presence of each other visually. It is easier for them to assess the situation and respond to each other's manoeuvres continuously as they approached and completed the interactions. For overtaking scenarios, on the other hand, pedestrians lost direct visual cues and even became unaware of ES riders approaching from behind. Not only would pedestrians lose control over the situation, but it would also be rather difficult for ES riders to anticipate pedestrians' movements and react accordingly, given that ES riders would not know when and how pedestrians could side-step haphazardly. Indeed, past studies had seldom focused on such pedestrian-ES interactions and their safety impact. In the area of motorised vehicle-bicycle collisions, drivers' misjudgement of cyclists' behaviour is found to induce more overtaking crashes (Kim et al., 2013). Herein, better shared space user education and clearer code of conduct (e.g., ringing bells when approaching, overtaking from the right etc.) may be effective ways to reduce perceived safety concerns, especially for the more critical overtaking cases.

4.2.3 Pedestrians' anger level

One of the key reasons to lower ES operating speed limit from 15km/h to 10km/h is that fast-moving ES' are considered to be a hazard source to pedestrians on shared footpath. Figure 4-6 presents pedestrian participants' anger levels in each VR scenario. While 20km/h distinctively induced more anger, pedestrian participants' anger levels at 15km/h and 10km/h did not differ significantly (two-tailed Wilcoxon signed rank test with $\alpha = 0.05$: 20km/h to 15km/h – $V = 36$, $p < 0.01$, effect size = 0.47; 15km/h to 10km/h – $V = 386$, $p = 0.10$, effect size = 0.21). As discussed earlier, while 10km/h is safer in cases of collisions, slower ES speed also means longer face-to-face interacting time and less stable manoeuvre for ES. These are likely to hinder the perceived safety level. Overall, in face-to-face scenarios, pedestrians did not perceive 15km/h any more negatively as compared to 10km/h.

Figure 4-6 Pedestrians' anger levels toward different ES speeds (30 pedestrians)

4.2.4 Riders' perception on celerity of ES movement

For ES riders, reducing their travelling speed for whatever reasons could also negatively impact their mobility. ES bridges the gap in first-last-mile commute as its small size allows an ES to be carried on board public transport like buses and trains. Its convenience depends on an ES' ability to move a traveller from one location to another in a short period of time effortlessly. As such, speed is a key reason for the popularity of ES. Figure 4-7 shows the ES rider subjects' attitudes toward different operating speeds. While riding at 20km/h was perceived to be

too fast for most ES riders, 15km/h was considered to be an optimum speed. As for 10km/h, it was considered to be too slow for most of the riders (two-tailed Wilcoxon signed rank test with $\alpha = 0.05$: 20km/h to 15km/h – $V = 483.5$, $p < 0.01$, effect size = 0.63; 15km/h to 10km/h – $V = 27$, $p < 0.01$, effect size = 0.74). The findings suggest that by enforcing 10km/h speed limit, it might either discourage riders from using ES at all, or result in more ES riders ignoring and violating the speed limit.

Figure 4-7 E-scooter riders' ratings on riding speeds (30 riders)

4.2.5 Users' estimation of ES speed

The reported results from participants' ratings suggest that the most well-received ES riding speed is not always 10km/h. Particularly in face-to-face interactions, pedestrians consider 15km/h to be safer. This is not entirely consistent with the stated preference survey results gathered by AMAP from the second public consultation. According to which, more than two thirds of the surveyed footpath users preferred the speed limit below 15km/h (Land Transport Authority, 2018a). There are two major aspects that the current study differed from the public consultation. Firstly, face-to-face and overtaking interaction types were not differentiated in the public consultation. Furthermore, footpath users may have under-estimated ES operating speeds. Afterall, speeds were only presented as numbers in km/h to footpath users in the public consultation. Figure 4-8 illustrates participants' under-estimation of ES operating speeds in the current study. In each VR scene, the speed was rated slightly lower as compared to the actual speed, nominally about 2-4km/h lower.

On the one hand, the speed estimation gap could be because that VR simulation does not replicate all real-world stimuli in an absolute sense. In other words, the finding from VR simulations shall only be interpreted on a relative scale. This is referred as relative validity in conventional simulation studies. Herein, participants experience stimuli through flat monitors displaying virtually created 3D models. A typical example would be a driving simulator (Meuleners & Fraser, 2015; Shechtman et al., 2009). However, not much research focuses on the fidelity of 360-degree content created from real world.

Notwithstanding, it is also possible that the afore-mentioned speed estimation gap actually exists, and pedestrians and ES riders associate the ES operating speed with a lower number. To back this up, there are field studies suggesting that bystanders (Scialfa et al., 1991) as well as people on vehicles (Conchillo et al., 2006; Evans, 1970) have the tendency to under-estimate vehicle speeds. The speed under-estimation is more significant if the vehicle speed is lower than 25mph (40km/h). ES speed estimation could also have the same phenomenon. In this regard, experiment through 360-degree content showed its advantage over conventional surveys. By directly displaying the scenes using HMD, participants no longer have to estimate the speeds using numbers, hence minimising the estimation gap. This also somewhat explains the inconsistency between the current study findings and the findings from AMAP's public consultation. In stated preference surveys, people may tend to associate their preferred speed with a number in km/h that is lower than the actual speed.

Figure 4-8 Estimated ES riding speed - means and standard errors with 0.95 CI

4.2.6 Sources of safety hazards

Towards the end of the experiment session, participants were asked to write down their own experiences of pedestrian/ES incidents. No actual crashes were reported from pedestrian participants. However, they did mention six near-misses with ES riders. Based on their description, four of such misses were due to misconduct of ES riders. Their behaviour included “ridden zigzag”, “approached silently from behind”, “swerving around people and accompanying children” and “does not bother about pedestrians”. The remaining two near-misses were due to “moved very fast” and “quite reckless”/ “without taking a look at the road (path) ahead”, combined. This shows that ES moving too fast is not the fundamental factor to conflicts. Similar conclusion can be drawn from ES riders’ experience.

The 30 participating ES riders mentioned seven crashes. Four of them were caused by non-ideal road conditions. Two crashes were due to misbehaviour of either motorised vehicle drivers or ES riders themselves. Only one crash involved a pedestrian, with the reasoning being “pedestrian not looking on the road but rather on the phone”.

This shows that most crashes encountered by pedestrians and ES riders were not directly speed-related. Misbehaviour and lack of code of conduct have played a bigger role. While lowering speed limit could reduce the severity of crashes, crash-inducing behaviour such as “on the phone”, “ridden zig zag” and “approached silently” is more likely to be resolved by education and enforcement.

4.3 Conclusion

To make the shared footpath a safer environment for users, Singapore’s authority has reduced the speed limit of personal mobility devices (PMDs, majority of them are ES) from 15km/h to 10km/h, as the likelihood and severity of injuries in a pedestrians-ES collision could be reduced (Ng & Lau, 2018). AMAP conducted an online consultation with more than 6,000 responses. The results also suggested that more than two thirds of the subjects preferred the speed limit below 15km/h. The current study adopted VR scenarios to examine pedestrians’ and ES riders’ attitudes towards various ES operating speed conditions, and provided a new perspective to understand users’ safety and speed perceptions.

The experiment’s findings suggest that for overtaking manoeuvres, lower ES speed at 10km/h was perceived to be safer. However, for face-to-face interactions with ES riders, pedestrians rated 15km/h as the safest ES speed. Being a more vulnerable user group, pedestrians’ perceived safety level was generally lower than ES riders. In all VR scenarios, participants had the tendency to under-estimate the ES operating speeds. It should also be noted that most ES rider participants perceived travelling at 10km/h to be rather slow. It may help to explain the unresolved high crash rates and violations after implementation of the 10km/h speed. If the 10km/h speed limit has been viewed as unrealistic and does not offer much greater safety improvement, ES riders might not be motivated to obey it.

The afore-mentioned findings suggest reducing the speed limit was not well accepted by both pedestrians and ES riders. Further analysis also showed that

speed might not be the fundamental factor to crashes on shared footpaths. Pedestrian participants rated their anger levels similarly at 10km/h and 15km/h ES operating speeds. By analysing the contributing factors to the pedestrian/ES incidents that the participants actually experienced, ES riders' poor behaviour such as "approached silently from the back" and "swerving around people and accompanying children" could be attributed to lack of control on shared space. Additionally, pedestrians viewing ES riders "not bother about pedestrians" revealed that there was conflict regarding right-of-way on shared footpaths. It suggests that factors like perceived control and perceived priority are likely the contributing factors to poor behaviour. This has implications on the framework formulation in later chapters. It provides a new perspective on how users form their attitudes and behaviour in interactive situations, which serves to draw out crucial hypotheses for modelling behavioural intention.

4.4 Chapter summary

This Chapter covers a VR case study into the impacts of ES speeds on users' attitudes. It reveals that operating speed is not a fundamental contributing factor to users' perceived safety levels. To improve the safety level of the shared space, the research needs to focus on poor user behaviour and attendant causes. The study reveals that the types of interacting scenarios (face-to-face encounter or overtaking) greatly influence users' attitudes. Factors such as perceived control and perceived priority are uncovered. They are the building blocks to the formation of the conceptual framework of behavioural intention, which is developed in the next chapter.

CHAPTER 5 THEORETICAL ANALYSIS OF ACTIVE MOBILITY USER BEHAVIOUR

The Chapter discusses the formation of the conceptual framework to study interactions of active mobility users (pedestrians and cyclists) along shared footpaths. The framework is built from the findings of the VR experiment described in Chapter 4, as well as several social behaviour theories reported in the literature, such as theory of reasoned action / planned behaviour, risk compensation theory and dyadic power theory.

5.1 Theory of reasoned action / planned behaviour

The theory of reasoned action (TRA) (Fishbein & Ajzen, 1977; Madden et al., 1992), along with its modified form, the theory of planned behaviour (TPB) (Madden et al., 1992), have been widely applied to model human behavioural intention. TRA and TPB theorise the modelling of a specific behaviour in a given situation as a psychological process (Ajzen, 1991).

TRA proposes attitude as an immediate antecedent to behavioural intention (Madden et al., 1992). Furthermore, beliefs could directly, or indirectly through attitude, influence people's behavioural intention (Fishbein & Ajzen, 1977). The belief-attitude-behavioural intention relationship derived from TRA has been widely applied in behavioural models across various fields such as last-mile logistics services (Wang et al., 2018), green product consumptions (Paul et al., 2016), tourists' behaviour (Kim et al., 2011) and so on. Herein, adopting such a relationship forms the basis for modelling shared space interactive behaviour. Applying the proposed attitude-behavioural intention relationship in TRA, it forms the first hypothesis:

H1: Positive users' attitude positively influence their cautious and positive behavioural intention on shared footpaths

TPB is further developed from TRA. It extends the boundary of belief aspects to include aspects additional to pure volitional control as previously defined in TRA (Ajzen, 1991). According to TPB, beliefs regarding the ability to requisite resources and opportunities for certain behaviour can be interpreted as the

perceived behaviour control, which has motivational implications for behavioural intention. This is commonly seen in studies such as health behaviour (Hagger et al., 2016), pro-environmental behaviour of students (de Leeuw et al., 2015), collaborative online consumer behaviour (Hamari et al., 2016) and so on. A study also showed that perceived behavioural control could directly influence users' attitudes and subsequently influence behavioural intention (Kan & Fabrigar, 2017). In TPB, one of the constructs for perceived behavioural control is perceived difficulty (Ajzen, 1991). Studies revealed that perceived difficulty could influence both users' attitudes and behavioural intention (Gagné & Godin, 2007; Kraft et al., 2005). Perceived behaviour control has particular implications for interacting behaviour on shared footpath. As discussed earlier, due to the speed and size gaps between different types of users on the footpaths, their ability to learn and control the interactions may vary, and subsequently affecting their cautious behavioural intention which leads to forming the following two hypotheses:

H2: Better control of perceived behaviour positively influences users' attitude

H3: Better control of perceived behaviour positively influences users' cautious and positive behavioural intention on shared footpaths

By adopting TRA and TPB, it lays out the general belief-attitude-behavioural intention framework to model human behaviour patterns (see Figure 5-1). However, for interactive behaviour in shared space specifically, crucial belief aspects are not determined. For this, other theories may offer specific belief constructs that describe dyadic behaviour in shared space.

Figure 5-1 Conceptual framework - step 1

5.2 Risk compensation theory

Risk compensation theory is commonly used in shared space users' behavioural studies (Karndacharuk et al., 2014; Peltzman, 1975). According to risk compensation theory, people adapt their behaviour in response to external changes in safety conditions, trying to return to a desired risk level (Adams & Hillman, 2001; Hedlund, 2000). It has implications in studying road safety (Wilde, 1998). On the one hand, measures that are supposed to improve safety, like antilock brakes (Grant, 1993) and airbags (Peterson et al., 1995), could result in fast and aggressive driving. Conversely, if the environment is considered as dangerous, users may take actions to reduce their perceived risk level, like using protective gears and lowering speeds (Phillips et al., 2011).

In the context of shared space in active mobility, the undefined right-of-way in shared environment urges users to act more cautiously due to the higher tendency to be involved in risks and conflicts (Hammond & Musselwhite, 2013; Karndacharuk et al., 2014). As such, higher perceived risks may lead to more cautious and positive behaviour such as reducing riding speeds (Che et al., 2020) and giving way (Useche et al., 2018), hence introducing hypothesis H4:

H4: Higher perceived level of risks positively influences users' attitudes towards cautious and positive behaviour on shared footpaths

A key criticism of the model is that risk, including individuals' perception of their own risk, involves not only evaluating their own risk, but also how their behaviour may impact on other people's risk (Hammond & Musselwhite, 2013; Pless, 2016). Past studies on risk compensation on the roads such as drivers adapting their seatbelt usage (Evans & Graham, 1991), adjusting driving speed (Ward & Wilde, 1996) and changing overtaking distance (Walker, 2007), or cycling speed in relation to helmet usage (Fyhri et al., 2018; Phillips et al., 2011), did not specifically differentiate between perception of own risk and other people's risk. In the case such as shared footpath, the conflicts are often seeded from dyadic interaction between two parties (cyclist-pedestrian). The concept of risk compensation needs to be modified to suit such case. Thus, hypothesis H4 can be further split into H4a and H4b (see Figure 5-2):

H4a: Higher perceived self-risks positively influence users' attitudes towards cautious and positive behaviour on shared footpaths

H4b: Higher perceived others' risks positively influence users' attitudes towards cautious and positive behaviour on shared footpaths

Figure 5-2 Conceptual framework - step 2

5.3 Dyadic power theory

Risk compensation theory proposes how perceived risk level could lead to positive behaviour. However, there are more aspects to be considered for the modelling of interactive behaviour patterns. One popular theory used to

describe such dyadic relationships is the dyadic power theory (DPT) that has been applied in the field of social behavioural study.

In studying interpersonal interactions, the ability to influence the behaviour of another person, defined as power, is often considered as one of the most important constructs (Dunbar, 2004; Neff & Harter, 2002). Particularly in DPT, it incorporates the interaction of two parties. Power is then considered to be a perception of one's own capacity relative to an interaction partner, not in an absolute sense (Dunbar, 2004, 2015).

In fact in the Woonerf concept of shared space, reducing the scale of vehicle transport influence is considered as a valid safety measure in some studies (Karndacharuk et al., 2013; Turoń et al., 2017). DPT further specifies and studies different constructs of power that contribute to the influence. According to DPT, power comes in different forms depending on the types of interactions (Dunbar & Abra, 2010).

Komter (1989) proposed the concepts of manifest power and invisible power, where the manifest power concerns the visible outcomes of power in occasions such as open conflicts. This type of power is commonly seen in studies of family violence (Sato et al., 2015), workplace dispute (Edwards, 2006) and so on. When studying the conflicts on shared space for mobility, the manifest power could be interpreted as the differences in speed and size of the two parties. The difference in kinetic energy and safety protection between road users results in disparity of the safety levels (Elvik, 2010). Consequently, any collision or crash would result in severe casualties (Grzebieta et al., 2011; Wegman et al., 2012). Therefore, power manifestation in this case is closely related to the perceived risk level, which is demonstrated in risk compensation theory.

Invisible power is mainly resulting from social mechanisms and closely related to situational expectations or other cultural expectancies. French et al. (1959) proposed the idea of legitimate power. It is associated with the hierarchical status sanctioned by the community (Gaski, 1986). This has particular

implication under Singapore's context of footpath-sharing. Up until 2017, most footpaths in Singapore were dedicated by law to the pedestrians. To cope with fast-growing number of cyclists, Singapore has enacted the Active Mobility Bill in Jan 2017 (Land Transport Authority, 2017a) to officially allow cyclists to share right-of-way on the footpaths with pedestrians.

In fact in Singapore, cyclists have been using the pedestrian footpaths even before the legislation (Nguyen et al., 2015). However, the footpath was traditionally designed for pedestrians whose priority on the path was not challenged by any other mode of users (Land Transport Authority, 2016). With the legislation in place, especially that the order of priority is not specified (Singapore Statutes Online, 2017), the pedestrians' legitimate power (priority) on the footpath space is compromised by new user groups (riders). Without clear official definition, the perceived priority levels would be influenced by users' free will beliefs (Martin et al., 2017) that moderate intolerance to unethical behaviour (Genschow et al., 2017). Hence, the current space sharing arrangement may have created potential difference in perceived priority status.

DPT proposes that relative power status influences people's attitudes towards interpersonal interactions (Dunbar, 2004; Dunbar & Abra, 2010). Supporting evidence can be found most commonly in close relationships (couples, families and etc.) where relative power status significantly influences complaint-related appraisals (Dunbar et al., 2008; Worley & Samp, 2014). The relationship between manifest power (perceived level of risks in current study) and attitudes has been described in risk compensation theory, as proposed in H4. Herein, the hypothesis regarding invisible power (perceived priority) and attitude is formed as follows:

H5: Higher perceived priority negatively influences users' attitudes towards cautious and positive behaviour on shared footpaths

In H4, the perceived risk is split into own risk and other people's risk in adaptation to the interactive shared space. Similarly, to differentiate the impact

of own power and other people's powers, H5 can be further split into H5a and H5b (see Figure 5-3):

H5a: Higher perceived self-priority negatively influences users' attitudes towards cautious and positive behaviour on shared footpaths

H5b: Higher perceived others' priority positively influences users' attitudes towards cautious and positive behaviour on shared footpaths

Figure 5-3 Conceptual framework - step 3

Figure 5-4 Conceptual framework

5.4 Chapter summary

The above stated hypotheses form the conceptual framework of footpath user (both pedestrians and cyclists) behavioural intention modelling (see Figure 5-4). TRA and TPB posit the belief-attitude-behavioural intention relationship, which forms the basic structure of the framework. Risk compensation theory and DPT serve to introduce specific belief aspects and form hypotheses for shared space interactive behaviour. To determine its effectiveness, the established framework needs to be validated. This is covered in the next chapter.

CHAPTER 6 VALIDATION OF CONCEPTUAL FRAMEWORK BY PERCEPTION SURVEY

The hypotheses in the established conceptual framework include five constructs, namely perceived control (PC), perceived risks (PR), perceived priority (PP), attitude (ATT) and behavioural intention (BI). This Chapter discusses how these constructs are administered in the perception survey forms for which the survey results are presented to validate the framework.

6.1 Formation of concept constructs and questionnaire design

Perceived control (PC) is an established construct in theory of planned behaviour (TPB) (Madden et al., 1992). When the theory is applied to encounters in shared space, it is often interpreted as the ease of avoiding the counterparts (Zhou et al., 2016) and the perceived capability of performing such actions (Barton et al., 2016).

Perceived risk (PR) in active mobility shared space studies can be interpreted in several aspects (Fernández-Heredia et al., 2014). In general, PR can be measured directly by a perceived rating of danger / injury level in pedestrians – bicycle/PMD interactions (Yu et al., 2019). However, PR could also be associated by more specific measures of the interactions. Pedestrians are shown to directly associate PR with interacting speeds and proximities (Che et al., 2020; Kuo et al., 2019).

Perceived priority (PP) in shared space interaction is comparatively a simpler concept. Different types of users have their own perceptions of right-of-way over the shared infrastructure (Delaney et al., 2017), and which users shall give way to their interactive counterparts (Paschalidis et al., 2016).

Attitude (ATT) is a direct measure of positivity or negativity of users' attitudes towards certain behavioural intentions, as proposed in theory of reasoned actions (Fishbein & Ajzen, 1977). In the context of interaction in shared space, it is measured as the attitudes towards being cautious (Papadimitriou et al., 2013) and give way behaviour (Paschalidis et al., 2016).

Behavioural intention (BI), more specifically positive behavioural intention, is the results of modelling within the framework. In shared space, positive behaviour could be viewed as being cautious (Papadimitriou et al., 2013) and manifestation of give way behaviour (Paschalidis et al., 2016). More specifically for riders, cautious behaviour can be further demonstrated as slowing down (Che et al., 2020) and alerting pedestrians (Useche et al., 2018).

All the afore-mentioned constructs are formed with 7-point Likert-scale questions. The ratings for each question have range (1-Strongly Disagree, 4-Neutral, 7-Strongly agree). The question statements for each construct are adopted from similar research and modified to fit the proposed framework (see Table 6-1).

Table 6-1 Items in each construct and their sources

Construct	Item	Source
Perceived control (PC) for pedestrian respondents (PCP)	PCP1. It is easy for pedestrians to spot approaching bicycles	<i>Barton et al. (2016); Zhou et al. (2016)</i>
	PCP2. If pedestrians want to, they can avoid approaching bicycles	
	PCP3. Pedestrians have complete control over how they interact with approaching bicycles	
Perceived control (PC) for cyclist respondents (PCC)	PCC1. It is easy for cyclists to spot nearby pedestrians	<i>Barton et al. (2016); Zhou et al. (2016)</i>
	PCC2. If cyclists want to, they can avoid nearby pedestrians	
	PCC3. Cyclists have complete control over how they interact with nearby pedestrians	
Perceived risks (PR)	PR1. Pedestrians are worried about being injured by bicycles	<i>Che et al. (2020); Fernández-Heredia et al. (2014); Kuo et al. (2019); Yu et al. (2019)</i>
	PR2. Interacting with bicycles is dangerous to pedestrians	
	PR3. For pedestrians, bicycles are usually too close when they pass	
	PR4. For pedestrians, bicycles are usually too fast when they pass	
	PR5. Cyclists are worried about being injured by pedestrians	
	PR6. Interacting with nearby pedestrians is dangerous to cyclists	
	PR7. Cyclists might fall when passing pedestrians	

Table 6-1 Items in each construct and their sources (continued)

Construct	Item	Source
Perceived priority (PP)	PP1. Pedestrians have priority	<i>Delaney et al. (2017); Paschalidis et al. (2016)</i>
	PP2. Bicycles are obligated to give way to pedestrians	
	PP3. Footpaths are designed for pedestrians	
	PP4. Cyclists have priority	
	PP5. Pedestrians are obligated to give way to cyclists	
	PP6. Footpaths are designed for cyclists	
Attitude (ATT) for pedestrian respondents (ATTP)	ATTP1. It is my responsibility to be cautious to approaching bicycles	<i>Papadimitriou et al. (2013); Paschalidis et al. (2016)</i>
	ATTP2. It is important to stay alerted to approaching bicycles	
	ATTP3. It is in my best interest to give way to approaching bicycles	
Attitude (ATT) for cyclist respondents (ATTC)	ATTC1. It is my responsibility to be cautious to nearby pedestrians	<i>Papadimitriou et al. (2013); Paschalidis et al. (2016)</i>
	ATTC2. It is important to stay alerted to nearby pedestrians	
	ATTC3. It is in my best interest to give way to nearby pedestrians	
Behavioural intention (BI) for pedestrian respondents (BIP)	BIP1. I will always give way to bicycles, regardless who have the right of way	<i>Che et al. (2020); Useche et al. (2018)</i>
	BIP2. I will always stay alerted to nearby bicycles	
	BIP3. I will always stay clear on one side in case a bicycle is approaching	
	BIP4. I will try my best to cautiously avoid bicycles on footpath	
Behavioural intention (BI) for cyclist respondents (BIC)	BIC1. I will always give way to pedestrians, regardless who have the right of way	<i>Che et al. (2020); Useche et al. (2018)</i>
	BIC2. I will always stay alerted to nearby pedestrians	
	BIC3. I will always alert pedestrians before approaching them	
	BIC4. I will always slow down when approaching pedestrians	

The questionnaire also includes questions to assess survey respondents' age and gender status to assess any possible influence on their behavioural intention due to users' demographics.

6.2 Survey scenarios and respondents

The validation of the framework used pedestrian-cyclist interactions on shared footpaths as a case study. With footpath being a narrow channel, two different types of pedestrian-cyclist interactions can be identified (see Figure 6-1), which include face-to-face (on-coming) pedestrian-cyclist passing, and a bicycle overtaking (from behind) a pedestrian.

Figure 6-1 Survey scenarios (top: on-coming passing; bottom: overtaking)

The developed framework focuses on one-to-one interactions in shared space. Travel behaviour on crowded paths is determined by many more factors apart from travellers' attitudes and belief. For example, crowded behaviour would also depend on the crowded speeds, movement directions and so on (Shahhoseini & Sarvi, 2019). Furthermore, the reported fatal or serious injury crashes between

cyclist and pedestrian often occur in one-to-one interactions (either on-coming or overtaking) (Alkhatib, 2019; Chan, 2019). As such, the current validation study centres the discussion around one-to-one interactions, as shown in Figure 6-1.

Questions presented in Table 6-1 were administered to pedestrian and cyclist respondents. For respondents to be categorised as cyclist respondents, the survey implemented a qualification question to only include those who ride a bicycle for at least twice a week on Singapore's shared footpaths. They were instructed to assume the role of cyclist throughout the entire survey. For those who indicated that they did not ride a bicycle for at least twice a week, they were instructed to act as a pedestrian throughout.

To examine both on-coming and overtaking scenarios, most of the questions were administered two times. As both pedestrians and cyclists were targeted, the developed framework was adopted into four different cases: pedestrian in on-coming (Ped_On) encounter, pedestrian in overtaking (Ped_Ov) encounter, cyclist in on-coming (Cyc_On) encounter, and cyclist in overtaking (Cyc_Ov) encounter. Table 6-2 presents how each questionnaire item in Table 6-1 was used in the four cases.

Table 6-2 Framework formations using developed questionnaire items

Frameworks formation	Perceived control	Perceived risks		Perceived priority		Attitude	Behavioural intention
		Self	Others	Self	Others		
Ped_On	PCP 1-3	PR 1-4	PR 5-7	PP 1-3	PP 4-6	ATTP 1-3	BIP 1-4
Ped_Ov	*PCP 1-3	*PR 1-4	*PR 5-7	*PP 1-3	*PP 4-6		
Cyc_On	PCP 1-3	PR 5-7	PR 1-4	PP 4-6	PP 1-3	ATTC 1-3	BIC 1-4
Cyc_Ov	*PCP 1-3	*PR 5-7	*PR 1-4	*PP 4-6	*PP 1-3		

*Questions asked for one more time to cover overtaking scenario

6.3 Survey administration and respondents' demographics

At the time of the survey, COVID-19 pandemic was influencing people's daily life. Singapore government has imposed strict social distancing measures that restrict physical contacts among strangers in public space (Ministry of Health, 2020). Conducting intercept survey in public was rather difficult. Online survey platform

was chosen to target Singapore's pedestrian and cyclist groups. Both the respondent recruitment and ensuing survey process were conducted online. To minimise selection bias, question groups within each row (PR 1-4, PR 5-7, PP 1-3 etc., as shown in Table 6-2) were shuffled in the orders of administering the questions to the respondents. The survey collected 897 responses. Validity checking was implemented. Survey responses from duplicated IP addresses were removed. Responses completed under 1/3 of the median completion time and straight liners were also removed from the dataset. After data cleaning process, 292 pedestrian and 300 cyclist responses were available for further analyses (see Table 6-3).

Table 6-3 Respondents' characteristics

Mode	Characteristic	Attribute	Frequency	Proportion (%)
Pedestrian (n=292)	Gender	Female	150	51.4
		Male	142	48.6
	Age	16*-20 years	18	6.2
		21-30 years	81	27.7
		31-40 years	78	26.7
		41-50 years	58	19.9
		51-60 years	35	12.0
		61-70** years	22	7.5
Cyclist (n=300)	Gender	Female	137	45.7
		Male	163	54.3
	Age	16*-20 years	18	6.0
		21-30 years	129	43.0
		31-40 years	79	26.3
		41-50 years	50	16.7
		51-60 years	17	5.7
		61-70** years	7	2.3

*Minimum interviewed age

**Maximum interviewed age

Table 6-3 also presents gender and age distributions from the valid responses. Overall, pedestrians' distributions are aligned with Singapore population profile (Department of Statistics Singapore, 2019), with a slightly lesser proportion of 71 years old and above. For cyclist respondents, there are no available cyclist population statistics in Singapore, but the gender and age distributions are

aligned with the authors' observation from Singapore streets. Young and male cyclists frequent the streets more as compared to other cyclist groups.

6.4 Findings

This section reports the general statistics of the survey results (see Table 6-4). To evaluate the goodness of fit and the validity of measurement items, confirmatory factor analysis was performed. The structural models derived from the four cases (Ped_On, Ped_Ov, Cyc_On and Cyc_Ov) are then presented.

6.4.1 Survey ratings

The collected survey ratings are assigned to the four cases to derive the models. Table 6-4 presents the average ratings (mean) and standard deviation (S.D.) for each model. The values are derived from 7-point Likert-scale ratings (1-7).

The ratings serve as a general assessment to each user group and interaction scenario. The ratings on perceived control (PC1-3) are found to be relatively low for pedestrian group and for overtaking scenarios. Particularly, Ped_Ov case had the lowest perceived control ratings. For ratings on perceived risk level, perceived pedestrians' risk level (PR1-4) was rated higher than cyclists' (PR5-7) by both pedestrian and cyclist respondents. Similarly, pedestrians' priority (PP1-3) on shared footpaths was rated relatively high by all respondents. In terms of attitude and behavioural intention, the ratings show that most pedestrians and cyclists were more prone (average between "somewhat agree" to "agree") to positive and cautious behaviour on shared footpaths.

6.4.2 Measurement model validation

Confirmatory factor analysis was conducted (see Table 6-5) to evaluate the model fit for measurement items. The results indicated a good fit, as the model fit indices meets the cut-off criteria ($CFI \geq 0.90$, $TLI \geq 0.90$ and $RMSEA \leq 0.06$) as recommended by Hu and Bentler (1999). Analysis on reliability, convergent and discriminant validity were also conducted. The values of composite reliability (CR) for all constructs are higher than 0.7, indicating that all measures are reliable.

The AVE (average variance extracted) values are above 0.5, which indicates good convergent validity (Hair et al., 1998).

Table 6-4 Mean and standard deviation for each measurement item

Construct	Measurement item	Ped_On		Ped_Ov		Cyc_On		Cyc_Ov	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Perceived control (PC) ¹	PC1	5.77	1.11	2.70	1.58	5.52	1.26	5.16	1.47
	PC2	5.53	1.11	2.88	1.61	5.41	1.30	4.98	1.49
	PC3	4.86	1.47	2.79	1.55	5.16	1.36	4.71	1.58
Perceived risks (PR)	PR1	4.40	1.54	5.61	1.17	4.64	1.55	4.99	1.50
	PR2	4.45	1.46	5.47	1.19	4.41	1.67	4.80	1.62
	PR3	4.78	1.33	5.49	1.20	4.72	1.51	5.13	1.41
	PR4	4.80	1.39	5.36	1.23	4.61	1.62	5.02	1.49
	PR5	3.24	1.64	3.61	1.75	3.99	1.70	4.57	1.69
	PR6	3.64	1.66	4.14	1.73	4.36	1.60	4.86	1.54
	PR7	3.71	1.63	4.16	1.62	4.11	1.71	4.57	1.69
Perceived priority (PP) ²	PP1	5.44	1.31	5.44	1.31	5.33	1.28	5.33	1.28
	PP2	5.47	1.31	5.47	1.31	5.34	1.30	5.34	1.30
	PP3	5.76	1.16	5.76	1.16	5.33	1.38	5.33	1.38
	PP4	2.82	1.31	2.82	1.31	3.51	1.55	3.51	1.55
	PP5	3.22	1.48	3.22	1.48	3.63	1.59	3.63	1.59
	PP6	2.45	1.28	2.45	1.28	3.69	1.59	3.69	1.59
Attitude (ATT) ³	ATT1	5.31	1.20	3.61	1.82	5.88	1.21	5.90	1.32
	ATT2	5.79	1.02	4.98	1.74	5.91	1.21	5.95	1.24
	ATT3	5.27	1.36	4.60	1.74	5.73	1.30	5.59	1.39
Behavioural intention (BI) ⁴	BI1	5.24	1.27	4.72	1.67	5.55	1.28	5.49	1.32
	BI2	5.69	0.97	4.99	1.47	5.87	1.13	5.84	1.22
	BI3	5.70	1.04	5.35	1.40	5.47	1.41	5.76	1.30
	BI4	5.65	1.07	5.24	1.43	5.80	1.20	5.79	1.31

¹PC corresponds to either PCP or PCCC in Table 6-1 depending on the type of respondents

²PP items are only assessed once for each user group. On-coming and overtaking share the same ratings

³ATT corresponds to either ATP or ATTC in Table 6-1 depending on the type of respondents

⁴BI corresponds to either BIP or BIC in Table 6-1 depending on the type of respondents

Table 6-5 Confirmatory factor analysis results

	Standardised factor loading	t-value	CR	AVE
PC1	0.89	***	0.90	0.76
PC2	0.90	41.99		
PC3	0.82	35.87		
PR1	0.83	***	0.86	0.60
PR2	0.87	31.49		
PR3	0.71	25.80		
PR4	0.67	23.85		
PR5	0.78	***	0.85	0.65
PR6	0.86	28.31		
PR7	0.78	26.68		
PP1	0.88	***	0.88	0.70
PP2	0.86	34.51		
PP3	0.76	30.72		
PP4	0.88	***	0.83	0.62
PP5	0.78	26.29		
PP6	0.69	23.95		
ATT1	0.80	***	0.82	0.60
ATT2	0.79	28.27		
ATT3	0.74	26.45		
BI1	0.70	***	0.85	0.59
BI2	0.84	25.76		
BI3	0.69	21.24		
BI4	0.83	25.30		
Model fit indices: $\chi^2 = 701.34$; df = 204; $\chi^2/\text{df} = 3.44$; IFI = 0.97; TLI = 0.96; CFI = 0.97; RMSEA = 0.05				

*** Donates a constrained relationship to 1 for identification

Table 6-6 shows the comparison of the squared correlations between constructs with AVE values. The AVE values are generally above the values of squared correlation, supporting the discriminant validity.

Table 6-6 AVE, construct correlation and squared correlation

Factor	PC	PR_Ped	PR_Cyc	PP_Ped	PP_Cyc	ATT	BI
PC	0.76 ¹	0.12 ³	0.00	0.00	0.02	0.00	0.00
PR_Ped	-0.35 ²	0.60	0.27	0.02	0.02	0.01	0.00
PR_Cyc	-0.07	0.52	0.65	0.01	0.03	0.02	0.08
PP_Ped	0.07	0.14	-0.08	0.70	0.14	0.01	0.00
PP_Cyc	0.14	-0.15	0.18	-0.38	0.62	0.44	0.24
ATT	0.00	0.10	0.16	0.08	0.66	0.60	0.77
BI	0.06	0.06	0.28	0.02	0.49	0.88	0.59

¹Average variance extracted values are along the main diagonal

²Correlations between constructs are below the main diagonal

³Squared correlations between constructs are above the main diagonal

6.4.3 Path analysis of structural models

Findings from structural model analysis are reported. The proposed pathway diagram for the overall conceptual framework (see Figure 5-4, Chapter 5) is shown for all four models. The path analysis results for each of the four models are presented in the following figures.

Figure 6-2 Path analysis for pedestrian in on-coming scenario

Figure 6-3 Path analysis for pedestrian in overtaking scenario

Figure 6-4 Path analysis for cyclist in on-coming scenario

Figure 6-5 Path analysis for cyclist in overtaking scenario

Across all figures, the reported modelling indices indicate good fit for all four models. With a confidence level of 0.95 ($\alpha=0.05$), the proposed hypotheses are partially supported. H1 and H2 as derived from TRA and TPB are supported universally across all four models, indicating their robustness in user behaviour modelling. It is also noted that some hypotheses are only supported in selected user groups or interaction scenarios. H4a hypothesises a positive relationship between perceived self-risks and attitude, which only stands true in pedestrian group (Ped-On and Ped_Ov, see Figures 6-2 and 6-3). Similarly, H4b and H5a are only supported in cyclist group (Cyc_On and/or Cyc_Ov, see Figures 6-4 and 6-5). Furthermore, H3 posits a positive relationship between perceived control and behavioural intention. However, an inverse relationship is found in Ped_On model (see Figure 6-2). Similar inverse relationship is also found for H4b in Ped_On model. In addition, the possible influence of gender and age groups were also tested. The results suggested no significant influence; therefore, they are removed from the path analysis.

6.4.4 Alternative models for all four cases

TRA argues that people's attitude towards an action is depicted by their readily formed belief aspects, and attitude is the direct antecedent of behavioural intention (Fishbein & Ajzen, 1977). This provides theoretical basis for hypothesising the mediated effects of perceived risk level (H4a and H4b) and perceived priority (H5a and H5b) on behavioural intention through attitude, which have been built into the developed model. However, some empirical studies directly related perceived risk level (Twisk et al., 2015) and perceived priority (Vlakveld et al., 2020) with behavioural intention. This suggests that there might be unmediated effects from perceived risk level and perceived priority to behavioural intention.

Figure 6-6 Alternative model

To assess the possible existence of direct effects from perceived risk level and perceived priority, an alternative model was proposed. Four more hypotheses were added (see Figure 6-6). H4aa and H4ba hypothesise direct relationships between perceived self-risks and behavioural intention, and between perceived others' risks and behavioural intention, respectively. H5aa and H5ba hypothesise direct relationships between perceived self-priority and behavioural intention,

and between perceived others' priority and behavioural intention, respectively. The proposed alternative model was adopted for all four cases. Table 6-7 summarises the path analysis results for each case.

Table 6-7 Path analysis for each case using alternative model

Hypothesis	Path	Ped_On		Ped_Ov		Cyc_On		Cyc_Ov	
		Std Coeff	P	Std Coeff	P	Std Coeff	p	Std Coeff	P
H1	ATT to BI	0.87¹	<0.001	0.90¹	<0.001	0.64¹	<0.001	0.78¹	<0.001
H2	PC to ATT	0.67¹	<0.001	0.35¹	<0.001	0.66¹	<0.001	0.48¹	<0.001
H3	PC to BI	-0.10	0.925	-0.27²	<0.001	0.29¹	<0.001	0.09	0.095
H4a	PR_Self to ATT	0.20¹	0.001	0.25¹	<0.001	0.06	0.579	-0.07	0.517
H4aa³	PR_Self to BI	-0.01	0.820	0.10	0.077	-0.07	0.403	0.10	0.251
H4b	PR_Others to ATT	-0.16²	0.009	-0.01	0.863	0.14	0.198	0.42¹	<0.001
H4ba³	PR_Others to BI	0.00	0.973	0.02	0.735	0.06	0.400	-0.11	0.212
H5a	PP_Self to ATT	0.08	0.234	-0.04	0.622	-0.16¹	0.002	-0.19¹	<0.001
H5aa³	PP_Self to BI	0.09	0.103	0.09	0.110	0.03	0.416	0.05	0.268
H5b	PP_Others to ATT	0.25¹	<0.001	0.38¹	<0.001	0.26¹	<0.001	0.30¹	<0.001
H5ba³	PP_Others to BI	0.00	0.948	-0.04	0.617	0.10	0.092	0.11	0.075

Model fit indices

Ped_On: $\chi^2 = 460.21$; $df = 215$; $\chi^2/df = 2.14$; IFI = 0.92; TLI = 0.91; CFI = 0.92; RMSEA = 0.06

Ped_Ov: $\chi^2 = 434.40$; $df = 215$; $\chi^2/df = 2.02$; IFI = 0.95; TLI = 0.94; CFI = 0.95; RMSEA = 0.06

Cyc_On: $\chi^2 = 498.98$; $df = 218$; $\chi^2/df = 2.29$; IFI = 0.93; TLI = 0.92; CFI = 0.93; RMSEA = 0.07

Cyc_Ov: $\chi^2 = 416.63$; $df = 218$; $\chi^2/df = 1.91$; IFI = 0.95; TLI = 0.94; CFI = 0.95; RMSEA = 0.06

¹Supported hypothesis with $\alpha=0.05$

²Hypothesis not supported, but a relationship inverse to the originally hypothesised found

³Hypothesis added from alternative model

The reported indices indicate good fit for all alternative cases. For each case, the supported hypotheses in the alternative model are identical to the original model. Furthermore, the standardised coefficients for each supported hypothesis are also similar as compared between the original model and the alternative model. However, with a confidence level of 0.95 ($\alpha=0.05$), the newly proposed H4aa, H4ba, H5aa and H5ab are not supported in the alternative model. This indicates that there are no significant direct effects from perceived risk level

and perceived priority to behavioural intention. Instead, the effects are mediated by attitude. Hence, the alternative models were rejected.

6.4.5 Reduced structural models for all four cases

Observing both the original model and alternative model, it has been noted that certain hypotheses are not supported in all four cases. To get the most effective model for each case, the unsupported hypotheses in each case were taken out to obtain reduced models for the four cases. The results are presented in the following figures.

Figure 6-7 Path analysis for pedestrian in on-coming scenario (reduced model)

Figure 6-8 Path analysis for pedestrian overtaking scenario (reduced model)

Figure 6-9 Path analysis for cyclist in on-coming scenario (reduced model)

Figure 6-10 Path analysis for cyclist in overtaking scenario (reduced model)

Comparing Figures 6-7, 6-8, 6-9 and 6-10 to the full models, the results are similar. The supported hypotheses in each model remain the same with nearly identical weightages. The reduced models serve to affirm that perceived self-priority has little effect on pedestrians' decision making. Similarly, perceived others' risk is only valid for cyclists.

Table 6-8 summarises the total effects of each construct in modelling users' behavioural intention. Both direct effect and indirect effect (as moderated by attitude) were taken into consideration and added up together.

The results show that the perceived control has relatively high effects on behavioural intention for cyclist group and in on-coming scenarios. Pedestrian respondents only factor in their own risks level but not cyclist's risks when deciding on their behavioural intention. On the contrary, cyclist respondents only factor in pedestrian's risks and do not consider their own risks. Particularly in Ped_Ov case, pedestrians may behave more aggressively if they view cyclist's risk level as high. Furthermore, perceived self-priority only has effects on cyclists.

It is also noted that as interaction scenarios and user groups vary, the total effects of the constructs also vary, with the only exception of users' attitude.

Table 6-8 Direct and indirect effects of constructs on users' behavioural intention (BI)

Construct	Effects	Ped_On	Ped_Ov	Cyc_On	Cyc_Ov
Perceived control	Direct effect	NA	-0.32	0.27	NA
	Indirect effect	0.56	0.32	0.46	0.39
	Total effect	0.56	0.00	0.73	0.39
Perceived self-risks	Direct effect	NA	NA		
	Indirect effect	0.17	0.27	No effect	No effect
	Total effect	0.17	0.27		
Perceived others' risks	Direct effect	NA			NA
	Indirect effect	-0.14	No effect	No effect	0.33
	Total effect	-0.14			0.33
Perceived self-priority	Direct effect			NA	NA
	Indirect effect	No effect	No effect	-0.10	-0.15
	Total effect			-0.10	-0.15
Perceived others' priority	Direct effect	NA	NA	NA	NA
	Indirect effect	0.20	0.35	0.21	0.28
	Total effect	0.20	0.35	0.21	0.28
Attitude	Direct effect	0.85	0.91	0.72	0.83
	Indirect effect	NA	NA	NA	NA
	Total effect	0.85	0.91	0.72	0.83

6.5 Discussion and conclusions

6.5.1 General users' perception based on ratings

The general statistics of the survey ratings reveal various users' perceptions on shared footpath interactions, including perceived behavioural control, perceived risk level, and perceived priority. It provides a profiling of the ground situation and serves to rationalise the path analysis results.

The findings show that as scenario varies, the amount of perceived control may also change. For example, users' perceived control in on-coming scenarios are generally higher than overtaking scenarios. Pedestrians are found to have extremely low control when being overtaken by cyclists. Users' perceived priority are also different on shared footpaths. As mentioned earlier, shared footpaths were originally dominated by pedestrians, and cyclists are allowed to use the space only quite recently. It results in higher perceived priority for pedestrians, which is confirmed by the survey results. Attitude and behavioural intention ratings suggest that more path users tend to behave positively and cautiously on the footpaths. However, negative ratings could also be found from some respondents, suggesting huge room for improvement.

6.5.2 Supported hypotheses and theories

Is belief-attitude-behavioural intention framework effective in behaviour modelling? To model shared space users' interactive behavioural intention, the current study relied on past literatures and gathered critical propositions to form hypotheses in the conceptual framework. Inspired by some criticisms to existing theories and considering the dyadic nature of the behaviour, the study further differentiated beliefs concerning oneself and beliefs concerning the interacting counterparts (others'). TRA and TPB propose the belief-attitude-behavioural intention framework (Fishbein & Ajzen, 1977; Madden et al., 1992), which unifies all proposed hypotheses in the current study. The path analysis results showed the robustness of such behaviour modelling framework. The tested relationship between attitude and behavioural intention stands true for all cases. Perceived control is also revealed to be a crucial factor to behavioural intention, as suggested by TPB (Ajzen, 1991).

Is it risk compensation or taking advantage of risk? Studies show that people adapt their behaviour in accordance with their perceived risk level (Adams, 2012; Phillips et al., 2011), which is supported by the survey findings in the current study. Both pedestrian and cyclist respondents have indicated their attitude to behaviour more positively and cautiously as their perceived risk level gets higher,

which agrees with the proposition in risk compensation theory. However, upon differentiating self-risks and others' risks, the results revealed some more controversial implications.

The path analysis has shown that the positive effects of perceived self-risks are only present on pedestrians. Pedestrians have the intention to act more cautiously if they think they are involved in high risks situations. However, they react to cyclist's risks differently. A negative relationship between perceived others' risks and behavioural intention is found in Ped_Ov. It indicates that pedestrians may behave more aggressively when they perceive cyclist's risk to be high. In other words, while self-risk compensation may be true for pedestrians, they may also take advantage of interacting counterpart's risk level. Cyclist respondents' case is completely different. Self-risk compensation is not found in cyclist models. Instead, cyclists tend to compensate for their counterpart's (pedestrian) risk level.

Do both manifest power and invisible power affect behaviour? DPT posits that powers are relative terms. In dyadic interaction, the relative power status may influence people's attitudes on behaviour (Dunbar, 2004; Worley & Samp, 2014). The current study identified two forms of power, namely perceived risk level (manifest power) and perceived priority (invisible power). Manifest power's impact has been assessed and discussed in TRA and TPB. The influence of invisible power is also evident as suggested by the survey findings. A negative relationship between perceived self-priority and attitude was found. This justifies DPT's argument that the people's relative power status would influence their attitude and behaviour in interactive scenarios.

Is it necessary to differentiate perceptions on oneself and perception on others?

The current study has made an important contribution to the existing body of literature on interactive behaviour. The perceptions toward oneself and toward the interacting counterparts were differentiated and analysed separately. This is inspired by one of the criticisms to the original risk compensation theory (Hammond & Musselwhite, 2013; Pless, 2016) whereby self-risks and others'

risks are not considered separately. The findings suggest the differentiation is necessary to interpret interactive behaviour. The effects of perceived self-priority and perceived others' priority were found to be totally different. Furthermore, upon closely analysing the different effects of perceived self-risks and perceived others' risks, it was concluded that while risk compensation could be true, taking advantage of others' risk may also be prominent depending on user groups and scenarios.

6.5.3 Pedestrian vs cyclist and on-coming vs overtaking

In path analysis, the proposed hypotheses were compared across all four cases to conclude on their theoretical implications. As revealed by the results, some hypotheses are only supported by selected cases. Their standardised coefficients also vary from case to case. This shows that the belief constructs' effects on behavioural intention change as scenario and user group change.

Comparing between pedestrian and cyclist groups, the most apparent difference is how they relate different types of perceived risk level to their behavioural intention. As concluded earlier, pedestrians show sign of self-risk compensation, but they may take advantage of interacting counterpart's risk level. This indicates a more competitive mindset for pedestrians. Cyclists are found to be more cooperative in the way that they tend to compensate for pedestrian's risk. Taking advantage of counterparty's risk is not present on cyclists. Another difference between pedestrian and cyclist can be seen in the effects of perceived control. The effects of cyclist's perceived control are observed to be higher than pedestrian's control. Tracing back to the mean values of perceived control ratings, cyclists' rating is also found to be higher than pedestrians' ratings. This may indicate that as users' perceived control increases, they rely more on their control to decide how they intend to behave.

Comparing between on-coming and overtaking scenarios, the effect of each construct also varies case by case. From on-coming scenarios to overtaking scenarios, as the perceived control decreases, the effect of perceived control weakens as well. On the contrary, the effect of perceived self-priority gets

stronger in such situations. This suggests that as users lose their control in interactive situations, the readily established power status becomes more important as to how they decide on their behavioural intention.

6.5.4 Practical implications

The conceptual framework aims to model pedestrian and cyclist behavioural intention on shared footpaths. The validation through perception survey data shows that the critical aspects (perceived self/others' risks, perceived others' priority, and perceived control) have significant influence on users' behavioural intention. Applying the findings to real-world practice, measures that raise footpath users' awareness of the potential risks involved in cyclist-pedestrian crashes may motivate them to behave more positively and cautiously, which consequently improve the safety level on shared footpaths. The study also revealed that pedestrians may consider cyclists as competitors in shared space. To resolve this, it is important to establish a coherent sharing scheme that promotes cooperation among all shared footpaths' users. Nation-wide education programme and advertisement could be implemented. To share the space cooperatively, it is also important to specify the right-of-way among all user groups with pedestrians' priority defined by regulations. This minimises conflicts in how different users' perceived priority depicts their behavioural intention. Lastly, the current study shows that users' perceived control has the most dominant influences on their attitudes and behavioural intention. Improving perceived control could significantly promote positive behaviour. While rebuilding the entire infrastructure may not be plausible in a short period of time, simple treatments such as promoting keeping to one side on the footpath may effectively reduce the complexity and uncertainty involved in interactions, especially for overtaking manoeuvres. In fact, such lane discipline has been endorsed by Singapore government in their recent revision of Active Mobility Bill (Land Transport Authority, 2020a), in which pedestrians are recommended to keep to the left side of the shared footpaths.

6.6 Chapter summary

This Chapter validates the proposed conceptual framework by designing and administering an online perception survey to shared footpath users (pedestrian and cyclist). The proposed hypotheses have been supported in the path analysis. It is found that as varying from case to case, the effects of perceived self/others' risks, perceived self-priority and perceived control may vary. The analysis results also indicate some critical implications to real-world practices. It should be noted that the framework is derived from social behavioural theories that assume people's behavioural intention is the direct antecedent to their action (actual behaviour). To complete the framework, it is important to examine this assumed relationship by a further field study, which is discussed in the next chapter.

CHAPTER 7 USERS' BEHAVIOURAL INTENTION AND THEIR ACTION

The Chapter discusses the relationship between behavioural intention and action (actual behaviour), adding one more aspect to the developed framework for shared space interactive behaviour modelling. A “keep left” experiment involving pedestrians’ and cyclists’ interactive behaviour on shared footpaths is used as a case study. Findings are derived from before-and-after experiments involving intercept survey data and naturalistic observations through video recordings.

7.1 Intention-action gap

Behavioural intentions are considered as the direct antecedent to actual behaviour by correlation studies (Sheeran & Webb, 2016). It supports the development of many social psychological models, including theory of reasoned action (TRA) (Fishbein & Ajzen, 1977), theory of planned behaviour (TPB) (Ajzen, 1991; Madden et al., 1992) and other theories that are used to assess mobility decisions (Rojas López & Wong, 2019). Building on the belief-attitude-behavioural intention relationship as proposed by TRA and TPB, the framework developed in this research study also assumes that behavioural intention is the most critical and direct predictor of individuals’ action. It is argued from comparison with other cognition factors such as attitudes and perception of risks that behavioural intentions are more closely related to actions (McEachan et al., 2011).

The assumed strong relationship between behavioural intention and action has received various criticisms. Meta-analysis using experimental data have suggested that a significant change in intention may only result in a minor change in action (Gourlan et al., 2019; Rhodes & Dickau, 2012). Some studies highlighted a few factors that interfere in the process of behavioural intention being translated to action. For example, if intention goal is set too high, the difficulty level of performing the action might be under-estimated, hence reducing the likelihood of achieving the goal (Sheeran et al., 2003). A study finds that intentions formed under descriptive norm (what the majority group does) have more significant influences on actions, as compared to intentions formed by

injunctive norm (what the society approves of) (Melnyk et al., 2019). Similarly, intentions formed by affection (pleasantness or unpleasantness) are more easily translated to actions, as compared to the intentions formed under cognition (perceived benefits of performing such actions) (Keer et al., 2014). Furthermore, there could be conflicts between what people want to do and what they should do (Milkman et al., 2008). For example, the intention to complete a manuscript and the desire to take a break is a dilemma faced by many researchers (Sheeran & Webb, 2016), which could significantly impede the intention realisation process (Abraham et al., 1999).

7.2 Habit as contrasted to intended behaviour

Habit is another extensively studied factor that could weaken the behavioural intention-action relationship. The intention to change a habit would involve shifting a mundane action that has been occurring repeatedly. The focal behaviour of the current study, “keep left” in daily travel, is a good example.

Habit is defined as a stable context that results from people repeating their action (Wood & Rünger, 2016). At the initial stage of habit formation, people still act according to their intentions. When such action is repeated under a stable context, it allows the direct pairing of context cues with the action being formed (Gardner & Tang, 2014). As the repetition continues, the pairing stabilises. Context cues could directly trigger action without the need to consciously set an intention first (Mazar & Wood, 2018). At this stage, performing an action out of habit no longer requires a reasoned-based antecedent (behavioural intention) (Neal et al., 2012), which usurps some social behaviour theories such as TRA and TPB.

Experimental studies have provided some evidence on the impact of habit. In a bicycle usage study, it is concluded that for cyclists who act out of their habits, their stated intention to ride a bicycle does not depict their actual riding frequencies (Danner et al., 2008). A travel mode choice study (Verplanken et al., 1998) also suggested that the strong relationship between behavioural intention and action is only present when habit is not formed. In the modelling of vehicle

drivers' energy conservation behaviour, habitual and situational processes have more significant effects as compared to normative and intentional processes (van den Broek et al., 2019). Such findings have implications to the current study where the targeted two user groups (pedestrian and cyclist) offer a contrast as regarding the presence of habit in behavioural intention-action translation process.

As mentioned in Chapter 2, while pedestrians have always been using the footpaths, cyclists are only recently allowed to share the space as legislated by the Active Mobility Bill (Attorney-General's Chambers, 2017). For pedestrians, how they walk on the footpaths is a readily formed habit. For cyclists, shared footpath is not a native environment. When the "keep left" treatment is applied, pedestrians' readily formed habit would continue to lead them to act as usual while cyclists may require changes in lane discipline. As such, the following two hypotheses are formed:

H_1: "Keep left" treatment raises both pedestrians' and cyclists' intentions to follow "keep left". However;

H_2: Due the different habits formed under different mobility settings, pedestrians' intention to keep left may not translate to action as effectively as cyclists.

7.3 Methodology

7.3.1 Study site and equipment

A straight stretch of shared footpath (1.5m in width) was chosen as the experiment site, which is located at Singapore Yishun Township. The site represents the most typical shared footpath in Singapore. It connects a large residential neighbourhood to Yishun MRT station and a large shopping mall. As such, frequent trips made by pedestrians and cyclists on the site include both daily commuting from/to work and local shopping/dining trips. It ensures the data captured in the experiment a fair representative of the most common trips occurred in Singapore. The "keep left" treatment applies three pairs of

directional markings on the surface of the shared footpath (see Figure 7-1a). Each pair is 30m apart from the next. Intercept perception surveys and naturalistic observations through video footage recordings were conducted both before-and-after the treatment.

Figure 7-1 Applied directional arrows and unobtrusive setup for video recording

The intercept surveys were used to assess potential changes in footpath users' (pedestrians and cyclists) perception and attitudes. More importantly, the surveys would determine whether users have the intention to keep left after the treatment. The surveys were conducted by interviewing travellers (pedestrians and cyclists) at the experimental site. For naturalistic observations, a camera setup was used to record users' on-site movements. The setup involved mounting a wide-angle action camera to an aluminium pole. When doing recording, the setup was mounted to the adjacent lamp pole (see Figure 7-1b). Its small size also makes it unobtrusive in order not to attract unnecessary public attention. Table 7-1 presents the data collection timeline.

Table 7-1 Study timeline

Data collection period	Paper-based perception survey	Recording to provide naturalistic observations
Before period	Jan-2019	Jan-2019
Directional arrows applied on 29-Jan-2019		
After period	Mar-2019	Mar-2019

7.3.2 Survey procedures and demographics

For the before-and-after intercept surveys, a 5-point Likert-scale questionnaire was administered to survey respondents. The questions included: “I would travel on the left side of the path”, “I feel I am conflicting with cyclists (for pedestrian respondents) / pedestrians (for cyclist respondents) on this path” and “I feel safe walking (or cycling) on this path”. All questions were rated from strongly agree (1) to strongly disagree (5). After removing invalid inputs, a total of 358 responses were collected. The age and gender groups of pedestrian and cyclist respondents are presented in Table 7-2. The age and gender groups of pedestrians generally fit Singapore population (Department of Statistics Singapore, 2019). For cyclist respondents, more responses came from male cyclists, which matches the authors’ observation of cyclist groups on Singapore shared footpaths.

Table 7-2 Age and gender groups of survey respondents

	Before period		After period	
	Pedestrians	Cyclists	Pedestrians	Cyclists
Age (years)				
≤ 20	10	13	8	7
21-30	23	30	17	9
31-40	28	16	8	19
41-50	24	30	13	10
51-60	20	12	9	7
≥ 61	15	18	4	8
Gender				
Male	60	78	26	41
Female	60	41	33	19
Total	120	119	59	60

To test the effects of the directional markings, it is important to ensure that more footpath users already have enough exposure to the treatment in the after-period data collection. As such, the intercept surveys also assessed respondents’

travel frequency on the experimented shared footpath (see Figure 7-2). The results show that most respondents travel on the footpath quite frequently.

Figure 7-2 Respondents' travel frequency along the shared footpath under study

7.3.3 Naturalistic observations

The naturalistic observations examined the actual change that occurred in shared footpath users' "keep left" actions before-and-after the treatment. The current study focuses on analysing individual's action under free-flow conditions, including a single traveller (pedestrian or cyclist) without interacting with others, and a single pedestrian interacting with a single cyclist.

Videos were recorded before-and-after the treatment. All recordings were conducted in sunny or cloudy weathers during the daytime. This eliminates any interference from the weather conditions to users' travelling demand and behaviour (Ahmed et al., 2013). The observation area in the video recordings is 14m long, as bounded by two manholes (see Figure 7-3). As mentioned earlier, the experiment's site had three pairs of directional arrows applied, with 30m spacing. The observation area was set near to the middle pair. This ensures that travellers entering from either end of the area had already seen at least one pair of arrows.

Figure 7-3 Video footage of study site to observe movement actions

During video data extractions, guiding lines were superimposed on top of the video footage such that the observation area is divided into two sides. Single travellers (without interacting with others) travelling on the left side were noted as “keeping left” (see Figure 7-3a), as seen from the traveller’s perspective. Single travellers travelling on the right side were noted as “keeping right” (see Figure 7-3b). Any single user who went across both sides within the observation area was noted as “going zigzag”. Figure 7-3 also shows the observation area before-and-after applying the treatment.

Single pedestrian interacting with single cyclist was also recorded. There are two types of pedestrian-cyclist interacting scenarios on shared footpath, including face-to-face (on-coming) encounter, and one cyclist overtaking one pedestrian (overtaking). In addition, if all footpath users strictly follow the “keep left” rule, a cyclist should pass a pedestrian from the pedestrian’s right side in both on-coming (see Figure 7-4a) and overtaking (see Figure 7-4b) scenarios. However, if lane keeping is not consistent with “keep-left” discipline, a cyclist could also pass a pedestrian from the pedestrian’s left side in both on-coming (see Figure 7-4c) and overtaking (see Figure 7-4d) scenarios.

Figure 7-4 Four interaction cases between a pedestrian and a cyclist (pedestrian as the pivot)

As shown in the timeline (see Table 7-1), the entire study period was from Dec-2018 to Mar-2019. During this two and half-month period, no infrastructure upgrades (aside from the treatment) were observed on shared footpaths. There were also no newly released policies or significant events that might have influenced users' attitudes or actions (actual behaviour) on shared footpaths. As such, any observed shifts in users' intention or lane-keeping actions in the study could be attributed to the effects of the study treatment (application of "keep left" markings).

7.4 Findings

Intercept perception survey results are presented. Pedestrians' and cyclists' actual lane keeping actions and interactions are also categorised and compared. The results shall determine the effectiveness of the treatment on both behavioural intention and action.

7.4.1 Users' intention from perception survey

Figure 7-5 Ratings of intention to keep left

Figure 7-5 shows the before-and-after ratings regarding pedestrians' and cyclists' intention to keep left while travelling on the shared footpaths. The ratings suggest that, without treatment, both pedestrians and cyclists have no particular tendency in their intention to follow lane keeping, with evenly distributed opinions on whether or not they would keep left. The treatment had significant effects on improving their lane keeping intention, with the majority of the pedestrians and cyclists intending to keep left (two-tailed Wilcoxon rank sum test with $\alpha=0.05$: pedestrians – $W = 2081$, $p < 0.001$, effect size = 0.71; cyclists – $W = 1999$, $p < 0.001$, effect size = 0.72).

Figure 7-6 presents the ratings from pedestrian and cyclist respondents regarding their perceived conflict level with each other. Unlike the significant increases in lane keep intention upon treatment, perceived conflict level only had only marginal reduction after the treatment, which is not statistically significant (two-tailed Wilcoxon rank sum test with $\alpha=0.05$: pedestrians – $W = 3412$, $p = 0.70$, effect size = 0.51; cyclists – $W = 3299$, $p = 0.41$, effect size = 0.54).

Figure 7-6 Ratings of perceived conflict level in pedestrian-cyclist interactions

Figure 7-7 shows the perceived safety ratings on shared footpath. Similar to perceived conflict level, only marginal increases in perceived safety level were observed for both pedestrian and cyclist respondents, which is also not statistically significant (two-tailed Wilcoxon rank sum test with $\alpha=0.05$: pedestrians – $W = 3280.5$, $p = 0.43$, effect size = 0.54; cyclists – $W = 3514$, $p = 0.87$, effect size = 0.51).

Figure 7-7 Perceived ratings safety of shared footpath under study

7.4.2 User behaviour from naturalistic observations

Naturalistic observations extracted users' movement profiles from video recordings, included: (1) lane-keeping actions of single pedestrian or cyclist

(without any interaction with others), and (2) single pedestrian-single cyclist interactions. Figure 7-8 shows the lane-keeping actions of individual pedestrian or cyclist on the shared footpath. Around 15 hours of footages were analysed for before and after periods combined. For single pedestrian movements, a total of 303 cases were extracted from before period and 262 cases from after period. For single cyclist movements, there were 148 and 174 cases, respectively. The results suggest that before the treatment, pedestrian and cyclist groups had similar distribution for lane-keeping actions. Around half of the shared footpath users kept left, while the other half travelled on the right side or exhibited zigzag movements. After the treatment, cyclists and pedestrian behaved differently. Substantial improvement could be observed in cyclists' keep-left actions, with over 30% more cyclists keeping left. However, pedestrians' lane keeping actions remained the same as before.

Figure 7-8 Individual (single traveller) lane-keeping actions in the absence of any interaction

As pedestrians' lane-keeping actions were not changed, it might have corroborated in the pair-wise pedestrian-cyclist interaction patterns (as presented from pedestrian's perspective) as shown in Figure 7-9. A total of 90 interactions in before period and 76 interactions in after period were extracted. Each interaction type remains proportionately similar before-and-after the treatment, which suggest that there were only marginal improvements in the perception of safety level and conflict level.

Figure 7-9 Categories of pedestrian-cyclist one-to-one interactions (pedestrian's perspective)

7.5 Discussion and conclusions

To assess users' behavioural intention and their actions, before-and-after intercept perception surveys and naturalistic observations were conducted. The study findings agree with the proposed hypotheses that (H_1) while "keep left" treatment may improve both pedestrians' and cyclists' intentions to keep left, (H_2) pedestrians' actual lane-keeping actions may not be improved as much as cyclists .

7.5.1 Complication in behavioural intention-action relationship

The perception survey findings suggest that the applied "keep left" markings significantly improved both pedestrians' and cyclists' intention to keep left. However, the ratings of perceived conflict level with each other only had marginal increases after the treatment. Consequently, both pedestrians' and cyclists' perceived safety level on the shared footpath did not improve significantly either. Naturalistic observation results could help to explain the inconsistent survey findings. Observing users' actual lane-keeping actions, cyclists actually behaved better after the treatment, with most of them keeping to the left side of the path. Pedestrians, on the other hand, did not show such change in actions. As a result, in the dyadic interaction between pedestrian and cyclist, the unchanged pedestrians' actions resulted in the overall interaction patterns to remain the same; therefore, the safety level and conflict level ratings

also remained similar as before. The afore-mentioned findings reveal a weak behavioural intention-action relationship for pedestrians, but the relationship for cyclists is found to be strong. The reviewed studies on habit could provide some justifications to the results.

The current study focuses on lane-keeping behaviour on shared footpaths that users perform on daily basis. Herein, context cues (location, environment, time of day etc.) would directly trigger habit (Gardner & Tang, 2014) without recourse to consciously-formed intention. It should be noted that pedestrians and cyclists belong to two distinctive user groups. Being influenced by Singapore mobility cultures, they may have different habit formation process.

7.5.2 Habits formed under different mobility settings

In Singapore, pedestrians had the sole priority on footpath before the introduction of Active Mobility Bill in 2017 (Land Transport Authority, 2017a). Walking has the highest manoeuvrability as compared to other mobility choices. Hence, it does not require strict lane discipline for people to move around safely. Most of the walking facilities in Singapore do not enforce keeping to one side either. Consequently, Singapore pedestrians have never been conditioned to keep to certain side of the path. Furthermore, no infrastructure change was implemented when the footpath was legislated for shared usage. Although the current study has applied directional markings on the path, they only serve as suggestive signage. With similar context cues (the same location, the same environment and the same travel mode), their previously formed habit on unshared footpaths would continue to prevail (Wood & Rünger, 2016), that is by not walking on any particular side of the path. On the other hand, cyclists are already used to the keep-left operations since conventionally they travel on the roadway alongside motorised vehicles. The travel directions on the roadway pavements are pre-designated and cyclists have to keep left. When the shared footpath is applied with directional arrows, cyclists' previously formed cues would work in unison with their intentions, and hence maintain their lane discipline consistently on the shared footpath. In essence, as hypothesised, due

the different habit formation process under different mobility setting, pedestrians' intention to keep left is not realised into actions as readily as cyclists.

7.5.3 Implications on behaviour modelling

Up until this point, the developed framework assumes a strong intention-action relationship. The hypotheses derived from TRA, TPB, DPT and risk compensation theory serve to understand shared space users' behavioural intention. People's perceived control, perceived risk level and perceived priority depict their attitudes and subsequently influence their behavioural intention. From there, it is assumed that people act on overt reasoning and utility maximisation. However, the current study shows that this may not always be true for a cluster of behaviour that involves recurring everyday activities.

Figure 7-10 Added dimension in the framework

Habit is context dependent (Mazar & Wood, 2018). Once it has been formed, context cues such as physical location, environment and time of day (Neal et al., 2012) could trigger the habit without any conscious rationalisation. In the case that habitual action conflict with rationalised intention, the modelling framework as based on belief-intention-behavioural intention may not effectively interpret actual behaviour anymore. Instead, in modelling such

repeating behaviour, the influence of habit must be taken into consideration. This adds a new dimension to the framework, for the stage that behavioural intention translates into action (see Figure 7-10).

7.5.4 Practical implications

The study findings have some implications in real-world practices. Depending on the type of behaviour, the strength of behavioural intention-action relationship could vary significantly. Habit impedes the translation from intention to action (Neal et al., 2012). Simply shifting people's intention may not guarantee a change in action. Travel behaviour is often habitual and can be triggered by familiar context cues. Hence, to strengthen such intention-action relationship, more obvious and apparent remediations to the infrastructure may be needed. A study on habit also suggested that introducing penalties and tighter enforcement could help to form a new norm (White et al., 2019). Furthermore, forming a new habit takes time. Implementing treatments that persists over a long period of time could be more effective in shifting habit (Mazar & Wood, 2018).

7.6 Chapter summary

This Chapter examines the intention-action relationship using a “keep left” experiment as a case study. It is revealed that forming intention does not guarantee a significant change in action. The manner that habit would impede the process must be carefully assessed. This Chapter completes the behaviour modelling framework by providing assessment to relationship between behavioural intention and action and adding the aspect of habit to the existing framework.

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

This concluding Chapter highlights and summarises the research activities as reported in the previous Chapters. Principal findings from each study are articulated. The real-world implications are summarised. Proposed measures to overcome limitations encountered in current studies are discussed as part of future work.

8.1 About the research

Active mobility development in Singapore is quite unique. With the Active Mobility Bill being enacted in 2017, pedestrians, bicycles and ES (electric scooters) sharing the footpaths became a norm. However, with the new space sharing scheme, crashes and conflicts also increased. The authority regulated the travelling speed (speed limit at 10km/h), but it did not solve the problem. ES was eventually banned from the shared footpath, as riding ES was considered the more dangerous active mobility mode as compared to pedestrian and cyclists. However, conflicts on the shared footpaths have persisted. This calls for research into shared footpath users' attitude and behaviour. If their behaviour can be analysed and modelled systematically, effective measures that resolve conflicts in space sharing should follow suit. To achieve this quest, the following steps are covered in the research:

1. An assessment to the current situation was conducted. Figuring out why speed regulation did not work on ES provides a starting point to understand what actually matters when users decide on their behaviour.
2. A conceptual framework that models shared space interactive behavioural intention was established.
3. With the developed framework, validation was performed to test its effectiveness for different user groups under different types of interactions.
4. To examine the relationship between intention and action (actual behaviour), a field experiment on "keep left" treatment was conducted.

It completes the behaviour modelling process by adding the aspect of habit into the framework.

8.2 Findings and conclusions

Each of the afore-mentioned steps is presented as covered in Chapters 4-7. Their findings and conclusions are summarised in this section.

Chapter 4 assesses users' perception towards various ES riding speeds (10km/h, 15km/h and 20km/h) using VR experiment. Pedestrian and ES rider groups were targeted as experiment participants. The pedestrian/ES conflicts that participants experienced were analysed. The findings show that for overtaking scenario, lower ES speed at 10km/h was perceived as the safest. However, in face-to-face interaction with ES, pedestrians perceived 15km/h to be the safest ES speed. Most ES riders reported travelling at 10km/h to be too slow. In those pedestrian/ES conflicts that participants actually experienced, ES riders' poor behaviour such as "approached silently from the back" and "swerving around people and accompanying children" were often mentioned, which is a sign of lack of control on shared space. Pedestrians also expressed that ES riders "not bother about pedestrians", revealing conflicts regarding right-of-way on shared footpath. Chapter 4 concludes that speed was not the fundamental factor to conflicts. For different interacting scenarios (face-to-face or overtaking), pedestrians' and ES riders' attitudes are also different. To further analyse and model behaviour, contributing factors such as perceived control and perceived priority need to be further considered. This serves as building block to forming the conceptual framework as covered in Chapter 5.

Chapter 5 builds the framework for behavioural intention modelling. Relying on past literature, several social psychological theories were reviewed. The belief-attitude-behavioural intention proposition from TRA and TPB was chosen as the basic structure. Drawing conclusion from Chapter 4, combined with reviews on risk compensation theory and DPT, three modelling belief aspects for dyadic interaction were identified, including perceived control, perceived risk level and perceived priority. As inspired by a criticism to the original risk compensation

theory, perceived risk level and perceived priority were further differentiated as perceived self-risks, perceived others' risks, perceived self-priority and perceived others' priority to suit the dyadic nature of interaction in shared space. In essence, people's perceived control, perceived self-risks, perceived others' risks, perceived self-priority and perceived others' priority influence their attitudes. Subsequently, their attitudes determine how they intend to act out. As such, a conceptual framework that models behavioural intention was formed.

Chapter 6 covers the validation of the built framework. An online perception survey was conducted on both pedestrian and cyclist respondents. The questionnaire was designed to cover all the proposed constructs, including perceived control, perceived self-risks, perceived others' risks, perceived self-priority, perceived others' priority, attitude, and behavioural intention. It is also noted that face-to-face and overtaking interactions are perceived differently, and different user groups also have different attitudes. The framework was thus adopted to four models, covering pedestrian in face-to-face scenario, pedestrians in overtaking scenario (being overtaken by a bicycle), cyclist in face-to-face scenario, and cyclist in overtaking scenario. The findings reveal that overtaking scenario is higher in risk level and lower in perceived control for all path users, which makes it a more critical case as compared to face-to-face interaction. The path analysis of the four models shows the robustness of the proposed belief-attitude-behavioural intention structure. Perceived control was found to have the most significant effects on behavioural intention as compared to perceived risk level and perceived priority. However, risk compensation was supported in some of the models. Pedestrians were found to compensate for their own risks but might take advantage of cyclist's risks and have the intention to behave more aggressively, indicating a more competitive mindset. Cyclists, on the other hand, compensate for pedestrian's risk and have the intention to behave more positively and cautiously, indicating a more cooperative mindset. The influence of perceived priority is also evident. With higher perceived others' priority, users are likely to behave more positively and cautiously. As such, the

proposed conceptual framework has been successfully validated and its effectiveness in modelling behavioural intention has been illustrated. However, it should be noted that the proposed framework only models behavioural intention. It assumes that intention is the direct antecedent to action. Such assumption needs to be further examined to complete the modelling process, which is covered in Chapter 7.

Chapter 7 assesses the behavioural intention-action relationship. A before-and-after experiment was conducted with a “keep left” treatment on a shared footpath. Pedestrians and cyclists were the subjects. It was anticipated that the “keep left” treatment may not be effective on pedestrians due to their readily formed habitual travelling behaviour on footpaths. Intercept perception surveys were administered to collect users’ behavioural intention regarding lane keeping. Naturalistic observations on video footages were adopted to assess actual lane-keeping actions. Findings suggest that while both pedestrians and cyclists had the intention to keep left after the treatment, only cyclists were observed with actual behavioural improvements in the after period. Pedestrians’ actions did not change as hypothesised. It is concluded that intention-action relationship is more complicated than previously assumed. As pedestrians are native to the footpaths, their readily formed habit (which does not concern lane discipline) impedes them from realising their intention into action. As cyclists are newly introduced to the footpaths, such impedance from habit is not present, resulting in a more significant improvement in lane keeping for cyclists. Habit could weaken the intention-action relationship. When habit is involved (which is often the case for travel behaviour studies), modelling behavioural intention alone is incomplete in revealing the behaviour pattern. The influence from habit would also needs to be taken into consideration. The framework development is thus completed.

8.3 Recommendations

The present studies have real-world implications. VR streaming through HMD was found to be an effective tool in speed perception research. It provides

immersive stimuli and effectively elicit users' perceptions. Through the VR experiment, it is understood that simply lowering the speed limit does not resolve conflicts. Interpreting from the framework, more efforts shall be put into measures that raise user's risk awareness, establish a clearly defined right-of-way, and improve users' perceived control in shared space. Such measures are likely to raise users' intention to behave better and conflicts could be reduced. However, the findings from "keep left" study implicates that motivating intention alone may not be as effective as expected. If the focal behaviour is habitual, like pedestrians' travel behaviour on shared footpaths, efforts must also be put into shifting the habits, such as apparent infrastructure change, penalties, and treatments that persist over time.

8.4 Limitations and future work

For developing a framework that models user behaviour, the research adopted VR to understand speed perception and what might have led to poor behaviour. A conceptual framework that models behavioural intention was built and validated based on reviewed social behaviour theories. A field experiment was conducted to assess the relationship of behavioural intention and action. However, these research activities have focused on one-to-one interactions in free-flow conditions. As the traffic flow and number of interacting agent changes, people's attitude and behaviour could vary. Future research shall extend the boundary by analysing how the traffic flow would influence the behaviour of one traveller or even a group of travellers.

Furthermore, the research has focused on only one type of shared space, which is the confined 1.5m-wide shared footpath in Singapore. In different countries, the mobility settings could be different. With open shared space, people's movement would be different. The number of interaction types would also increase. The generalisability of the proposed framework under such conditions needs to be further validated.

Another limitation is regarding the VR application. VR applied in this research has provided immersive stimuli for better speed perception assessment.

However, its fidelity as compared to real-world experience is not studied extensively. For VR experiment findings to be more definitive, a validation of speed perception in VR against real-world experience is needed. Moreover, the current VR experiment involved 30 pedestrian respondents with an average age of 29.9 years. The elderly are therefore under-represented. Considering that they represent the more vulnerable user group, their opinions should be critically evaluated. There shall be greater participation of the elderly group in future work.

Lastly, it is concluded that habit weakens the intention-action link due to the unchanged pedestrians' actions one month after the treatment. Literature suggests that habit shifting happens over time. Repeated assessment of pedestrians' actions may reveal habit's long-term effect. Furthermore, quantifying the measurement of habit using surveys alongside the long-term observation could help to better explain its effect. It shall be addressed as part of the future work.

There are some more aspects that have not been included in this research. The current research focuses on how users' behaviour intention/actual behaviour could be influenced by their own beliefs and attitudes. Factors such as positive reinforcement and negative punishment from external enforcement are not considered and integrated into the framework. The year of 2020 is the year of pandemic. Cities around the world have seen lockdowns and work-from-home orders, which has led to plummets in motorised transport usage. The necessity of social distancing refrains people from using crowded public transit and making physical contacts with others. In such a case, users' attitudes and behaviour towards active mobility may have significantly changed, as travel modes such as bicycles offer a convenient alternative for users to be outdoors and avoid close contacts, and this opens a new front for active mobility research. In addition, how social distancing would influence people's perception towards personal space and subsequently change the way they interact with others in shared space which provides interesting points in user behaviour studies.

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