AN EVACUATION SIMULATION MODEL (ESM) FOR BUILDING EVALUATION

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(Received 5 July 2004; Accepted 21 December 2004)

ABSTRACT

This study tries to develop an Evacuation Simulation Model (ESM) by which the architecture plans for egress routes can be compared at normal condition evacuation or emergency evacuation with static (fixed blockage of selected target spaces, e.g. earthquake; bomb) or dynamic (timed blocked of target spaces, e.g. fire) blocking. ESM can be used to identify the potential risk of the egress routes in the building evaluated and then some fire protection measures can be produced. It can also compare the evacuation performance for buildings, which include ones that meet the codes and those that do not. ESM can identify the potential risk of the egress paths in the building evaluated and then some fire protection measures can be produced.

1. INTRODUCTION

The evaluation of static routes implies the egress paths remain the same in the time of escape while dynamic egress analysis means an egress system will not maintain its original pattern during the time of evacuation. That egress system keeps changing according to the emergency situations. In a building fire, the combustion products, especially the smoke, will transport to many compartments and give those spaces only a limited period of time for occupants to pass through. In other words, part(s) of the egress system could only remain tenable for certain time and would become untenable after a period of time. This can result in a sequential blocking to an egress system. Different parts of blocking to the egress routes will lead to various types of evacuation effects. When some portions of escape routes are blocked, there may lead to big trouble for the whole evacuation, a much longer time to escape or even no chance for some of the occupants to escape out from the building. Therefore, the dynamic consideration of blocking is very important to an egress system of a building.

Computer simulation is an important tool in doing evacuation calculation. This study develops a simulation method (ESM) for evacuation times under prediction of different situations by which various architectural layouts can be compared.

The main contents of this paper are the following: the development of a model, which can be used to predict the people movement in a building, the reasons why an ESM model was developed, the capabilities of an ESM model, the model structure and information it needs, the output information and the validation of this model.

2. MODELS IN EVACUATION SIMULATION

According to the research of Gwynne and Galea [1] to perfectly assess the potential evacuation efficiency of a building or an enclosure, it is necessary to consider four aspects, which are configuration, environment, behavior and procedures. Configuration consideration involves building layout, number of exits, exit width, travel distance etc. Environmental aspect needs to consider the debilitating effects on the occupants of heat, toxic and irritant gases and the influence of smoke density on person’s travel speeds and way-finding abilities. Procedural aspect includes level of occupant evacuation training, staff action in an emergency, occupant’s familiarity of the building. Behavioral aspect covers occupant’s initial responses in an emergency and their movement in the building.

Every evacuation model usually has its designed purposes and its limitations. They can be categorized into three kinds, which are:

- Optimization models: this kind of models assumes the occupants will evacuate efficiently and ignore non-evacuation activities. The designers treat the occupants as a homogeneous ensemble and not recognizing individual behavior. EVACNET and TAKAHASHI’S MODEL [1] are this category.

- Simulation models: designers in this group tried to represent the behavior and movement in evacuation in order to achieve accurate results and to simulate path selection in evacuation. This family includes BGRAF,
DONEGAN’S ENTROPY MODEL, EXIT89, EGRESS, E-ESCAPE, EVACSIM, EXITT, EXODUS, MAGNETODEL, PAXPORT, SIMULEX, and VEGAS [1].

- **Risk assessment:** the developers in this category try to quantify risk by performing large amount of runs with statistically variations related compartment designs or fire protection measures. CRISP II, and WAYOUT [1] belong to this sort.

In all the models, the environments in which evacuations take place are usually represented by two methods, which are fine network approach (such as EGRESS, BGRAF, EXODUS, MAGNETOMODEL, SUMULEX, VEGAU) and coarse network method (like CRISP II, DONAGAN’S ENTROPY MODEL, EXIT89, EXITT, E-SCAPE, EVACSIM, EVACNET4, PAXPORT, TAKAHASHI’S MODEL, WAYOUT) [1]. In the fine network approach, the compartments in a floor space are usually divided and covered with tiles or nodes, whose sizes and shapes vary from model to model. This kind of model is more complex and usually needs more memory, input time, and running duration but can accurately represent the real space layout of the enclosure and locate the internal obstacles and each individual at any time. For the coarse network method, nodes and arcs are used to represent the floor configurations. Irrespective of the enclosure sizes, each node stands for a compartment, which includes a room, a corridor, a hallway, etc. This method is simpler and needs less input work and running time. However, it is not easy to trace the individual movement in the simulation.

Here are characteristic descriptions of some models [1]:

- **EXIT89:** was developed at National Fire Protection Association (NFPA) and used to simulate the movement of large amount of occupants for high-rise buildings.
- **PAXPORT:** was designed to model the passenger flow through passenger terminals and was developed by Halcrow Fox.
- **EXITT:** this model was created by Levin at The National Institute of Standards and Technology (NIST) and can predict individual actions as a function of location, detectors, smoke/fire, time, individual capabilities, the gender of the individual through linear programming techniques.
- **EVACSIM:** is an event simulator created at the Center for Environmental Safety and Risk Engineering (CESARE). It can predict individual movement and identify critical events during an evacuation.
- **E-Scape:** is a behavioral system, which tries to map the cognitive decisions during an evacuation.
- **SIMULEX:** through the use of spatial analysis, it concentrates on the physical aspects of the occupants and their effects in evacuation times. The way to describe SIMULEX are:
  - Determine the building space
  - Define escape routes
  - Identify individuals (personal characteristics and location)
  - Incorporate speed reduction effects due to surrounding population.
- **BGRAF:** a stochastic model established at the University of Michigan, which can simulate cognitive processes in evacuation, through the implementation of a graphical user interface.
- **BuildingEXODUS:** is a model designed to simulate the evacuation of large numbers of occupants from different enclosures and was developed by the Fire Safety Engineering Group of the University of Greenwich. This model can track the trajectory of all occupants as they escape from the enclosure, or are affected by heat and toxic gases.
- **EGRESS:** designed to evaluate the decision-making process during evacuation by the intelligence techniques.
- **EVACNET4:** created by the University of Florida and is a network model, in which nodes stands for the building spaces, and arcs represent the passageways between spaces.
- **WAYOUT:** developed at the Australian Commonwealth Scientific Industrial Research Organization to predict merging traffic flow in a PC-Window based environment.
- **CRISP II:** uses probability biased event trees to predict the evacuation behavior of families in domestic residencies.

3. **ESM**

The Evacuation Simulation Model (ESM) developed in this study can meet the requirements to simulate different situations in a static or dynamic blockage of evacuation in a building. In the simulation of dynamic blocking, ESM can make any path in an egress system to become unavailable at any time during the evacuation. For example, path one cannot be used in two minutes after the beginning of evacuation; path two will become unavailable in three minutes due to the
smoke pollution to that passage. ESM is able to let the user set different available times for all paths in a building egress system. If all paths’ available times can be set according to the emergency situations, such as the smoke movement or fire spread between the spaces in a building, the evacuation simulation of dynamic blocking in the egress system can then be predicted.

This model can also simulate the optimized evacuation, and the phased evacuation by setting different pre-movement times for every space in which occupants are located. It is also capable of tracing the occupant changes in every compartment of the building during evacuation, and describing the values of passages between compartments during simulation because the numbers of occupants in every room can be recorded at every time step. ESM is a network model consisting of spaces connected by passages. Spaces include rooms, corridors, hallways, stairs, landings and lobbies. The passages represent the connections between compartments.

This model (ESM) used system-programming software named STELLA, to do the simulation. STELLA is developed by the High Performance Systems, Incorporation in the United States. It can simulate the flows between different containers and give the user to design any variables to control the flows [2]. STELLA can construct a diagram based on the real situation, such as Fig. 3, which is arranged according to building floor layouts. It is also capable of creating system equations to simulate the values of various variables at different time steps. The equations created in Fig. 1 people movement between room 1 and room 2 are the following:

1. \[ F_{pre} = \begin{cases} 0 & \text{IF (TIME < premovement\_time)} \\ 1 & \text{ELSE} \end{cases} \]
2. \[ F_{ten} = \begin{cases} 0 & \text{IF (TIME > tenable\_time)} \\ 1 & \text{ELSE} \end{cases} \]
3. \[ \text{passage} = (\text{flow\_rate}) \times (F_{fam}) \times (F_{compl}) \times (F_{affi}) \times (F_{pre}) \times (F_{ten}) \times (F_{vis}) \]
4. \[ \text{density} = \frac{\text{room\_1}}{\text{area1}} \]
5. \[ \text{speed} = \begin{cases} 1.19 & \text{IF (density < 0.54)} \\ 1.4(1-0.266*\text{density}) & \text{IF (density < 3.8)} \\ 0.01 & \text{ELSE} \end{cases} \]
6. \[ \text{adjust\_speed} = (F_{mov}) \times \text{(speed)} \]
7. \[ \text{travel\_time} = \frac{\text{distance}}{\text{adjust\_speed}} \]
8. \[ \text{unit\_flow\_rate} = \text{adjust\_speed} \times \text{(density)} \]
9. \[ \text{width\_flow\_rate} = \text{(width)} \times \text{(unit\_flow\_rate)} \]

In order to have easier input and shorter running time, ESM use the coarse network approach to describe the building. Though ESM is not able to trace individuals during simulation, it can describe the numbers of occupants in every compartment. Therefore, this model can identify the clearing time of a specific compartment (the time when the last occupant passed by). To consider the behavioral features, ESM can also simulate turning back behavior, like other fine network methods do. It is also possible to do the phased evacuation by giving different pre-movement time for various compartments. This model can also predict the possible trapped occupants in every space, given distinct tenable duration for every enclosure or just the ones interested.

This model simulates the occupants in every compartment at every time step, which can be set by users. The results of the simulation can be demonstrated in tables, which describe the numbers of occupants in the compartments concerned, and in graphs, which depict the changes of occupants, flow rates or other variables defined in this model by users. The results of ESM can be compared with tenable duration for every compartment and easily used to find out the possibly trapped occupants in a building fire.

ESM can be categorized into the optimization models according to the three kinds divided by Gwynne and Galea. Even though it is similar to EVACNET4, it still has some important functions in the following:

1. Simulate dynamic blockage of evacuation.
2. Set different available times for all paths.
3. Predict phased evacuation.
4. Trace the occupant changes in every compartment.
5. Describe the values of passages between compartments.
6. Identify the clearing time of a specific compartment.
7. Simulate turning back behavior.
8. Calculate the possible trapped occupants in every space.
9. Consider the mobility of the handicapped.
10. Regard the effects of human behavior if necessary.

4. CONSTRUCTION OF MODEL

The preliminary activities needed to create ESM are:

1. Establish the factors controlling people movement between spaces.
2. Construct a people flow configuration (ESM) according to the layout of the building simulated.
3. Set different assumed situations (such as ideal evacuation, phased evacuation, dynamic or static blocking of critical compartments during evacuation), or input necessary
information, like occupant number, travel distance, width etc.

4. Obtain the outputs.

4.1 Factors Controlling People Movement Between Spaces

The flow rate of occupants between different compartments depends on some factors, such as travel distances, widths between the passages of the two compartments, walking speeds (determined by the density of occupants), pre-movement times, tenable duration, mobility, visibility, familiarity, affiliation, and complexity. All these factors can affect the flow rates of passages, and can be compressed into a Space Compressed Object (SCO), a symbol representing some variables. SCO is a space in STELLA to put relative or similar variables, which have relations between, together for further calculation without making the whole graph too complicated. SCO can be hidden from the desktop graph but still has influence on the desktop variables, such as the flow rate between compartments. The relations between control factors and the flow rate are demonstrated in Fig. 1.

In Fig. 1, every circle represents a factor or a computed variable that will influence the passage between two compartments. The arrows among factors indicate the relations among factors or variables. All the variables stand for the following:

- Faff: the factor of social affiliation of occupants
- Ffam: the factor of familiarity of occupants
- Fvis: the factor of access visibility
- Fcompl: the factor of complexity (difficulties) for a space to another
- Fpre: the factor of pre-movement time for one compartment
- Ften: the factor of tenable time for one space
- Fmov: the factor of occupant mobility

The “passage” variable is affected by the variables of “Faff”, “Ffam”, “Fvis”, “Fcompl”, “Fpre”, “Ften”, and “flow rate”. “Fpre” is produced from “pre-movement time” variable and “Ften” is created from “tenable time”. “Fpre” will open the passage from the beginning if pre-movement time is zero (occupants in room 1 escape immediately) and will close the passage if the simulation clock time is still smaller than the assumed pre-movement time (occupants will not move until they decide to). “Ften” has the same effects as “Fpre” except that it depends on the tenable duration of room 2. “Faff”, “Ffam”, “Fvis”, “Fcompl” will all be set to be one (open) in the following simulations to simply the movements. The “flow rate” is decided mainly from “distance”, “width”, “Fmov” (factor of occupant mobility), and “area1”.

The variable “density” can be computed from “area” and the occupant number of room1. With “density” value, the speed of occupants will be achieved by using the equation of Nelson and Maclennan [3]. After considering the mobility of occupants, the variable “adjusted speed” can be obtained by multiplying “speed” and “Fmov”. With the information of travel distance and speed, the travel time of occupants to room 2 can be calculated by dividing distance with speed. The variable “unit flow rate” means the flow rate per meter per second and can be estimated from the “density”. By multiplying “width” and “unit flow rate”, the width flow rate can thus be computed. All the variables in Fig. 1 are the main concepts of controlling the occupant movement from room 1 to room 2. The arrow between variables means the variable with the head of that arrow is affected by the variable with the start point of the same arrow. Therefore, in Fig. 1 we can identify that “flow rate” is affected by “width flow rate” and “travel time”. “travel time” is influenced by “distance” and “adjust speed”, and so on.

4.2 Constructing an ESM Configuration for the Building Evaluated

The next step is to construct the ESM configuration based on the physical geometry of the building. Fig. 2 [4] is the layout of an example building and Fig. 3 represents the ESM configuration for that building. In Fig. 3, “r” represents rooms. “l” stands for landings, “s” is stairs, “c” symbolizes corridors, “lo” depicts lobbies, and “d” presents destination. The first number behind the character is the floor where that room is located and the second one represents the enclosure number. For example: r31 represents the first room on the third floor. The passage between two rooms is named with the enclosures connected. For instance, r31_c31 stands for the passage between compartment r31 and compartment c31.

5. INFORMATION REQUIREMENTS

Because the study considered a more performance-based approach, both the people movement through the egress system, as well as the tenable duration inside the building must be reviewed. The former has to review the location of occupants, the pre-movement time factors (such as alertness, role, commitment, or status), the movement speeds related features (like, familiarity, clothing, audibility, visibility, moving ability, age, gender, training and occupant density) and the egress design. The latter needs to, if in a dynamic
situation, examine the design fire pertaining to the occupancy of that environment, smoke movement between compartments and the egress system, and the life safety criteria. After considering the race between occupant evacuation and smoke movement, the performance of an egress system -- how they can conduct the occupants out from the building safely, can thus be evaluated.

Based on the performance concept, an ESM model needs the information, which includes:

- The locations and numbers of building occupants
- Geometry layouts of egress paths and exits
- Selection of the room of fire origin
- Identification of the target spaces
- Development of design fires
- Decision of the tenability criteria (smoke layer height, smoke temperature, smoke toxicity etc.)
- Estimation of the tenable duration based on the criteria chosen
- Situations assumption (static or dynamic blockage)

After collecting the information needed and running the ESM model, some output can be obtained.

Fig. 1: Factors controlling the occupant flow rate between two rooms
6. OUTPUT INFORMATION

The output information of an ESM model can demonstrate the value changes of different variables, such as occupants in every compartment, flow rate at any passage and the operational variables (such as “open” or “close”), during simulations. Fig. 4 to Fig. 8 are the relations of simulation clock time to the numbers of successful evacuees at the destinations in both cases (ROO, representing the room of fire origin, at r31 and r21) with various pre-movement times (0-0-0 means an ideal evacuation; 10-20-30 indicates 10 seconds for the ROO, 20 seconds for the other rooms on the fire floor and 30 seconds for the rooms on non-fire floors). Fig. 4 demonstrated the occupant numbers arriving destination 1 and destination 2 with no pre-movement time, which means occupants escaping immediately. X-axis stands for the time in seconds, while Y-axis represented the occupant numbers. More people seemed to escape to destination 2 at about 160 seconds. In Fig. 5, with different pre-movement time, the shape of the curves seemed similar to Fig. 4, but the total evacuation time became increased. In Fig. 6, with longer pre-movement time than those of Fig. 5, occupants tended to have two sections of arrivals in curve 2. In Fig. 7, the room of fire origin was changed but the pre-movement times were the same as those of Fig. 5. It explained that more occupants using destination 2 but spending less time than that of Fig. 5. Fig. 8 showed different curves from those of Fig. 6 with other room of fire origin. Fig. 9 illustrated the flow rates of passages in the third floor. The passages near the room of fire origin seemed to have persons movement sooner than others.

The changes of occupants in every enclosure and the flow rate at any passage selected can also be the output of ESM. Fig. 9 to Fig. 11 demonstrated the occupant changes in different floors when ROO is at R31 and the Pre-movement time is 30,60,120.

7. VALIDATION OF MODEL

In this section, the ESM method will be used to simulate two experiments in one terminal of Taipei Mass Transportation System in Taiwan [5]. This terminal has three floors, one ground level and two underground storeys. The upper underground floor is a lobby, which connects with some underground shopping streets. The lower underground level is a platform. In the future, this terminal is planned to link with other stations by constructing more underground streets at the lobby level.

The experiments of people movement were conducted on January 30th in 1997. In the exercises, there were totally 513 persons involved, including 478 college students and 35 staff from this terminal. The student occupants were located at the platform area (Fig. 12) in the beginning of each experiment and evacuated to the ground level. There were some rules in this evacuation:

- All the occupants evacuated at the same time when the fire alarm system went off.
- In the process of evacuation, people did not turn back.
- Occupants did not delay for escape.
- Human responses were not considered in this experiment.
- Evacuees located in the platform area in average density.
- Involved persons knew the escape routes and would choose the nearest exit except when led by staff arranged in the exercise (the second experiment).
Fig. 3: Constructed ESM Model for the example building (with SCO hidden)

Fig. 4: Evacuees at Destinations (ROO: R31; 0,0,0)
(Y-axis means no. of occupants)
Graph 1: p6 (destination-pre-10,20)
Fig. 5: Evacuees at Destinations (ROO: R31; 10,20,30)
(Y-axis means no. of occupants)

Graph 1: p6 (destination-pre-30,60)
Fig. 6: Evacuees at Destinations (ROO: R31; 30,60,120)
(Y-axis means no. of occupants)

Graph 1: p6 (r21-destination-pre-)
Fig. 7: Evacuees at Destinations (ROO: R21; 10,20,30)
(Y-axis means no. of occupants)
Fig. 8: Evacuees at Destinations (ROO: R21; 30,60,120)  
(Y-axis means no. of occupants)
7.1 Experiment Results

In the beginning of experiments, the passengers are assumed to stay at the platform areas and evacuate to the ground level. The platform was divided into four areas: A, B, C, and D (Fig. 12). The first experiment was in Area-A and assumed to have 172 persons in this area. All occupants escaped from the two sides of the stair in Area-A. The area clearing time (the time when the last passenger entered the staircase) for this experiment is 23 second and the total evacuation time was one minute and 40 seconds. The second experiment was conducted at Area-B and 506 participants were arranged. In the first 23 seconds of the experiment, occupants had to use one of two escalators because another one could not be used. After 23 seconds, some occupants could walk to Area-A and use the stair (only one side of the stair) to evacuate due to the instruction of terminal staff. The area clearing time for experiment 2 was 2 minutes 40 seconds and the total evacuation time was 4 minutes 34 seconds.

7.2 ESM Simulations

This study constructed two ESM models to simulate the two evacuations. Fig. 13 was the model of the first experiment, while Fig. 14 represented the arrangement of the second one. In these two models, “R” depicted the divided spaces; “S” described the staircase; “E” displayed the escalator, which was not in operation during the evacuations; and “D” illustrated the destinations. In Area-B simulation, the flow from Area-B to Area-A was blocked for 23 seconds.

The output of two models is collected from Figs. 15 to 18. Table 1 depicted the main results of ESM simulations. From this table, we can identify that both the platform clearing time and the total evacuation time of the ESM simulations are within 4.3 % differences when compared to the experiment results.
Table 1: Experiments and simulation results

<table>
<thead>
<tr>
<th>Platform clearing time (sec)</th>
<th>Area A (172 persons)</th>
<th>Area B (506 persons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>23 s</td>
<td>160 s</td>
</tr>
<tr>
<td>Simulation</td>
<td>24 s (4.3 %)</td>
<td>167 s (4.3 %)</td>
</tr>
<tr>
<td>Total evacuation time (sec)</td>
<td>Experiment</td>
<td>100 s</td>
</tr>
<tr>
<td></td>
<td>Simulation</td>
<td>98 s (2 %)</td>
</tr>
</tbody>
</table>

Fig. 13: ESM model for Area-A Experiment
Fig. 14: ESM model for Area-B Experiment
7.3 Sensitivity Test of ESM

This section will discuss the sensitivity tests of the main variables in ESM to the total evacuation times. Speed and Flow rate can be selected as the important factors that affect the evacuation times. In order to have simple illustration and to demonstrate their total influence of ESM’s result, the factors of “Faff”, “Ffam”, “Fvis”, “Fcompl” will be combined to be one element (called Factor F), which has influence on speed and flow rate. One limitation of ESM has to be mentioned that the factors of “Faff”, “Ffam”, “Fvis”, “Fcompl” can only be demonstrated in the passage between two spaces. They cannot be connected to individuals. This is also the feature of a network model and also becomes the confinement of ESM.

Tables 2 to 5 demonstrate the different evacuation times by changing various variables (such as speed, flow rate, and Factor F) for the example building. Figs. 19 to 22 represent the trend lines from Tables 2 to 5. From these Tables, we can identify that these variables have influence on the total evacuation time. When the speed is less than 0.9 ms⁻¹ or flow rate is below 1.3 persons/sec/m, they have greater impacts on the results (Figs. 19 and 20). If Factor F affects flow rate directly, it has more effect on the total evacuation time (Figs. 21 and 22).
Table 2: Evacuation times from different travel speeds

<table>
<thead>
<tr>
<th>Speed (ms(^{-1}))</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evacuation time (sec)</td>
<td>209</td>
<td>195</td>
<td>184</td>
<td>174</td>
<td>156</td>
<td>156</td>
<td>156</td>
<td>152</td>
<td>151</td>
<td>149</td>
<td>148</td>
</tr>
</tbody>
</table>

Table 3: Evacuation times from different flow rates

<table>
<thead>
<tr>
<th>Flow rate (persons/sec)</th>
<th>1</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evacuation time (sec)</td>
<td>192</td>
<td>178</td>
<td>168</td>
<td>156</td>
<td>147</td>
<td>145</td>
</tr>
</tbody>
</table>
Table 4: Evacuation times from different values of factor affecting speed

<table>
<thead>
<tr>
<th>Factor (speed)</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evacuation time (sec)</td>
<td>359</td>
<td>275</td>
<td>233</td>
<td>209</td>
<td>195</td>
<td>184</td>
<td>174</td>
<td>156</td>
<td>156</td>
</tr>
</tbody>
</table>

Table 5: Evacuation times from different values of factor affecting flow rate

<table>
<thead>
<tr>
<th>Factor (flow rate)</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evacuation time (sec)</td>
<td>646</td>
<td>443</td>
<td>337</td>
<td>274</td>
<td>234</td>
<td>206</td>
<td>187</td>
<td>171</td>
<td>156</td>
</tr>
</tbody>
</table>

Fig. 19: Relation of speed and evacuation time

Fig. 20: Relation of unit flow rate and evacuation time
8. CONCLUSION

ESM can simulate the occupant movement in static or dynamic blocking building during an emergency. ESM can also be used to predict the occupant movement situations, such as the clearing times of different compartments or floors, the destination arrival times and numbers of occupants, and the changes of destination conditions when any path is blocked. ESM can be applied to understand the performance of a building egress system in emergencies and thus to identify the potential risk of the egress paths in the building evaluated and then producing some fire protection measures. If an egress system is appropriately evaluated or designed, the victims during an emergency may decrease.

REFERENCES