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AIRPORT EVACUATION ON COMPARING SIMULEX AGAINST BUILDINGEXODUS

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ABSTRACT

Many egress models for the evacuation of buildings were developed and used in the literatures. Of which, buildingEXODUS and SIMULEX are popular. Both used networks of nodes to simulate the movement of a large number of individuals through a number of exits of different widths from large buildings.

The evacuation software buildingEXODUS and SIMULEX would be reviewed in this paper. In assessing the evacuation time of the occupants, the total evacuation time should be determined. It is the maximum time for the last occupant to get out of the exit and reach a safe place. The time can be used to assess the number of occupants that are able to evacuate within the assigned target time.

The airport terminal building is taken as an example for assessing the two software by simulating the total evacuation time of occupants. Simulations with different designed occupancy levels would be carried out under normal condition in the departure level and arrival level. Four sets of scenarios will be assessed in each level.

1. INTRODUCTION

Many developed evacuation models are applied for simulating the evacuation pattern in large and geometrically complex spaces with high occupant level [1]. Buildings with new architectural features such as big halls and uncompartmented areas are examples. Those models are intended to use as design tools for analyzing the evacuation of large populations through a wide range of environments.

When the areas are densely populated, individual movement of occupants would be affected [2]. They will only be carried along by the crowd and their movements are only decided by group flow [1]. Therefore, crowd movement is a concern in dealing with safety. Evacuation pattern should be considered by paying attention to the occupant distribution, the knowledge of occupants on the building geometry and their familiarity with exits, environmental factors inside the building, and human behaviour in the evacuation procedure [3-6]. Crowded conditions would be determined through identifying the evacuation patterns inside different parts of buildings, accompany with the evacuation time determined from an assumed distribution of passengers. Weak points in the means of escape design would also be identified.

In this paper, the evacuation model buildingEXODUS [7] and SIMULEX [8] were selected as the simulator to determine the evacuation time of occupants under normal conditions. Four sets of scenarios were assessed for the departure level and arrival level of the airport terminals. Evacuation time simulated by buildingEXODUS [7] and SIMULEX [8] would be compared, so as to determine the difference in working principles for those models.

2. THE EVACUATION MODELS BUILDINGEXODUS

Evacuation pattern can be understood by using simulation programs. The software buildingEXODUS [7,9-11] is a well-verified software based on overseas data and demonstrated to be applicable to many buildings. Such software is utilized the particle tracking technique, i.e. seeking the flow with particles which are assumed to follow the fluid, and measuring their movement over a known period of time by tracking the particles among different instantaneous pictures [12,13]. Particle tracking is one of the simplest and most powerful methods of qualitative flow visualization. In buildingEXODUS, it is included not only tracking instantaneous positions of the persons staying inside a building but also the psychological factors on human behaviour in an accidental fire [14,15]. Paths of each person are tracked while moving out of the enclosure.

It is an egress model [16-20] designed to simulate the evacuation of a large number of individuals from large buildings. The model takes into account not only the physical characteristics of the enclosure, but also the response of each individual to stimuli such as the various fire hazards and individual behaviour such as personal reaction times [4]. The movement of each individual is accommodated by stepping one node, i.e. a single and defined area, to the next [21]. Each node represents a portion of space 0.5 m x 0.5 m [9] and can be occupied by only one person [1]. The fine network of nodes is connected by arcs that defined the available path of movement from one position to another [1,8].

Change of direction of occupants would be occurred during the simulation [9]. For example, five occupants want to enter the same node at the same time. There would be conflicts between all occupants and only one occupant can occupy the node at the end. Other occupants should be either waited until that person left or carried out another action such as change the direction of movement and find an alternative node.

There are five core interacting sub-models used in the software, i.e. Movement, Behaviour, Occupant, Hazard and Toxicity [22]. The followings are the descriptions for those sub-models:

- Movement sub-model

  Movement of individual occupants from the current positions to the most suitable positions will be controlled together with the waiting period.

- Behaviour sub-model

  Based on the personal attributes, response of individuals to the current situation will be identified. Decision will be passed to the movement sub-model. This model is functioned on two levels: global and local. The local behaviour determines an individual's response to the local condition, while the global behaviour represents the overall strategy of the individual.

- Occupant sub-model

  Attributes and variables such as gender, age, fast walking speed, walking speed, response time and nimbleness of individual are described by this sub-model.

- Hazard sub-model

  Atmospheric and physical environment will be monitored. Fire hazards such as heat, smoke and toxicity throughout the environment are described. Availability of exits will also be controlled.

- Toxicity sub-model

  Effects on an individual exposed to the toxic products described by the hazard sub-model will be determined. Results are then transferred to the behaviour sub-model to determine movement of individuals.

The functions of sub-models are for describing the configurational, environmental, behavioral, and procedural influence on the evacuation efficiency in the evacuation process [4,10,23]. Interactions between people and people, people and fire, people and structure are all considered in the model. These interactions may affect the movement of occupants on three levels [5]:

- Psychological

  The response of occupants may be based on the signal given under a fire threat. It may cause the occupants rearing away from the fire and then stimulate intention to evacuate.

- Sociological

  The response of occupants is based on the interaction with other occupants. In case of a fire, the occupants may participate in fire fighting, rescue or alert other occupants.

- Physiological

  It is related to the surrounding environment and the capabilities of occupants will be affected. The occupants may result in intoxication and irritation exposed to the narcotic gases and irritant gases while evacuation.

In buildingEXODUS, an important parameter known as the Optimal Performance Statistic (OPS) is used to describe the evacuation efficiency [5] of the exits in buildings with multiple exits. It is given in terms of the number of exits n used in evacuation; Exit Evacuation Time EET_i, i.e. time for the last person to get out of the i^{th} Exit (in s); and Total Evacuation Time TET (in s), which is the maximum value of EET_i out of all n exits, as:

$$OPS = \frac{\sum_{i=1}^{n} TET - EET_i}{(n-1) \cdot TET} \tag{1}$$

Zero value of OPS means well-balanced evacuation, i.e. evacuation at all exits will be completed at the same time. An OPS value of 1 means a poor evacuation with at least one exit not attracting any occupants. More detailed information can be found in the literature [11,24].

Large amount of data, e.g. age, weight, travel distance, response time (RT) (in s), cumulative waiting time (CWT) (in s) and evacuation time of each occupant, would be generated in each simulation. The CWT attribute is a dynamic attribute calculated by buildingEXODUS and defined as a measure of the total waiting time encountered on the way to exit the building, i.e. the total amount of congestion that they have experienced and remained stationary after they have started to evacuate [25]. The waiting time spent in each congestion will be recorded. For example, the waiting time of an occupant is started when an individual starts to congest. It is ended after the person caught in the congestion is free to move again, say t_{wait1}, in the first congestion. The magnitude of the first waiting time, i.e t_{wait1}, will be recorded. When next congestion is occurred, the waiting time will then be ended at, say t_{wait2}. For n congestion occurred, CWT is:

$$CWT = \sum_{i=1}^{n} t_{waiti} \quad (2)$$

Based on the TET, RT and CWT, the moving time (MT) of the occupants can be determined.

$$MT = TET - RT - CWT \quad (3)$$

The waiting and moving components in TET (i.e. MT and CWT) can be used as a measure of the evacuation efficiency [25] and acted as an indicator to identify the proportion of time that most occupants are likely to spend on queuing and travelling during evacuation.

3. THE EVACUATION MODELS SIMULEX

For the computer model SIMULEX, it is also utilized the particle tracking technique [1]. Fluid modelling provides a greater degree of understanding about the mechanism of crowd flow. A crowd flow can be understood as a collection of particles whose mass and movement interact mutually, while moving fluid provides the potential for pressure fluctuations and universal motive force for crowd particles.

SIMULEX is developed for the escape movement of large numbers of individuals in single level or multi-level buildings [26,27]. It has the flexibility in handling infinite spatial variations and the routines for automatic route assessment. The 'distance mapping' technique is employed in the software, which allows the user to assess the building space in terms of the travel distance and final exit [21].

A 'distance map' is defined by a fine mesh of spatial blocks which covers the plan area of a building [21]. The numerical value assigned to each block is equal to the optimal 'travel distance' from the centre of that block to the nearest available final exit. This value takes account of all changes in the direction of travel, when the occupants are blocked by obstructions such as walls and slower persons which prevent the forward movement. The software can also find the furthest point in a building from any exit, i.e. most remote point, and illustrates the route to exit from this point and the total travel distance [21].

In SIMULEX, the size of each node is 0.25 m x 0.25 m. For the occupants simulated, the shape of a human body is represented by using three circles (one for main body and two for shoulders). Each person is assigned the same average body size, but with different body dimensions, which is depending on age and gender. The software Average body size used is 0.5 m x 0.3 m [21].

The speed of occupants is assessed individually at each time step. In the simulation, each person is assigned a random unimpeded speed between 0.8 m/s, i.e. an elder woman, and 1.7 m/s i.e. an able-bodied adult male. The speed of an individual is related to the distance between centre co-ordinates of the person and others in the obstruction zone [1].

For a single obstructing person, the inter-person distance d (m) is related to the density D (number of person/ m^2) by:

$$d = \sqrt{\frac{1}{D}} \quad (4)$$

The formula for walking speed v was derived in terms of the unimpeded walking speed V (m/s) and plan body depth b (m):

$$v = \left(\frac{V(d-b)}{0.87} \right) \quad (5)$$

The speed is assumed to be unimpeded when d > 1.12 m. 1.12 m is the 'distance threshold' and value of d can be adjusted, depending on occupant characteristics such as aggression and familiarity.

The movement of occupants produced a degree of jostling in the high density crowds. Occupant would be slowed down if obstructed by another person. When the speed of the person is reduced, the program will examine the direction of travel of that person [21]. If there is a significant change in speed, the direction of travel would be changed to a new and deviated angle. Overtaking is occurred when there is enough space available to the person for the deviation of route. It will not be applied in areas when the crowd density is exceeded 2 persons/ m^2 [1].

Queuing is occurred in the simulation when groups of people 'merge' in the corridors or pathway junctions of a building structure. Each person would be moved into unoccupied space and will become stationary if standing exactly behind another person, with no space to move sideways [1].

The number of people through all exits in a period of 5 s would be generated in each simulation. Evacuation performance of occupants can be solved by some number distribution functions. As the number of evacuating occupants would be a function of the evacuation time, plotting this relationship can help to understand the transient number or percentage of people evacuated. Results are useful to judge whether the occupants can be escaped within the target time.

4. EVACUATION SCENARIO OF THE AIRPORT TERMINALS

As the airport terminal is a symbolic building of Hong Kong, there might be possibilities of having arson fires or even terrorist attack fires. Evacuation of occupants is an important part in fire hazard assessment for the airport terminals [16,17]. The occupant loading is high as many people are waiting inside the waiting areas of the arrival hall or taking their hand-carrying baggage with them and queuing up at the check-in counters of the departure hall. Besides, retail areas are provided inside the departure level (Level 7) and arrival level (Level 5). Therefore, it is necessary to focus on the evacuation.

The departure and arrival levels are illustrated with their geometry shown in Figs. 1 and 2. A scenario in the departure level under normal condition, i.e. without having a fire, will be considered in this paper. This scenario would be simulated by buildingEXODUS and SIMULEX to compare the difference in evacuation time.

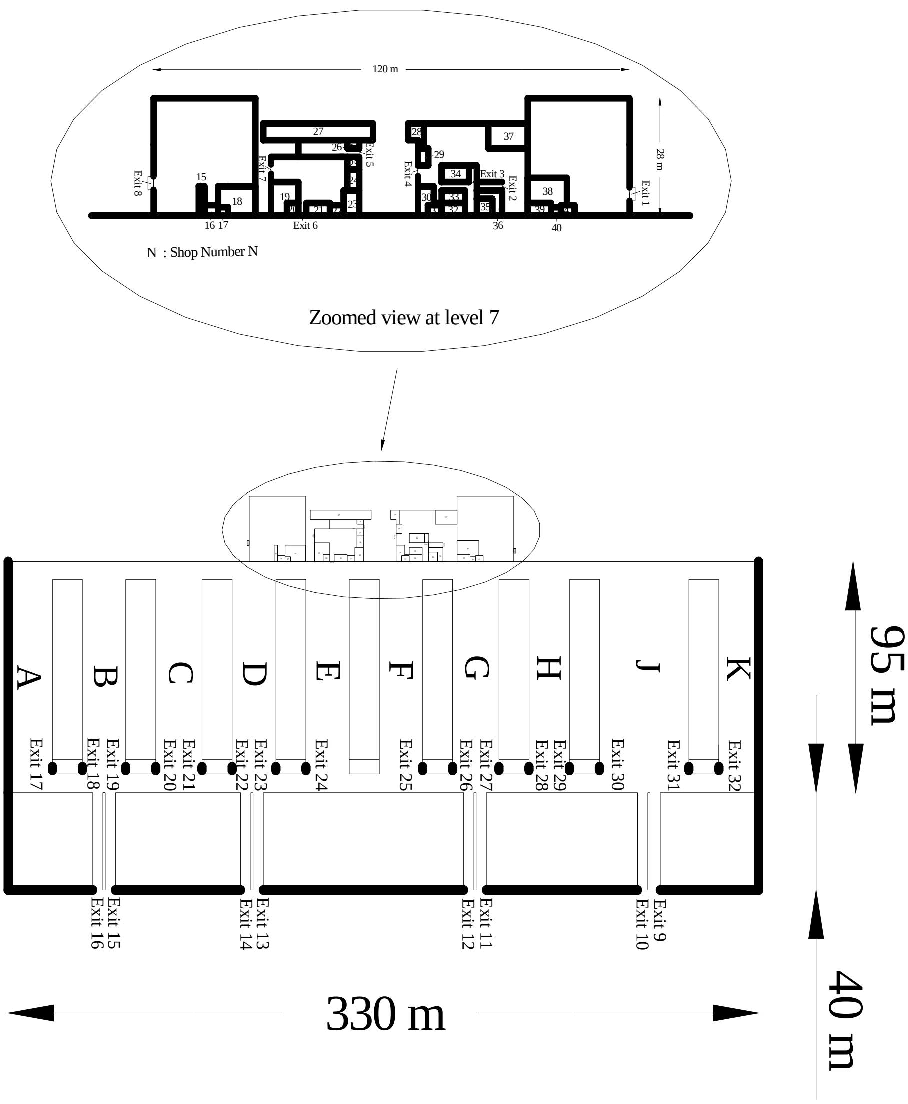

Fig. 1: The layout of departure level of the Airport Terminal Building

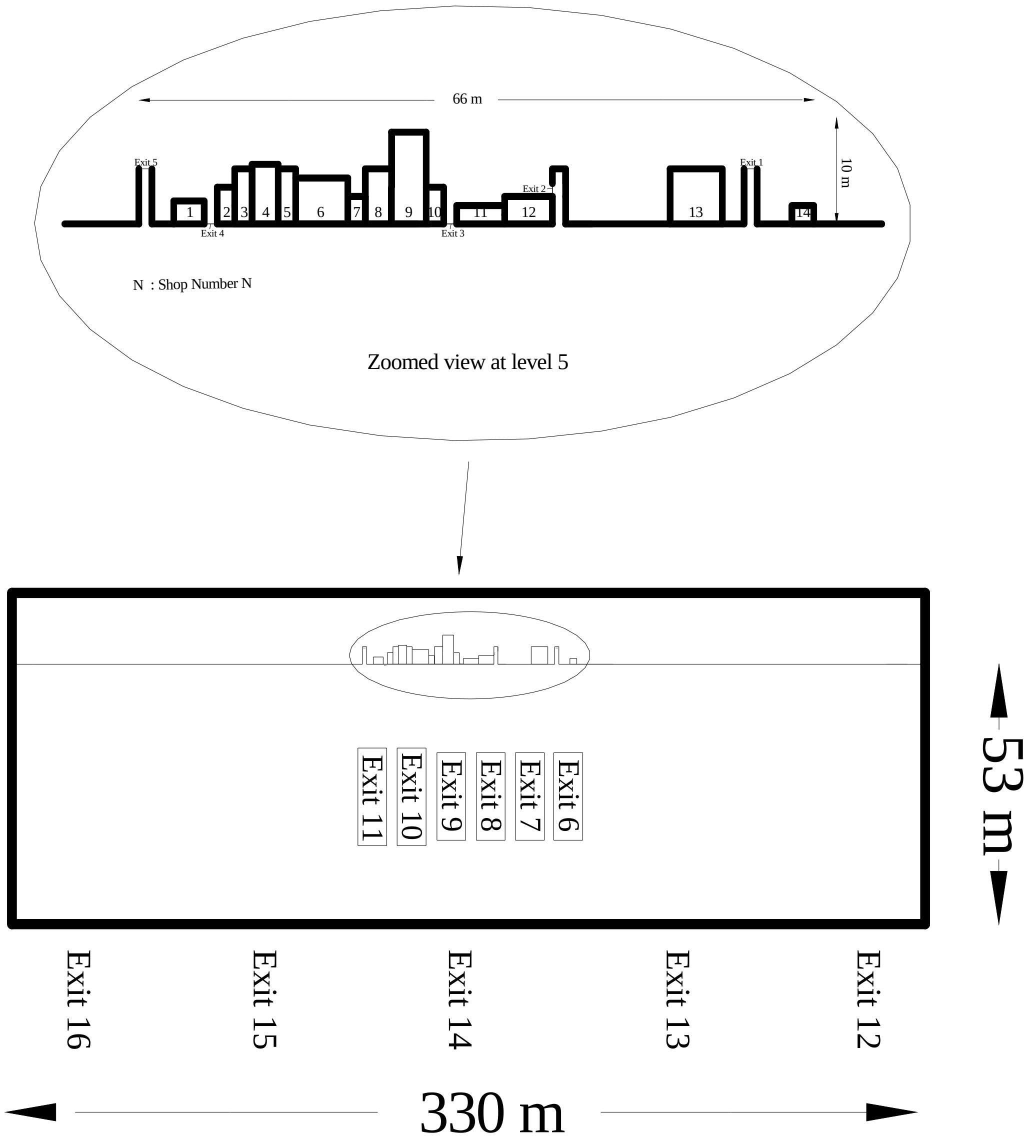

Fig. 2: The layout of arrival level of the Airport Terminal Building

According to the local MoE codes [17], evacuation should be within a notional period 300 s. 270 s is adopted as the phase evacuation target time for the evacuation analysis in many railway stations in Hong Kong. The railway terminal is classified as assembly occupancy in following the NFPA 101 [28], i.e. an occupancy used for a gathering of 50 or more persons awaiting transportation. As the airport terminals are classified as the same occupancy as the railway terminal [28], the targeted Total Evacuation Time (TET) at the departure level was also set to 270 s in this study. On the other hand, the maximum sum of the direct distance and travel distance would be set within 45 m inside the retail areas of the airport terminals as mentioned in the MoE codes [17].

5. SIMULATION RESULTS

According to the MoE codes [17], the usable floor area for the retail areas is 3 m^2 per person. Therefore, the maximum occupant loading would be 224 for floor area 672 m^2. Eight exits would be connected to the staircases from level 7 to outside. Results predicted by the buildingEXODUS of average evacuation time and TET are 45 s and 98 s, while the TET simulated in SIMULEX is in infinity, i.e. some occupants cannot be escaped to a safe place. Occupants are stopped to evacuate at 720 s. At that time, only 203 occupants can leave the hall.

Only buildingEXODUS can give the longest CWT and MT. Values of 72 s and 38 s regarding. Number of occupants leaving the zone with a certain evacuation time would be shown in Fig. 3. Computing time in a pentium of buildingEXODUS and SIMULEX is about 300 s and 60 s respectively. Evacuation patterns for random distribution of occupants at time 40 s in buildingEXODUS and SIMULEX are shown in Figs. 4 and 5. The summary of results for the departure level would be shown in Table 1.

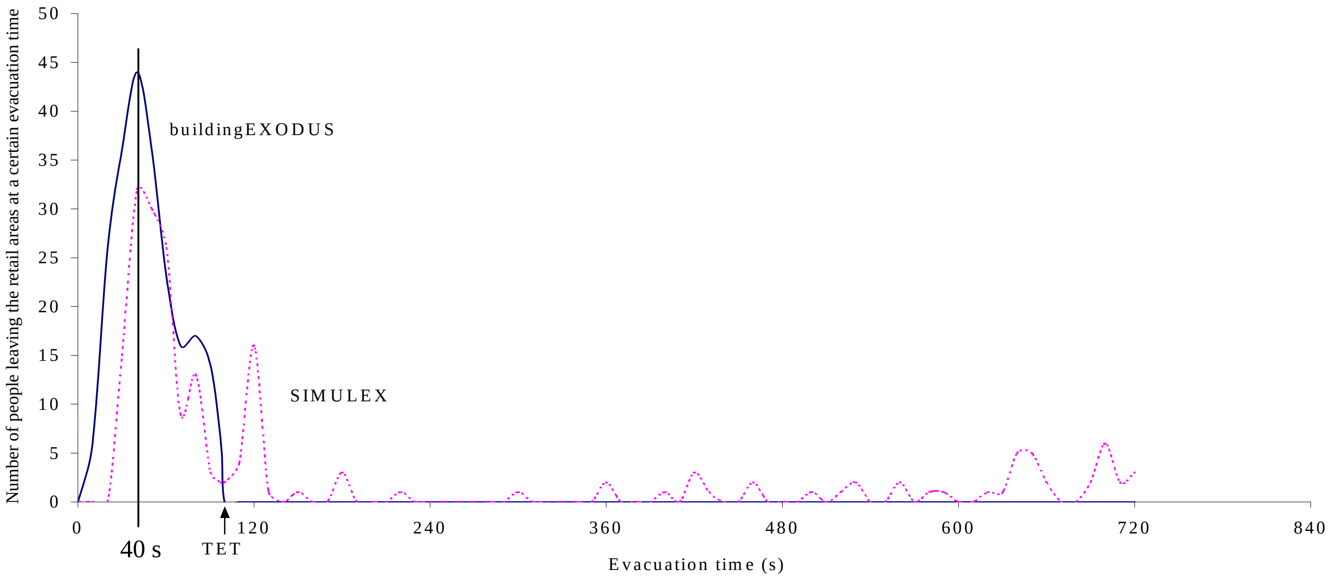

Fig. 3: The comparisons of evacuation times

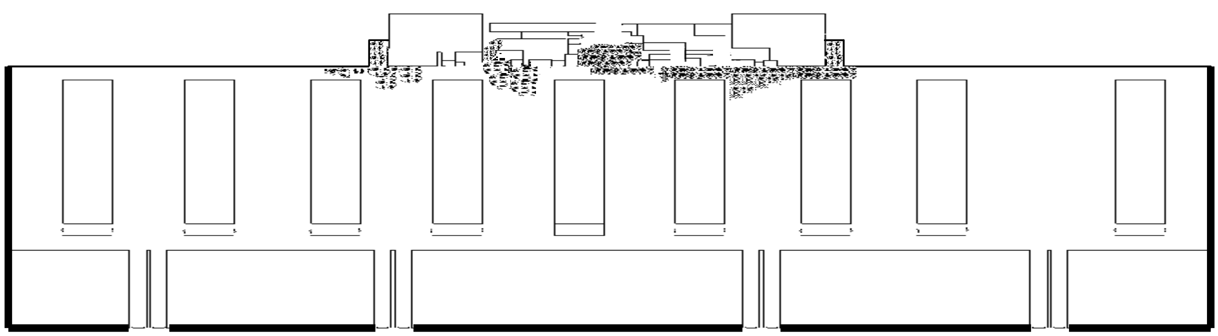

Fig. 4: Evacuation pattern of buildingEXODUS (at time = 40 s)

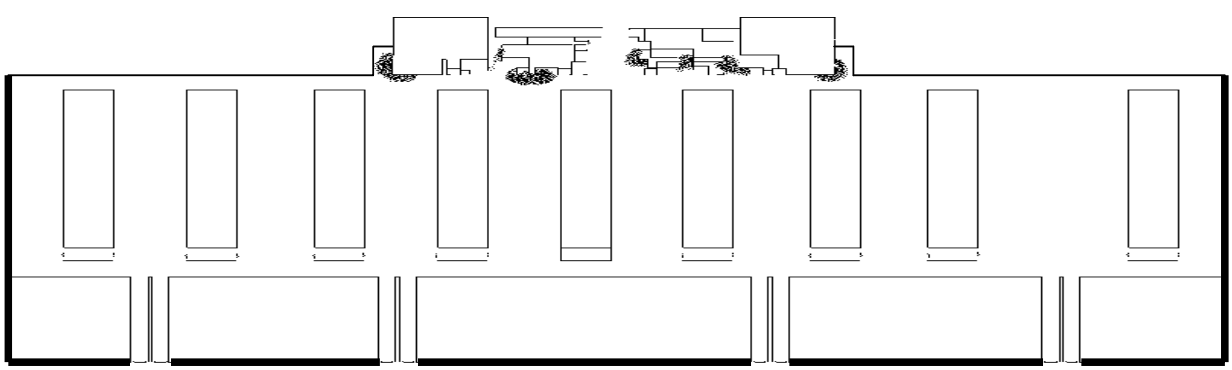

Fig. 5: Evacuation pattern of SIMULEX (at time = 40 s)

Table 1: The summary of results

Exit	Number of people passed through the door		Evacuation time of the first occupant (s)		Evacuation time of the last occupant (s)	
	buildingEXODUS	SIMULEX	buildingEXODUS	SIMULEX	buildingEXODUS	SIMULEX
1	1	0	30	0	30	0
2	58	57	9	25	54	720
3	35	14	6	25	49	50
4	0	20	0	30	0	65
5	77	56	4	30	92	135
6	0	22	0	30	0	65
7	49	31	16	35	98	95
8	4	3	37	45	55	55
Total: 8	**Total: 224**	**Total: 203**	**Minimum: 4**	**Minimum: 25**	**Maximum: 98**	**Maximum: 720**

6. DISCUSSION

• Maximum Number of Occupants Leaving the Zone

In this scenario, the maximum number of occupants, i.e. 19.6 % (buildingEXODUS) and 15.8 % (SIMULEX), leaving the zone at 40 s. The maximum number of people leaving the areas in buildingEXODUS is more than SIMULEX. Only a large part of occupants is able to evacuate in SIMULEX due to the crowd condition generate around those exits during the simulation.

• Number of Occupants Escaped Within the Target TET

For the scenario simulated by the buildingEXODUS, all the occupants are able to escape within the target TET, i.e. 98 s. However, TET is in infinity, i.e. some occupants cannot be escaped, for the same scenario simulated in SIMULEX. Only 203 occupants are escaped at 720 s, i.e. around 90 % of all occupants can be escaped. Inside this percentage, about 77.8 % of occupants would be escaped within the target TET.

From the result, it indicated that in the retail areas, even without a fire and no blockage of the escape routes, occupants are not able to evacuate within the targeted time as simulated by SIMULEX. If there is a fire, the situation will become worse as the occupants may have difficulties in evacuation when the radiant heat exposure and smoke density are increased [29]. Thus, decrease in mobility may result in the crawl speed evacuated by the occupants in case of fire [30].

When fire is occurred near the exits of the staircases, those staircases may not be used. This will reduce the number of staircases that can be escaped by the occupants and hence increase the TET. Occupants were forced to use the other exits even those exits were the nearest for them. Therefore, TET would be increased at fire condition as occupants are needed to travel to the exits which might not be the nearest.

• Waiting Time of Occupants

The longest CWT in this scenario is shorter than the longest MT. It is only 7 s and 14 % in TET. However, the longest CWT of occupants may give a very large component in TET in case of fire, where the MT needed by occupants is comparatively much smaller. This is due to overcrowding occurred during the evacuation of occupants. Most occupants were needed to queue up before the exits and wait to pass through.

• Travel Distances

According to the figures mentioned in the MoE codes [17], the maximum sum of the direct distance and travel distance should be within 45 m inside the retail areas of the airport terminals. The longest travel distance for this scenario is not exceeded the targeted distance. However, attention should be paid on the travel distances of the occupants in order to ensure all the occupants can be evacuated within the targeted distance.

• The Occupant Loading in Real Situations

In real situations, occupant loading in the retail areas would be higher than the figures mentioned in the MoE codes [17]. Therefore, real TET for the retail areas would be much longer than the simulated result. Large amount of people inside the departure hall and waiting areas of the arrival hall would further deteriorate the conditions. Even it is seldom to have a large number of people inside the departure hall and arrival hall [17], the effects should not be neglected as chaotic conditions may easily be happened in both departure hall or arrival hall and retail areas in case of emergency.

7. CONCLUSION

Scenario simulated by buildingEXODUS and SIMULEX show that crowd condition is occurred around the exits of the retail areas in the departure level. The results of TET generated by both models were different. It is difficult to compare the accuracy of those simulations. However, both results indicated that occupants may need to queue up before entering the exits. This is due to the number and width of the exits and staircases are not enough in the departure level of the airport terminals. Those occupants may have difficulties in evacuation and should be helped by the others in order to reach a safe place.

People become panic would have longer response time and movement time during evacuation. When some staircases were blocked because of a fire occurred nearby, occupants would be evacuated through the other exits. Reducing the number of exits would give a longer time to queue up (if there is still an orderly queue!) in front of the exits and the waiting time for evacuation would be extended. The risk of occupants being subject to fire and smoke would then be increased.

On the other hand, the travel distance of the occupants is also an important issue but might not be as important as expected. This distance can only be taken as a reference for the fire safety management team in designing the location of the exits and staircases. Other means should be worked out to ensure that the occupants can travel to the nearest exits and staircases within a targeted agreed evacuation time.

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