A State-of-the-Art of the Emergency Evacuation Capacity (EEC) Assessment for Rail Transit Terminal (RTT) in Malaysia

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Abstract Railway system has evolved as one of the important modes of public transport and a favorite alternative method in resolving traffic congestion problem especially in urban areas like Kuala Lumpur, Malaysia. It is reported that rail passenger volume is increasing yearly which caused more attention are made to the safety and emergency evacuation plan, especially if unexpected accident or emergency occurs in Rail Transit Terminal (RTT). The failure of emergency evacuation in any public buildings such as RTT may lead to a large scale of injuries or death. Despite the fact that a lot of safety measures and emergency response plans are taken as an initial preparation to face any emergencies that may occur in RTT, the emergency evacuation capacity (EEC) assessment studies are necessary to assess the effectiveness of the system implementation. Before employing any methods of assessment, it is crucial to scrutinize the factors that affect the effectiveness of EEC for any rail transit terminal. To the best of our knowledge, there are limited studies conducted on the EEC assessment at RTT in Malaysia. By virtue of this, we expect this paper provides a comprehensive review of a state-of-the-art of the emergency evacuation capacity (EEC) assessment for rail transit terminal in Malaysia by focusing on two important elements: (1) factors affected the effectiveness of evacuation capacity; and (2) methods of evacuation capacity assessment.

Keywords Emergency evacuation capacity · Rail transit terminal · Evacuees' behavior · Evacuation facilities · Methods of emergency evacuation capacity assessment

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1 Introduction

Initially, in the late 19th century, a railway system in Malaysia was developed to speed up the transportation of tin from the mining areas to ports along the coast. However, with time, the introduction of new technologies in rail transportation had drawn the interest of the public at large to use it as one of the means of transportation since it offers a more reliable and punctual services [9]. Undoubtedly, the rail transport system has played a vital role as a preferred mode of public transport as it promises timely service, and at the same time could reduce traffic congestion. From open literature, it can be concluded that rail traffic users are keep on increasing worldwide. For example, in Malaysia, the busiest and largest rail transit terminal (RTT), namely KL Sentral Station receives about 180,000 passengers per day on average which exceeds its maximum initial design capacity of 100,000 daily passengers [8]. Other example like Cheng and Yang [3], in their study, discovered that Beijing's the capital of China recorded has 34 thousand commuters per hour during the peak hour. With this current trend of high number of users every day, the terminal is becoming a crowded transport terminal, which exposes users to calamity. According to Chen et al. [2], a crowded transportation terminal with a very high density of user risk a larger number of accidents during its operation. This phenomenon indirectly making issues becoming the main concern.

Improper an evacuation response plan at RTT in servicing a massive passenger flows could lead to cost an inestimable loss from the accident and cause serious consequences. In any emergency evacuation process, it is the utmost important to ensure all passengers involved can reach an evacuation area safely by the ability to choose a short and safe evacuation routes [2]. Evacuating people quickly and safely from the accident area can reduce casualty and economic losses. Therefore, one of the proper measurements that can be done immediately is by estimating emergency evacuation capacity (EEC) in RTT including in Malaysia.

According to Cheng and Yang et al. [3], the evacuation capacity is described as the fundamental in analyzing overall evacuation time and designing emergency evacuation plan of the terminal. Whilst, Wu et al. [16] relates the evacuation capacity to the number of maximum passengers successfully evacuated to the safe zone over a period of time. Although the railway network has evolved tremendously in Malaysia and the awareness of emergency evacuation in rail transit terminal is crucial in regards to emergency preparedness of the passenger, but not many case studies related to evacuation capacity has been carried out in Malaysia. Nordin et al. [9] have reviewed rail services and safety in Malaysia and discussed three case studies specifically on train accidents happened in Malaysia. Meanwhile, a few drill exercises have been carried out by the respective authorities, for instance, Achiaram [1] and Zolkepli [22] reported two different drill exercises have been carried out in KL Sentral Station, Malaysia. However, none of the above touch on the evacuation capacity.

This paper shall review related factors which affect the effectiveness of evacuation capacity and the state-of-the-art of methods utilized in the assessment of the

emergency evacuation capacity (EEC) at rail transit terminal (RTT). In this contribution, we focusing this review only related to rail transit terminal with massive pedestrian scale, without considering other public buildings like busy bus stations and also airport terminal system.

2 Related Factors in Evacuation Capacity Assessment

A lot of research studies have attempted to determine several factors that affect the assessment of the emergency evacuation capacity. Some of the related studies focus on walking behaviors of the pedestrian in stations [6, 13] and some evaluate the effectiveness of evacuation facilities of the terminal [17]. Cheng and Yang [3] indicated that passengers requiring timely evacuation during an emergency are passengers on the arriving train on the waiting platform and station hall, including working personnel during the emergency evacuation process.

In research presented by Wang [15], there are three factors affecting emergency evacuation capacity of a subway, which are the subway operation early warning ability, emergency preparedness ability of subway operation and subway emergency response ability. However, it is different to Cheng and Yang [3] who believed the key factors that affect the emergency evacuation capacity are characteristic of evacuees, evacuation facility, and evacuation organization and management.

In this paper, the review is conducted by focusing on the two critical factors in evacuation capacity assessment, namely evacuee's behavior and evacuation facilities. According to Zanariah et al. [18], detailed consideration of pedestrian behavior in RTT in Malaysia is lacking. There is a necessity to integrate transportation engineering and pedestrian behavior in order to quantify the performance of evacuation strategies in RTT. Meanwhile, the estimation of evacuation capacity (EC) of evacuation facilities in RTT is crucial since it is a fundamental in calculating an overall evacuation time and designing emergency evacuation plan. These two major factors are selected to be reviewed in this paper as these factors affected the most on the evacuation capacity assessment of RTT. Besides give input to the RTT designers in future, this review shall educate the readers to increase the awareness of effective emergency evacuation in RTT among the passengers.

2.1 Evacuee's Behavior

The understanding of evacuees' behavior is useful due to a variety of complex collective behavior emerging from individual interaction in a crowd [11]. This understanding offers significant application in managing crowd safety efficiently. Whilst, according to Dubroca et al. [4], pedestrian or evacuee's behavior can change from one element to another, hence, thoroughly understand the evacuees'

behavior inevitably become crucial in evaluation of emergency evacuation capacity (EEC). The evacuee's behavior is not dependent on country. This statement is supported by a research conducted by Galea et al. [5] in their study of investigating the impact of culture on evacuation behavior.

According to Chen et al. [2] in their study on modelling and analysis of emergency evacuation from Metro Stations, besides individual physiological and psychological characteristics, the evacuee's behavior also affected by density of crowd and their emotional state. Meanwhile, Cheng and Yang [3] concluded in their study that factors affected the evacuee's characteristic in EEC assessment are the walking speed and density. A high density is a reason that leads to the reduction of the evacuation speed and subsequently, cause a serious congestion during evacuation. A case study conducted by Cheng and Yang [3] in Shuangjing station, Beijing shows that, age, gender, action ability and unfamiliar evacuees also affected the effectiveness of EEC assessment.

Through the reviews conducted, the surrounding conditions and circumstances affecting the evacuee's behavior during the evacuation. For example, coupled with the researches evidence by Wu et al. [16] and Vanumu et al. [14], the exit selection behavior of occupants during emergency evacuation depends on the density around the exits which mean when the density is high enough, occupants tend to select a more distant exit in order to exit quicker. It can be concluded that the crowd density has a great impact on the evacuation process. As the density increases, the space of the evacuees decreases as well as the average of the walking speed during the evacuation process. Vanumu et al. [14] mentioned that evacuation characteristics of pedestrians can be captured in two different conditions which are the normal and emergency condition. Just as Cheng and Yang [3] stated in their study, because of the nature to survive existed in the evacuees, the walking speed of evacuees during emergency evacuation is higher than normal walking speed. However, finding by Zhao et al. [19] is contradicted to Cheng and Yang [3]. In Zhao et al. [19], the average walking speed in normal condition is higher than the emergency condition. Which implies that during emergencies, pedestrians can slow the free velocity to zero in a shorter secure response time.

Another study by Zhao et al. [21] has proposed to adopt an evacuation leader to lead the evacuee's and make the crowd evacuation in RTT more efficient. The researchers agreed that the evacuee's behavior during emergency situation affect the evacuation efficiency. By introducing the leader, the emergency evacuation process will be more manageable as the well-trained escape leaders could guide the passengers to the safest place. Therefore, a proper guidance to the evacuees during emergency situation plays a significant role to ensure the maximum capacity of evacuees can be escaped from an area that contains an imminent threat or an ongoing threat or a hazard. By having an efficient evacuation, casualty, injury, and loss can be reduced [16].

2.2 Evacuation Facilities

Besides the aesthetically pleasing attraction in RTT design, the effective design of the pedestrian facilities must be undertaken the characteristic of the emergency evacuation capacity to achieve an optimal evacuation performance. The train terminal should be an evacuation friendly place since passengers gather for boarding or alight at these places. Most of the RTT facilities are designed by rule of thumb, especially stairways, largely governed by ideal pedestrian behavior [12].

The facilities related to the EEC in RTT mainly include staircases, escalators, corridors, connecting corridors, and automatic fare gate. Difference facilities' capacity will affect the evacuation speed, thus affecting the overall evacuation efficiency [16]. Wu et al. [16] mentioned RTT can be regarded as an evacuation network, and in the consideration of the optimal paths to evacuate all evacuees to the safety areas in the shortest period of time, the facilities of emergency evacuation network should be constructed first.

Cheng and Yang [3] has deliberated on the possibility the evacuees used the major evacuation facilities in order to reach the evacuation area safely, like passage, stair, escalator, turnstile and exit and affect the most on the emergency evacuation efficiency. They concluded that the EEC of the station is affected by three main factors which are spatial arrangement of facilities, the matching degree of critical evacuation facility and the evacuation routes.

Cheng and Yang [3] had defined that the EEC of the station is the sum of emergency evacuation capacity of total independent evacuation routes through the evacuation facilities inside the station, in which the maximum time passenger flow that passing through the evacuation bottleneck section of evacuation corridor is within 6 min. Whilst, Wu et al. [16] defined EEC as the maximum number of evacuees that can be evacuated to safer areas in a unit time, typically 1 min, under ideal conditions. In brief, the evacuation time in normal condition without considering damage facilities, blocked and design capacity of the facilities is faster than the evacuation time through the bottleneck due to the facilities distraction. The EEC can be improved with the implementation of high technology equipment or evacuation facilities installed in the RTT.

It is interesting to note that Patra et al. [10], in their study on evaluation of pedestrian flow characteristics across different facilities inside a railway station discovered that the speed of pedestrian on the stairway varies from those on the passageway. For example, pedestrian on the passageway, be it single or in a group prone to follow the person in front constantly without changing lanes and in this scenario, overtaking is rarely taking place. On the contrary, pedestrian on the stairway tend to change their directions where there is available space in order to reach the far end of the facility continuously.

In essence, the design and planning of the evacuation facilities give a significant impact to the emergency evacuation capacity of RTT and if it is not well designed, are very likely to become bottleneck for evacuation and will cause serious consequences due to the lack of evacuation performance [3, 7].

In Malaysia, one of the requirements to get building approval is the designer needs to submit Fire Safety Design Philosophy (FSDP) report to BOMBA (the private organization that provides fire protection services to the level of enforcement, whether municipal, subdivision, district, state or national) and the design must comply with the Fire Service Act (FSA). Over and above that, there are the standard guidelines for the design of pedestrian facilities in Malaysia in connection with emergency evacuation: (1) Uniform Building By-Laws (UBBL) and (2) MS 1183: 2015.

Therefore, when considering the evacuation routes design of the RTT, designers may consider the actual demand reflected from the building configuration. Then the effectiveness of the design can be improved significantly.

3 Methods of Emergency Evacuation Capacity Assessment

Over the years, researchers have adopted various methods to study the problem which may arise during the emergency evacuation process which can generally be classified into field observation and computer simulation. This paper provides an exhaustive review of the method of assessment on emergency evacuation capacity conducted by researchers all over the world.

3.1 Field Observation

Field observations are usually conducted to prove the accuracy of study by other methods. It may be used in a variety way from a different samples or locations for the accuracy measurement of the concept.

Chen et al. [2] has carried out a field study at the Xizhimen metro station in Beijing, China to validate the effectiveness of the mathematical analysis which has been introduced in their study inclusive China CDM, NFPA 130, control volume, and M/G/c/c models and a multi agent-based simulation approach. To validate the model and algorithm, Wu et al. [16] conducted a simulation of evacuation process at Fuxingmen Station of Beijing Subway by taking the capacity estimation as an example, in order to get the optimal routes and proper estimation.

Whilst nevertheless, some researchers conducted field observation to obtain the empirical data for the input of the computer modelling and simulation purposes. Wang [15] has investigating 18 stations in Beijing to get the set up of three layer of neural network structure. Vanumu et al. [14] conducted 17 field observation experiments in two different places with different group of pedestrians and the data collected from the experiments is used to analyze the pedestrian evacuation

characteristics and the data was extracted using the MATLAB based tools for the purpose of model development.

Cheng and Yang [3] has conducted a video observation survey of Xizhimen station in Beijing, China to study on the evacuation speed on exit. Meanwhile Shuangjing station in Beijing, China was used as location of a case study to validate and verify the mathematical formulas of evacuation capacity assessment that Cheng and Yang [3] has developed.

Differ with Patra et al. [10], a field observation study has carried out in Secunderabad Railway station, India to analyze and compare with previous researcher result data on the effectiveness of an evacuation capacity in each evacuation facility.

3.2 *Modelling and Simulation*

The number of researches using modelling and simulation has proliferated rapidly in response to the emergency evacuation capacity assessment of the RTT.

Chen et al. [2] has introduced five methodologies to achieve an effective evacuation performance and each method has its own advantages in terms of design, management, and technical application. Table 1 summarizes the five methodologies introduced by Chen et al. [2].

An innovative approach was developed by Wu et al. [16] to estimate the EEC of the station by building a bi-level programming model of evacuee equilibrium which consider the travel time on walking facilities with various degree of congestion. Previously, Zheng et al. [20] has identified seven methodological approaches for crowd evacuation with one of it based on field experiment with animal and the other six are modelling approaches. However, Zheng et al. [20] agreed that all these

Table 1 Methodologies to achieve an effective evacuation performance [2]

Methodologies	Remarks
China CDM NFPA 130	i. Succinct methodologies that only take into account the most critical facilities and the most detrimental situations of evacuation and generally provide high and low levels of evacuation within the given evacuation time ii. The national design regulation, are two authentic criteria and effective quantitative methods to achieve evacuation requirements for planners and designers
Control volume M/G/c/c Multi agent-based model	i. Introduce the geometry and capacity of facilities, relationship between density and speed, and connections among evacuees and are able to reflect the waiting time, congestion extent, and evacuation bottlenecks through analyzing the efficiency of each evacuation route ii. Beneficial to evaluate the entire evacuation process, particularly when using the multiagent-based strategy to integrate more details for operational improvement and risk management during evacuation

Table 2 Advantages of approaches model [20]

Approaches model		Advantages
Microscopic model	Cellular automata	i. discrete in space, time and state variables ii. Impeccable for large-scale computer simulations iii. have strong expressive power to represent many collective behaviors
	Lattice gas	
	Social force	i. successfully simulate the most typical phenomena observed in pedestrian dynamics and achieve very realistic simulation results ii. can take high-pressure characteristic of pedestrian in panic situation iii. can reproduce some observed behaviors of pedestrian flow such as "faster-is-slower", arching and clogging due to the interactions among pedestrians
	Agent-based (ABM)	i. beneficial from the advancement of cognitive science ii. captures emergent phenomena iii. provides a natural description of a system and flexible
Macroscopic model	Fluid-dynamic	i. use the analogy of fluid dynamics to describe the crowd flow in the form of partial differential equations ii. usually applied to simulate the jamming situations in which the crowd flow is dense
	Game theoretic	i. imitate the evacuee's behavior which strongly depends on the other pedestrian in the crowd ii. ideally suited to analyze of human reasoning and strategic thinking in an evacuation

approaches obey some defined sets of rules under certain restricted conditions, which have inherent advantages and disadvantages. Advantages of all the approaches models in EEC assessment as described by Zheng et al. [20] are summarized in Table 2.

4 Conclusions

This paper reviewed the emergency evacuation capacity (EEC) assessment for rail transit terminal (RTT) in Malaysia by focusing on two important elements during emergency: (1) the factors affected the effectiveness of evacuation capacity; and (2) methods of evacuation capacity assessment.

Although the EEC assessment is essential to create an effective emergency evacuation plan for public buildings with the highest pedestrian density such as RTT, very limited studies have been conducted on the EEC assessment of RTT in Malaysia. Most of the researcher conceded that the factor of evacuee's behavior and evacuation facilities give great impact in the efficiency of the EEC assessment of RTT and a lot of improvement can be made to empower the current standards and plan.

The selection of appropriate assessment method is very imperative to obtain most useful and relevant data. For the emergency evacuation assessment, this paper reviewed the field observation method and modelling and simulation method used by other researchers around the world. More studies shall be conducted to assess the effectiveness of existing emergency evacuation systems of RTT in Malaysia and improve the visible shortcomings.

On the other hand, in current modern day living, technology has improved the social lives of many people with almost 99% of adults own electronic devices. This scenario creates secondary activities of pedestrian during locomotion in RTT which affect the overall pedestrians' movement. Hence, the variation of pedestrian activities while walking need to be considered in future researches since it gives a significant impact on evacuation capacity assessment.

This assessment is very important to give the right input to the experts involved in designing RTT and the related authority that provide the best early emergency evacuation plan for the RTT in Malaysia.

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