Investigation of Avoidance Assistance System for the Driver of a Personal Transporter Using Personal Space: A Simulation Based Study

Pham Quoc Thai
The University of Danang, University of Science and Technology,
Faculty of Transportation Mechanical Engineering, 54 Nguyen Luong Bang street, Danang city, Vietnam
Email: pqthai@dut.udn.vn

***Abstract*—This study describes a microscopic simulation model considering the interaction between a personal transporter and multiple pedestrians and proposed an avoidance assistance system using the concept of personal space, which is the space in which invasion by others induces a psychological strain. The simulation was examined under the condition that the personal transporter traveling toward pedestrian flow under different conditions of road width and different pedestrian densities. To evaluate the mutual effects of a personal transporter on nearby pedestrians, the invasion ratio and crossing time were introduced as evaluation indexes. The simulation results reveal that the effectiveness of the assistance system was clearly confirmed. In particular, the personal transporter equipped with the assistance system had invasion ratio and crossing time lower than those of the personal transporter without such system.**

***Index Terms*—avoidance assistance system, personal transporter, personal space, pedestrian, simulation**

I. Introduction

The technological improvement of means of transportation has helped people travel in cities more conveniently and quickly. The development of internal combustion engine vehicles, especially automobiles, is one of the greatest achievements of modern technology enabling higher mobility in daily life. However, the large number of automobiles in use around the world has caused serious problems for the environment and human life. Air pollution, global warming, and the rapid depletion of fossil fuel are now problems of paramount concern. In recent decades, the research and development activities related to transportation have emphasized the development of highly efficient, clean, and safe transportation. Fully electric, hybrid, and fuel cell vehicles have been typically proposed to replace conventional ones [1], [2]. For short-distance trips, personal mobility vehicles (PMVs) or personal transporters (PTs) are expected as next-generation vehicles that offer potential benefits to solve the current problems, such as mobility issues of the elderly, downtown area revitalization, and development of low-carbon transportation systems [3]. Consequently, many types of two-wheeled PTs have been recently proposed, such as Segway [4] and Winglet [5]. However, injuries related to operating PTs have arisen [6], [7]. It is thus essential to consider the psychological effects of PTs on pedestrians when PTs are allowed to be used in pedestrian flows. There has been a growing trend toward the psychological effects of PTs on surrounding pedestrians [8]–[10].

To investigate the effects of a PT on nearby pedestrians, in this study, a simulation model based on the concept of personal space (PS) is constructed. Traffic simulation commonly employs macroscopic and microscopic models. A macroscopic model regards the traffic flow as a cluster whereas the microscopic model considers individuals in the traffic stream [11]–[13]. In this study, we built a microscopic model of a PT travelling in pedestrian flows and evaluate the effect of the avoidance assistance system for the PT to enhance the safety and comfort for surrounding pedestrians in the presence of PTs.

The remaining of this paper is organized as follows. Section II outlines the modeling and simulation, including the concept of an assistance system for a PT, analysis of behavior model of the PT, evaluation index, simulation condition. Simulation results are presented and discussed in Section III. Finally, Section IV provides conclusions and future work.

II. Modeling and Simulation

A. Concept of Avoidance Assistance System

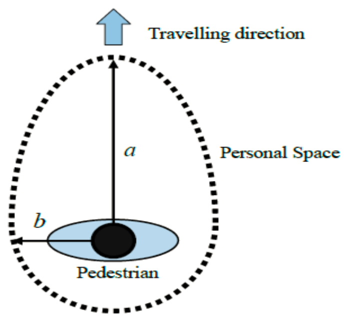


Figure 1. Personal space of a pedestrian.

Manuscript received August 15, 2018; revised February 1, 2019.

doi: 10.18178/ijmerr.8.2.254-259

The concept of avoidance assistance system for a personal transporter was derived from the concept of personal space (PS), which is the space surrounding a pedestrian in which invasion by others induces a psychological strain. Most people may assess their PS and feel uncomfortable or fearful when their PS is encroached on [14]. Front and side PSs are frontal and lateral distances between two heads when one starts avoiding the other [15], as shown in Fig. 1.

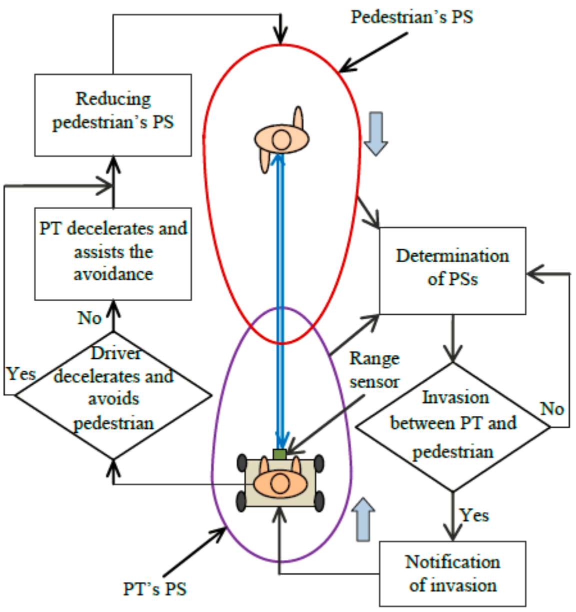


Figure 2. Procedure of avoidance assistance system for a PT.

The avoidance assistance system is illustrated in Fig. 2, in which a PT detects nearby pedestrians using range sensors and determines the PSs of pedestrians from state quantities such as distance and velocity. When the PT enters the PS of a pedestrian, the assistance system will inform the driver of the PT about the invasion using a micro vibration motor and a light signal. The driver then avoids the pedestrian; otherwise, the PT will automatically decelerate and evade the pedestrian. This may result in pedestrians feeling safer and more comfortable when sharing space with a PT.

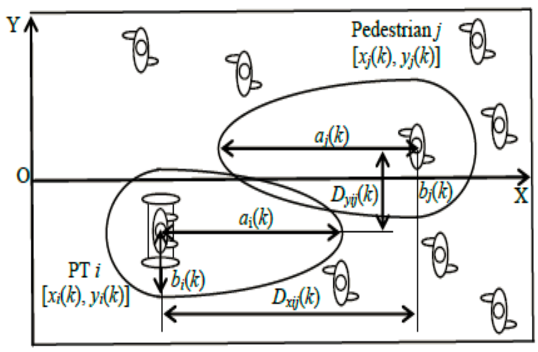


Figure 3. Calculation model.

To recognize the invasion, it is essential to determine the position of PTs and pedestrians. Fig. 3 shows the calculation model of multiple PTs travel toward pedestrians [16].

From the theory of personal space, we built boundaries that are similar shapes to the PS of the PT and pedestrian. When the PT travel against the pedestrian, PT's boundary can be computed as the boundary of an ellipse

$$S_{ij}(k) = \frac{D_{xij}^2(k)}{a_i^2(k)} + \frac{D_{yij}^2(k)}{b_i^2(k)} \tag{1}$$

and pedestrian's boundary can be calculated as

$$S_{ji}(k) = \frac{D_{xji}^2(k)}{a_j^2(k)} + \frac{D_{yji}^2(k)}{b_j^2(k)} \tag{2}$$

On the other hand, when the PT passes the pedestrian, the boundary of PT can be determined as a circumference

$$S_{ij}(k) = \frac{D_{xij}^2(k) + D_{yij}^2(k)}{b_i^2(k)} \tag{3}$$

and pedestrian's boundary can be calculated as

$$S_{ji}(k) = \frac{D_{xji}^2(k) + D_{yji}^2(k)}{b_j^2(k)} \tag{4}$$

where $D_{xij}(k)$, $D_{yij}(k)$ are distances between PT i and pedestrian j in x and y directions, respectively whereas $D_{xji}(k)$, $D_{yji}(k)$ are distances between pedestrian j and PT i; $a_i(k)$, $b_i(k)$, $a_j(k)$, $b_j(k)$ are front PS and side PS of PT i and of pedestrian j, respectively.

By comparing the values with 1 we can determine if the PTs and/or pedestrians are within PS of others or not. If $S_{ij}(k) \leq 1$ then PS of PT i is invaded by pedestrian j, and if $S_{ji}(k) \leq 1$ then PS of pedestrian j is invaded by PT i.

B. Behavior of PT in the Flow of Pedestrians

1) PT with the avoidance assistance system

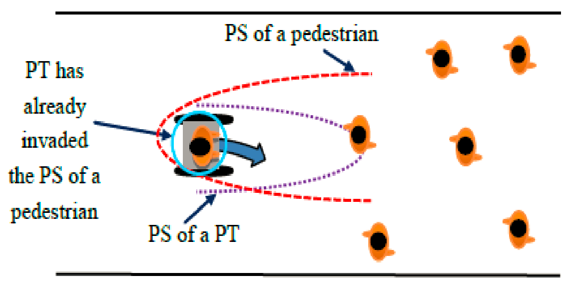


Figure 4. Behavior of a PT without the assistance system.

When a PT without an avoidance assistance system travels in a pedestrian flow, the behavior of the PT only depends on the PS of the PT. Initially, the PT travel toward pedestrians, the driver judges whether the pedestrians are within the PS of the PT. If a pedestrian enters the PS of the PT, then the process of avoidance will begin. Fig. 4 illustrates that a PT without an avoidance assistance system begins avoidance when a pedestrian enters the PS of the PT; meanwhile, the PT greatly invades the PS of the pedestrian. This may result in pedestrians feeling fearful and uncomfortable.

2) PT with the avoidance assistance system

To reduce the levels of fear and discomfort of pedestrians felt toward the PT, we proposed an assistance system for the PT. The behavior of the PT with an avoidance assistance system depends on both PSs of the PT and pedestrians. When a pedestrian invades the PS of the PT or when the PT enters the PS of a pedestrian, the PT then decelerates and avoids the pedestrian. The deceleration of the vehicle leads to a decrease in the PS of the pedestrian.

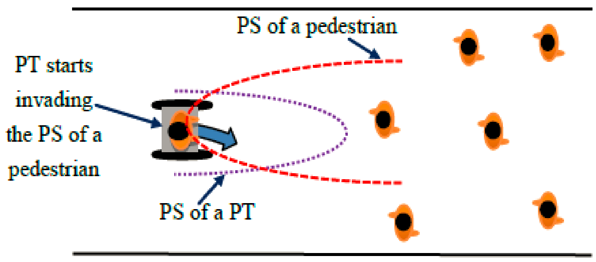


Figure 5. Behavior of a PT with the assistance system.

Fig. 5 shows the behavior of the PT equipped with the assistance system. By considering both the PS of the driver and the PSs of nearby pedestrians, the PT begins decelerating and avoiding a pedestrian when the PT starts invading the PS of the pedestrian even though the pedestrian is outside the PS of the PT. This may make the pedestrians feel safer and more comfortable when sharing space with a PT.

C. Evaluation Index

In this study, invasion ratio and crossing time are used to evaluate the effect of a PT on surrounding pedestrians [17]. The invasion ratio is defined as a physical index that expresses the extent to which the PS of a pedestrian is invaded, as depicted in Fig. 6. The invasion ratio (I) is expressed as

$$I = \frac{l_b}{l_a} \times 100\% \tag{5}$$

where l_a is the length of the PS, and l_b is the length of invasion.

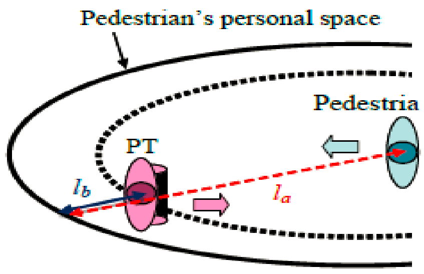


Figure 6. Definition of the invasion ratio.

The crossing time (t_c) is the time from when a PT enters the PS of a pedestrian to when the PT leaves the PS of the pedestrian. The average of the invasion ratio during the crossing time is referred to as the average invasion ratio I_{av}, which is expressed as

$$I_{av} = \frac{\int_0^{t_c} I(t)dt}{t_c} \tag{6}$$

where $I(t)$ is the instantaneous value of the invasion ratio.

The average invasion ratio for N pedestrians ($\bar{I}_{av}$) is determined as

$$\bar{I}_{av} = \frac{\sum_{k=1}^{N} I_{avk}}{N} \tag{7}$$

where I_{avk} is the average invasion ratio for pedestrian k.

D. Simulation Condition

In the simulation, a PT travels toward a flow of pedestrians, and the effect of the assistance system for the PT was investigated under the different conditions of pedestrian density. In this study, the simulation parameters for the simulation given in Table I were taken from previous studies [17]–[18].

TABLE I. PARAMETERS FOR THE SIMULATION

Parameter	**Value**
Shoulder width [m]	0.45
Body thickness [m]	0.25
Head diameter [m]	0.2
Pedestrians' velocity [km/h]	4
Pedestrian density [people/m^2]	0.1–0.3
Pedestrian's visual viewing angle [°]	180
Road width [m]	2.5–3.5
PT width [m]	0.45
PT's initial velocity [km/h]	4
PT's acceleration [m/s^2]	0.3
Driver's visual viewing angle [°]	180

The simulation was examined under the condition that the PT encountered a flow of pedestrians, and the effects of the assistance system for the PT were investigated. We constructed a model with a PT traveling toward 10 pedestrians for different pedestrian densities of 0.1, 0.2, and 0.3 people/m^2, and under different conditions of road width. In this simulation, we assumed that there is no lag time. Therefore, the PT equipped with the assistance system will automatically decelerate and avoid a pedestrian as soon as recognizing the PS invasion of the PT.

III. Simulation Results and Discussion

A. PT and A Pedestrian

Figs. 7 and 8 show the behavior of a PT without and with the assistance system respectively when the PT travels toward a single pedestrian. Fig. 8 shows that the PS of the pedestrian decreases with a decrease in the velocity of the PT equipped with the assistance system because the size of the pedestrian's PS depends on the PT's velocity.

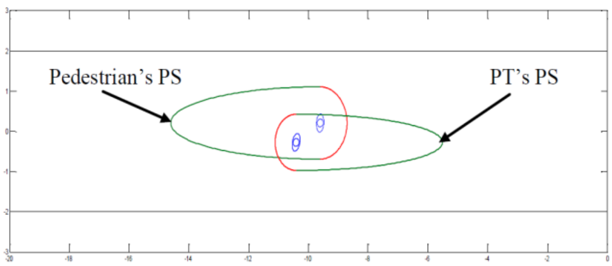


Figure 7. Behavior of a PT without the assistance system.

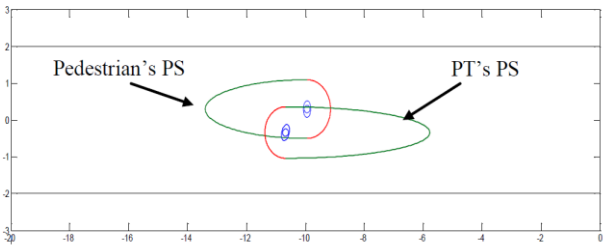


Figure 8. Behavior of a PT with the assistance system

Figs. 9 and 10 depict the average invasion ratio and the crossing time according to the width of the road. The results were also compared in two cases of PTs with and without the assistance system. Simulation results show that the invasion ratio and the crossing time decreased with increasing the width of the road. When the road width was 2.5 m, the value of invasion ratio was comparatively high, even though in the cases of the PT with the assistance system. However, in the cases of the road width of 3 m and 3.5 m, the invasion ratio significantly decreased because the vehicle has enough space to avoid the pedestrian.

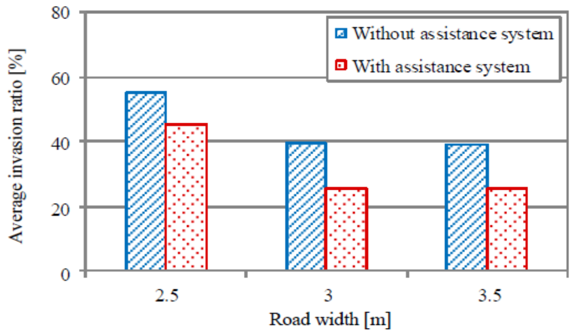


Figure 9. Average invasion ratio according to road width.

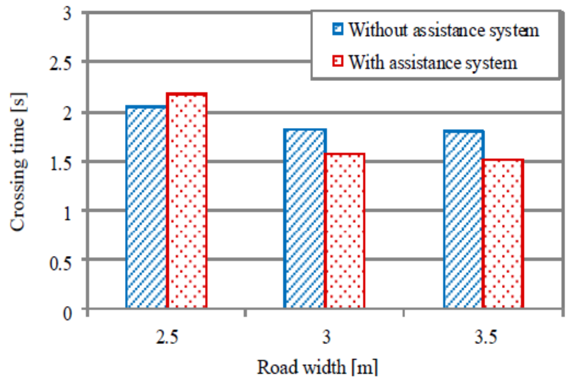


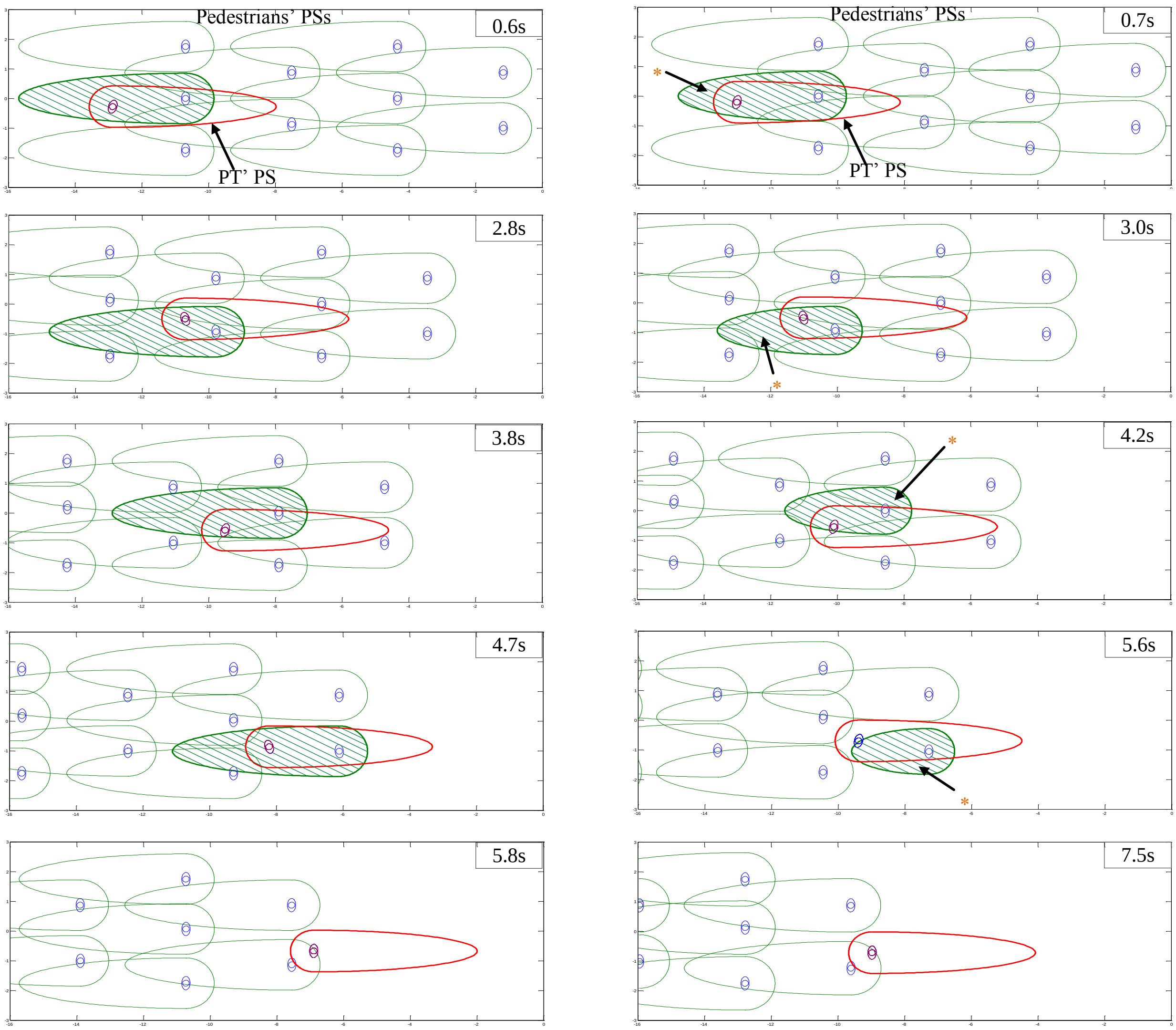
Figure 10. Crossing time according to road width.

B. PT and Multiple Pedestrians

Fig. 11 shows the simulation results for the behavior of a PT without the assistance system (Figs. 11(a)) and with the assistance system (Figs. 11(b)), respectively, when the PT travels toward a pedestrian flow with a pedestrian density of 0.3 people/m^2. Fig. 11(b) shows a decrease in the pedestrian's PS when the PT was equipped with the assistance system because the PT decelerated in recognition of its invasion of the pedestrian's PS.

Fig. 12 shows the simulation results for the average invasion ratio for 10 pedestrians whereas Fig. 13 depicts the crossing time according to pedestrian density. The simulation results reveal that an increase in the pedestrian density led to more invasion of the pedestrians' PSs by the PT and a long crossing time because the PT finds it more difficult to avoid pedestrians at higher pedestrian density.

In addition, the simulation results are compared for the PT equipped with and without the assistance system. The results show that the PT equipped with the assistance system had an average invasion ratio that was lower than that for the PT without the assistance system.



(a) Without assistance system (b) With assistance system

Figure 11. Behavior of the PT without and with the assistance system in a pedestrian flow at five different positions of the PT and pedestrians (pedestrian density of 0.3 people/m^2). The asterisk (*) indicates the reduction of pedestrians' PSs due to decreasing the velocity of the PT.

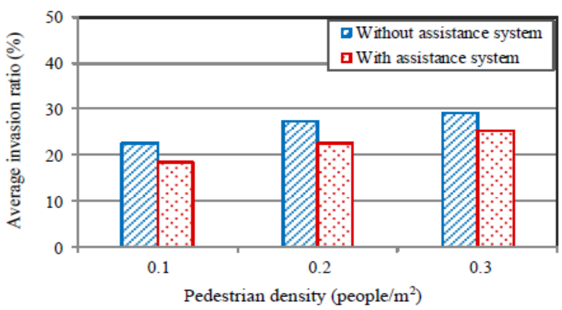


Figure 12. Average invasion ratio according to pedestrian density.

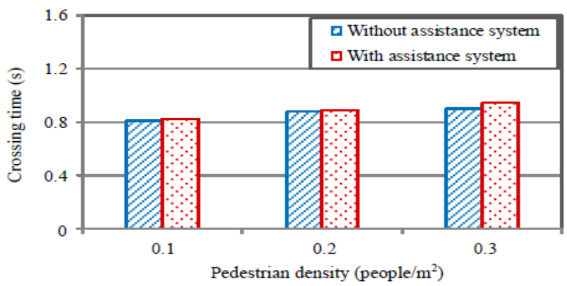


Figure 13. Crossing time according to pedestrian density.

IV. Conclusions and Future Work

In this study, we investigated the behavior model of a PT using the concept of personal space. In addition, the assistance system for PT was proposed and analyzed in different conditions of road width and pedestrian density.

The findings show that the proposed assistance system was clearly effective by simulations. The results reveal that the PT equipped with the assistance system had an average invasion ratio lower than that for the PT without the assistance system. This study will be a key to lead to the development of PTs considering the psychological effects on pedestrians. Future work will concentrate on developing a prototype PT equipped with the assistance system, then conduct experiments using such a PT, and analyze the driver's reaction in order to verify the validity of our proposed method and the effectiveness of the assistance system for PTs. In addition, other evaluation factors such as avoidance angle will be considered in future studies.

ACKNOWLEDGMENT

This work was supported by the University of Danang, University of Science and Technology, Project number: T2018-02-04.

REFERENCES

[1] A. E. Mehrdad Ehsani and Y.Gao, *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*, CRC Press, 2005.

[2] J. M. William, E. Christopher Bonrroni-Bird, and D. B. Lawrence, *Reinventing the Automobile Personal Urban Mobility for the 21st Century*, 2010.

[3] Y. Suda, "Vehicle dynamics and control for sustainable transport," in *Proc. 13th Asia Pacific Vibration Conf.,* New Zealand: Christchurch, 2009, pp. 1-11.

[4] Segway — The leader in personal, green transportation. [Online]. Available: http://www.segway.com/

[5] Toyota — Personal mobility — Winglet. [Online]. Available: http:// www.toyota.co.jp/jpn/tech/personal_mobility/winglet.html

[6] I. Repository, "Current and future trends in vulnerable road users accidents in Europe — Why we need ITS solutions," in *Proc. of 22nd ITS World Congress*, 2015, pp. 1–14.

[7] K. Boniface, M. P. Mckay, R. Lucas, A. Shaffer, and N. Sikka, "Serious injuries related to the segway ® personal transporter: A case series," *YMEM*, vol. 57, no. 4, pp. 370-374, 2011.

[8] J. Xu, S. Shang, H. Qi, G. Yu, Y. Wang, and P. Chen, "Simulative investigation on head injuries of electric self-balancing scooter riders subject to ground impact," *Accident Analysis and Prevention*, no. 89, pp. 128-141, 2016.

[9] M. L. Walters, K. Dautenhahn, R. Boekhorst, C. Kaouri, S. Woods, C. Nehaniv, D. Lee, and I. Werry, "The influence of subjects' personality traits on personal spatial zones in a human–robot interaction experiment," in *Proc. of IEEE International Workshop on Robot and Human Interactive Communication,* 2005, pp. 347-352.

[10] I. Kaparias, M. G. H. Bell, T. Biagioli, L. Bellezza, and B. Mount, "Behavioural analysis of interactions between pedestrians and vehicles in street designs with elements of shared space," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 30, pp. 115-127, 2015.

[11] K. Salimifard and M. Ansari, "Modeling and simulation of urban traffic signals," *International Journal of Modeling and Optimization*, vol. 3, no. 2, pp. 172-175, 2013.

[12] W. H. K. Lam, S. C. Wong, and H. K. Lo, *Transportation and* Traffic *Theory 2009: Golden Jubilee*, Boston, MA: Springer US, 2009.

[13] A. Tapani, "Traffic simulation modelling of rural roads and driver assistance systems," Ph.D dissertation, Department of Science and Technology, Linköping Univ., Norrköping, 2008.

[14] E. T. Hall, "The hidden dimension," *Anchor Books*, New York, 1982.

[15] C. Nakagawa, "Evaluation of personal space for pedestrians encountering personal mobility vehicles," in *Proc. of 20th Intelligent Transport Systems World Congress*, Tokyo, Japan, 2013, pp. 1-10.

[16] T. Q. Pham, C. Nakagawa, A. Shintani, and T. Ito, "Evaluation of the effects of a personal mobility vehicle on multiple pedestrians using personal space," *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 4, pp. 2028-2037, 2015.

[17] T. Q. Pham, C. Nakagawa, A. Shintani, and T. Ito, "Experimental Evaluation of an assistance system for the driver of a personal mobility vehicle," *Advanced Science Letters*, vol. 22, no. 9, pp. 2077–2081, 2016.

[18] T. Q. Pham, C. Nakagawa, A. Shintani, and T. Ito, "The effect of a semi-active driving assistance system on the driver of a four-wheeled personal mobility vehicle," *International Journal of Mechanical Engineering and Robotics Research*, vol. 6, no. 4, pp. 322-326, 2017.

Pham Quoc Thai received the B.S. degree in electrical engineering and the M.S degree in control engineering and automation from University of Science and Technology, the University of Danang, Danang, Vietnam, in 2005 and 2009, respectively, and the Ph.D degree in mechanical engineering from Osaka Prefecture University, Japan in 2017.

Since 2006 he has been a lecturer with the Faculty of Transportation Mechanical Engineering, University of Science and Technology, the University of Danang. He was the Vice Dean in 2017 and has been the Dean of Faculty of Transportation Mechanical Engineering since 2018. His study interests include modeling, simulation, control of vehicles, and intelligent transportation systems.

Dr. Pham has been a recipient of the Japanese Government (MEXT) Scholarship for his study in Japan. Since December 2015, he has served as the Reviewer of IEEE Transactions on Intelligent Transportation Systems and the Reviewer of International Journal of Intelligent Transportation Systems Research. He also served as the Section Co-Chair of the 2015 International Conference on Integrated and Sustainable Transportation.