Pedestrians' Acceptance of Personal Mobility Devices on the Shared Path: A Structural Equation Modelling Approach

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***Abstract*— In order to promote active mobility, a pleasant and safe walking experience should be provided. However, the increasing use of personal mobility devices (PMDs) on footpaths has created new challenges for urban designers in Singapore. In this study, we conducted an online questionnaire to understand pedestrians' attitudes towards the use of PMDs on a shared path. The main hypothesis was that, in accordance with the technology acceptance model (TAM), pedestrians who have experienced PMDs will tend to be accommodating of them. Based on 303 valid responses, this study analysed pedestrians' levels of acceptance of PMDs. Structural equation modelling (SEM) was used to evaluate five constructs: the intention to use a PMD, ease of use, usefulness, perceived risk from PMD riders, and the environment. The results indicate that prior PMD riding experience does not affect the subject's degree of acceptance of PMDs on a shared path. A high correlation was found between the environment and intention to use, as well as the perceived risk from PMD riders and the speed of the PMD. The findings of this study will provide insights for planners in making walking on a shared path a more pleasant experience for pedestrians while introducing PMDs as a new mobility service.**

Index Terms*— *personal mobility device (PMD), pedestrian, technology acceptance model (TAM), shared path, structural equation modelling (SEM)

I. INTRODUCTION

Walking is a sustainable mode of travel when the distance to be covered is short. It brings many health benefits as well. In acknowledgement of this, the government of Singapore has promoted walking through Active Mobility Act [1]. Through this motive, government is planning to make walking, cycling, and usage of public transport attractive to the users. One way of encouraging people to walk is by ensuring a safe and comfortable walking experience. Factors which affect this include the weather, pavement conditions, the length of the trip/distance to be covered and levels of noise, air quality, and traffic volume encountered [1, 2]. The walking experience is also in part affected by the purpose of the walk. For example, scenic views are preferred for a leisure walk while public transport connectivity is preferred for first or last mile trips. Additionally, worldwide growth of the old population increases the demand for a pleasant walking experience [3]. Elderly persons often prefer to walk than to drive a car or ride a bicycle as ageing reduces the ability to drive [4, 5].

Due to existing provisions, infrastructure, or land scarcity, pedestrians often need to share their walking space with other road users. Therefore, there is a debate on whether an imposed segregation might improve the pedestrian experience in terms of safety, efficiency, and variety [6, 7]. Generally, the quality of the shared space can be measured through assessment of traffic characteristics such as flow, density, speed, and approaching direction through simple video surveillance [8]. However, in addition to reducing the actual collision risk, subjective feelings are also an important consideration in creating a pleasant walking experience. This is because conflicts between shared path users can be behaviour-based [9]. For instance, cyclists can be confused about who has the right of way (whether to yield to pedestrians), and on matters of instruction (such as keeping to the left). Perceived responsibility can also be an issue (for instance, pedestrians might pay little attention to these rules).

Recently, pedestrians have encountered more motorised vehicles on the footpath. These electric vehicles comprise of a new transportation mode termed as 'smart mobility' or 'micro-mobility'. These devices aim to improve the first and last mile connectivity of the public transit users in an environmentally friendly manner. Depending on the vehicle size and the power required to drive them, authors of [10] classify them into low-powered vehicles (LPVs), personal mobility vehicles (PMVs), personal transportation devices (PTDs), and electric self-balancing scooters (ESSs). However, it has to be noted that the classifications are not rigid and different regions have their own regulations for the vehicles. For instance, Germany allows the devices on roads and bans them on footpaths while in Singapore it is vice versa. In this study, we follow the recommendations of the Singapore Land Transport Authority (LTA). According to LTA, all smart mobility devices are collectively called as personal mobility devices (PMDs). The same terminology is followed throughout this paper. The devices must satisfy the criteria defined by LTA. The width of the device cannot

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exceed 0.7 m and the maximum weight cannot be more than 25 kg. For the safety of the user, the maximum speed cannot exceed 25 kmph and the device must be certified to the UL2272 standard to prevent fire hazards. Generally, electric scooters, self-balancing hoverboards, and electric unicycles fall into the class of PMDs, but power-assisted bicycles (PABs) would not.

Despite the obvious advantages and increasing use of PMDs, their impact on the pedestrians walking experience remains unclear. Introducing a new mobility vehicle on the footpaths without any change in infrastructure causes inconvenience to the pedestrians. Yet previous research on bicycles [6, 7] cannot be used as basis to determine the impact of PMD on pedestrians. Hence, this paper presents an online survey to address the gap. Specifically, the focus is to determine a general framework for pedestrians' acceptance of PMDs to answer questions such as "How would pedestrians react to a growing number of motorised devices on the shared path?"

The remainder of this paper is organised as follows. In Section II, the related studies about pedestrians' opinions on PMD riders and the technology acceptance model (TAM) are reviewed. In Section III, details of the online survey such as the structure of the questionnaire, the procedure of data collection and screening and the analysis are discussed along with the results. Finally, conclusions and recommendations for future work are discussed in Section IV.

II. RELATED STUDIES

A. *Pedestrians' opinions on PMD riders*

Several studies have investigated public opinion on PMDs. Many of these have been initiated by local governments in order to propose suitable rules and codes of conduct regarding PMD use. A recent nationwide survey in Singapore found that 65% of respondents are willing to share the footpath with non-motorised devices, whereas only 49% are willing to share it with motorised vehicles. The primary concern for respondents in this study was the speed of PMDs. It is generally assumed that the design of PMDs allows the rider to achieve higher speeds than electric bicycles. This is understandable since a major distinction between electric bicycles and PMDs is that PMDs have no pedals, thus requiring less physical effort. Furthermore, research indicates that there is anticipation of certain driving behaviours based on a vehicle's appearance [11].

However, there is insufficient evidence for the impact of motorised vehicles on pedestrians' safety on the footpath [10, 12]. Cyclists can also ride fast and be hazardous to pedestrians, given that the average cycling speed on shared paths is 5.11 m/s [7]. The perceived threat of PMDs may be linked to their unfamiliarity and lack of awareness about their capabilities, including their braking systems—whether they are able to stop completely when necessary. In reality, some PMDs even have advanced self-balancing technology and assist the rider in being stable, unlike a bicycle, that may 'wobble' at walking pace and deliver a bad impression to pedestrians [13]. Therefore, another key factor is the behaviour of the rider in terms of their ability to control the device. Currently, riding a PMD does not require a licence (which would likely deter reckless riding behaviour). Consequently, pedestrians are distrustful of such devices and tend to have a higher perception of risks, in turn making PMDs appear less acceptable.

Given that the concept of the PMD is new, it is often necessary for researchers to 'create' a PMD environment in order to test attitudes. For instance, Dowling et al. [14] deployed 17 PMD users around a campus and collected 200 responses by way of pedestrian feedback. Their results suggested that the acceptance of PMDs was not determined by the PMD type, but by the footpath width (32%). The next important determinant was the predictability of users' movements (29%), followed by pedestrian density (17%). Nevertheless, such ad hoc observations are limited by the design of the field experiment. For instance, pedestrians are likely to express concern over the PMDs' speed in real-life situations [1, 10], but do not express such a concern when the PMD used in the study is restricted to a lower than average speed of 1.67-2.78 m/s [14, 15]. In addition, most of the PMD investigations to date are interpreted by basic statistics only. Hence, they lack a comprehensive insight which can be generalised to other regions. To propose a subjective measure to assess the quality of the shared path experience, it is necessary to identify the key factors underlying pedestrians' acceptance of PMDs on the shared path. To achieve this, exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) are carried out to validate the independent latent variables (Section III, C).

B. *Technology acceptance model*

The technology acceptance model (TAM) has been extensively applied in transportation research to help understand how users adopt information systems [16-18]. The basis of TAM is two constructs: ease of use (freedom from effort) and usefulness (enhanced performance). Based on how users perceive these two constructs, we can determine their acceptance of technology and the intention to use it. Further, TAM has been expanded to fit various contexts. For instance, researchers [16] have found that awareness of ecological benefit is positively correlated with the acceptance of a bicycle-sharing system for early adopters. A certain demographic group (male drivers) is more accepting of in-vehicle technology [17]. Similarly, Wolf and Seebauer [19] ran a multi-group comparison of users' characteristics such as their age and the purpose of the trip (work, leisure, shopping) in the use of electric bicycles. Their findings suggest that people aged 60 years or older mainly use an electric bicycle for leisure.

The difference between 'acceptability' and 'acceptance' hinges on when the judgement is made. In general, people are more accepting of, and have a positive attitude to technology after exposure. This is why participants in previous studies have tended to give higher ratings to PMDs following actual riding experience [10, 15]. A similar finding [18] was that when a particular type of vehicle is held within the respondent's household, they are more accepting towards such a transportation mode. In other words, if the respondents are potential PMD riders, they are more able to predict movement and give credit to other riders. Hence, it is important to consider respondents' prior experience when conducting surveys on acceptance of PMDs.

Ando et al. [13] asked 66 participants to evaluate two types of PMD in a designated area and did not find any significant differences between their ages, gender and perceived acceptability. However, their findings suggest that people expect different use scenarios (indoors or outdoors) based on the type of PMD. Also, the respondents who had a driving licence were more satisfied with one of the PMDs (model: i-REAL) and regarded it as more useful on the road. Later, Li and Ando [15] applied structural equation modelling (SEM) to test if a certain attribute reflects the acceptability of PMD. Based on 124 responses, they found that the user's attitude towards the PMD (that is, the design, size, passenger capacity, and whether or not it is eco-friendly) has a direct effect on their attitude to the use scenarios (indoors or outdoors) in terms of usefulness, safety, and harmoniousness. However, the latent variables used in their model were predefined by the researchers. Hence, it may fail to accurately represent the respondents' psychological construct. The online questionnaire designed in this paper overcomes the shortfalls of [15]. It helps reduce the risk of bias using the factor analysis. Instead of focusing on individual perception towards the characteristics of PMDs, the questionnaire is modelled to investigate the social interactions of PMDs and pedestrians based on the technology acceptance model (TAM). Hence, the findings can derive a general framework for pedestrians' acceptance of PMDs.

III. METHODOLOGY

In this work, the TAM is used to assess concerns about the introduction of PMDs as a new mobility service. In order to understand pedestrians' levels of acceptance about sharing the path with PMDs, an online questionnaire was conducted.

A. Questionnaire

The questionnaire comprised two sections and took participants 5-10 minutes to complete. It begins by asking participants to provide their personal background details, such as age, gender, and the frequency of riding or encountering a PMD. The definition of PMDs was shown on the landing page and several PMD pictures were presented for visual references. They were also asked to indicate whether they had been a resident of Singapore over the prior six months. Singapore can be regarded as a suitable sampling pool because people have shared their walking space with PMDs over recent years and are generally familiar with government policy [1]. Next, participants answered questions on the importance of various items to their acceptance of PMDs on the shared path. The 32 questionnaire items were organised into five constructs: perceived risk of PMD (PP), environment (EV), intention to use (IN), ease of use (ES), and usefulness (US). Their responses were rated on a 7-point Likert Scale (where 7 = very important, and 1 = not important at all).

B. Data collection and screening

The questionnaire was sent out to the general public by email, posted on social media, and distributed in the neighbourhoods near campus via advertisements. In total, 349 responses were collected between December 2018 and February 2019. Of these, 46 responses were deleted on account of duplicated responses (filling out the survey twice) and 'unengaged' responses (selecting the same answer for all items or failing to answer the 'bogus' question correctly). This left a remaining 303 responses for testing the proposed model. Of this number, 55.1% were male (167) and 44.9% female (136), and all were aged between 18 and 62 years (M = 24.53, *SD* = 9.99). Also, 94.7% of the respondents (287) had been residents of Singapore for at least six months. Table 1 illustrates the respondents' prior experience with PMDs. 53.1% of them have never ridden a PMD before while most have encountered a PMD on shared paths.

TABLE I. THE RESPONDENTS' PRIOR PMD EXPERIENCE

Frequency	***How often do you ride on a PMD?***	***How often do you encounter a PMD?***
Never	53.1%	2%
Occasionally	41.9%	30%
Often	4.3%	54.8%
Always	0.7%	13.2%

In the following, we elaborate on each construct, namely, perceived risk of PMD, environment, intention to use, ease of use and usefulness, as well as provide statistics on the responses of the participants (having ridden or not ridden a PMD) for each construct.

Perceived Risk of PMD (PP): Participants answered 11 questions about the perceived risk posed by PMD riders. These covered the types of PMD (apparent size and weight), the noisiness, its approaching speed/direction, its proximity to the pedestrian, its movement, the age/gender of the PMD rider, and whether PMD users give advance warning. Fig. 1 shows the mean and margin of error for each question; the asterisk (*) represents a significant difference in groups. The speed of the PMD was rated the most important item in terms of perceived risk (PP) for both riders (M = 6.2, *SD* = 1.09) and non-riders (M = 6.43, *SD* = 0.86).

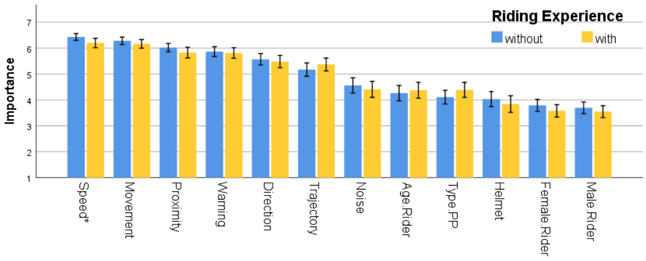

Fig. 1. Importance of perceived risk of PMDs (PP).

Environment (EV): Participants answered six questions related to the outdoor environment such as weather, footpath width, the degree of daylight, the degree of slope, pedestrian density (crowdedness) and frequency of encountering PMDs. Fig. 2 shows the mean and standard error for each question. Footpath width was rated the most important factor in terms of the environment (EV) for both riders (M = 6.23, *SD* = 1.02) and non-riders (M = 6.18, *SD* = 1.06).

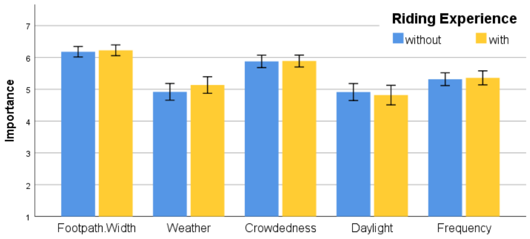

Fig. 2. Importance of the environment (EV).

Intention to use (IN): Participants answered seven questions regarding factors that could affect their intention to use a PMD on the shared path such as possibility of sharing the devices with other people, whether or not they had a driving licence, the riding purpose, the speed limit, the involved cost, the walking distance to the next destination, and the rules for registering the device. Fig. 3 shows the mean and standard error for each question. The cost involved was found to be the most important factor affecting intention to use a PMD, for existing riders' (M = 5.83, *SD* = 1.36) and non-riders' (M = 5.59, *SD* = 1.63).

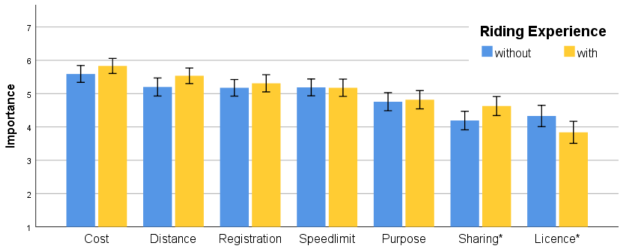

Fig. 3. Importance of intention to use (IN).

Ease of use (ES): Participants answered four questions regarding perceived ease of use. These are age, the ability to keep one's balance, the weight of the PMD, and the type of PMD. Fig. 4 illustrates that ease of keeping balance on a PMD was regarded as the most important factor, for both riders (M = 5.87, *SD* = 1.3), and non-riders (M = 5.98, *SD* = 1.2).

Usefulness (US): After conducting the pre-test (39 responses collected), we noticed that some items were not suitable for representing perceived usefulness. For example, the power and the battery life of the PMD, which highly correlate with PMD performance and which are therefore rated by respondents as very important, are hidden features (not observable based on a PMD's appearance). The items were therefore revised to the following: portability, passenger capacity, provision of a seat, and suspension system. Fig. 4 shows that both riders (M = 5.73, *SD* = 1.3) and non-riders (M = 5.97, *SD* = 1.34) regarded a portable PMD as very useful.

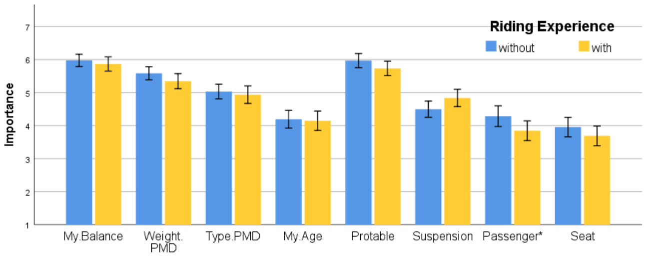

Fig. 4. Importance of ease of use (ES) and usefulness (US).

Lastly, after running t-tests for all items, results (Table 2) indicate that three items are significantly more important for non-riders and less so for riders: the speed of PMDs, passenger capacity and whether or not they had a driving licence. In contrast, the possibility of sharing PMDs with other people was more important for existing riders.

TABLE II. THE SIGNIFICANT IMPORTANCE OF ITEMS

Items	***Riders***	***Non-riders***	***P-value***
Speed	6.20 ± 1.09	6.43 ± 0.86	.043
Passenger	3.81 ± 1.64	4.41 ± 2.01	.046
Licence	3.84 ± 1.99	4.33 ± 2.06	.036
Sharing	4.63 ± 1.72	4.19 ± 1.80	.033

C. *Factor analysis*

We further tested the proposed model in SPSS 25 as follows. First, we conducted an exploratory factor analysis (EFA) to reduce questionnaire items to a smaller set of variables. We applied the maximum likelihood extraction method based on an eigenvalue greater than 1, and Varimax as the rotation method.

Several cross-loadings between questionnaire items were found. Initially, we kept factor loadings greater than 0.4, and in all cases of the cross-loading, the gap had to be greater than 0.2, otherwise, the item was deleted. For example, "*PMD rider wears a helmet*" was originally categorised under 'perceived risk of PMD' (PP), but it appeared to fit better under 'usefulness' (US), according to the EFA loadings. In addition, items such as, "*PMD rider is female/male*" turned out not to belong to any designated factor and hence were excluded from further analysis.

TABLE III. THE EFA OUTCOME AND LOADINGS

Factor	***Code***	***Observed variable***	***Loading***
Perceived Risk of PMD (PP)	Q03	Speed	.698
	Q05	Proximity	.652
	Q04	Direction	.594
	Q07	Movement	.543
Environment (EV)	Q16	Crowdedness	.751
	Q14	Footpath width	.622
	Q17	Frequency	.434
Intention to use (IN)	Q19	Distance	.747
	Q20	Cost	.673
	Q22	Purpose	.477
	Q18	Registration	.436
Usefulness (US)	Q27	Passenger	.736
	Q26	Seat	.599
	Q09	Helmet	.531
	Q23	Licence	.456
Ease of use (ES)	Q32	Weight PMD	.939
	Q31	Type PMD	.471

The remaining 17 questionnaire items and their loading values are shown in Table 3. The reported Kaiser-Meyer-Olkin (KMO) value is 0.77, the total variance explained is 45.2%, and the percentage of non-redundant residuals with absolute values greater than 0.05, is 11%.

Next, confirmatory factor analysis (CFA) was conducted, followed by the test of goodness of fit, to validate the five constructs. The outcome of the CFA showed a low correlation coefficient (less than 0.8), implying low covariance between five constructs. Hence, each construct is regarded as independent. We also present the model fit indices: CMIN/DF=1.94, the Comparative Fit Index (CFI) is 0.91, RMSEA=0.06. The Composite Reliability (CR) for each construct respectively is: PP =0.68, IN=0.74, EV=0.70, ES=0.69, US=0.68. This confirms the validity of the construct.

D. Structural equation modelling

Structural equation modelling (SEM) is a statistical technique that can reveal causal relations between latent variables that cannot be observed directly—in this case, pedestrians' acceptance of PMDs. Given an anticipated effect size of 0.3, a desired statistical power level of 0.8, and a probability level of 0.05 for 5 latent variables and 17 observed variables, the minimum sample size for detecting an effect is 150.

The standardized coefficient path loadings are shown in Fig. 5 and the values in brackets refer to respondents without riding experience. Regarding the basic TAM constructs, usefulness (US) and ease of use (ES) were both found to have a positive effect on the intention to use (IN). This is to be expected, in that TAM is a well-established theory for transportation technology. One of our hypotheses is to check the effect of prior experience (riding or non-riding) on people's acceptance of PMDs on the shared path. Therefore, we carried out a multi-group SEM, which revealed that no significant difference was found (CMIN=25.5, DF=20, *p*=.185). This means the model can explain the two designated groups well. Moreover, our finding accords with previous studies [9] that found that, car drivers who are also cyclists do not find cycling to be more acceptable on the road.

Of the five constructs, environment (EV) had the highest coefficient path loading, suggesting this has the strongest positive effect on the perceived risk of PMD (PP). Environment (EV) also has a strong impact on the intention to use a PMD on the shared path. This finding reflects those of previous studies [17] on the acceptance of in-vehicle technology, where the authors examined the environment in terms of highways, urban, and rural roads.

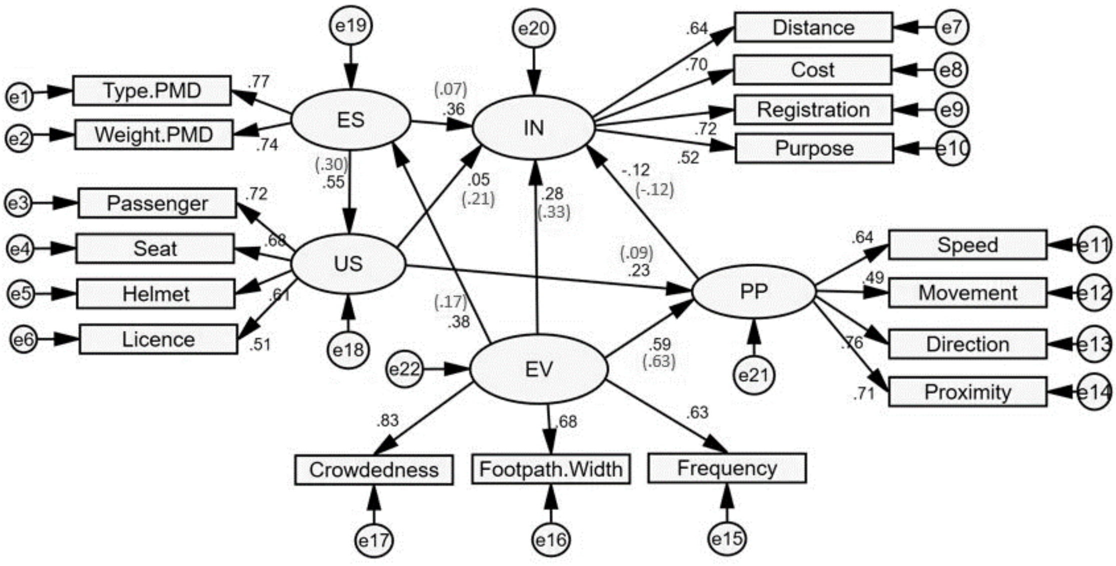

Fig. 5. The outcome of SEM for riders (non-riders).

IV. CONCLUSION

This study identified key factors that underly pedestrians' acceptance of PMD as a form of urban mobility, particularly on shared paths. We designed a questionnaire and conducted statistical analysis to validate the proposed structural model. Initially, the questionnaire included all the factors mentioned in the literature, but it was subsequently revised several times, following pre-tests, to keep only those items with good discriminatory power. Thus, the number of questionnaire items was reduced based on the result of EFA, which was further validated by CFA. We demonstrated the advantage of such a method over the descriptive statistics used in previous studies, thereby helping researchers explore the set of variables and focus on the most relevant factors in a psychological construct.

Through SEM analysis, we found that both pedestrians with and without riding experience shared the same structural model based on TAM. Regardless of prior riding experience, environment (EV) has a stronger effect than the perceived risk of PMD (PP) on pedestrians' intention to use (IN). This implies that pedestrians' acceptance of PMDs on the shared path is affected more by context (for instance, footpath width and crowdedness) than by individual behaviour (such as PMDs' speed and movement). It is therefore recommended that policymakers focus on the environment, and not just regulations regarding use. However, an extended survey is needed to understand why people are unwilling to share the path with PMD riders despite having accepted PMD as a form of technology and being riders themselves. The extended survey can also integrate the theory of planned behaviour and promote effective campaigns for encouraging use of the shared path. In future, we will try to include more participants beyond university students, especially elderly people. Other socio-economic characteristics of the respondents can also be taken into consideration.

Overall, this study is an effort to obtain empirical results from Singapore, where pedestrians and PMD riders share paths. The findings can help other cities in embracing new modes of transportation alongside ensuring that pedestrians feel safe and comfortable on shared paths, with the aim of making active mobility an attractive choice for citizens.

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