

EVALUATING PASSENGER EVACUATION STRATEGIES IN A MASS RAPID TRANSIT STATION IN THAILAND

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ABSTRACT: Rail transit plays a significant role to serve major commuters in many large and congested cities. In Bangkok metropolitan region in Thailand, several mass rapid transit (MRT) lines and stations are currently being constructed and operated. To perform efficient safety and operational performances, the analysis of pedestrian traffic flow within transit stations under normal and emergency circumstances is a crucial step for planning, design, and operations of station facilities. This study focuses on applying the pedestrian traffic simulation to model the characteristics of passengers and then evaluate passenger evacuation strategies in mass rapid transit stations. The pedestrian's walking behavior and characteristics were observed. Three evacuation strategies were examined including (a) Evacuation to Ground Level; (b) Evacuation to Train; and (c) Evacuation to Track Level. The evacuation times under a given number of evacuate occupants were evaluated, and the bottleneck of evacuation strategies was identified. A case study of Tao Poon mass rapid transit station was carried out. The results showed that the pedestrian traffic simulation technique provides great flexibility in modeling different scenarios in emergency situations and evaluating the dynamic nature of pedestrian flow characteristics. It is also useful to planners, designers, and operators of rail transit systems in practice.

Keywords: Rail transport, Evacuation, Safety, Pedestrian simulation, Station design

1. INTRODUCTION

Rail transit plays a significant role to serve commuters in many large and congested cities. In Bangkok metropolitan region in Thailand, two mass rapid transit (MRT) lines are now being operated: Blue Line and Purple Line; and ten more lines are being planned and constructed. According to the ridership data, the growth of passenger ridership is about 6% each year. [1] With the increasing number of MRT lines and stations along with the estimated growth of passengers, evaluating the performance of station facilities and emergency evacuation strategies in MRT stations are needed.

Many international standard codes defined minimum evacuation requirements and calculation procedures, such as National Fire Protection Association 130 (NFPA 130), China CDM and Japanese Safety Evacuation. [2-4] For instance, NFPA 130, which is also being implemented by Mass Rapid Transit Authority of Thailand (MRTA), specified two criteria for station evacuation efficacy. The first is referred to the time required to evacuate the platform within 4 minutes or less; and the second gives the time frame to evacuate the whole station and to reach a point of safety within 6 minutes or less. However, such standard codes

provide macro-scale equations, which rely on static hand calculation and overlook the behavior of passengers and interaction among them.

To overcome the limitation, a microscale study on evacuation using microscopic traffic simulation models is proposed. It is capable to simulate the dynamic environment of evacuation situations and to provide visible results through 3-D animations. More importantly, the use of simulation models in emergency situations provides great flexibility in modeling and evaluating evacuation strategies.

This research aims to evaluate the effectiveness of evacuation strategies for passengers within mass rapid transit stations in Thailand. The focus of this research is on applying a microscopic pedestrian traffic simulation model to the evaluation of evacuation plans.

2. LITERATURE REVIEW

Research studies on emergency evacuation of passengers in a metro station mainly focused on the development of sound and applicable evaluation methods for emergency evacuation. Two principal approaches were found in the literature.

First, the traditional approach applies macroscopic equations of traffic flow theory [2-3]. The macro approach uses the basic concept of time

and space to describe the evacuation process and estimate its performance. However, it overlooked the interactions among pedestrians and between pedestrians and facilities [4].

Second, the groundbreaking approach applies a microscopic pedestrian traffic simulation for pedestrian flow evaluation. Since last decade, the number of research studies on pedestrian evacuation using microscopic pedestrian traffic simulation has increased greatly. The micro approach accounts for the detailed representation of space, individual person and personal capabilities and characteristics; as a result, it provides more reasonable and realistic. [5]

Using a micro approach, many research studies examined how different evacuation policies and passenger characteristics affect the performances of evacuation. For the evacuation policies, several aspects were examined, such as the effect of one-way and two-way pedestrian traffic flows, the effect of lane-line segregation policy, the effect of escalator and staircases, and the effect of exit placement and exit route availability. For passenger characteristics, the effect of different age groups of passengers, the occupant loads, and the occupant's speed. [6] Among these studies, the evacuation performances were measured using different indicators including length of evacuation route, time of evacuation process, and density of pedestrian flow. [7-9]

Moreover, recent studies have combined both anticipation behavior and the route choice behavior of individuals to precisely replicate the interaction of passengers and evacuation decision of passengers. [10]

3. MODEL DEVELOPMENT

3.1 Study Area

The study selected Tao Poon mass rapid transit station in Bangkok as a case study. Tao Poon MRT station is an aboveground interchange station connecting between 2 train lines (Blue Line and Purple Line). It consists of 4 levels.

- Ground level with four entrances/exits (Entrances/Exits A to D);
- Concourse level with six emergency exits (E1-E6) and two staircases (S1-S2);
- Blue-line platform (with six emergency exits and two staircases); and
- Purple-line platform (with two emergency exits and two staircases).

Details on station facilities of each level are shown in Fig. 1 to Fig. 4.

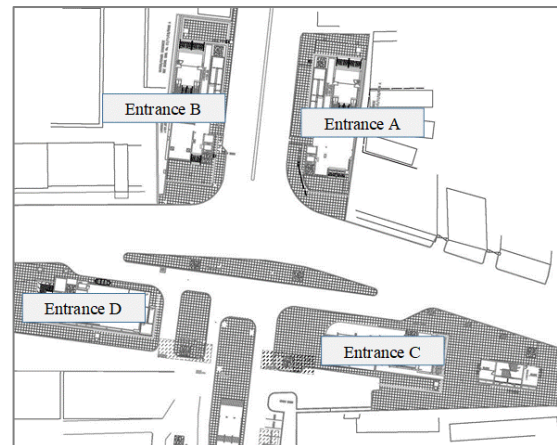


Fig. 1 Locations of main entrances/exits on Ground Level of Tao Poon MRT station

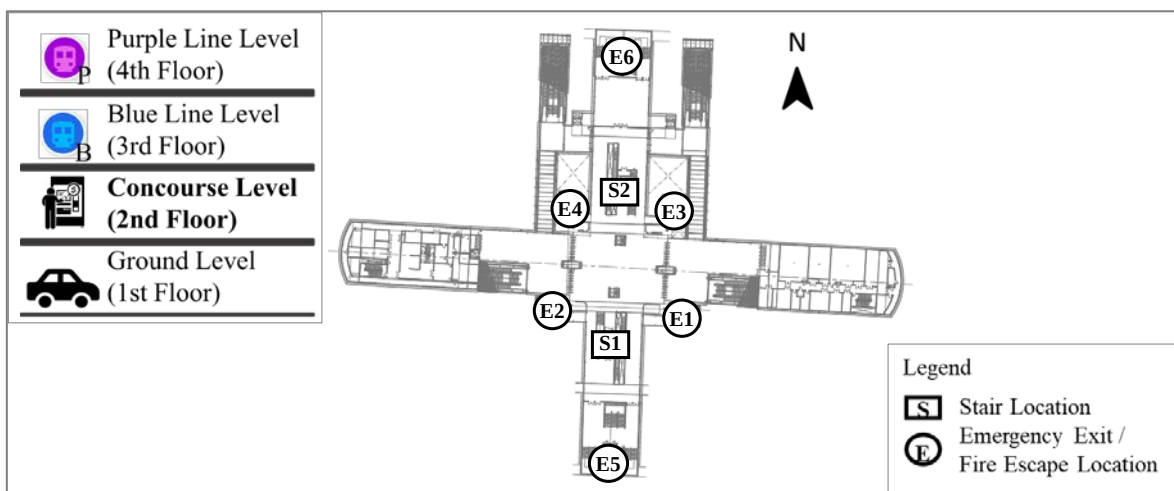


Fig. 2 Locations of emergency exits and staircases on Concourse Level

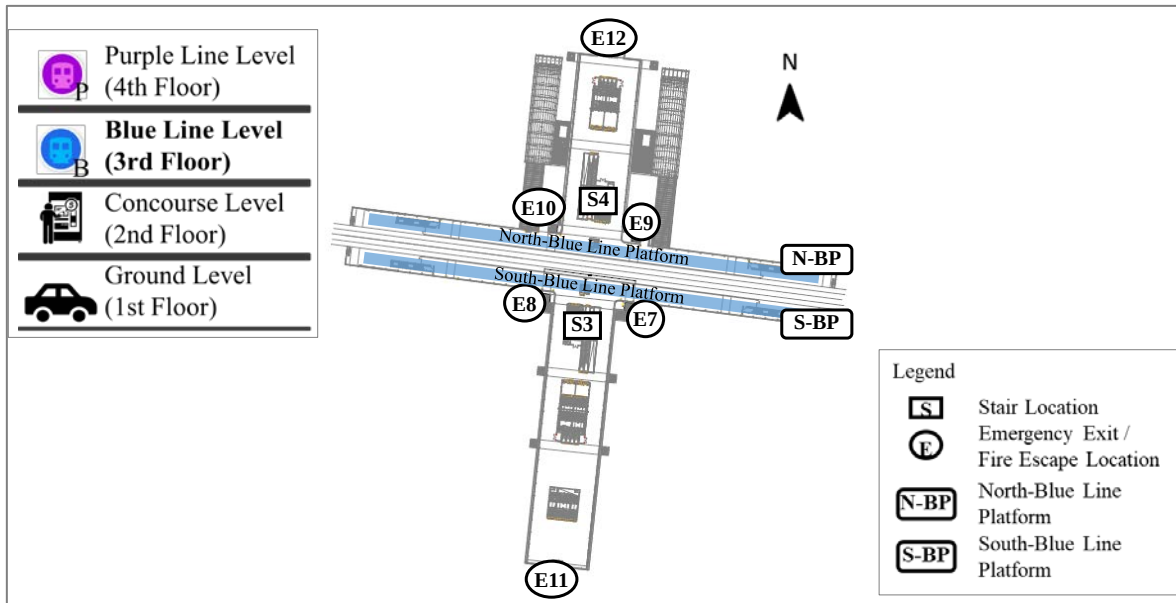


Fig. 3 Locations of emergency exits and staircases on Blue-line platform Level

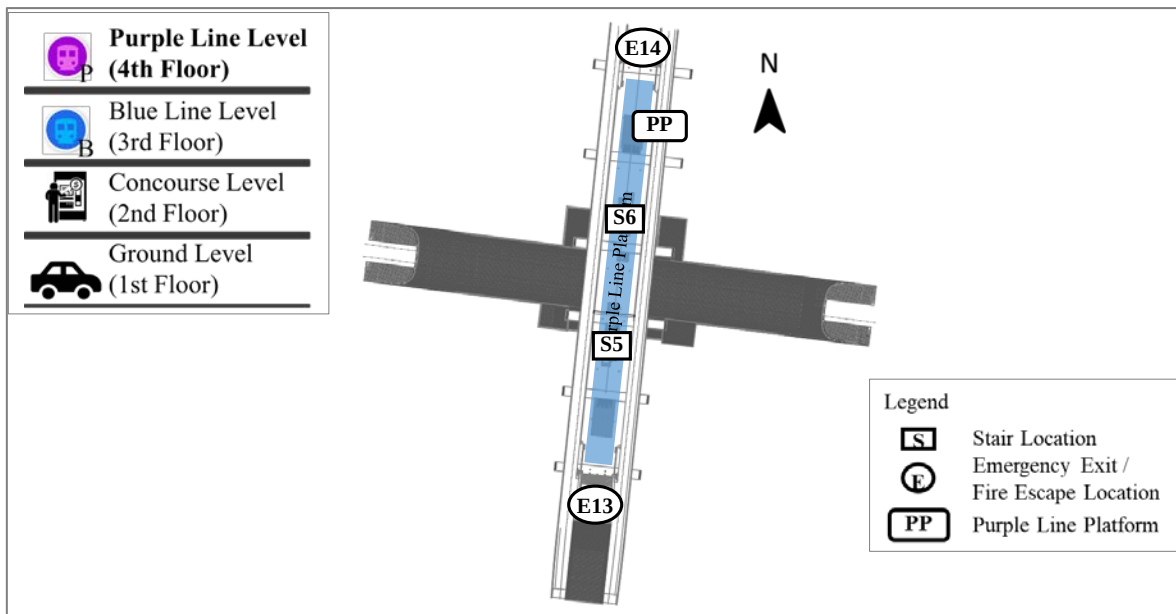


Fig. 4 Locations of emergency exits and staircases on Purple-line platform Level

3.2 Data Collection

Data collection is a necessary step to build the fine simulation model. The more data inputs, the more accuracy and realistic the model is. Data needed for building the models include

3.2.1 Occupant Load

One of the key inputs in developing the evacuation model is the occupant load. In this study, hourly arrival and departure rates were collected at Tao Poon MRT station during October to December in 2016 as shown in Fig. 5.

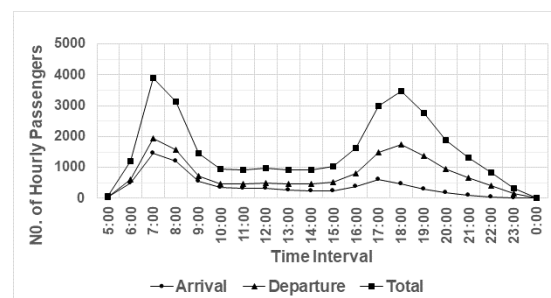


Fig. 5 Hourly passenger volume

The peak-hour passenger arrival and departure rates were converted to occupant loads during peak period. The total number of occupants to be evacuated in the model was 1,010 passengers per hour. They were 50 occupants from the Concourse level, 483 occupants from Blue-Line platform, 322 occupants from Purple-line platform, 105 occupants boarding Blue-Line trains, and 50 occupants boarding Purple-Line trains.

3.1.2 Walking Speed

The walking speed of passengers is another important parameter affecting the performance of evacuation strategies. Walking speed on different facilities: concourse and staircase were measured from close-circuit television (CCTV) installed in the station. Table 1 presents the average walking speed by age group in this study.

Table 1 Average walking speed by age group

Age Group	Average walking speed (m/s)		
	Concourse	Staircase (upward)	Staircase (downward)
Children	1.36	0.61	0.75
Adult	1.45	0.82	1.15
Elderly	1.06	0.55	0.81

4. MODEL RESULTS

Evacuation situations of the case study were developed using a microscopic pedestrian traffic

simulation program. Fig. 6 shows the 3D simulation model of the Tao Poon MRT station.

Three emergency evacuation strategies are proposed according to the evacuation action plans by Mass Rapid Transit Authority of Thailand.

- Strategy A: “Evacuation to Ground Level” strategy is applied when fire is present.
- Strategy B: “Evacuation to Train” strategy is applied when entrances and exits are not accessible or not considered as a safe area.
- Strategy C: “Evacuation to Track Level” strategy is applied to the same situations as Strategy B, but trains are unable to operate by any means.

In this study, the evacuation time and pedestrian density of three strategies were measured, and their level-of-service (LOS) were evaluated based on Highway Capacity Manual (HCM) [11] criteria shown in Table 2.

Table 2 Level-of-Service (LOS) criteria

Level of Service (LOS)	Pedestrian density (peds/sq.m.)	Color defined in the model
LOS A	≤ 0.179	Blue
LOS B	0.180 – 0.269	Cyan
LOS C	0.270 – 0.454	Green
LOS D	0.455 – 0.713	Yellow
LOS E	0.714 – 1.333	Orange
LOS F	≥ 1.334	Red

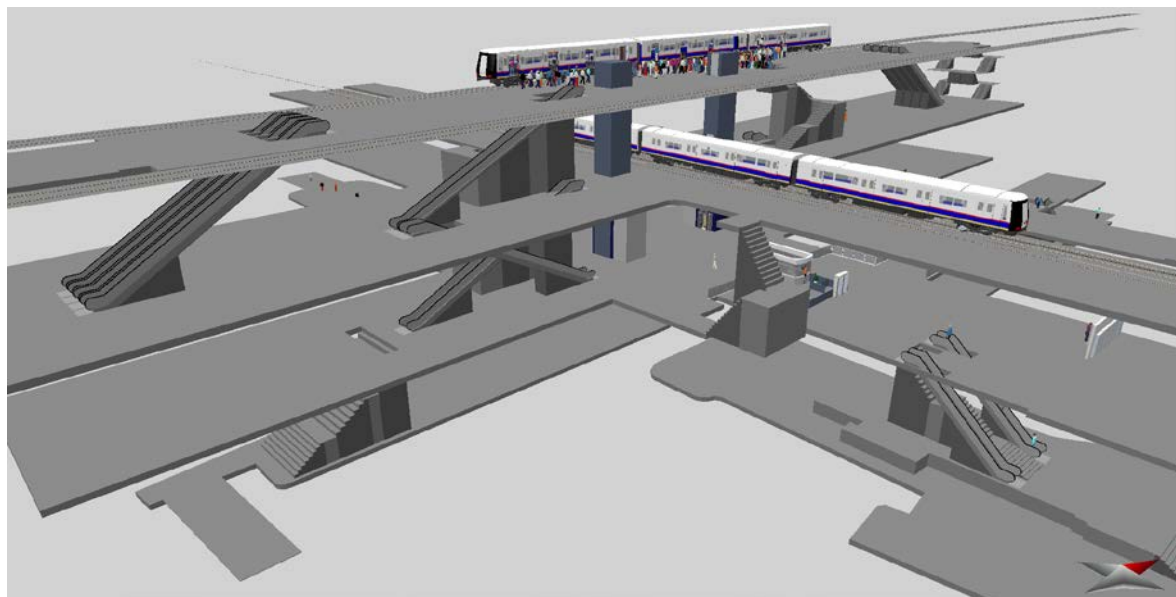


Fig. 6 3D simulation model of Tao Poon MRT station

4.1 Strategy A: Evacuation to Ground Level

Occupants from all floors were evacuated to the Ground Level through 4 entrances (Entrances A-D). There are in total 6 designated evacuation routes (Route A1 to A6): two from 2nd floor, two from 3rd floor, and two from 4th floor, as shown in Fig. 7.

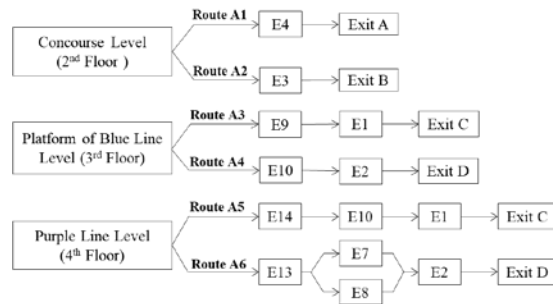


Fig. 7 Evacuation routes to ground level

This strategy evacuates occupants to the ground level or where entrances/exits are located. The results revealed that the evacuation time of 6 different evacuation routes meets the NFPA 130 thresholds. Routes A5 and A6, which are the longest evacuation route from 4th floor (Purple-Line platform), have the evacuation time less than the NFPA. Routes A3 and A4, which are the evacuation routes from Blue-line platform, have the evacuation

time less than 2 minutes. Routes A1 and A2, which are evacuation routes from Concourse Level, are not as crowded as those from the platform levels. Their evacuation times are less than 1 minute. Evacuation time and evacuation rate of each route are shown in Table 3.

Table 3 Model results for strategy A (evacuation to ground level)

Route	Evacuation time (mins)	Evacuation rate (peds/min)
Route A1	0.87	11
Route A2	0.72	11
Route A3	1.83	82
Route A4	1.62	94
Route A5	2.85	57
Route A6	2.95	58

It should be noted that in the model the evacuation preparation time is excluded. If 1-minute preparation time is added, the total evacuation time will still meet the NFPA standard.

The heat maps presenting pedestrian density on each level for evacuation strategy A (evacuation to the ground) are shown in Fig. 8. The red color represents the highest density, while the blue color represents the lowest density.

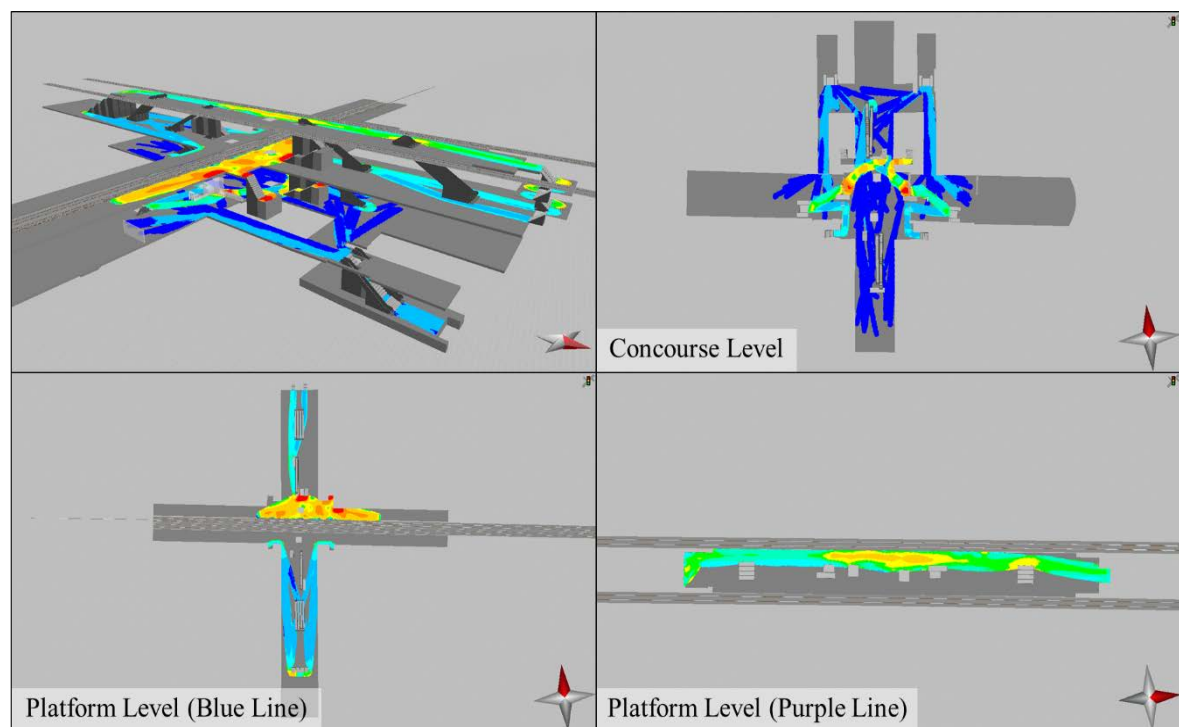


Fig. 8 Pedestrian density associated with strategy A (evacuation to ground level)

4.2 Strategy B: Evacuation to Train

This evacuation strategy is to evacuate all occupants in the station to the nearest platforms and evacuated them by trains. This strategy consists of 9 designated evacuation routes (Routes B1 to B9): 6 routes from 2nd floor (Concourse Level), 2 routes from 3rd floor (Blue-line platform) and 1 route from 4th floor (Purple-line platform) as shown in Fig. 9.

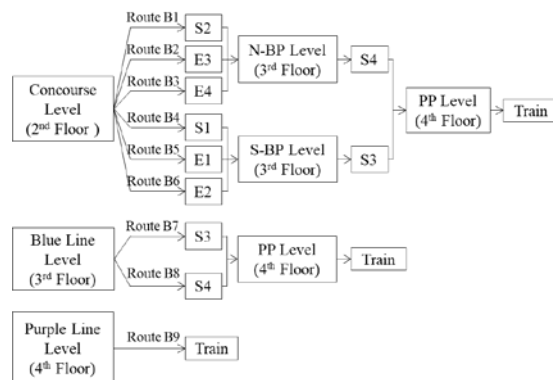


Fig. 9 Evacuation routes to train

In this evacuation strategy, all occupants are evacuated through trains. Table 4 shows that the longest evacuation time is below 6-minute threshold. However, if the preparation stage takes longer than 1 minute, this strategy may fail. Hence, more trains should be allocated in this evacuation situation. The pedestrian density maps associated with evacuation strategy B (evacuation to train) are shown in Fig. 10.

Table 4 Model results for strategy B (evacuation to train)

Route	Evacuation time (mins)	Evacuation rate (peds/min)
Route B1	3.6	1
Route B2	3.7	2
Route B3	4.5	1
Route B4	4.3	1
Route B5	4.3	1
Route B6	4.4	2
Route B7	4.0	65
Route B8	3.9	87
Route B9	2.1	154

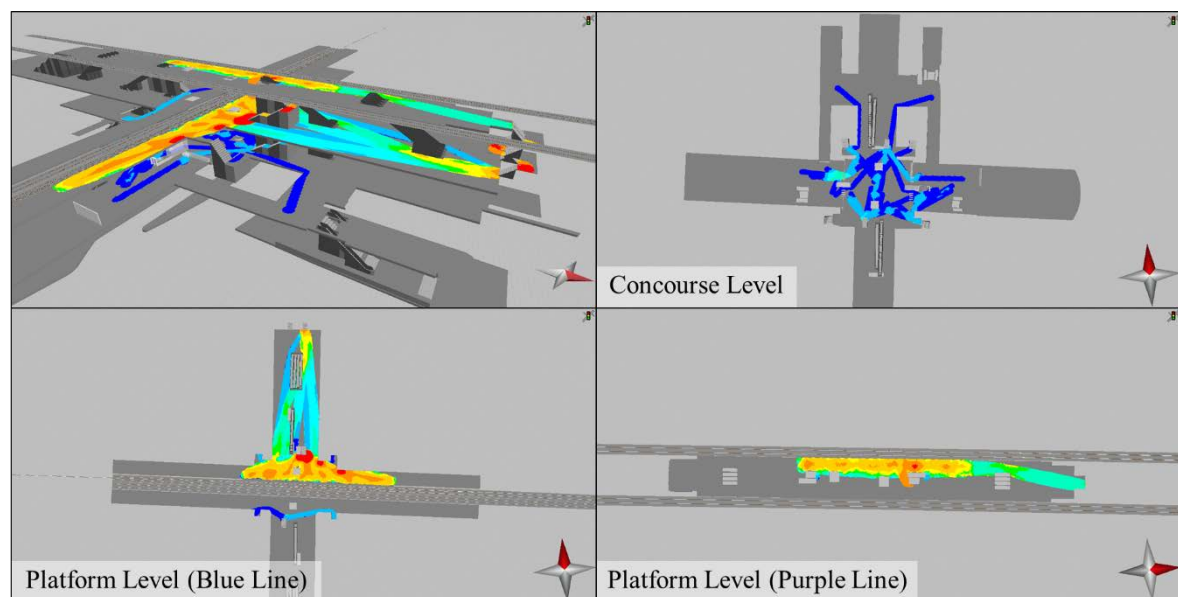


Fig. 10 Pedestrian density associated with strategy B (evacuation to train)

4.3 Strategy C: Evacuation to Track Level

This evacuation strategy evacuates occupants to railway tracks, which are out of operation. It should be noted that to deploy this strategy, the electrical system needs to be cut off for the safety reason. This

strategy consists of 9 designated evacuation routes (Routes C1 to C9) as shown in Fig. 11.

Evacuation to Track Level strategy can be deployed when the ground level outside the station is unsafe, or when the trains are not available to help evacuate. The results show that evacuation time of this strategy are less than 3 minutes including

preparation time. This is because occupants can evacuate immediately when an emergency occurs.

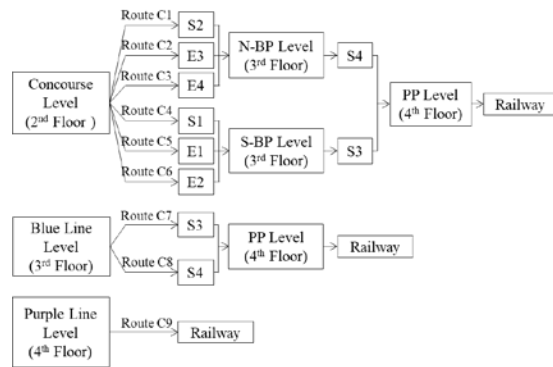


Fig. 11 Evacuation to the track level strategy

When deploying this strategy, safety concern is needed. There should be trained staff helping navigate occupants to the safe areas, and no train must be operated. The results showed that the evacuation time of this strategy is low. However, it does not include the preparation stage, which may

be longer than strategy B and C. The evacuation time and evacuation rate for each route are shown in Table 5.

Table 5 Model results for strategy C (evacuation to track level)

Route	Evacuation time (mins)	Evacuation rate (peds/min)
Route C1	1.8	4
Route C2	1.8	5
Route C3	1.7	2
Route C4	1.8	2
Route C5	1.9	2
Route C6	1.8	4
Route C7	1.8	196
Route C8	1.6	211
Route C9	1.0	337

The pedestrian density maps for strategy C (evacuation to track level) are shown in Fig. 13.

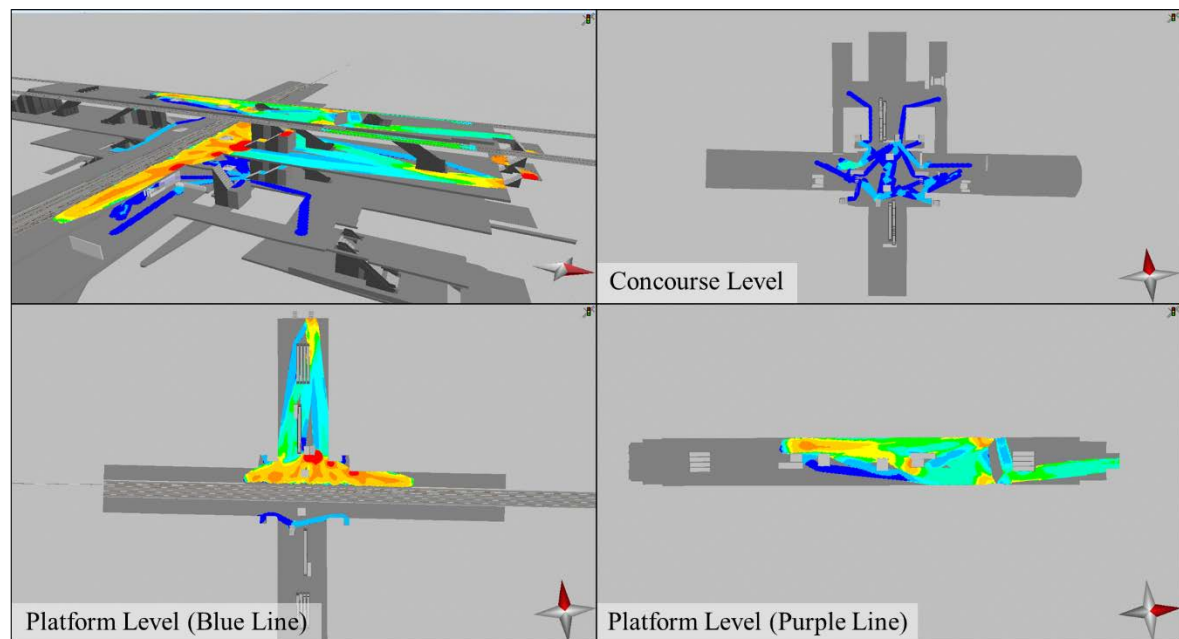


Fig. 13 Pedestrian density associated with evacuation to track level strategy

5. CONCLUSIONS

This research developed the microscopic pedestrian traffic simulation models to evaluate the effectiveness of passenger evacuation strategies within a mass rapid transit station in Thailand. Three evacuation strategies were tested including (a) Evacuation to Ground Level; (b) Evacuation to

Train, and (c) Evacuation to Track Level. A number of input parameters are used in the models. They are the number of occupants, the locations of station facilities (e.g. stairways, escalators), evacuation route availability, and the passenger characteristics (e.g. walking speed by age group.)

Evacuation strategies were evaluated in terms of the evacuation time, evacuation rate and pedestrian

density. The results showed that all three evacuation strategies meet the requirement of NFPA evacuation time. In other word, the station design complied with the NFPA standard (evacuation time from platform is below the 4-min threshold, and evacuation time to point of safety is below the 6-min threshold).

This research emphasizes the capability of a microscopic traffic simulation in modeling dynamic environment of evacuation events and its flexibility in testing different evacuation routes and strategies. It allows planners, designers, and operators of rail transit systems to determine whether certain building designs meet the requirement of a standard.

For future research, more operational strategies should be taken into consideration in order to obtain the most effective evacuation strategies, such as the use of escalators, and types of exit gates. Moreover, the severity of emergency incidents should be included in the model to evaluate more comprehensive and realistic passenger evacuation strategies for a mass rapid transit station.

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