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Evacuation Hazards in Crowded Subway Stations

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ABSTRACT

Evacuation hazards of crowded subway stations in the Asia-Oceania region were studied in this presentation. Two examples in Hong Kong, with one being an interchange station and a deep underground station were used. The evacuation time was estimated by using hydraulic models. Different scenarios were assigned on off peak train time and rush hour. Different exit widths and blockage of some exit routes were assumed. Fire safety management is identified to be a key part in keeping evacuation time short.

1. INTRODUCTION

Underground subway system is the key transportation means in dense urban areas in the Asian-Oceania region. Subway stations are crowded with passengers waiting observed to squeeze into the carriages during rush hours (Lee, 2014; Cheung, 2014). As reported in Hong Kong (Lee, 2014), after following the change in maximum capacity from six passengers per meter square to four, the capacity is only 70% full at rush hour. However, the capacity can be over 90% of full loading as observed under emergency or suspension of operation due to whatever reasons (Chow et al., 2011). Subway stations become more crowded with an average weekday patronage of nearly 5.3 million passengers (Cheung, 2014).

Subway stations are mostly located in the basement or ground levels connecting the shopping mall, commercial or residential building in downtown areas. The occupancy density of passengers can be much higher than expected during special events (The Sun, 2016; Apple Daily, 2014) such as fireworks. Therefore, evacuation time in emergency situation will be prolonged. Putting in platform screen doors (Qu and Chow, 2012) as in Figure 1 made the evacuation more difficult. To have better understanding of the safety issue in the subway station, evacuation time in the emergency situation will be studied in this paper.

Two subway stations in Hong Kong, Station I and Station II are selected to study the evacuation hazard in crowded stations when a fire occurs. Station I is an interchange between two railway lines, being one of the most crowded stations with high occupancy density. Station II is the first station (Tam, 2014) in the local rail network to feature a special design - "Lift-only Entrances". This is a deep underground station which lies under 70 m of ground level and, the passengers have to be evacuated by lift. The occupancy density in Station II is built relatively much lower than Station I under normal conditions at the moment, though the subway stations were observed to be very crowded whenever there were delays on train services (Chow et al., 2011), such as signal failure.

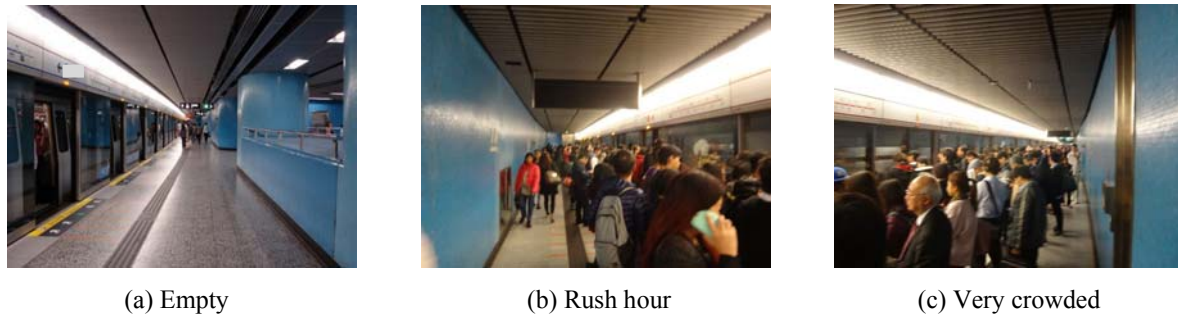


Figure 1: Crowded subway station with platform screen door

The evacuation of Station I and Station II are studied with three scenarios. Evacuation time in these three different scenarios will be considered by using hydraulic model calculation (Proulx, 2002; Nelson and Mowrer, 2002) in this presentation. Moreover, the special evacuation feature of “Lift-only Entrances” in Station II (Tam 2014) and the fire safety management strategies for emergency evacuation are also discussed.

2. LOCAL EVACUATION REQUIREMENTS

The Stations in railway systems are considered to have a primary purpose for passenger transit as specified in the local codes (Buildings Department, 2011; Fire Services Department, 2011, 2013). Occupants normally stay within a building for a period of time not longer than that necessary to wait for and board a departing vehicle/ship/aircraft or exit the terminal after arrival in an incoming vehicle/ship/aircraft.

The subway station population should be complied with local codes (Buildings Department, 2011; Fire Services Department, 2011,2013). The use classification for subway station is 5c (Transport facilities like passenger terminals, railway station), the occupancy factor is based on actual design and layout. Therefore, the layout of the two stations should follow requirement.

3. EVACUATION TIME

Considering the evacuation effectiveness from crowded station and also the evacuation time when the fire is occurred, the sequence of occupant response to fire should be known as reviewed with a time chart summarized before (Ng and Chow, 2006). The movement time is only a small part of the evacuation time as passengers are not expected to react effectively in emergency situation without appropriate notification by fire safety management (Proulx, 2002). The hydraulic model calculation can be applied to study egress time under different population densities.

The evacuation time with various passenger loadings can be calculated by hydraulic model (Nelson and Mowrer, 2002). The total evacuation time (TET) is calculated by human response time t_{resp} , travel time t_{tra} and waiting time t_{wait} :

$$TET = t_{resp} + t_{tra} + t_{wait} \quad (1)$$

Time delay (Proulx et al., 1996; Proulx and Fahy, 1997) to start evacuation is a concern. The waiting time (Ng and Chow, 2006) should be watched in the TET as some passenger may be jammed when all the passengers resist at the same time. It is impossible for passengers or small groups of passengers to move under high population density. The waiting time for passengers to escape will be extended. However, there is basically no systematic study with clinical psychology on human behavior in Hong Kong (Chow, 2012, 2015). Therefore, values adopted elsewhere have to be used.

The speed along the line of travel S (in m/s) can be expressed in terms of density D (in persons per unit area) and a constant k (Proulx, 2002):

$$S = k - akD \quad (2)$$

The actual flow rate F_c can be expressed in terms of specific flow rate F_s (in person/s/effective width) and effective width W_e (in m) as:

$$F_c = F_s W_e = SDW_e \quad (3)$$

The total egress time t_p can be expressed in terms of population P (in number of persons):

$$t_p = \frac{P}{F_c} \quad (4)$$

4. IDENTIFIED SCENARIOS TO STUDY

Three identified scenarios will be studied in each station:

Scenario 1: Assuming that the passengers are evenly distributed in different exits in emergency situation. All the possible factors such as passenger behaviors and conditions are eliminated.

Scenario 2: Passengers have higher tendency to evacuate at the larger exit. This is one of the passenger behaviors in emergency situation. Therefore, the passenger distribution depending on exit width will be studied.

Scenario 3: Assuming that some of the exit routes were blocked.

5. INTERCHANGE SUBWAY STATION : STATION I

The layout of the Station I is shown in Figure 2a. There are nine exits in the Station I and all the exits are located at the concourse. There are two major concourses which the locations are circled in Figure 2a. The door width and evacuation distance of different exits are measured in order to calculate the evacuation effectiveness. The concourse area in station I is 1800 m² (Buildings Department, 2011) and 5 passengers were observed for 1.53 m² in peak hour as in Figure 2b.

Associated key data in studying evacuation about the passenger density in concourse is 0.31m² per passenger. Total passenger in the Station I concourse will be 1800/ 0.31 or 5800 persons.

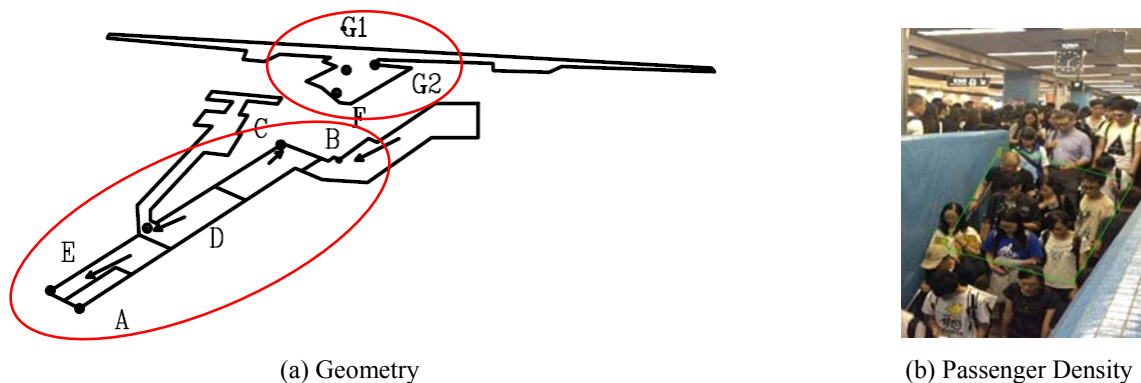
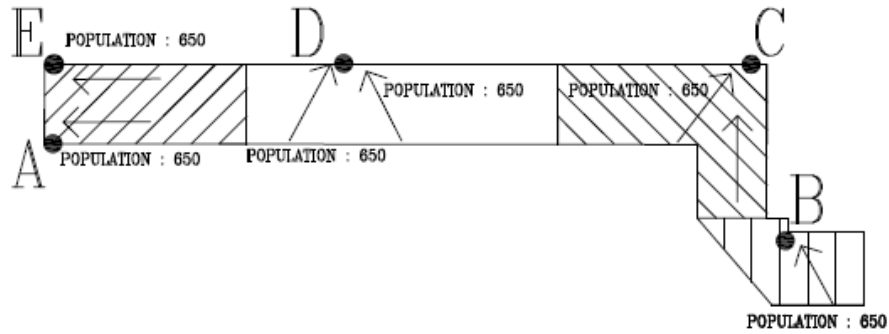
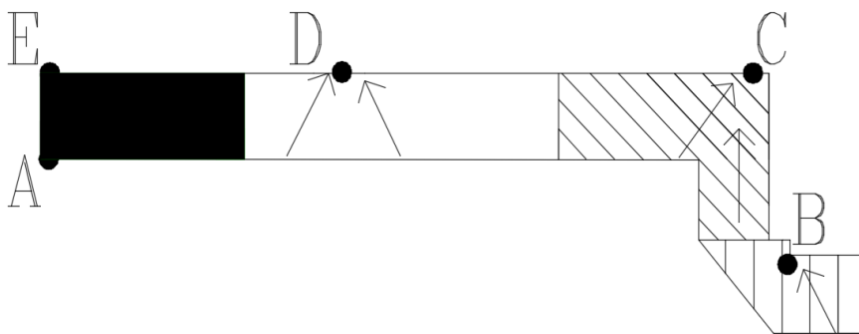


Figure 2: Station I



(a) Concourse for scenarios 1 and 2



(b) Concourse for scenario 3

Figure 3: Passenger flow in Station I

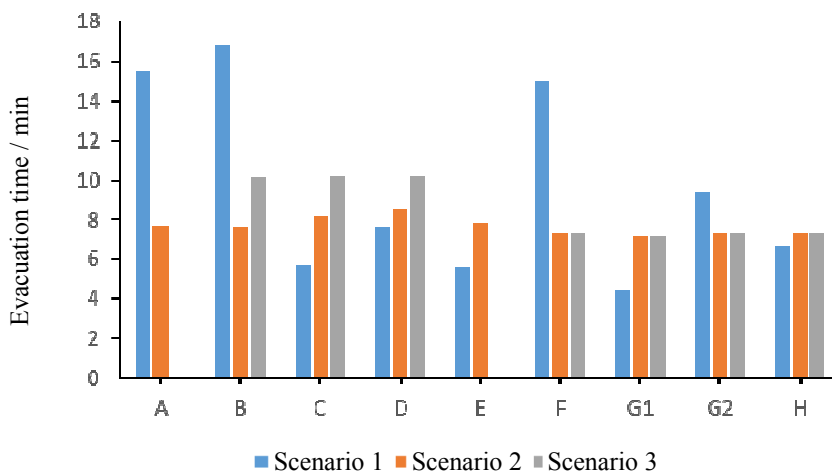


Figure 4: TET in different scenarios for Station I

For scenario 1:

The population density in each exit is assumed to be the same, and thus, there are 645 persons (5800/9, i.e. 11%) in each exit. The passenger flow in different exits from one of the concourse is shown in Figure 3a. The evacuation time for scenario 1 is calculated by using the hydraulic model with results shown in Figure 4.

For scenario 2:

The population density in each exit depends on exit width, the passengers in the basement using Exit A, B, C, D and E. The passengers on the ground floor will be using Exit F, G1, G2 and H. The passenger flow is same as scenario 1 and is shown in Figure 3a, but the density in each exit is different. In order to calculate the evacuation time for scenario 2, the effective width for different exits should be measured and shown in Table 1. The result of evacuation time for scenario 2 is shown in Figure 4.

For scenario 3:

Assuming the exit A and E in the main concourse are blocked. Therefore, only exit B, C and D can be used. In this situation, the number of passenger assuming to evacuate in each exit will depend on exit width and the passenger flow is shown in Figure 3b. The result of evacuation time for scenario C is shown in Figure 4.

From the Figure 4, it shows that the TET in scenario 1 in different exits was not evenly distributed. The TET in exit G1 and B is 4.4 minutes and 16.8 minutes respectively which the difference is very large. That was not reliable as TET in different exits should be similar as the passenger would try their best to evacuate as fast as they could. Thus, they would find the nearest exit or the less crowded exit to evacuate. The result for the scenario 2 was more reliable as the TET was depending on the exit width, and passengers would choose the exit to evacuate immediately, and thus, the TET in different exit should be similar. For the scenario C, the exit A and E are blocked in the main concourse, thus, the evacuation time in exit B, C and D would be longer.

Table 1: Effective width for different exit in Station I

Exit	A	B	C	D	E	F	G1	G2	H
Effective width (m)	1.8	1.65	5.68	4.25	5.42	1.8	6.2	2.9	4.12

6. DEEP UNDERGROUND SUBWAY STATION : STATION II

The layout of station II is studied with schematic shown in Figure 5. There are five exits and one concourse in station II which the concourse location is circled. The passenger density in station II is different from station I as the density should be built much lower than the station I. The station II is not an interchange station and the concourse area is much smaller than station I, and thus, the passenger density is assumed to be 600 only.

For scenario 1:

The population density in each exit is assumed to be the same, and thus, there are $600/3 = 200$ persons in each exit. The evacuation time for scenario A is calculated by using hydraulic model with results shown in Figure 6.

For scenario 2:

Same as the scenario 1, as the all the exit width in station II are the same. Thus, the evacuation time is the same as scenario 1.

For scenario 3:

Assuming the exit A in the main concourse is blocked. Therefore, only exit B and C can be used. The result of evacuation time for scenario 3 is shown in Figure 6.

For the passengers who evacuate at exit A, the TET calculated from the Figure 6 is the evacuation time from the exit A to the lift lobby. During emergency situation, the lift will stop serving the lift lobby and the fire curtains installed in front of the lift door will automatically close in order to stop the smoke and fire spread into the lift shaft. The passengers then will be directed to the refuge floor through the emergency exit in Station II. The passengers will wait for the lift in the pressurized refuge lift lobby. The fire resistant material is used in the refuge area to ensure the passengers are safe in the refuge floor.

From the Figure 6, it shows that the TET for all exits in scenarios 1 and 2 are similar, except exit C2. The reason why the TET in C2 is much longer than the other exit as the length of exit route is nearly 320 m, and thus, the TET is double of C1. Although the TET in exit C2 is much longer than the other, the passengers can egress safely as the exit route is pressurized. For the scenario 3, Figure 6 shows that when the exit A is blocked, the TET for the other

exits slightly increases. It is because the population density is not very high in station II, therefore, when one exit is being blocked, the TET of the other exit will not increase sharply.

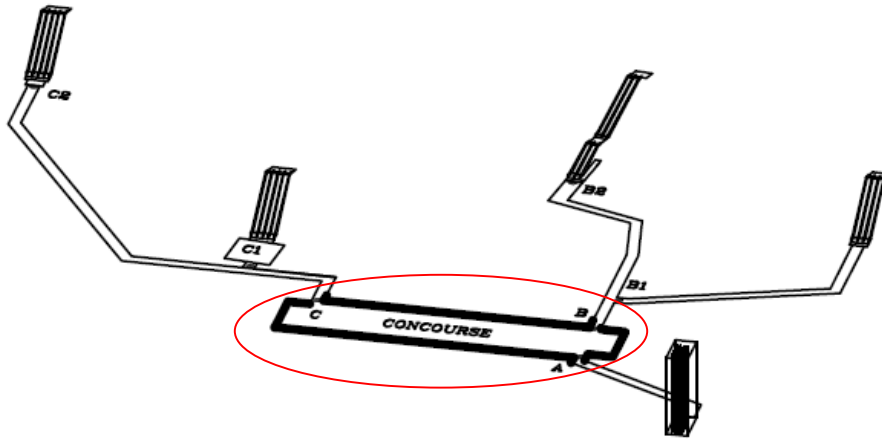


Figure 5: Exits location in Station II

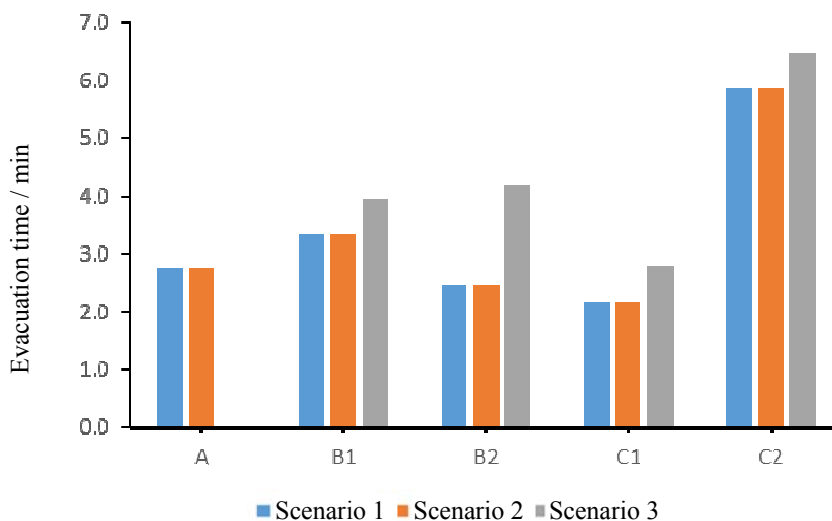


Figure 6: TET in different scenarios for Station II

7. FIRE SAFETY MANAGEMENT

Comparing the TET in station I and station II, the TET in station I is relatively longer than station II as the number of passengers in station I is very high at peak hour. Based on the result, appropriate fire safety management (Malhotra, 1987; Lui and Chow, 2000) should be worked out properly in station I.

For example, crowd control measures during the peak hour should be provided, closing one third to half of the ticket gates can avoid having excessive number of passengers getting into the concourse and the platform.

From the TET for scenario 1 of station I in Figure 3b, the population density in exit A, B and F is relatively higher than the other exit. Management staff should be allocated to guide the passengers at the peak hour.

Besides, the fire alarm signal is the basic warning signal in subway station. However, many passengers would misunderstand the signal to be the false alarms and the passenger response time will be longer.

In order to have better awareness of passengers safety and improvement on the response time in evacuation, public address system should be designed properly in both stations I and II. Passengers can take the immediate action when

live broadcasting message is provided with the emergency information. Real-time broadcasting message should be clear, simple and no delay. Moreover, clear instruction that could direct the passengers to a specific exit route should be provided. Such communication method can provide reliable information, and thus, the passengers are more alerted with the live broadcasting message as it can reflect whether the situation is emergency or not.

In the staff training plan under the fire safety management scheme, staff must be trained to take appropriate and immediate actions for crowd control under emergency situation. Fire hazard scenarios should be identified through the use of fire dynamics evaluation. Management staff are trained to be familiar with all the exit routes in the subway station. Besides, they are expected to arrange to announce broadcasting message through the public address system in the first instance during the emergency situation so that passengers can be evacuated in appropriate time.

8. CONCLUSIONS

From the above study on evacuation times of two railway stations I and II in Hong Kong, it is concluded that the evacuation time depends on different factors, such as population, movement speed and exit width. Behaviour of the passengers would affect the evacuation time as observed in scenario 2. Therefore, appropriate fire management system (Malhotra, 1987; Lui and Chow, 2000) should be worked out for crowd control.

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