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Walking Speed in a Motorbike Lane Considering the Density of Evacuees and Motorbikes

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Abstract: In countries with a high motorbike utilization rate, road tunnels can feature motorbike lanes, bringing an additional risk to evacuation from tunnels during a fire or emergency. To better understand the walking speed in motorbike lanes to enhance risk assessment in tunnels, in the present study, we conducted evacuation experiments to investigate the influence of motorbike and evacuee density on the walking speed of motorbike users. According to the experimental results, the walking speed was slightly reduced even when the evacuee density was relatively lower (around 0.1 person/m^2). To further analyze the influence of motorbikes in the lane, the walking speed decreased significantly with the increase in motorbike density. The decrease in walking speed presented an exponential relationship with evacuee and motorbike density. Considering this exponential relationship, nonlinear regression was applied to estimate the parameters of the walking speed model. The proposed model consisting of the evacuee density, motorbike density, and free walking speed as variables can serve as an approach to describe the walking speed of motorbike lane evacuation in tunnels.

Keywords: walking speed; evacuee density; motorbike density; tunnel evacuation; evacuation model

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1. Introduction

Tunnels represent a critical transportation system for various vehicles, and they are widely built as infrastructure around the world. However, once a fire occurs in a road tunnel, hazards such as smoke, toxic gases, and high temperatures threaten the lives of users. A catastrophic incident would inevitably cause difficulty in evacuation. Previous tunnel fire incidents have led to serious casualties [1–6] and have pointed out the necessity of accurate risk assessment to establish strategies for reducing the consequences of fires.

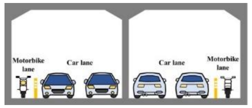
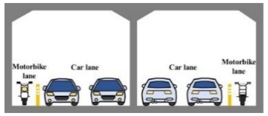
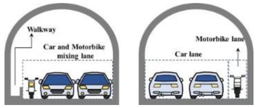
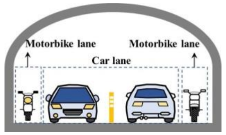
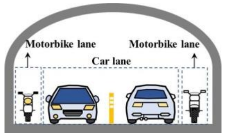
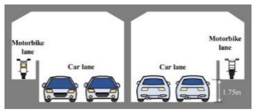
To promote tunnel fire safety, pioneering researchers in Europe and Japan have been working on the clarification of evacuation behavior during tunnel fires. The issues on evacuation safety involve the establishment of an evacuation safety assessment approach [7,8], the walking speed and behavior in the smoke with various extinction coefficients [9–14], the speed in a darkened tunnel environment with and without smoke [15,16], the speed in an emergency evacuation scenario [17], the evaluation of the stress and connection to human behavior in tunnel evacuation [18], motorists' responses and emotional state [19], the influence of different wayfinding installations on exit choice [10–12,20], and the design of emergency exits [21,22]. Other countries have taken the risk assessment approach and safety criteria of Europe and Japan as the reference for determining tunnel fire safety strategies. Since the proportion of motorbikes is small in Europe and Japan, the evacuation safety of motorbike users was not included in their risk assessment in the event of a tunnel fire.

However, in many Asian countries where the utilization ratio of motorbikes is extremely high, it is not uncommon for more than half of road users to be motorbike users. Studies on motorbike traffic in Taiwan, Malaysia, and Vietnam reported that the proportion of registered motorbikes in these countries was around 67%, 50%, and 90% of all registered vehicles [23,24]. Figure 1 shows a scene at a traffic light in Taipei city in Taiwan, revealing that a mix of motorbikes and cars on the roads is a common phenomenon. Once a fire occurs in a tunnel in countries with a high utilization ratio of motorbikes, there would be a higher risk than expected due to the tunnel involving additional motorbike users who need evacuation.

Figure 1. Scene at a traffic light in Taipei city in Taiwan.

According to our investigation of the tunnels that allow motorbikes (Table 1), some motorbike lanes are designed as not completely separated from car lanes. Although motorbike users in these tunnels can move to the car lanes for evacuation, additional motorbikes and their users also increase the fire risk of motorbike accidents, posing extra hazards to users in car lanes, and overall increasing the number of people who need to evacuate the tunnel. In particular, the Cross-Harbor Tunnel in Kaohsiung City in Taiwan reflects a more dangerous situation for motorbike users due to its special geometry. The motorbike lane of the Cross-Harbor Tunnel is designed with a relatively higher horizontal plane than the car lane, increasing its susceptibility to fire and smoke. Moreover, the motorbike lane is independent in the tunnel. The difficulty in evacuation is that motorbike users have no choice but to evacuate to the portal through the motorbike lane. With regard to the potential fire risk and evacuation restriction of the motorbike lane in tunnels, it is important to better understand the evacuation behavior in motorbike lanes for preventing disastrous fatalities in tunnels with motorbike lanes.

Table 1. Road tunnels that allow motorbikes.

Tunnel Name	Cross-Section	Tunnel Length	Country	Independent Lane for Motorbikes	Motorbike Height (from the Ground)	Motorbike Traffic Flow	Four-Wheeled Vehicle Traffic Flow
Qiao-Zhong Road Tunnel		295 m	China	Yes	0	–	–
Saigon River Tunnel		1490 m	Vietnam	Yes	0	–	–
Zi-Qiang Tunnel		820 m	Taiwan	Yes	0	602/h [1]	187/h [1]
Da-Hu Tunnel		519 m	Taiwan	Yes	0	–	-
Kang-Le Tunnel		586 m	Taiwan	Yes	0	-	-
Xin-Hai Tunnel		490 m	Taiwan	No	0	1515/h [1]	139/h [1]
Cross-Harbor Tunnel		1670 m	Taiwan	Yes	1.75 m	1160/h	1270/h

Note: Motorbike traffic flow indicates the number of motorbikes traversing the tunnel during rush hour. [1] Reference from Taipei City Traffic Control Engineering Office, Survey of Traffic Flow and Characteristics in Taipei City in 2017 (unidirectional traffic flow during rush hour).

Regarding previous tunnel evacuation studies, tunnel users are usually assumed to begin evacuating when they (1) see smoke along the ceiling or around them, (2) see other people evacuating, and (3) hear an emergency announcement [9]; hence, they may not begin evacuating at the same time. Moreover, evacuees are considered to not typically be crowded in the tunnel space, thereby easily passing between vehicles on the road without difficulty because the car lanes are relatively large (i.e., neither the vehicles nor other evacuees interfere with individual evacuee movement) [8]. However, taking the Cross-Harbor Tunnel as an example, its motorbike lanes are much narrower than the car lane and have the characteristic of heavy traffic. Inevitably, there would be many people and motorbikes in a small area. Moreover, motorbikes would obstruct evacuation behavior. The interference between motorbikes and evacuees is non-negligible. Even if the interference between vehicles and evacuees causes a minor reduction in individuals' walk speed, the required total evacuation time would increase significantly due to the long travel distance to the tunnel portal. Thus, it is critical to clarify the interference between motorbikes and evacuees; however, research on this topic is scarce.

The studies on interference between evacuees (people) are usually in terms of clarifying the relationship between walking speed and human density (in the present paper, "human density" refers to the research of pedestrian facilities and buildings, whereas "evacuee density" refers to motorbike lane evacuation) [25,26]. Pauls (1987) studied building evacuation and pointed out that if the human density is less than 0.50–0.54 persons/m^2, individuals would walk alone at 1.25 m/s, independent of the speed of others. When the human density exceeds about 3.8 persons/m^2, no movement would take place [26]. Moreover, we also reviewed the experimental or observational literature regarding the relationship between walking speed and human density in both pedestrian and building facilities (Table 2). Many studies on walking speed have been performed, including an investigation of walking speed characteristics of different pedestrian facilities [27,28], a model of the relationship between walking speed and human density [29,30], fundamental diagrams (speed-density relation, flow-density relation) of unidirectional and bidirectional flow [31,32], an estimation of the level of service of pedestrian facilities [33], and an investigation of walking speed at extremely high human densities [34]. Previous studies thoroughly investigated general motion parameters, such as the total crowd flow rate and the overall speed of crowd movement. Many diagrams have also been established for describing the relationship between walking speed and human density. However, most studies on the speed–density relationship focused on the normal walking movement of pedestrians, rather than evacuation scenarios in tunnels. The studied human density focused on the range over 1 person/m^2, or the range corresponding to a null speed. (i.e., speed close to 0 m/s) at which people cannot move.

Motorbike lanes in tunnels have the characteristics of narrow width, hundreds of meters of distance, and the obstruction of motorbikes. The human density is relatively low, as it is not designed for crowds. Whether existing speed–density diagrams and developed models can completely describe the walking speed characteristics in motorbike lanes is unclear. Therefore, the present study was aimed at developing an evacuation model considering the effect of motorbike density and evacuee density on the walking speed of motorbike users. The problems to be addressed are as follows: Does the walking speed decrease with motorbike density and evacuee density? If yes, by how much? If these things are clarified, it would help in the development of a sub-evacuation model that can be applied to analyze the event of a tunnel fire in countries with a high motorbike utilization rate, as well as further improve the safety assessment process for tunnel fires. Considering the relatively higher danger due to the geometry of the Cross-Harbor Tunnel, the present study chose a motorbike lane in the Cross-Harbor Tunnel as the model. Experimental studies were carried out to discuss the effects of motorbike density and evacuee density.

Table 2. Literature review of experimental or observational studies on walking speed and the speed–density relationship.

Item	Oeding (1963) [28]	Mōri and Tsukaguchi (1987) [33]	Virkler and Elayadath (1994) [30]	Seyfried et al. (2005) [31]	Helbing et al. (2007) [34]	Zhang and Seyfried (2013) [32]	Das et al. (2015) [29]	Rastogi et al. (2013) [27]	Present Study
Scenario	Uncontrolled walking (commuters)	Uncontrolled walking (commuters)	Uncontrolled walking (after watching a football game)	Controlled normal walking	The scene of the Muslim pilgrimage	Controlled normal walking	Uncontrolled walking	Uncontrolled walking	Evacuation assumption (assumed commuters)
The direction of the human flow	Bidirectional	Bidirectional	Unidirectional	Unidirectional	Unidirectional	Both unidirectional and bidirectional	Bidirectional	Bidirectional	Unidirectional
Density range (persons/m^2)	0.16–2.61	0.11–6.07	0.16–3.14	0.75–4.29	1.16–9.90	0.06–3.93	0.01–1.58	0.02–2.32	0.05–0.56
Methodology	Observational	Observational	Observational	Experimental	Observational	Experimental	Observational	Observational	Experimental
The geometry of walking space	Shopping streets, footpaths along company buildings, etc.	Side walkway and underground walkway (length: 20 m; width: 2.2–4.5 m)	A walkway (length: 12 m; width: 8.5, 10, 12, and 13 m in four 3 m sections)	A circular passageway (selecting 2 m of the straight part of the passageway; width: 0.8 m)	A large area (length: 27.7 m; width: 22.5 m)	Straight corridor (width: 1.8, 2.4, and 3.0 m), closed ring, T-junctions, and around a corner	Sidewalks and carriageways around transport terminals (observation section: length: 10 m; width: 2.7 m)	Sidewalk (width: 1.6–4.0 m)	Modeled motorbike lane (length: 50 m; width: 2.6 m)
Number of participants	–	–	–	Six cases (subject Nos. 1, 15, 20, 25, 30, and 34)	–	Up to 400 people	418 (sidewalk)	674	40
Age	–	–	–	–	–	19.3–30.7	–	–	25–61

The detailed experiment setup and the calculation method for evacuee and motorbike density are described in Section 2. The influence of evacuee density on walking speed and its modeling process is analyzed in Section 3. Further analysis involving the influence of motorbike density is presented in Section 4. The main findings of the present study are summarized in Section 5.

2. Experimental Analysis of Evacuation in the Assumed Motorbike Lane

2.1. Differential Analysis of Assumed Motorbike Lane and Real Motorbike Lane in Cross-Harbor Tunnel

Comparing the structures of various tunnels (see Table 2), it can be found that the motorbike lane in the Cross-Harbor Tunnel in Kaohsiung City, Taiwan, is installed 1.75 m higher than the car lane, and it is designed as an independent lane for motorbike users (see Figure 2). The thermal fume of fire flow along the tunnel ceiling would result in the motorbike lane with a relatively high horizontal plane being influenced earlier by fire and smoke, thus requiring faster evacuation. Independent motorbike lanes also prevent evacuation from the motorbike lanes to the car lanes, instead necessitating evacuation to the tunnel portal via the motorbike lane. The higher risk of evacuation caused by this special geometry needs to be considered. Thus, the present study takes the motorbike lane in the Cross-Harbor Tunnel as the study object.

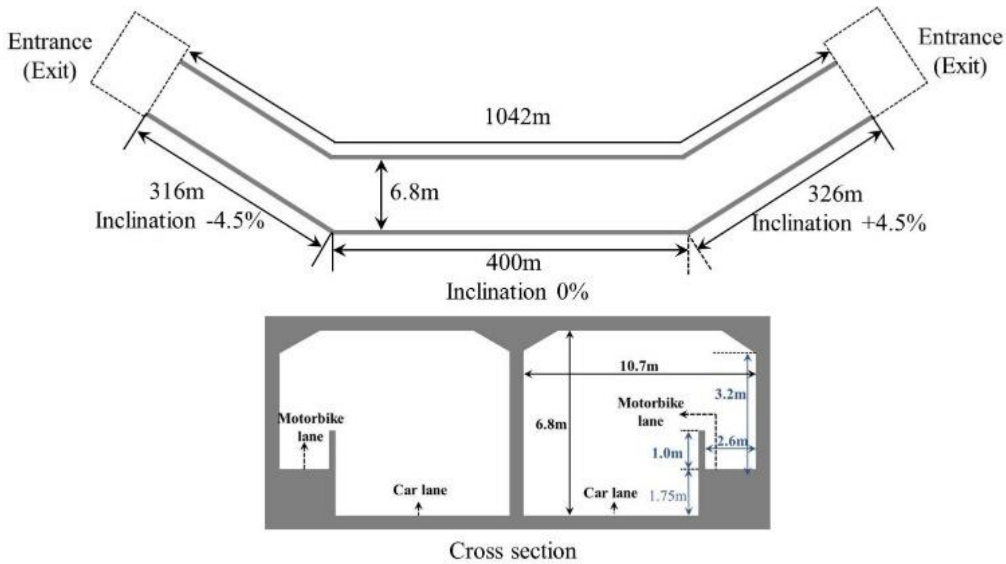


Figure 2. Cross-Harbor Tunnel geometry.

Ideally, the experiment should be conducted in an actual tunnel with a motorbike lane; however, there would be problems such as road traffic control. Therefore, an underground walkway was chosen as the experimental site to reflect a motorbike lane in the present study. Nevertheless, there exist some differences between the assumed motorbike lane and the real motorbike lanes of the Cross-Harbor Tunnel, as outlined in Table 3.

Table 3. Differential analysis of assumed motorbike lane and real motorbike lane in Cross-Harbor Tunnel.

	Assumed Motorbike Lane (Underground Walkway)	Real Motorbike Lane (in Cross-Harbor Tunnel)
Geometric	Length 50 m; width 2.6 m	Length 1042 m; width 2.6 m
Inclination	0%	−4.5%, 0%, 4.5%

Table 3. *Cont.*

	Assumed Motorbike Lane (Underground Walkway)	Real Motorbike Lane (in Cross-Harbor Tunnel)
Evacuation scenario	■ Evacuation only occurs using the lane in the experiment. ■ Subjects only bypass stationary motorbikes, resulting in less risk of collision or injury.	■ Evacuation only occurs using the motorbike lane (no car lanes can be used). ■ Evacuees might encounter moving motorbikes, increasing the risk of collision or injury.
Evacuation direction	Instructed to be in only one direction.	Without instruction, evacuation in both directions is possible.
Evacuee density	Controlled by experiment setup.	Variable (depending on situation).
Motorbike density	Controlled by experiment setup.	Variable (depending on situation).

As shown in Table 3, the chosen experimental site reproduced the real motorbike lane geometry in terms of width, flat region in the partial motorbike lane, and the difficulty of evacuation in that subjects had no choice but to evacuate to the portal through the motorbike lane. The evacuation scenario regarding subjects bypassing motorbikes was investigated through controlled evacuee and motorbike density.

The underground walkway used to reflect the motorbike lanes was located in Chiayi Chang Gung Memorial Hospital in Taiwan. Experiments were conducted on 1 July 2017. The underground walkway was around 60 m long and 5.5 m wide. Figure 3 shows the experimental site (consisting of longitudinal intervals and transverse sections).

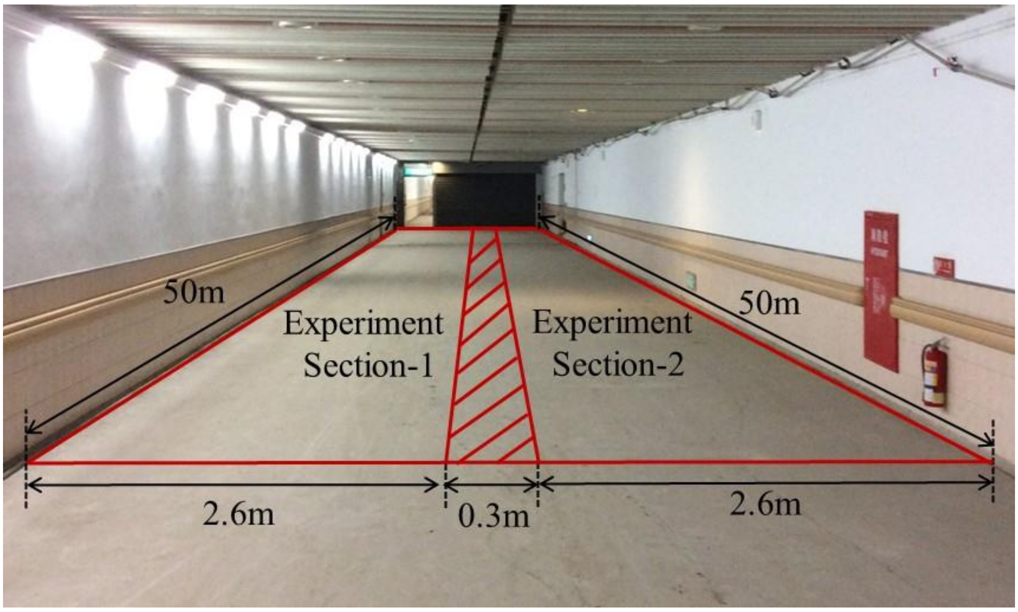


Figure 3. Evacuation experiment place.

2.2. Experimental Conditions and Process

We considered the underground walkway as having two motorbike lanes with a width of 2.6 m and a length of 50 m. Each lane was divided into three sections (see Figure 4). To ensure a stable walking speed of subjects bypassing the area with motorbikes, we set up non-motorbike sections in front and behind the motorbike section to avoid subjects suddenly moving and stopping.

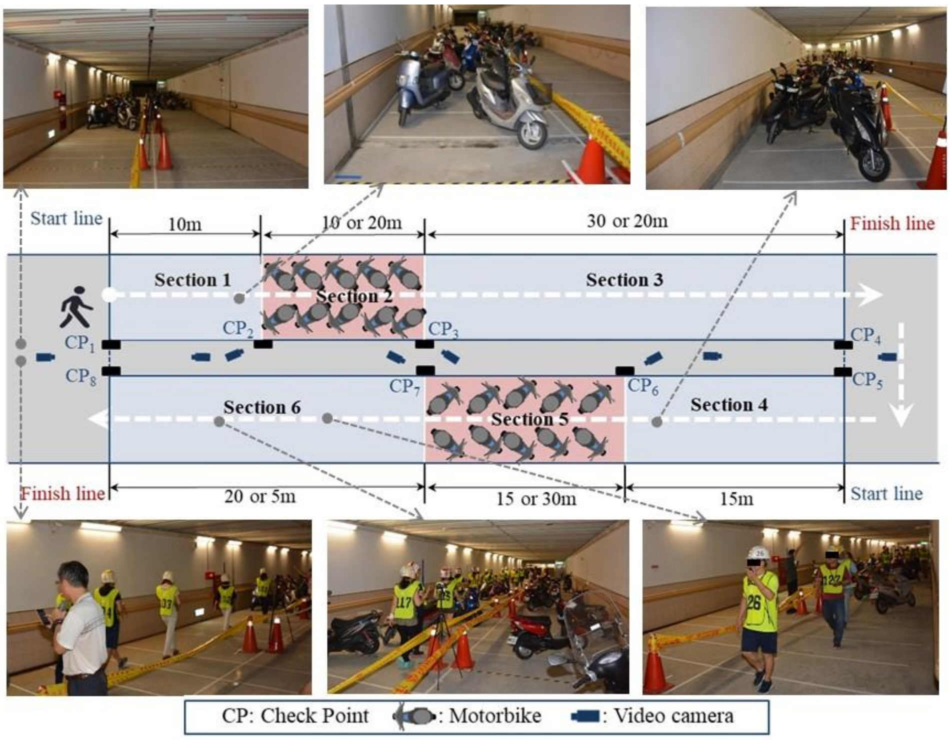


Figure 4. Schematic of motorbike lane experiments.

As demonstrated in Figure 4, subjects wore numbered vests and were asked to orderly start walking (according to the vest number) from the start line to the finish line (CP_1 to CP_4) to complete the experimental evaluation. Then, subjects were requested to return in the opposite direction according to the staff's instructions to evaluate evacuation from CP_5 to CP_8 as a supplementary experimental evaluation (see Figure 4).

Typically, users involved in tunnel fire incidents decide to begin evacuating when they (1) see smoke along the ceiling or around them, (2) see other people evacuating, or (3) hear an emergency announcement [8]. In the present study, we focused on clarifying the normal walking speed to investigate the basic evacuation performance characteristics in an emergency such as a fire rather than the maximum evacuation speed considering an extremely urgent condition (i.e., where people may be jogging or semi-jogging). To reproduce the evacuation situation with a purposeful movement characteristic, participants were instructed to walk according to the following oral explanation: "Please walk through the tunnel as you would normally walk, e.g., as if going to work" (with the aim of reproducing a situation where subjects walked with a clear destination and not aimlessly).

Walking speeds were calculated on the basis of the time passed between checkpoints. Checkpoints (CPs) were set using triangular cones and masking tape on the floor. Subjects measured the time passed themselves by pushing the lap time buttons of the stopwatches they carried. To address any issues with the data not being successfully recorded due to the stopwatch button not being pushed, eight video cameras were also placed to record the evacuation process. In addition, the present experiments did not consider hazards such as fire and smoke to ensure the safety of the subjects. Furthermore, the experiments were also aimed at clarifying an evacuation situation where the smoke layer has not yet descended to obscure the evacuation path.

To investigate the characteristics of the walking speed of motorbike users in the tunnel, we considered two factors that might influence the walking speed of subjects: motorbike density and evacuee density. A detailed consideration regarding these two factors is described in the next two sections.

2.3. Motorbike Setup and Density Calculation

Since motorbike lanes are narrow, a scenario that needs to be investigated is where motorbikes would obstruct evacuation behavior if a traffic incident occurred in the motorbike lane, along with a secondary fire incident at a later point. Thus, the interference of motorbike density is a critical factor influencing the walking speed. To grasp the characteristics of motorbikes density, especially the congestion situation in an emergency, a record of past traffic accidents in motorbike lanes in the Kaohsiung Cross-Harbor Tunnel was analyzed. According to the video record, motorbikes stopped behind the accident point, with subsequent motorbikes also stopping one after the other, accumulating slowly. We counted the number of motorbikes accumulated over 5 min in intervals of 30 s following a traffic accident in the motorbike lane (Figure 5).

Figure 5. Screenshot of a real traffic accident in the motorbike lane (data source: Taiwan).

In Figure 5, we considered the sidewall lamp post as the starting point to calculate the distance of motorbikes stopping with time. The distance between lamp posts was 7 m, enabling the total length to be calculated. The distance of accumulated motorbikes was defined as the straight length of stopped motorbikes along the direction toward the portal of the tunnel. The cumulative number of motorbikes was defined as the motorbikes that stopped in the lanes over time (excluding moving motorbikes). The accumulated distance and cumulative numbers are shown in Table 4.

Table 4. The cumulative number of motorbikes in a real traffic accident.

Cumulative Time (s)	Cumulative Number of Motorbikes	Distance of Accumulated Motorbikes (m)
30	5	10
60	6	11
90	7	13
120	10	18
150	18	24
180	21	26
210	24	30
240	30	36
270	35	42
300	36	42

On the other hand, we also recorded the real traffic flow rate in the motorbike lane in the Cross-Harbor Tunnel in Kaohsiung city, Taiwan, on 18 January 2016 (see Table 5). We observed that the flow of motorbikes was around 0.26–0.36 motorbikes/s (mean: 0.32 motorbikes/s) during rush hour (7:00–8:00 a.m.). Table 5 reveals that the worst evacuation scenario would occur with the motorbike flow rate of around 0.35 motorbikes/s, lasting approximately 40 min during rush hour. Comparing the traffic flow from a real traffic accident (Table 4) revealed that the motorbike flow rate during the accident (36/300 = 0.12 motorbikes/s) was only around one-third of the flow rate during rush hour. This implies that once an incident occurs in a tunnel during rush hour, there would be three times as many motorbike users stranded inside the tunnel. Therefore, it can be expected that the difficulty in motorbike lane evacuation would increase once a fire occurs during rush hour.

Table 5. Traffic flow of Cross-Harbor Tunnel motorbike lane during rush hour (Date: 18 January 2016).

Time (a.m.)	7:00–7:10	7:10–7:20	7:20–7:30	7:30–7:40	7:40–7:50	7:50–8:00	Total
Number of motorbikes	157	214	208	205	211	165	1160
Number of passengers	177	232	219	214	222	174	1238
Motorbike flow rate (motorbikes/s)	0.26	0.36	0.35	0.34	0.35	0.28	0.32
Passenger flow rate (persons/s)	0.30	0.39	0.37	0.36	0.37	0.29	0.35

Moreover, the cumulative motorbike number and corresponding accumulated distance are shown in Figure 6. The distance of stopped motorbikes increased with the cumulative number of motorbikes, and the tendency presented a linear regression function ($y = 0.98x - 5.42$). The linear function in Figure 6 also reveals that the distance was 5.42 m ($x = 5.42$) when no motorbike stopped ($y = 0$), indicating that the first motorbike stopped approximately 5.42 m from the starting point of the calculation (sidewall lamp post).

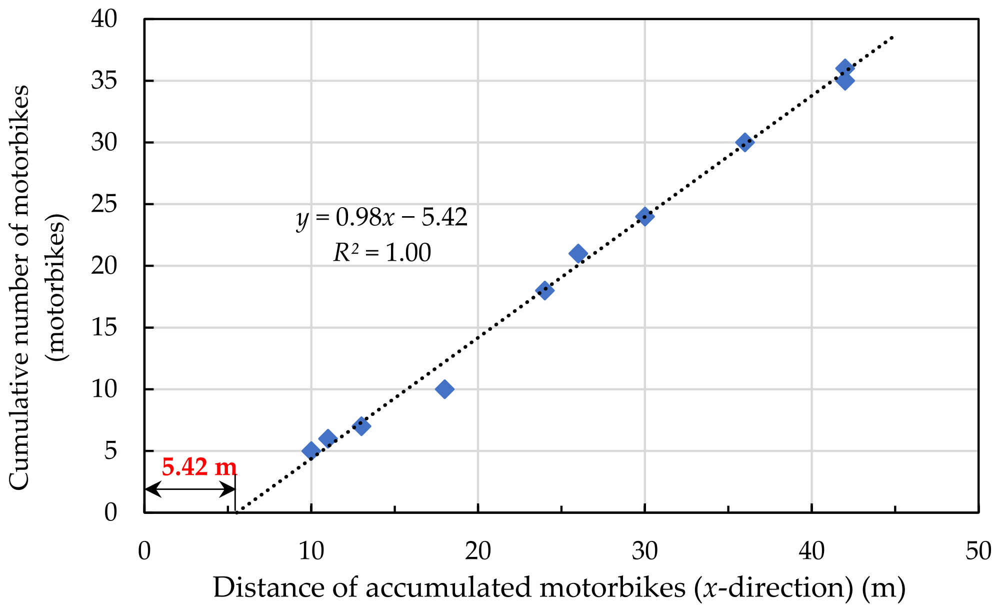


Figure 6. The cumulative number of motorbikes and corresponding accumulated distance.

In addition, the slope of the linear regression function was 0.98, indicating the presence of approximately 0.98 stopped motorbikes in the lane per meter. As a function of the motorbike lane width (2.6 m), this corresponded to 0.38 motorbikes/m^2. The result of linear regression indicated that the density of stagnant motorbikes would be a constant value close to 0.38 motorbikes/m^2, independent of time. Considering the investigation of a real traffic accident in the motorbike lane, we set up a similar motorbike density condition in the experiment (0.38 motorbikes/m^2). Considering the possibility of tunnel motorbike lanes with different densities of congested motorbikes due to fires or other traffic accidents, we also assumed various motorbike densities in the experiments. For safety during the experiments, motorbikes were assumed to be stationary to avoid the danger of collision.

As demonstrated in Figure 4, we set up 10 motorbikes in the motorbike section (see the red section in Figure 4) in the experiments. The section lengths with parked motorbikes were set as 10, 15, 20, and 30 m. Motorbikes were evenly dispersed in the section. Therefore, the motorbike density changed with the section length, controlled at 0.38, 0.26, 0.19, and 0.13 motorbikes/m^2, respectively. To simplify the calculation process, the motorbike density (ρ_b) was expressed as $\rho_b = N/(wL)$ considering the section length (L) and motorbike lane width (w).

2.4. Experimental Subjects and Density Calculation

To investigate the influence of evacuee density on walking speed in the motorbike lane, the present experiments simulated the behavior of individual evacuees in a 2D space with motorbike lane characteristics. In motorbike lane evacuation, evacuees typically need to stop their motorbike and evacuate in the opposite direction in the event of an emergency. Accordingly, evacuees must walk in the narrow motorbike lane. Individuals are expected to move in one direction toward the portal. However, in contrast to walking in car lanes, accumulated motorbikes in the tunnel would form obstacles, causing a relatively crowded condition. The degree of influence and how to model the walking speed in such a situation are issues that need to be clarified.

Thus, before investigating the walking speed in such a scenario, we reviewed past studies related to speed–density models of pedestrian flow. Most of the well-known speed–density models are listed in Table 6.

Table 6. Deterministic speed–density models applied in pedestrian flow.

Model Name	Function	Definition of Terms
Greenshields model (1935) [35]	$V = V_f\left(1 - \frac{k}{k_j}\right)$	V_f: Free flow speed V_m: Optimal speed k: Observed density k_j: Jam density k_o: Optimal density (density with maximum flow or capacity) k_m: Maximum density when speed is zero
Greenberg model (1959) [36]	$V = V_m\, log(\frac{k_j}{k})$	
Underwood model (1961) [37]	$V = V_f\, e^{-\frac{k}{k_o}}$	
Kladek model (1966) [38]	$V = V_f\left[1 - e^{\left(\frac{1}{k} - \frac{1}{k_m}\right)}\right]$	
Drake model (1967) [39]	$V = V_f\, e^{-\frac{1}{2}\left(\frac{k}{k_j}\right)^2}$	

The proposed speed–density models in Table 6 reveal that both linear and exponential models have been used to describe the relationship, considering the free walking speed (i.e., walking speeds when people are not influenced by others) and different density conditions [35–39].

On the other hand, Seyfried et al. (2005) pointed out that there is a small and increasing decline in walking speed at low densities (density <0.7 person/m^2) [31]. The speed is mainly determined by the individual free velocity of pedestrians. Passing maneuvers cause a decrease in walking speed. Pauls (1987) indicated that individuals walk alone at 1.25 m/s, independent of the speed of others, when human density is less than 0.50–0.54 persons/m^2 [26] in building evacuation. There are various opinions on walking speed in low-density conditions. The influence of the interference between adjacent people on walking speed in low-density conditions is still lacking sufficient investigation. The reason could be that the occupied area required by the individual walking process is usually deemed sufficient when the human density is low; thus, the speed in the low-density condition is considered to be determined by the individual's free walking speed. However, the research of Bruno and Venuti (2008) on the relationship between speed and density mentioned that the required area for walking depends on the required width (w) and the required forward distance (l). The required forward distance (l) can be expressed as the sum of two terms, the step length (lp) and the sensory distance (ls), whereas the former can be physically measured, and the latter depends to a great extent on cultural and psychological factors [40]. In Thompson et al.'s (2020) study, a similar concept of sensory distance (ls) was defined as the "contact buffer" [41]. Thus, the influence of interference between people during evacuation must be considered when the analysis of walking speed is aimed at a crowd rather than at individuals.

Motorbike lanes in tunnels have the characteristics of several meters in width, hundreds of meters in length, obstruction of motorbikes, and relatively low human density. Whether existing models for pedestrian flow or building evacuation can completely explain the walking speed characteristics in motorbike lanes is unclear, particularly the influence of the interference between adjacent people on walking speed, even in a low-density state. Since the present study focuses on the scenario in which evacuees walk in a motorbike lane, it was expected that the interference between evacuees would be a critical factor even at a relatively low evacuee density. Thus, to investigate the effect of the interference between adjacent evacuees on the walking speed of tunnel evacuation in conditions of low human density, we instructed the subjects to start walking 1, 2, or 3 s after the previous subject. This instruction was provided to the subjects at both start lines (CP_1 and CP_5) in Figure 4.

To minimize the number of variables to be considered in the walking speed model, we embedded the concept of "interference between adjacent evacuees" into the variable of evacuee density. Regarding the density calculation, we considered the width of the motorbike lane rather than only the lateral space required for walking. Thus, the influence of the interference between adjacent evacuees would mainly be reflected by a change in evacuee density.

The real-time interval between adjacent subjects would dynamically change with time when walking through each section in the experiment region. Therefore, to distinguish this difference, the time difference after instructing subjects to start walking was denoted the "starting interval time", while the time difference between subjects walking was denoted the "time interval" in the present study. The time intervals between adjacent subjects would change with distance between subjects, thus influencing the density of subjects in the motorbike lane. The detailed calculation of "time interval" and "evacuee density" is described in Section 2.5.

Regarding the composition of the subjects, there were 40 subjects (20 male and 20 female) in the present study. There were five males and five females in each age bracket (30 years old or younger, 30 to 40 years old, 40 to 50 years old, and 50 years old or older). By observing the walking speed (including the mean and 95% confidence interval) of males and females (starting interval time designed as 1 s) in the present experiments (see Figure 7), one can find that the influence of age and gender was difficult to clarify, including an unexpected situation where females walked faster than males. We consider that the possible reason is related to the order of start walking. To avoid the situation that males walk fast and maintain suitable space for preventing topical evacuee density extremely unevenness, the order of start walking is designed as younger female, older female, younger male, and older male sequentially. However, it rather results in an additional unexpected situation that younger males (relatively move fast) were obstructed by older females (relatively move slowly). The walking speed of younger males is close to older females, as revealed in Figure 7. Considering this point, the experimental results in the next section only focus on discussing the relationship between walking speed and evacuee density. The influence of different ages and genders was not further explored.

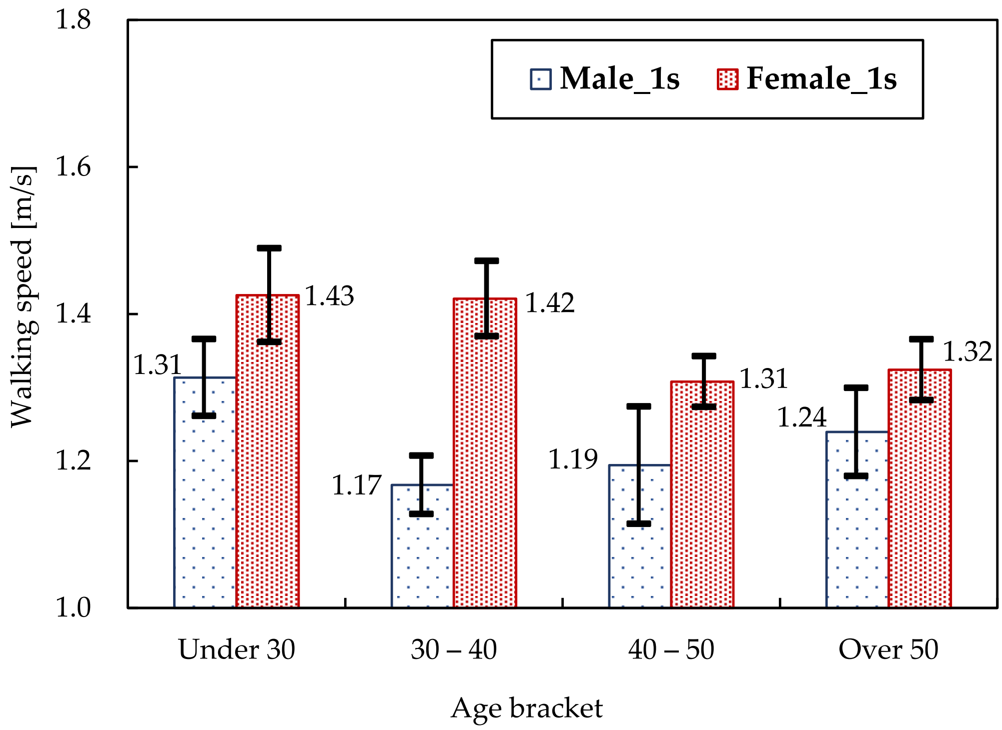


Figure 7. Walking speeds in the no motorbike section.

A total of 12 rounds were conducted in the present experiments (see Table 7). The front no-motorbike section in each round is considered as a buffer to minimize the effect upon entering the lane so as not to be further analyzed in Section 3. Considering the short distance would also influence the stability of walking speed, the data in the relatively short section of 5 m were also not further analyzed.

Table 7. Experimental conditions.

Rounds	Instruction of Starting Interval Time (s)	No-Motorbike Section (m)	Motorbike Section (10 Motorbike Setting Length (m))
1	1	10 (front), 30 (rear)	10
2		15 (front), 20 (rear)	15
3		10 (front), 20 (rear)	20
4		15 (front), 5 (rear)	30
5	2	10 (front), 30 (rear)	10
6		15 (front), 20 (rear)	15
7		10 (front), 20 (rear)	20
8		15 (front), 5 (rear)	30
9	3	10 (front), 30 (rear)	10
10		15 (front), 20 (rear)	15
11		10 (front), 20 (rear)	20
12		15 (front), 5 (rear)	30

2.5. Calculation of Time Intervals in Specific Sections

Our aim was to investigate the interference between adjacent evacuees on the walking speed; thus, we instructed the subject to start walking 1, 2, or 3 s after the previous subject. By considering the evacuee density, the number of people per unit area and the area can be expressed by the distance between adjacent subjects multiplied by the width. We calculated the individual time interval ($\Delta t_n^{k,k+1}$) and then calculated the evacuee density of individuals in specific sections as a function of the individual time interval. Nonetheless, after subjects started to move, there was a mutual influence due to their proximity, which changed the density.

Since we could not specifically determine the change in distance between adjacent subjects throughout the walking process, we applied the approach of "time averaging" to estimate the distance between adjacent subjects (i.e., considering the mean time interval when adjacent subjects entered and left a specific section in the motorbike lane).

Firstly, we calculated the timepoint (T_n^k) of subjects passing each checkpoint as a function of the time when the first subject started walking. The formula can be expressed as

$$T_n^k = (n-1)\Delta T + t_n^k, \tag{1}$$

where T_n^k denotes the timepoint when the n-th subject passed checkpoint k, which is relative to the time when the first subject started walking; ΔT denotes the starting interval time (1 s, 2 s, or 3 s); t_n^k denotes the time from the n-th subject starting at CP_1 or CP_5 to CP_k (according to a personal stopwatch); n denotes the order in which subjects started walking (1–40); k denotes the checkpoint (CP) number, divided into two sections (1–4 and 5–8).

Next, the time interval of the n-th subject was determined from their behavior, as well as that of four other subjects (see Figure 8). When each subject entered a specific section (CP_k), the timepoint (T_n^k) was recorded, while the timepoint of the rear subject was also recorded when they entered the specific section (CP_k) (see Figure 8a,b). Similarly, these adjacent subjects at the front and rear kept walking until leaving a specific section (CP_{k+1}), and the timepoint (T_n^{k+1}) was recorded (see Figure 8c,d).

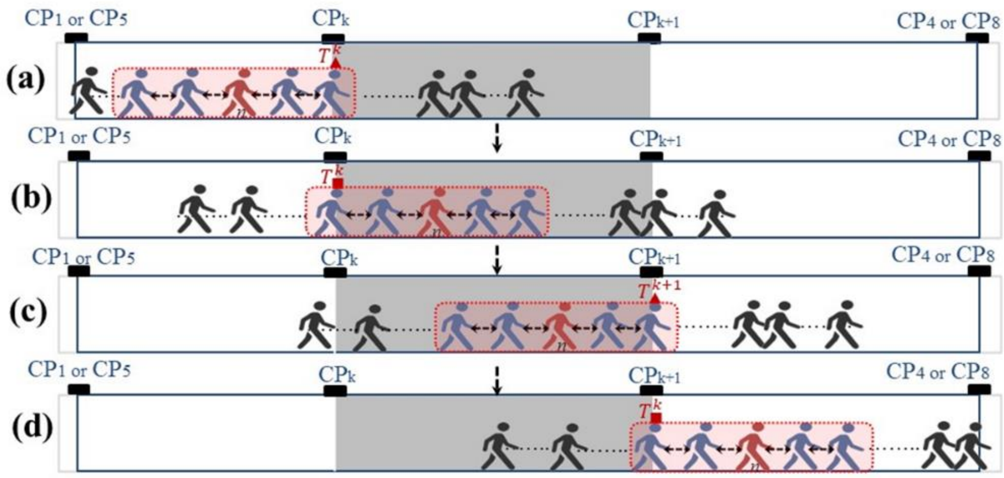


Figure 8. Schematic diagram of average interval time calculation.

However, some subjects bypassed others, yielding a negative time interval and, thus, a negative density.

As the present study does not further discuss the influence of passing maneuvers, to avoid this peculiar phenomenon of negative time interval values, we considered a subject's time interval in a specific section to be based on the time difference between two subjects to the front and rear upon passing the checkpoint rather than on the starting order. Thus, we calculated the average time difference of four adjacent subjects (red humanoid icon in Figure 8) when the target subject passed a checkpoint. The average of these time differences was defined as the time interval of the target subject. By averaging the time difference of four adjacent subjects, the calculation error in density caused by passing maneuvers was mitigated.

The formula for the time interval of the n-th subject entering a specific section can be expressed as

$$\Delta t_n^k = \frac{1}{4}\left(T_{\blacksquare}^k - T_{\blacktriangle}^k\right), \tag{2}$$

where $T_{\blacktriangle}^k$ denotes the timepoint of the front two subjects with respect to the n-th subject upon passing checkpoint k, and $T_{\blacksquare}^k$ denotes the timepoint of the rear two subjects with respect to the n-th subject upon passing checkpoint k. For the first two and the last two subjects entering or exiting the section, considering there would be no subjects or only one subject in front or behind them, "4" in Equation (2) was adjusted to "3" or "2".

The time interval of an individual in a specific section can be expressed as

$$\Delta t_n^{k,k+1} = \frac{1}{2}\left(\Delta t_n^k + \Delta t_n^{k+1}\right). \tag{3}$$

As a function of the personal time interval ($\Delta t_n^{k,k+1}$) in a specific section, the evacuee density (ρ_e) can be expressed as $\rho_e = 1/(wV\Delta t_n^{k,k+1})$, where w is the width of the specific section, V is the individual's walking speed in the specific section, and $V\Delta t_n^{k,k+1}$ is the distance between adjacent subjects in the x-direction.

3. Influence of Evacuee Density on Walking Speed

3.1. Walking Speed in the No-Motorbike Section and Modeling

To model the walking speed considering the evacuee density, we also analyzed the diagram of the speed–density relationship from the present experimental data of no-motorbike sections and reviewed the literature on the speed–density relationship in pedestrian facilities and buildings (see Figure 9 and Table 2).

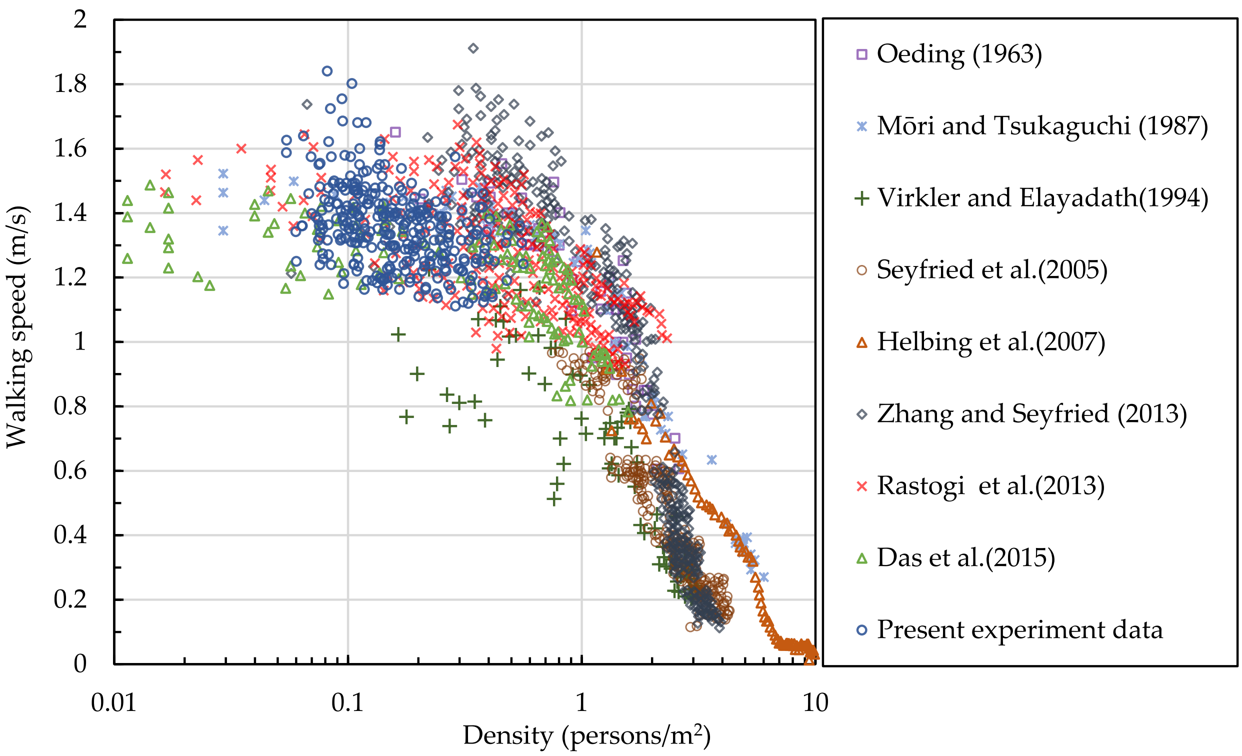


Figure 9. Macroscopic fundamental diagram of speed–density relationship from experimental and observational data [27–34].

According to the review of the experimental or observational literature in Table 2 and Figure 9, existing studies can be found over a wide range of walking speeds [27–34]. In addition to the relationship between density and walking speed, Oeding (1963), Mōri and

Tsukaguchi (1987), Rastogi et al. (2013), and Das et al. (2015) investigated different pedestrian facilities through actual observations, thereby considering bidirectional pedestrian movement [27–29,33]. Helbing et al. (2007) discussed an extremely high-density condition close to crowd panic [34].

The fundamental diagram of the speed–density relationship in Figure 9 reveals the diversity of the findings considering different factors (i.e., various types of infrastructure, the composition of age and nationality, the direction of the human flow, travel purpose, etc.), which varied across the studies. To confirm whether the various research data could be integrated, we compared the similarity of four aspects (i.e., the scenarios, direction of human flow, density range, and geometry of the walking space) with other studies (see Table 2). It can be seen from Table 2 that the present study was not similar to the other studies in these four aspects. Furthermore, Figure 9 indicates that the present experiment featured a much smaller range of density than previous studies. Accordingly, the walking speed modeling process was performed using the present experimental data.

On the other hand, regarding the individual walking speed in a road tunnel, an evacuation experiment was conducted in a full-scale tunnel (with ceiling lighting) in 2015. The average age of subjects was 35.1 years old. In the experiments at that time, the walking speed was measured under the condition that subjects started walking at an interval of more than 30 s (assuming no interference between adjacent evacuees). The scenario assumed a normal situation such as commuting to work or school (a nonurgent evacuation situation). According to the results, the walking speed of an individual was in the range of 0.94–1.88 m/s (mean 1.45 m/s) [42].

Considering that subjects in the front no-motorbike section (i.e., sections 1 and 4) would suddenly speed up and slow down upon entering the motorbike section (see Figure 4), a steady-state speed was not guaranteed before timing began. As we focused on the walking speed in a steady state, we considered the front no-motorbike section as a buffer to minimize the effect upon entering the lane and then analyzed the data of the rear no-motorbike section (i.e., sections 3 and 6) except for a relatively short section of 5 m. Moreover, since the present study aimed to clarify the influence of the interference between adjacent people on walking speed in conditions of low human density, the first few subjects who started walking were not affected by others. Thus, we excluded the data of the first five subjects when analyzing the walking speed.

To more clearly show the influence of low evacuee density on walking speed, Figure 10 illustrates the walking speed data from Figure 9 with respect to $1/\rho_e$ (personal area module). The walking speed ranged from 1.11 to 1.84 m/s with a personal area module of 1.78–18.31 m^2 (evacuee density: 0.05–0.56 person/m^2). Moreover, the walking speed slightly decreased with the increase in density even when the personal area module was around 10 m^2 (evacuee density: 0.1 person/m^2) and asymptotically reached a constant value as $1/\rho_e$ increased. Therefore, to develop the deterministic model, as the first step, we assumed the walking speed (V) to be influenced by the factor of evacuee density, as expressed below:

$$V = V_0\, f(\rho_e) = V_0 \left(1 - ae^{\frac{b}{\rho_e}}\right), \tag{4}$$

where $f(\rho_e)$ is a function to quantify the influence of evacuee density on walking speed. V_0 denotes the free walking speed not affected by the evacuee density in the present study (i.e., the individual's walking speed without being affected by others). a and b are parameters affecting the shape of the assumed function.

V_0 varies as a function of travel purpose. The average free walking speed was previously reported as 1.34 m/s [43]. Studies in Japan reported an average walking speed in evacuation of 1.30–1.33 m/s [44–46]. The walking speed when going to work in the morning was found to be close to 1.50 m/s [47,48]. Hence, free walking speed can be considered as a stochastic variable with a distribution [49] depending on various factors despite excluding the effect of human density. However, it is also a reasonable approach to simply describe the free walking speed (V_0) using a mean value. To reasonably determine free walking speed (V_0), we took the normal walking speed from real tunnel evacuation experiments (Yamashita, 2018) [42] as a reference, which was higher than the mean value reported by Buchmueller and Weidmann (2006) [43], but still in the range of past research on free walking speed and much closer to a scenario of evacuation.

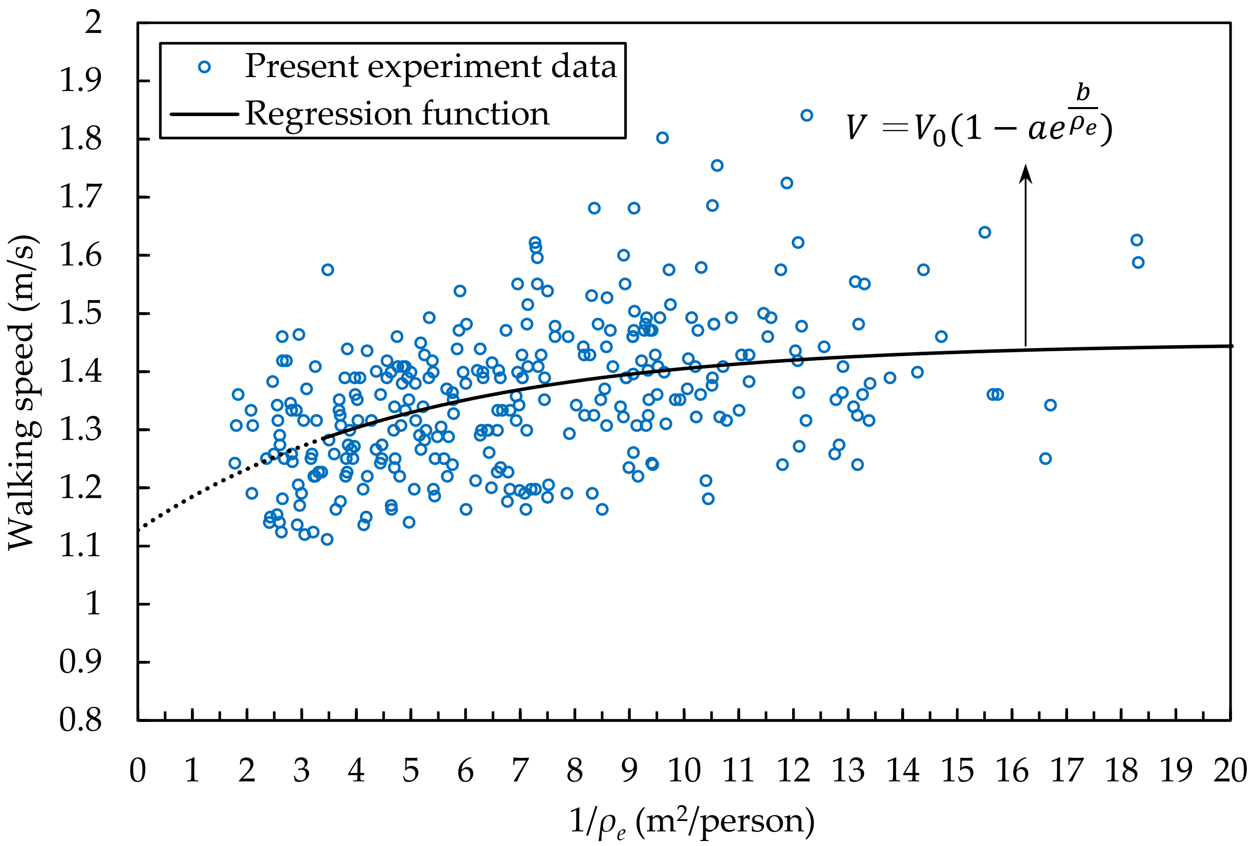


Figure 10. Relationship between speed and personal area module.

Parameters a and b in Equation (4) were estimated through a nonlinear regression by applying the least square method. The regression curve is shown as a black line in Figure 10, and the regression function is expressed as follows:

$$V = V_0\, f(\rho_e) = 1.45\left(1 - 0.22e^{-\frac{0.20}{\rho_e}}\right). \tag{5}$$

3.2. Two-Regime Models for Walking Speed

In this subsection, we discuss the modeling process of walking speed. It is well known that the walking speed should naturally decrease and approach zero when the area occupied by an individual becomes extremely small. However, a further examination of the regression function in Figure 10 and Equation (5) reveals that the value is close to 1.1 m/s when the area occupied by an individual becomes small. This tendency is different from actual crowd characteristics. It can be considered that the regression function in Equation (5) cannot explain regions where the evacuee density is higher than the experimental range. Therefore, to establish a model that can be used for walking speed at low density and high density, we further considered that the relationship between walking speed and evacuee density can be described by a two-regime model, and we assumed another exponential function for describing walking speed in a high-density state by taking the Kladek model (1966) [38] as a reference:

$$V = c\left[e^{-\rho_e d} - e^{-5.4d}\right];\ \rho_i < \rho_e \le 5.4, \tag{6}$$

where c and d are the parameters that affect the shape of the assumed function, 5.4 persons/m^2 is the maximum admissible density corresponding to null speed (speed close to 0 m/s) according to Weidmann (1993) [50], and ρ_i is the dividing condition for Equations (5) and (6). When ρ_i is known, the shape parameters c and d can be determined from the following conditions:

- (1) The same walking speed between Equations (5) and (6) in the condition of density ρ_i.
- (2) The same slope conditions between Equations (5) and (6).

In this paper, ρ_i was determined by trial and error at 0.3 person/m^2. The calculated function can be expressed as follows:

$$V = 2.42\left[e^{-0.16\rho_e} - e^{-0.86}\right];\ 0.3 < \rho_e \leq 5.4. \tag{7}$$

Figure 11 illustrates the scatter plot of the walking speed against evacuee density of the no-motorbike section and the speed–density models proposed by Rastogi et al. (2013) [27], Das et al. (2015) [29], and Kladek (1966) [38]. To present the low-density data distribution more clearly, the x-axis is expressed in logarithmic coordinates.

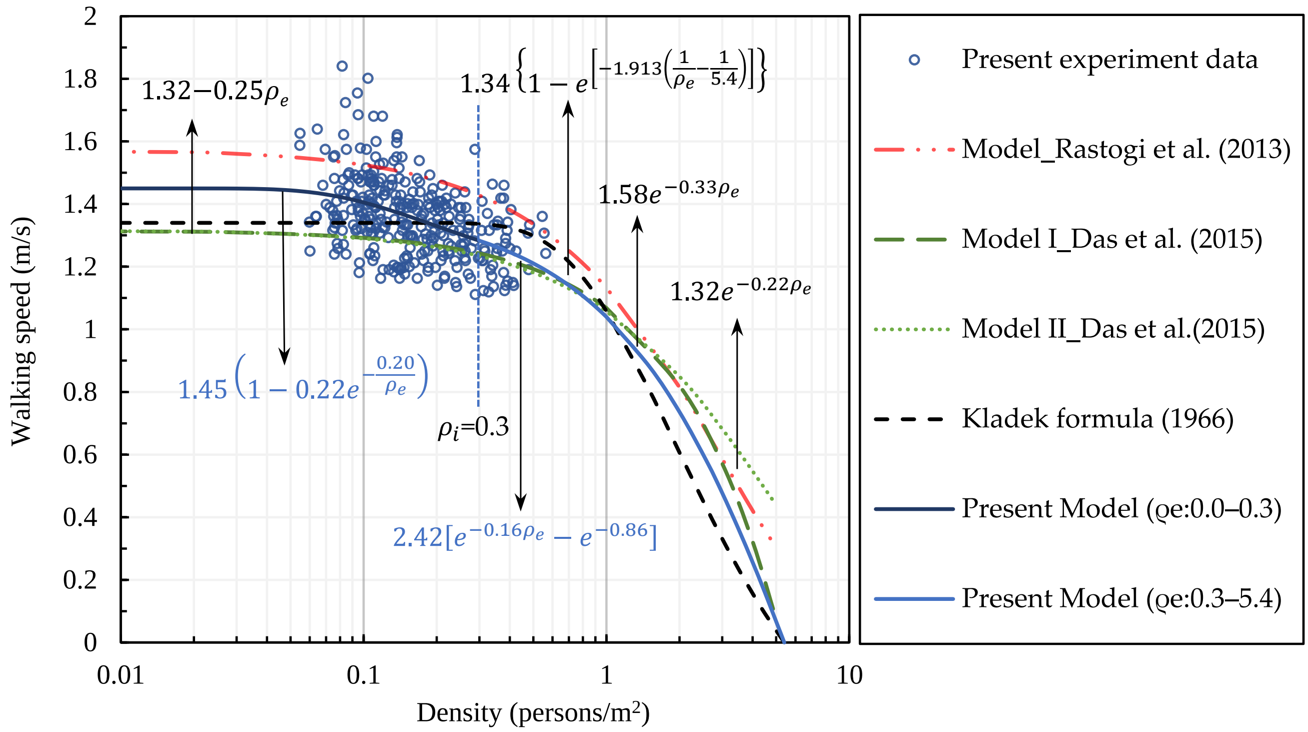


Figure 11. Speed–density relationship and modeling function [27,29,38,50].

Rastogi et al.'s (2013) model [27] revisited the Underwood model (1961) [37] based on the original data from different pedestrian facilities. Das et al.'s (2015) model [29] revisited the Greenshields model (1935) [35] and Underwood model (1961) [37] based on the original data from sidewalks and carriageways around transport terminals (the model only revisited the sidewalk data shown in Figure 11). Kladek (1966) [38] proposed a single formula to describe the relationship between the speed and density of urban road traffic. Weidmann (1993) [50] further revisited the formula to express the natural human movement characteristics at high and low densities as follows:

$$V = 1.34\left\{1 - \mathrm{e}^{\left[-1.913\left(\frac{1}{\rho_e} - \frac{1}{5.4}\right)\right]}\right\}, \tag{8}$$

where 1.34 m/s is the free walking speed, −1.913 is the parameter affecting the shape of the Kladek formula, and 5.4 persons/m^2 is the maximum admissible density corresponding to the null speed [38,50].

Rastogi et al.'s (2013) model [27] and Das et al.'s (2015) model [29] in Figure 11 reveal that walking speed decreases with an increase in density, even when the density is extremely low. However, in general, if an individual keeps a certain personal space, they can walk freely without being affected by others [47,48]. Therefore, it should be considered that in a state of extremely low density, the walking speed is independent of the influence of densities. Thus, the proposed models from Rastogi et al. (2013) [27] and Das et al. (2015) [29] may be unrealistic in a low-density state. On the other hand, the Kladek formula [38,50] in Figure 11 reveals that the walking speed begins to decrease when the density is around 0.4 person/m^2. This prediction overestimates the density condition when the walking speed begins to decrease, compared to our experimental results. The proposed two-regime models (light- and dark-blue lines) appear in relative agreement with the current experimental data.

However, the establishment of the present walking model is based on the premise that the evacuee density and motorbike density are independent variables of each other (i.e., evacuee density is not the function of motorbike density). This means that the modeling process would mainly focus on the low-evacuee density state. The walking speed model in the high-density state (Equation (7)) mainly hopes to express the possible changes in walking speed with the condition of no motorbike. However, the high-density state is not the main situation of motorbike lane evacuation. A correlation likely exists between evacuee densities and motorbike densities when evacuee densities increase to extremely high. Thus, the proposed model in the high-density state should be treated carefully as its low performance in representing the walking speed in motorbike lane evacuation.

4. Influence of Motorbike Density on Walking Speed

4.1. Walking Speed in the Motorbike Section and Modeling

In this section, we further clarify the influence of motorbike density on walking speed and discuss the modeling process. As demonstrated in Figure 4 (red section), there were 10 motorbikes set up in the motorbike section. The section lengths (L) with motorbikes were set as 10, 15, 20, and 30 m depending on the experiment cases. Considering the width (w) of the motorbike lane, the motorbike density (ρ_b) can be expressed as $\rho_b = N/(wL)$.

Moreover, the function $V = V_0 f(\rho_e)$ in Section 3.1 further considers the influence of motorbike density, which can be rewritten in the following form:

$$V = V_0\, f(\rho_e) g(\rho_b), \tag{9}$$

where the function $g(\rho_b)$ is assumed to represent the influence of motorbike density, which can also be rewritten as $V/(V_0\, f(\rho e))$. Since the $f(\rho_e)$ was calculated in Sections 3.1 and 3.2, and the evacuee density in the motorbike section was around 0.06–0.79 person/m^2, we could further apply Equations (5) and (7) to Equation (9). In addition, to establish a criterion of walking speed not affected by "motorbike density (ρ_b)", we also considered V_0 as the average walking speed (1.45 m/s), as mentioned in Section 3.1. The relationship between function $g(\rho_b)$ and the reciprocal of ρ_b is shown in Figure 12.

Figure 12 indicates that $g(\rho_b)$ could be mainly divided into four groups, as four motorbike densities were considered in experiments. Moreover, the distribution of data points in Figure 12 reveals that $g(\rho_b)$ gradually decreased with the increase in motorbike density (i.e., $1/\rho_b$ decreased), and the tendency seemingly showed an exponential relationship. Thus, we further assumed function $g(\rho_b)$ to be in the same form as in Equation (4) and conducted a nonlinear regression by applying the least square method to estimate parameters in the function $g(\rho_b)$. The regression curve is shown as a black line in Figure 12, and the regression function was generated as follows:

$$g(\rho_b) = \left(1 - 1.14e^{-\frac{0.55}{\rho_b}}\right). \tag{10}$$

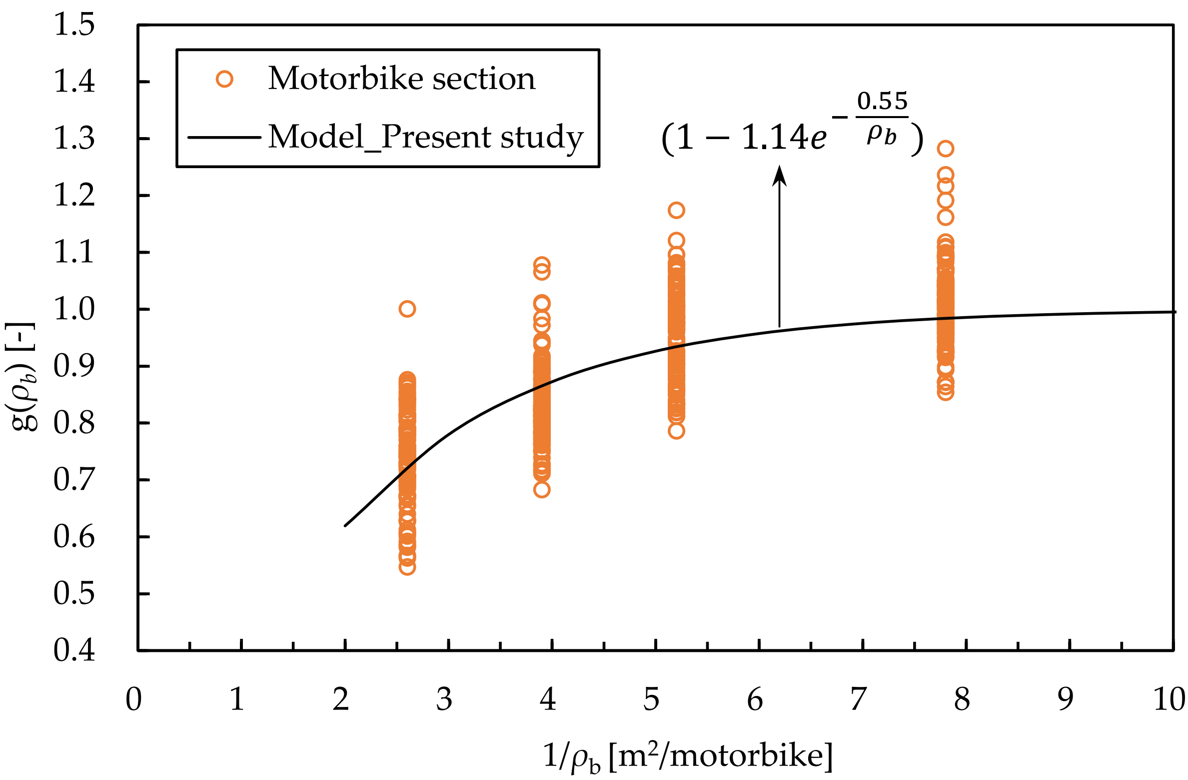


Figure 12. Relationship between $g(\rho_b)$ and motorbike density (ρ_b).

Apparently, the regression function was well fitted by the mean of function $g(\rho_b)$ for each motorbike density. However, for the same motorbike density, the difference in individual walking speed persisted.

Moreover, we mainly focused on actual motorbike density in an accident and a relatively lower density than an actual accident, according to the investigation in Section 2.2. When a tunnel fire accident occurs, an extreme situation is that motorbikes are probably congested in the lane such that people cannot walk in the motorbike lane; however, such motorbike density conditions were not explored in the present experiments. Whether the current regression function can explain the walking speed under the condition of high motorbike density is unclear. Therefore, the regression function in Figure 12 is only expressed until the reciprocal of ρ_b is 2 (i.e., the motorbike density is equal to 0.50 motorbikes/m^2).

4.2. Motorbike Lane Evacuation Models and Limitations

Figures 11 and 12 reveal the relationships among walking speed, evacuee density, and motorbike density; accordingly, the function for modeling motorbike lane evacuation considering both evacuee density and motorbike density can be expressed as follows:

$$V = V_0\left(1 - 0.22e^{-\frac{0.20}{\rho_e}}\right)\left(1 - 1.14e^{-\frac{0.55}{\rho_b}}\right);\ 0 < \rho_e \leq 0.3. \tag{11}$$

$$V = V_0\left\{1.67\left[e^{-0.16\rho_e} - e^{-0.86}\right]\right\}\left(1 - 1.14e^{-\frac{0.55}{\rho_b}}\right);\ 0.3 < \rho_e \leq 5.4. \tag{12}$$

To verify the models of walking speed, we applied Equations (11) and (12) to estimate the walking speed and compared the measured walking speed in the present experiments. V_0 was assumed to be 1.45 m/s. Each modeled walking speed was calculated on the basis of the same conditions of evacuee density and motorbike density from the measured walking speed. The modeled walking speed is shown on the y-axis, and the measured walking speed is shown on the x-axis in Figure 13.

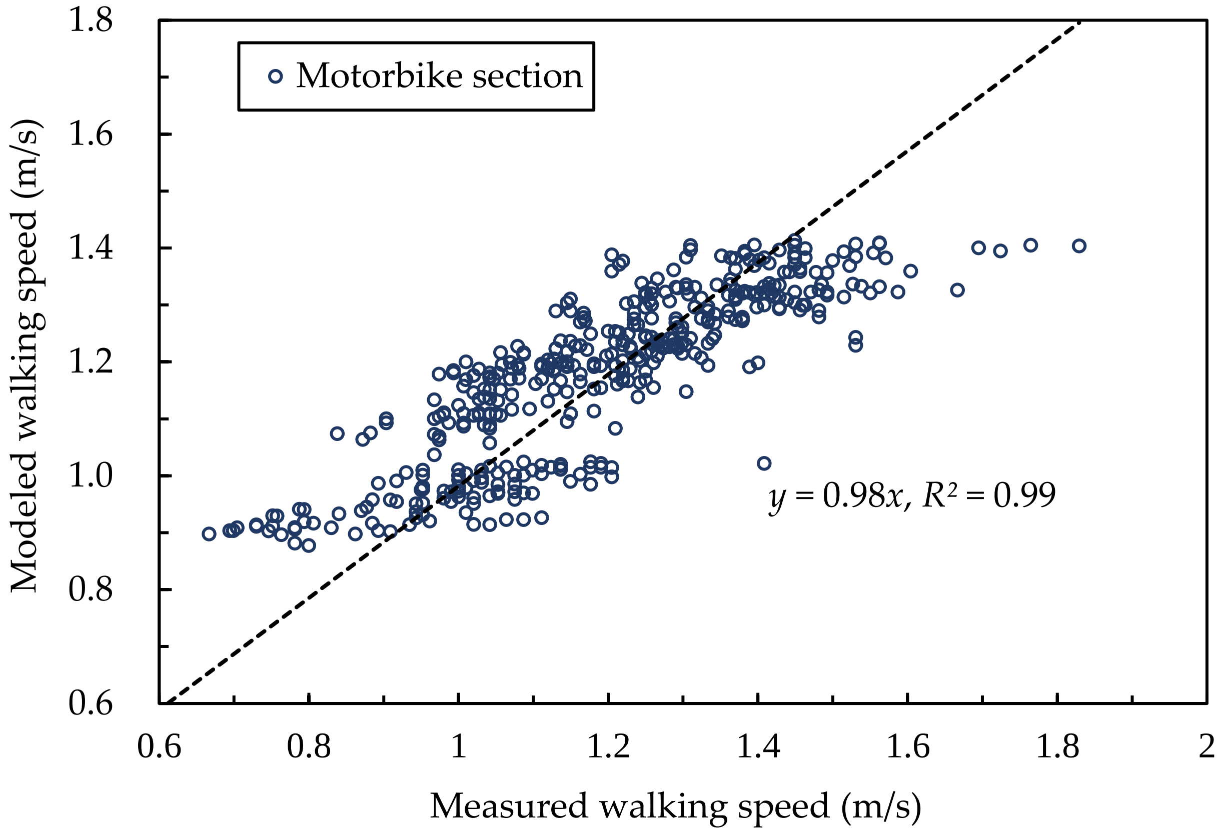


Figure 13. Measured walking speed and modeled walking speed.

The results reveal that the slope of the linear regression in Figure 13 was 0.98, with R^2 = 0.99. The modeled walking speeds are in acceptable agreement with the walking speed in the experiments. Therefore, regression models that consider variables of evacuee density and motorbike density can be used to reproduce the walking speed during motorbike lane evacuation in a tunnel.

However, there were some limitations to the development of the model. The focus of the present study was on developing models that can explain the relationships among walking speed, evacuee density, and motorbike density in a motorbike lane in a tunnel. The composition of the model indicates that the prediction of free walking speed (V_0) greatly affects the reproducibility of the model. Moreover, the proposed model in the present study should be considered a deterministic model based on experimental data and the past literature to determine the necessary parameters. In particular, the variation of density in this study mainly depended on the designated "starting interval time" of 1 to 3 s; hence, the experiments only covered a narrow density. The estimation of the parameters in the model should also be adjusted or revised when more samples in low- and high-density states are included.

Furthermore, we considered a heterogeneous composition of subjects in the present experiments (i.e., mixed with different genders and age brackets). Because the experimental design regarding the order of start walking resulted in difficulty in the analysis of the influence of genders, ages, and body sizes on walking speed in the motorbike lane, the aforementioned factors have not been clarified in current experiments. The walking speed in the condition of motorbike density larger than 0.38 motorbikes/m^2 was not fully investigated through the present experiments. Therefore, further investigation on the influence of various participant compositions and motorbike densities on walking speed still needs to be progressed to make the evacuation models of motorbike lane walking speed more comprehensive.

5. Conclusions

This study conducted a series of motorbike lane evacuation experiments to investigate walking speed. A preliminary video analysis of a motorbike lane incident in the Kaohsiung Cross-Harbor Tunnel was also conducted to understand the actual scenario of motorbike lane evacuation. The research findings are presented below.

The analysis of a past traffic accident revealed that motorbikes congested the lane, and the motorbike density reached a constant value with limited lane space. This indicates that motorbikes involved in a tunnel accident would result in the accumulated distance of motorbike congestion extending rather than the motorbike density increasing. This reflects the necessity of timely traffic control for motorbike lanes in an emergency to prevent an increase in tunnel users needing evacuation. The experimental analysis clarified that the walking speed is reduced with the increases in motorbike density and evacuee density, even in conditions of low evacuee density (around 0.1 person/m^2). The proposed exponential model consisting of the evacuee density, the motorbike density, and free walking speed as variables provides a good representation of the walking speed in motorbike lane evacuation.

The above findings contribute to expanding the understanding of evacuation behavior in the motorbike lane of a tunnel and arouse notice of motorbike lane evacuation issues for countries with high motorbike utilization.

Additionally, wider ranges of evacuee and motorbike density are still needed for evacuation model calibration. The influence of various participant compositions on walking speed has also yet to be studied. The development of an evacuation model that can be applied in lanes of mixed motorbikes and four-wheeled vehicles remains a future task that needs to be progressed.

Author Contributions: Conceptualization, C.-C.C., H.-C.C. and N.K.; methodology, C.-C.C. and N.K.; validation, C.-C.C., H.-C.C. and N.K.; formal analysis, C.-C.C., H.-C.C. and N.K.; investigation, C.-C.C., H.-C.C. and N.K.; resources, C.-C.C.; data curation, C.-C.C. and H.-C.C.; writing—original draft preparation, C.-C.C. and H.-C.C.; writing—review and editing, N.K., M.S. and M.H.; visualization, C.-C.C. and H.-C.C. supervision, N.K., M.S., M.H., S.-W.C. and T.-S.S.; project administration, N.K., S.-W.C. and T.-S.S.; funding acquisition, C.-C.C., N.K. and M.S. All authors have read and agreed to the published version of the manuscript.

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Nomenclature

$f(\rho_e)$	Function describing the influence of evacuee density on walking speed
$g(\rho_b)$	Function describing the influence of motorbike density on walking speed
ρ_e	Evacuee density $= 1/(wV\Delta t_n^{k,k+1})$ (unit: persons/m^2)
ρ_b	Motorbike density = $N/(wL)$ (unit: motorbikes/m^2)
N	Motorbike numbers (unit: motorbikes)
w	Motorbike lane width (unit: m)
$\Delta t_n^{k,k+1}$	Individual time interval in a specific section of the lane (unit: s)
ΔT	The starting interval time (1, 2, or 3 s)
T_n^k	The timepoint when the n-th subject passes checkpoint k (unit: s)
T	The measured time in a specific section of the lane (unit: s)
L	The measured section length in the motorbike lane (unit: m)
V	Walking speed = L/T (unit: m/s)
V_0	Walking speed not affected by the evacuee density and motorbike density

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