Transportation Research Part F 56 (2018) 256–267

Contents lists available at ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

Modeling pedestrians' subjective danger perception toward personal mobility vehicles

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ARTICLE INFO

Article history:
Received 5 December 2017
Received in revised form 28 March 2018
Accepted 18 April 2018

Keywords:
Pedestrians
Danger perception model
Subjective safety measurement
Personal mobility vehicles
Shared space users

ABSTRACT

Personal mobility vehicles (PMVs) are gaining popularity as an eco-friendly transport mode for short-distance trips in urban environments. These vehicles can provide numerous economic, environmental, and social benefits and are likely to become more common in urban spaces in the near future. Before permitting them in shared environments, the impacts of the PMVs on the other users of the shared space should be properly evaluated, particularly from a safety perspective.

This study focuses on pedestrians' danger perception toward PMVs interacting with them in shared spaces. To estimate the perceived danger, a model was developed. The developed model is inspired by the social-force concept, and it estimates a safety index called subjective danger index (SDI). The model is then calibrated with data collected through controlled laboratory experiments.

The experiments revealed two important features of the pedestrians' subjective danger perception against PMVs. First, the pedestrians' sensitivity to the distance between a PMV and them is higher when the PMV is in front of them compared to when it is behind them. Secondly, pedestrians perceive a PMV in front of them as more dangerous compared to a PMV behind them when they are near the PMV, although they perceive higher danger when a PMV is approaching from behind them compared to when a PMV is approaching from the front of them when they are relatively far from the PMV. The calibration results demonstrate that the enhanced model can accurately capture such trends and therefore the perception of danger.

A case study that uses experimental trajectory data from a PMV–pedestrian interaction situation is also presented to clarify potential applications, characteristics, and limitations of the calibrated SDI model.

1. Introduction

As the requirement for sustainable transportation is growing, particularly in the city centers of developed countries, many technologically advanced personal mobility vehicle (PMV) types have been developed and released to the public by different

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https://doi.org/10.1016/j.trf.2018.04.016
1369-8478/

manufacturers over the last decade (e.g., Segway, Toyota winglet, Honda UNI-CUB, Robstep, Ninebot, Hyundai E4U, Whill PEV, and DTV Shredder). Although there are several definitions for PMVs, this study uses the definition that PMVs are motorized compact vehicles for one passenger, e.g., electric personal assistive mobility devices (EPAMDs). However, PMVs are a wider concept than EPAMDs, and PMVs include self-balancing devices with two wheels such as Segway as well as other moving mechanism vehicles. Emerging as a highly advanced transportation mode, PMVs can provide numerous economic, environmental, and social benefits such as reducing congestion in urban centers, reducing noxious emissions, and providing a means of transport for people with impaired mobility (e.g., elderly and disabled pedestrians) (Ulrich, 2005). Liu and Parthasarathy (2003) explained that if a small portion of the short trips made by vehicles in urban environments can be replaced by Segway trips, a considerable amount of vehicle miles traveled (VMT) can be removed from the roads, thereby substantially reducing congestion and pollutant emissions. Shaheen and Finson (2003) studied the feasibility of the shared use of Segway as a connectivity device for improving the accessibility to transit stations, thus increasing public transport ridership, reducing the number of single-occupancy vehicles, and decreasing congestion and air pollution in urban environments. Sawatzky et al. (2007) explored the usability of Segway as an alternative mobility device for people with disabilities. In addition to such tremendous benefits, the public acceptability or attitude toward the use of PMVs is also positive (Ando & Li, 2012). Thus, PMVs are likely to become more common in urban spaces in the near future.

PMVs are more stable than bicycles and scooters at lower speeds. However, it is not practical to provide a separate space (e.g., separate lanes) for such vehicles. Thus, the feasibility of permitting PMVs in the existing infrastructure for vehicles, bicycles, or pedestrians should be examined (Landis, Petritsch, Huang, & Do, 2004; Litman, 2006). With certain restrictions and requirements, PMVs are permitted on sidewalks or roads in numerous cities in Europe and the United States (Litman, 2006). Meanwhile, Japan and other Asian countries currently have a few legal restrictions for riding PMVs in all public spaces apart from certain areas such as airports and large parks with special permission. PMVs do not satisfy the standards of current safety regulations for conventional vehicles as they incorporate alternative control mechanisms such as self-balancing and inverted pendulum type control. Nevertheless, discussions and proposals are underway to amend policies and legislations to permit PMVs on sidewalks in Asian cities, where pedestrian and cyclist demand is relatively high, as a versatile and eco-friendly alternative transport mode (Hashimoto et al., 2015). Before permitting PMVs in shared environments, it is important to understand their impacts on other shared space users (e.g., drivers, cyclists, and pedestrians), particularly from a safety perspective. Although the impacts of PMVs toward all types of shared space users need to be examined, this research focuses on the impacts on pedestrians because pedestrians are the most vulnerable road users.

The safety of shared space users can be mainly classified into two categories: objective or physical safety and subjective or psychological safety. The major focus is on the objective safety, such as prevention and mitigation of accidents. Previous studies on objective safety have focused on operational or performance (Landis et al., 2004; Litman, 2006), behavioral (Miller, Molino, Kennedy, Emo, & Do, 2008), and accident analytical (Boniface, McKay, Lucas, Shaffer, & Sikka, 2011; Roider, Busch, Spitaler, & Hertz, 2016) aspects. However, considering the acceptability of new types of vehicles such as PMVs on shared spaces, conventional concepts for objective safety are necessary albeit inadequate to estimate safety. Thus, subjective safety measurement concepts should be explored because of the following three reasons: First, unlike lane-based vehicular traffic, PMVs and other shared space users are anticipated to interact in two-dimension space such as on sidewalks. In such situations, it is challenging to construct objective and straightforward safety indexes such as time-to-collision (TTC). Subjective safety measures can overcome the limitations of objective safety measures, particularly when those are applied to pedestrian traffic, and estimate the preferable safe or dangerous situation by combining objective and subjective safety indexes (A in Table 1). Secondly, the gap between objective and subjective safety is likely to cause the hazardous situations. If shared space users notice danger from PMVs (subjective danger), they can prepare for evading accidents. In contrast, they are unlikely to evade accidents if they are not aware of the danger approaching them (subjective safe and objective dangerous situation, i.e., B in Table 1). That is, objective safety can detect only situations B and D in Table 1 together and cannot evaluate situation C. The combination of both objective and subjective safety enables the identification of situation C as well as exclusion of situation B, which should be examined carefully. Thirdly, subjective danger indexes (SDIs) provide the criteria for social acceptability of PMVs because subjective danger could be a barrier for expanding the usage of PMVs notwithstanding whether objective safety is ensured. Previous studies have also highlighted that perception of safety and comfort is important particularly when evaluating safety in shared spaces and mixed traffic situations (Castanier, Paran, & Delhomme, 2012; Chataway, Kaplan, Nielsen, & Prato, 2014; Kaparias, Bell, Miri, Chan, & Mount, 2012; Lehtonen, Havia, Kovanen, Leminen, & Saure, 2016; Vansteenkiste, Zeuwts, Cardon, & Lenoir 2016; Zhuang & Wu, 2012). Therefore, this study concentrates on the SDI with focus on pedestrian perception.

Table 1
Objective vs subjective safety measure.

		Estimated objectively	
		Safe	Dangerous
Estimated subjectively	Safe	A. Preferable situations	B. Hazardous situations
	Dangerous	C. Safe, but socially unacceptable	D. Dangerous, albeit avoidable accidents