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A Theoretical Framework for Understanding Pedestrian Behaviour Attributes Based on Spatial Interaction

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Abstract. Current trend shows there is an exponential increase in rail traffic passenger volume in Malaysia, causing authorities to be aware in improving the pedestrians' facilities and safety. Kuala Lumpur Sentral Station (KLSS) is the largest transportation hub in Malaysia and, as of May 2017, the user reaches up to 180,000 users daily. In this contribution, a theoretical framework is presented to understand the pedestrians' behaviour attributes at rail transit terminal based on pedestrians' spatial interactions. The Distinct Element Method (DEM) will be employed to model the dynamics of pedestrian's crowd behaviour. The validated crowd dynamics model will be demonstrated in evacuation capacity estimation in KLSS. Evacuating people quickly and safely can greatly reduce casualty and economic losses. As for this contribution, more concern is on the spatial interaction of pedestrian at the RTT and the proposed framework. This framework paper will describe the flow in details on conducting the study of spatial intersection.

1. Introduction

Study on dynamic of pedestrian's crowd behaviour at Rail Transit Terminal (RTT) in Malaysia is not being focus and according to Bohari [1], public buildings such as nodes, terminal and stations experiencing movement of people that generate massive walking behaviour. Kuala Lumpur Sentral Station (KLSS) is the biggest RTT in Malaysia located at the heart of Kuala Lumpur that connect almost all the public transport facilities such as rail (KTM, LRT, Monorail and MRT), buses and taxi in one hub with up to 180,000 users daily (The Star Online, 2017). Therefore, it is crucial to study the pedestrian behaviour to address the issue of security, convenience, the facility utilization, spacestructure and equipment layout of the terminal.

On the other hand, pedestrian spatial interaction represents the pedestrian behaviour towards the space around them. In recent literature review, some researches or guidelines address spatial interaction as proxemics behaviour, personal space, shy distance, buffer zone, cushion, psychological space and perception domain. Although it comes with many names, the mail objective if spatial interaction is to determine the pedestrian behaviour towards other pedestrian or obstacle around them. The Strait Times Online (2017) reported that the East Coast Rail Link (ECRL) that linking east cost to

Port Klang on the west coast is slated to be completed in 2024 with estimated 5.4 million passengers and 53 million tonnes of cargo will use the service annually by 2030. Thus, study on dynamic of pedestrian's crowd behaviour at RTT in Malaysia based on pedestrian spatial interaction is crucial to support the increasing demand in rail services.

2. Recent Studies on Pedestrian Behaviour Attributes, Evacuation of Egress Facilities and Spatial Interaction

2.1. Pedestrian Behaviour Attributes

Pedestrian behaviour is normally interpreted in term of speed, flow, density and rarely in term of evacuation time. Table 1 shows the list of past researches involving pedestrian behaviour attributes and most of the researcher study the pedestrian behaviour based on the walking speed follow by flow, density and evacuation time as shown in Table 1 and Table 2. Walking speed is the most pedestrians' attributes being studied so far (Table 1 and 2).

Table 1. List of previous studies on pedestrian behaviour attributes.

Authors	Speed	Flow	Density	Evacuation Time
Bohari [1]	✓			
Abustan [2]	✓			
Patra [3]	✓	✓	✓	
Von [4]	✓			✓
Han and Liu [5]			✓	✓
Zhang [6]			✓	✓
Li [7]				✓
Zhao and Liang [8]	✓			
Zhao [9]				✓
Zhao [10]	✓	✓		
Gotoh [11]	✓			
Yeo and He [12]	✓	✓		

Pedestrian speed is mostly determined by analysing the video recording of pedestrian walking from fix distance (usually 1.5 m) over time. Some studies conducted at Malaysia, India, China, Japan and Singapore show different pedestrian walking speed. According to Bohari [1] and Abustan [2] the walking speed of pedestrian at Masjid Jamek LRT Station varies from 1.12 m/s to 1.48 m/s and at Miami Beach, Penang varies from 0.89 m/s to 1.38 m/s. Higher walking speed was observed at Masjid Jamek LRT Station, rapid transit station in Kuala Lumpur, Malaysia compared to Miami Beach, recreational place in Penang, Malaysia.Although both places have different purposes, the different in walking velocity is about 20%. As reported by Yeo and He [12], in Singapore, their pedestrian walking speed at MRT stations is in the range of 1.04 m/s to 1.30 m/s which contribute to 12% different from Bohari [1]. Zhao and Liang [8] from China reported that the pedestrian walking speed at Guangzhou Metro varies from 0.92 m/s to 1.18 m/s which contribute 20% different from Bohari [1]. Meanwhile, Secunderabad Railway, India recorded slowest walking speed which is 0.65 m/s (Patra [3]). This may be due to substantial number of user daily which reach up to 23 million pedestrians daily with comparatively less spaced level changing facilities which become bottlenecks at most of the time. Japan, country with the most advanced rail technology recorded 1.47 m/s pedestrian walking speed [8].

Pedestrian level-of-service (LOS) is calculated by counting pedestrian who cross a point over a certain period (usually 15 minutes), reducing figures to pedestrian per minute and divided by the effective width, and hence produce the flow rate (Highway Capacity Manual (HCM), 2010). The LOS is characterised as A for free flow to F as virtually no movement possible. Not many studies on pedestrian flow were conducted. Patra [3] found that the pedestrian flow at Secunderabad Railway, India is 24 ped./m/min meanwhile Zhao [10] found that the pedestrian flow at Guangzhou Metro, China was 58 ped./m/min. Up to 59% difference calculated of the pedestrian flow between China and India. This scenario may be due to the pedestrian physical difference, such as body size between those countries, and the weight and physical dimension of the pedestrian facilities. Unfortunately, there is no study found about pedestrian flow in Malaysia especially at the RTT.

Table 2. Conducted studies on pedestrian walking speed based on countries.

Country	Author	Walking Speed (m/s)
Malaysia	Bohari [1]	1.12 to 1.48
	Abustan [2]	0.89 to 1.38
India	Patra [3]	0.65
China	Zhao and Liang [8]	0.92 to 1.18
Japan	Gotoh [11]	1.47
Singapore	Yeo and He [12]	1.04 to 1.30

Density is the number of pedestrians present on an area at given moment and noted as p/m^2. Patra [3] recorded the density of pedestrian at Secunderabad Railway, India is 1.5 p/m^2 and Zhang [6] found that the density of pedestrian at Wuhan Metro Station, China is 1.83 p/m^2. There are 18% difference between China and India. This shows that pedestrian in India need more space compare to China. This may differ for Malaysia case due to cultural difference.

Evacuation time is important to make an effective building egress process. Evacuation time is the elapsed time between the instant that occupants receive an emergency alarm and their arrival at a destination where it is normally a safe location inside or outside the building. Many factors can affect the evacuation time such as group forming, information transmission, route planning, bottleneck effect and code of practice chosen. Von [4] studied the effect of social group towards evacuation time shows that queue in front of the door can make evacuation faster compare to broad distribution around the exit. Information sharing is important especially in pristine environment. Like in Han and Liu [5], with the used of modified social force model based on information transmission to model the evacuation process, the evacuation time is effectively shortened, and evacuation efficiency is improved. Besides, Zhang [6] reported that by improving the route planning strategies for evacuation process, it helps in reducing the evacuation time by choosing the shortest evacuation route. But, this approach has some limitation since subjective factors like physiology and psychology of the crowd were not considered in this study. Most of the rail station have turnstile that will cause bottleneck effect during emergency evacuation and prolong the evacuation time according to Li [7]. Zhao [9] suggested the use of right code of practice will affect the evacuation process of a building. In their study, the Chinese code tends to give errors in the result of evacuation time, while the American and Japanese standards show certain superiorities such that they correctly reflect the effect of the structural layout of the station and represents predictive bottlenecks.

Although there are many research done on this matter, Malaysia are still lacking in its pedestrian behaviour at RTT. Pedestrian behaviour such as speed, flow, density and evacuation time need advanced studied to help improving the operation and safety level of pedestrian at transport terminals in Malaysia. A lot of works need to be done since the above issue have many application and impact to the society. RTT in Malaysia is becoming one of the choice of transportation mode. Hence, the necessity to understand the specific behaviour of passengers in RTT is crucial. This understanding will become a reference information to the traffic engineers in designing walking infrastructures for other places (i.e.: shopping mall, side walk facilities, stadium, crosswalk facilities, etc.). On the other hand, with the establishment of crowd behaviour model, an analytical evaluation of the quality of urban space can be provided.

2.2. Spatial Interaction

Many models of crowd behaviour have been proposed so far to understand how pedestrian move, however modelling and visualizing the dynamics of pedestrian crowd behaviour in relation to pedestrian spatial interaction, particularly at railway stations is none in Malaysia. A better understanding of crowd behaviour in railway station is the key to plan and manage the pedestrians' flow in Rail Transit Terminal (RTT). There are many names used to address spatial interaction such as the "shy distance" by Highway Capacity Manual (HCM), 2010 that clearly defined as the space that pedestrian tends to keep between themselves and obstacle. Some researcher does refer "shy distance" as "buffer zone" or "cushion". The shy distance was estimated to be 30 cm to 45 cm and affected by number of pedestrian, time of day, and surrounding land use. Campanella [13] study the microscopic modelling of walking behaviour using the Nomad simulator that used three levels of spatial isolation of isolated, in-range and in-collision. Isolated is the stage where pedestrian have no other pedestrian or obstacles within their influence area. In-range is the stage where pedestrian have other pedestrian or obstacle inside or close to their influence area but no possibilities of colliding. In-collision is the stage where pedestrian is very closed to other or to obstacle.

Some study does implement spatial interaction in different concept as shown in the Table3. From those studies, only two studies of the spatial interaction were at rail station with different concept and none at RTT. Guo [14] study the spatial and temporal separation rules to reproduce self-organizing movement through bottleneck (train door) indicated that pedestrian efficiency of passing through the bottleneck can be improved by implement the spatial separation rule. Pedestrian pass through the middle tend to move to the right and pedestrian pass near two sides of the door tend to move to the left. Meanwhile, Yang [15] study the guided crowd modified social force model to predict the evacuation of Beijing South Railway Station found that pedestrians in the group who choose to follow the guide instead of walking independently before knowing the position of exit can escape with a larger velocity. Both of those concepts were studied in China. Do Malaysia RTT users follow the same spatial interaction pattern as China especially with the evacuation process described by Yang [15]? Therefore, it is important to study the spatial interaction to know the pedestrian behaviour at RTT in Malaysia.

Table 3. Concept of spatial interaction used in the previous studies.

Author	Concept
Mohd Ibrahim [16]	Game theory
Von [4]	Lane formation
Han and Liu [5]	Group formation
Liu [17]	Effect of wall and door
Campanella [13]	Modelling of walking behaviour
Guo [14]	Bottleneck effect of train door
Yang [15]	Guided crowd at railway station
Fridman [18]	Impact of cultural differences

Mohd Ibrahim [16] use game theory as the concept of their study and come out with 40 cm as their spatial distance and 130° as their maximum angle between conflicting agents. In this stage, real life Malaysian pedestrians at RTT are the same as the game theory needs to be clarified. Study from China conducted by Liu [17] came with spatial distance of 46 cm. Liu [17] study the effect of wall and door towards the distribution of pedestrian in a room mention that pedestrian tend to locate themselves near the boundary (wall) and far from entrance (door). This can be one of the considerations in determining the pedestrian spatial distribution at RTT. Since the study about spatial distribution at RTT in Malaysia are none, study need to be done to provide the accurate information for future development of RTT.

Fridman [18] study the impact of cultural differences towards personal space or spatial distance through video recording. They found that the spatial distance for Iraq, French, England and Canada are 32.7 cm, 41.7 cm, 50.3 cm and 67.9 cm. Among those countries, Iraq and French have the closes value of spatial distance to the value produced by the game theory from Malaysia. Since, Malaysia and Iraq are Asia countries, they may share some similarities in their culture that lead to only 18.25% difference in spatial distance. French the European country may have diverged culture from the Asia but the fact that Eiffel Tower in Paris, French are the recreational place which most of the visitor are family, couples, friends and close relatives fall under categorised as intimate distance in interaction zones that lead to spatial distance of 0 cm to 45 cm give 4.25% difference in spatial distance from game theory.

Table 4. The spatial distance obtains from different country.

	Spatial distance (cm)							
Country / Author	Malaysia	China	Japan	French	England	Canada	Iraq	Brazil
Mohd Ibrahim [16]	40							
Liu [17]		46						
Campanella [13]								65.4
Fridman [18]				41.7	50.3	67.9	32.7	

Modelling and simulation is one of the most used method to study pedestrian spatial interaction. Gotoh [19] developed the Distinct Element Method (DEM)-based crowd behavior simulator, which was applied to a simulation for evacuation against tsunami and Gotoh [11] modified the governing equation by adding the self-evasive force to develop self-evasive action model call DEM-based multi-agent model with self-evasive action model. Figure1 illustrate the perception domain used by Gotoh [11]to describe the model of vision which is symmetrical to the travelling direction of each individual pedestrian for both physical and psychological repulsive force. The physical repulsive force acts when the distance of pedestrian *i* and *j*, or distance of pedestrian *i* and the virtual wall element are less or equal to the average diameter of pedestrian *i* and *j*, or pedestrian *i* and the virtual wall element. Meanwhile, the psychological repulsive force act when the distance of pedestrian *i* and *j* is less or equal to the psychological radius as shown in Figure 1. The angle of vision and the psychological radius were the element considered to determine the perception domain of psychological repulsive force. The psychological radius was interpreted as the representative length scale of personal space.

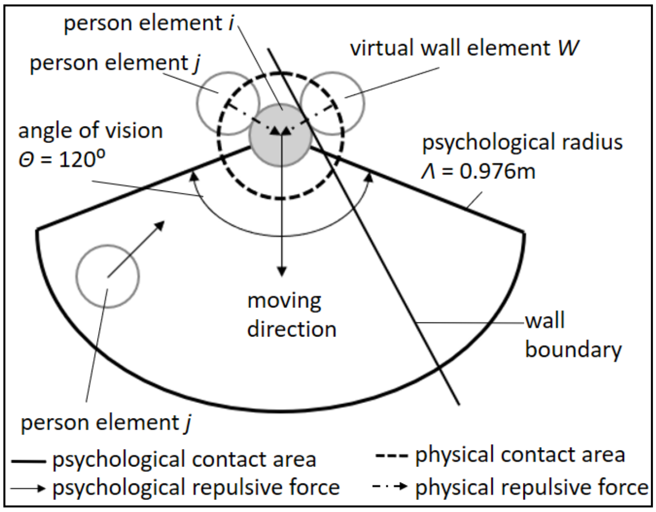

Figure 1. Perception domain by Gotoh [11].

Study the spatial interaction is crucial in planning and managing the pedestrians' flow in RTT.The dynamics of crowd motion is mainly driven by local interactions among pedestrians and their surrounding environment. Many models of crowd behaviour have been proposed so far to understand how pedestrian move, however modelling and visualizing the dynamics of pedestrian crowd behaviour in relation to pedestrian spatial interaction, particularly at railway stations is none in Malaysia.The DEM will be used to model the dynamics of crowd behaviour in RTT by considering the interactions between the pedestrians and between pedestrians and physical environment. The pedestrians are considered as assembly of particles of rigid bodies. Conceptually, particles move according to Newton's second law of motion.

3. A theoretical framework

3.1 Introduction

This proposed theoretical framework work to model and simulate the dynamics of pedestrian's crowd behaviour in Rail Transit Terminal (RTT) and hence to advocate the repercussions towards the evacuation behaviour of the crowd during emergency. In relation to that, a study of crowd evacuation is piloted at the largest transportation hub in Malaysia which is the KL Sentral Station (KLSS), Kuala Lumpur. Figure 2 shows the ground floor (noted as Level 1 from the building authorities) plan with estimated dimension of KLS. The KLSS is chosen as a study area due to its exponential increase in rail traffic passenger volume since its 15 years built. The Distinct Element Method (DEM) will be employed to model the dynamics of pedestrians' crowd behaviour. To confirm the reliability of the model, the validation is performed by statistical analysis. Validation through simulation and reproduction of walking scenario in KLS also will be performed. Subsequently, comparison with real life walking scenario in KLS is conducted. Then, the validated crowd dynamics model is demonstrated in evacuation capacity estimation of egress facilities in KLS. Evacuating people quickly and safely can greatly reduce casualty and economic losses. The outcomes from this study will be beneficial for future planning and design of mass transit and transit spaces.

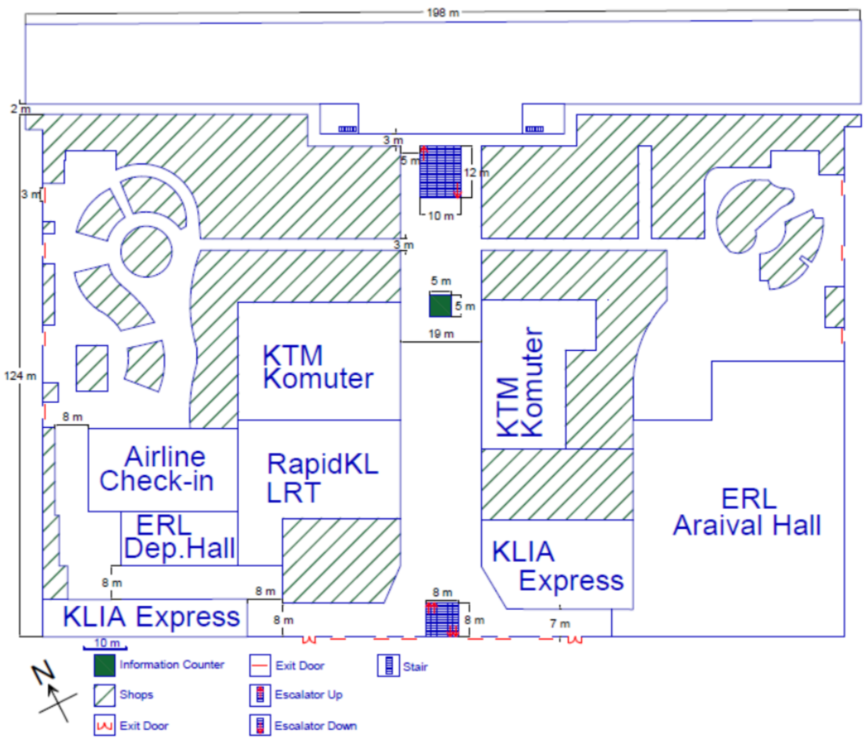

Figure 2. Level 1 floor plan.

The objective of this research is to determine crowd behaviour attributes in RTT such as walking speed, spatial pattern, spatial interaction parameters (distance and angles) and local collision avoidance during locomotion. Besides, this research was conducted to formulate the dynamic of crowd behaviour based on empirical result obtained using DEM and to assess the evacuation capacity of egress facilities in RTT and determine the evacuation time. The hypothesis of this research can be said as the number of passengers per unit area (density) increase, the spatial pattern of walking pedestrians has negative effect on the walking velocity. The pedestrians interact with other pedestrians through their perception domain by keeping a constant interaction distance and angle between pedestrians and physical environment and, pedestrians have their psychological radius to avoid collision with oncoming pedestrians. Furthermore, the hypothesis is that the maximum pedestrians flow that can pass the evacuation bottleneck section of egress facilities in RTT must be within given times.

From the hypothesis, it is important to know how crowd organize in space and affect the crowd dynamics, how walking pedestrians interact with each other, how pedestrian in crowd avoid collision with pedestrians and what is the condition of current evacuation capacity of egress facilities in RTT.

3.2. Flow of Methodology

The activities involved in this research are field observations and video footage at KLSS. The video data gathering will be analysed using Adobe After Effects CS6, Autodesk MAYA 2016 and HBS tool. The empirical results obtained have important implications for the validation of a model to replicate crowd dynamics in KLSS. The DEM-based model will be established to portray the crowd dynamics of Malaysian pedestrians in railway station. This crowd dynamics model will describe how a person interacts with other pedestrians and physical environment. The validation between simulated scenarios and the real situation are compared by taking video image as references. The effect of the newly developed model is shown in the ability of pedestrian to avoid collision of oncoming pedestrians. After the reliability of the model is confirmed, the evacuation capacity (EC) of egress facilities in RTT will be performed. The overall assessment of EC will be a basis in quantifying the overall evacuation time in RTT, and to look at if the capacity of RTT can meet the evacuation demand under emergency.

This research will be conducted in five phases starting from data gathering and end at the result obtaining stage as elaboration of those five phases will be described in this sub-topic.

3.2.1. Phase 1: Data Gathering. Data collections of the study area are the crucial part in this study.Data needed are: detail layout of KLSS, population distribution in KLSS and human crowd motion. Human crowd motion, particularly walking pedestrian will be collected through video footage. Population distribution is obtained through survey. And, the detail layout of the KLSS will be obtained from the authority.

3.2.2. Phase 2: Data Analysis. During this phase, the video films will be gathered and bring to the laboratory for analysis. There are three stages involved in video analysis and three different software will be used. The video analysis will first, convert from video to image sequence, second, track of pedestrian trajectories, and third, determine the average walking velocity, physical and psychological contact area, psychological radius and angle of vision. The three software are, Autodesk MAYA 2016 (MAYA), Adobe After Effect CS6 (AE) and HBS tool (in-house developed tool). Table 5 shows the process involved in this phase. The end product of this phase will reveal features of pedestrians' crowd behaviours as stated in the outcome of Stage 2 in Table 5 and Figure 1. Velocity are used instead of speed due to the pedestrian walking with direction as shown in Figure 1 and it is based on case study that involve walking with varies direction. Compare to previous studies described in sub-topic **2.1**, most of the researcher used speed because it is experiment based studied with fix walking direction and distance.

3.2.3. Phase 3: Modeling and Simulation. To model the dynamics of the crowd behaviour, the DEM (Figure 1) is employed. The DEM is known as a suitable method for the simulation ofthe dynamic behaviour of an assembly of particles. This approach explicitly provides the mechanical behaviour of the individualparticles and their contacts. Its computational modelling framework allows finite displacements and rotations of discrete particles andrecognizes new contacts automatically.DEM-based crowd behaviour simulator, named Crowd Behaviour Simulator for Disaster Evacuation (CBS-DE) has been developed.

Table 5. Process in video analysis.

	Video analysis		
	STAGE 1	STAGE 2	STAGE 3
	Conversion from video image to image sequence.	Track of pedestrian's trajectories.	Determination of crowd attributes.
SOFTWARE	Adobe After Effect	Autodesk MAYA 2016 with HBS tool plug-in	Microsoft Excel
OUTCOME	Image sequence with frame rate of 25 fps.	Trajectories (path coordinate) of each pedestrian motion for every 0.4s interval.	Walking velocity, physical and psychological contact area, psychological radius and angle of vision.

The DEM models particles distinctly as a group of rigid bodies and the behaviour of each particle is governed by translational and rotational equations of motion of $\boldsymbol{F} = m\boldsymbol{a}$ and $\boldsymbol{T} = I\boldsymbol{\alpha}$, where $\boldsymbol{F}$ reflects internal and external forces, $\boldsymbol{T}$ is a torque, m is a mass of a particle, i is a moment of inertia of a particle, $\boldsymbol{a}$ refers an acceleration of a particle and $\boldsymbol{\alpha}$ is an angular acceleration of a particle. The motion of a pedestrian element in contact with neighbouring elements is described in accordance with Newton's law of motion. Each pedestrian element is governed by translational and rotational equations of motion. The combination of an autonomous driving force, repulsive forces and the self-evasive force describe the motion of a pedestrian. The autonomous driving force reflects the motivation of a pedestrian to move in a prescribed walking velocity and orientation while repulsive forces reflect inter-element (contact) forces due to collisions, and the self-evasive force treats collision avoidance and pedestrian alignment. Hence, the motion of the pedestrian i in CBS-DE is written as Formula (1).

$$m_{hi}\boldsymbol{v}_{hi} = \boldsymbol{F}_{inhi} + \boldsymbol{F}_{awhi} + \boldsymbol{F}_{sehi} \text{ and } I_{hi}\boldsymbol{\omega}_{hi} = \boldsymbol{T}_{hi} \quad (1)$$

Where m_{hi} and I_{hi} are two parameters that refer to the mass and moment of inertia of the pedestrian i, respectively. $\boldsymbol{v}_{hi}$ is the velocity of the pedestrian i, $\boldsymbol{\omega}_{hi}$ is the angular velocity of the pedestrian i, " ̇" indicates a time-derivative, $\boldsymbol{F}_{inhi}$ is the inter-element (contact) force acting on the pedestrian i, $\boldsymbol{F}_{awhi}$ is the autonomous walking force of the pedestrian i, $\boldsymbol{F}_{sehi}$ is the self-evasive force acting on the pedestrian i and $\boldsymbol{T}_{hi}$ is the torque acting on the pedestrian i. The behaviour of the pedestrian element is computed explicitly by numerical integration of those equations.

3.2.4. Phase 4: Validation. The validation works are executed to confirm the reliability of the model by three methods. First, statistical data analysis involving the use of statistics to analyze data for analytical method validation such as mean, standard deviation, confidence intervals, linear regression and t-test will be performed. Second, reproducing the dynamics of crowd behaviour by comparing the simulated walking pedestrian scenario with the real-life scenario of walking pedestrian in KLSS. There are two procedure performed in this validation work. The first procedure is looking for preferred scenario from the footage. The footage will manually examined. The criteria for the preferred scenario are contra-flow and involved multiple groups pedestrians who walk in KLSS. The chosen scenario is then saved in sequence images of PNG format. In the second procedure, simulation of the chosen scenario is performed by employing the established model. The third step in validation phase is visualization that involved visualized simulated crowd dynamics of pedestrian at RTT in Autodesk MAYA software. This visualization is important in order to display any deficiencies or violations in calculations performed.

3.2.5. Phase 5: CG Movie. In the final phase, the computer graphic (CG) movie, is presented through Autodesk MAYA software to visualize the simulated evacuation process. It is an effective mean to display any deficiencies or violations in calculations performed. In addition, the CG movie presents complex scenario in a form that is easier to understand and interpret to the public.

4. Conclusions
Pedestrian behaviour such as speed, flow, density and evacuation time need advanced studied to help improving the operation and safety level of pedestrian at transport terminals in Malaysia. A lot of works need to be done since the above issue have many application and impact to the society. RTT in Malaysia is becoming one of the choice of transportation mode. Hence, the necessity to understand the specific behaviour of passengers in RTT is crucial. This proposed framework paper will work as a guide or reference for researcher to conduct more research on pedestrian behaviour at RTT particularly in Malaysia. In order to support the increasing demand in rail services, this understanding will become a reference information to the traffic engineer in designing walking infrastructure not only for RTT but including other places that attract crowd such as shopping mall, stadium, etc.

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