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Modeling the occupant evacuation of the mass rapid transit station using the control volume model

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A B S T R A C T

In this study, a control volume model is applied to simulate the process of evacuation in mass rapid transit (MRT) station using different scenarios. The control volume model assumes that each individual is an independent particle. When the evacuation occupant flow is larger than the capacity of the exit so that a virtual closed surface called the control surface that can be formed by connecting the waiting occupants at the exit. The change of the control volume is dependent on the transient number of the waiting occupants only. Based on the homogeneous flow with neglecting the behavior of the individual, the dynamic change of the evacuation occupant at the exit of the platform and the concourse can be formulated and analyzed. In addition, the number and capacity of the exits used in the total evacuation time analysis were measured with the aid of video recording and on-site observations. Using the control volume model, the dynamic characteristics of the evacuation process at each time-step for each of the exits are calculated and discussed. Comparisons are also made with the results found from other studies and NFPA 130.

1. Introduction

Since 1970s, many studies have investigated on occupant evacuation problems. Nowadays, a large number of approaches to the evacuation models have been developed to provide designers with the ways of forecasting evacuation times in buildings [1–23]. For the underground MRT station, the total evacuation time and the platform evacuation time are the important indexes of the fire protection requirements to evaluate human safety.

Basically, the occupant evacuation models can be divided into two major categories: macroscopic and microscopic models [5,6]. Macroscopic models ignore the non-evacuation actives and consider the evacuees as an integer with regular characteristics so that the evacuation flow depends on the crowd density, physical factors of architectures such as EVACENT4 [8], regression models [9], queuing models [10], gas-kinetic models [11], and Takahashi's model [12], etc. Microscopic models not only consider the physical factors of architectures but also treat each individual as an active factor. The individual behavior and movement exhibited during evacuations is considered to predict the decision-making and escape routes, etc. For examples, social forces [13,14], time-varying network [15], integrated network approach [16], spatial-grid evacuation (SGEM) [17–19] and cellular automata models [5,20–23]. In addition, evacuation simulation models, such as EXODUS [24–26], SIMULEX [27], and EXITT [28] are microscopic models and can be used to predict the performance of evacuation and thus become an important tool for the analysis of the building evacuation.

Recently, Zheng et al. [29] summarized systematically crowd evacuation models based on seven methodological approaches and discussed the advantages and disadvantaged of these approaches. Pelechano and Malkawi [5] presented a review of crow simulation models and commercial software tools for high rise building evacuation simulation. Tavares and Galea [7] developed a methodology which combines the use of evacuation models with numerical techniques used in the operation research field, such as Design of Experiments (DOE), Response Surface Models (RSM) and numerical optimization techniques. Moreover, database on occupant's behavior is particularly needed for evacuation software or engineering assessment. It is well known that a minor adjustment to a critical parameter might result in a huge difference in the simulated results [30]. To collect an extensive data such as premovement time, walking speed, occupant characteristics, and exit choice decisions, many of evacuation experiments and surveys have been carried out to gain data in mass rapid transit stations [31–34]. The major purpose of the above models and researches is to simulate escape patterns of occupants and predict the performance of evacuations and thus provide valuable information for designing buildings.

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In Taiwan, the egress of subway safety evacuation mainly adopts NFPA 130 [35] standard except the occupant load. However, as more advanced optimization evacuation models and tools have been developed in recent years, the course of evacuation has attracted the interest of research and management units to establish comprehensive emergency responding plans and operation procedures.

The aim of this study is to obtain a theoretical model which formulates the dynamic course of evacuation in a subway metro station. The control volume method is based on the homogeneous flow with neglecting the behavior of the individual, the evacuation route choice, the efficiency of using the exits, etc. It is assumed that all of the passengers divide into groups nearly in proportion to the exit capacities on various routes of the platform.

In this study, the calculation is based on the actual layout of Gon-Guan station in Taipei MRT system. Additionally, the occupant loads of the exits recorded by the video cameras have been mentioned and summarized in this study. Using the control volume method, the results of the evacuation times from the platform and the most remote point on the platform to a point of safety were derived for two scenarios. The simulation results of the control volume model, NFPA 130, and the SIMULEX are shown in this paper. Some characteristics of the evacuation course at each time-step on the platform and the concourse derived by the control model are also discussed.

2. The control volume model

2.1. Physical assumptions

In this paper, the control volume model assumes that each individual passenger is an independent particle. When the evacuation occupant flow is larger than the capacity of the exit, a virtual closed surface is formed by connecting the particles at the exit. The control volume model is applied to the platform as shown in Fig. 1 with the passengers moving from the carriages to the platform level and then to the exits. The closed surface is changed with time and the summation of different rate between the inflow and outflow. By setting the height of the particle (each individual) as 1, the area of the closed surface is equal to the control volume, thus, the closed surface is called the control surface.

Therefore, the change of particle number in the control volume can be determined by deducting the number of the outflow particles from the inflow ones. Assuming the particle number per unit area as a constant, the transient area of the control volume can be easily derived from particle number within the control volume. The physical assumptions of the control volume model are as follows:

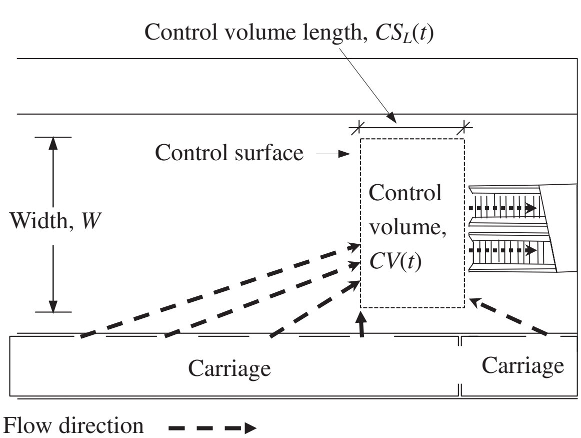

Fig. 1. Control volume model.

1. The control volume method is based on the homogeneous flow neglecting the behavior of the individual passenger. The crowd moves at the same speed as the individual.
2. Under the circumstance of a constant passenger flow per unit width at the exit, flow is equal to speed multiplies the density and width.
3. The crowd moves following the predefined routes, there is no separation of the crowd.
4. In case of stagnation, the particle number per unit area remains constant.
5. The conditions of various exits are the same. All of the passengers are divided into groups nearly in proportion to the exit capacities provided by various routes on the platform.
6. The pre-movement time-lag, alarming response, and broadcasting response are not considered.

Under the above assumptions, the application of the control volume model to the station evacuation is influenced by many factors including the number of passengers in the carriage, the flow rate of the carriage doorways, the crowd velocity, the distance of the carriage to the emergency exits, the flow rate of the emergency exits, and the number of people waiting on the platform. The change of passengers in the control volume can be obtained from the above-mentioned factors.

2.2. Calculation procedures

The formula for calculating the control volume is shown below. It is assumed that there are independent outflows from various doorway exits during the evacuation with the starting time of the doorway exit is when the first passenger arrives at the control surface and the ending time is when the last passenger arrives at the control surface. Therefore, the initial and ending time of the Nth doorway exit to the control surface is defined as follows:

$$T(N): \quad T_0(N) \le t \le T_0(N) + TP/(\dot{Q}_1 \times W_1/60) \tag{1}$$

where $T_0(N)$ is the initial time when the first passenger of the Nth doorway exit to reach the control surface (s), TP is the amount of people who flow through a certain doorway exit, $\dot{Q}_1$ is the capacity of carriage door (people/mm-min), W_1 is the width of the doorway exit (m). It can be seen from the above assumptions that $T_i(N)+TP/(\dot{Q}_1 \times W_1/60)$ represents the time when the last passenger of the Nth carriage reaches the control surface. To obtain T_0 (N), the distance between the first passenger of the Nth carriage at certain time point t and the control surface can be written as follows:

$$D_N(t) = [D_N(0) - CS_L(t)] - V \times t \tag{2}$$

where V is the velocity of the crowd move (m/s), $D_N(0)$ is the distance between the initial distance ($t=0$) and the doorway exit (m), $CS_L(t)$ is the length of the control volume (m). Hence the condition $D_N(t)=0$ is the solution of the T_0 (N) in Eq. (1) and there is no distance between the first passenger of the Nth doorway exit and control surface.

The second part of the calculation is to obtain the number of people stagnating at the exits at certain time point t. From Eq. (1), the flow rate of the passengers, $\dot{Q}_N(t)$, at the Nth carriage doorway exit moving to the control volume can be described as follows:

$$\dot{Q}_N(t) = \begin{cases} 0, & t < T_0(N) \\ \dot{Q}_1 \times W, & T_0(N) \le t \le T_0(N) + TP/(\dot{Q}_1 \times W_1) \\ 0, & t > T_0(N) + TP/(\dot{Q}_1 \times W_1) \end{cases} \tag{3}$$