Evaluation of Fire Safety Measures in Care Facilities for the Elderly by Simulating Evacuation Behavior

SHUJI KAKEGAWA and YOSHIRO YASHIRO
Institute of Technology, Shimizu Corporation
3-4-17 Etchujima Koto-ku Tokyo 135, Japan

MANABU EBIHARA and AKIRA OHTSUKI
Ohsaki Research Institute, Shimizu Corporation
2-2-2 Uchisaiwai-cho Chiyoda-ku Tokyo 100, Japan

ABSTRACT

The purpose of this study was to evaluate the effects of fire safety measures on evacuation safety in care facilities for the elderly. Fire safety measures include fire protection provisions and management profiles. In order to accomplish this goal, the authors developed an evacuation simulation model, which could simulate rescuers' behavior to assist non-ambulatory occupants. It is implemented by using the object-oriented computer language, Smalltalk. The model can set conditions concerning each occupant's egress ability and track the movements of individual occupants or rescuers. To examine the performance of the model, several case studies were conducted for two types of care facilities. In the case studies, the effects of several fire safety measures were evaluated from two points of view: building safety features in relation to the spread of smoke and the evacuation risk. From the results of the case studies, the effectiveness of fire safety measures was discussed.
KEYWORDS: evacuation model, object-oriented modeling technique, care facility, rescuing behavior, fire safety measures

1. INTRODUCTION

In incorporating fire safety into the design of a building, the presence of disabled persons has rarely been taken into account. However, recently some regulations addressed the requirements of accessibility and egressibility for disabled persons [1], necessitating consideration of disabled occupants in fire safety design. For that reason, a quantitative evaluation method on evacuation safety for the disabled has become necessary. Archea [2] addressed the problem of the evacuation of non-ambulatory patients in hospitals and nursing homes. In that study, several phases during an evacuation, for example, manpower supply or patient preparation, were identified as factors influencing evacuation behavior.

Evacuation behavior of the disabled has several characteristics compared with the able-bodied; 1) need for assistance in movement, 2) preparation by staff for the evacuation and 3) use of appliances in movement. Based on these behavioral characteristics, Shield et al.[3]

suggested that the next generation of evacuation models: 1) should accommodate people with mixed abilities 2) are not predicated on invalid assumptions, 3) accept management fire safety profiles as input and 4) cope with contra flows which in reality occur in escape routes.

Many models simulating evacuation behavior have been proposed. However, only a few of these models are capable of simulating the rescuing behavior [3]. Modeling methods of evacuation and rescue are a little different among these models. For example, the Escape and Rescue Model [4] handles network flow, so it can predict global aspects of evacuation. BFIRES-II [5] can track the individual movements of people based on perceptual and behavioral response. It can get more detailed information about the results of evacuation.

The safety of the occupants during an evacuation is also influenced by fire safety measures; fire protection provisions and management profiles. The spread of smoke in a building is influenced by fire protection provisions such as an automatic sprinkler system. Evacuation risk is influenced by management profiles such as the number of facility staff members. For disabled occupants, in particular, management profiles seem to have a great influence on evacuation safety because such people need assistance to egress.

The purpose of this study was to evaluate the relative effects of fire safety measures on evacuation safety in care facilities for the elderly. In an effort to meet this need, the authors have therefore developed a model to simulate evacuation behavior during a fire. This model can take into account the rescuers' behavior to help non-ambulatory occupants. In this study, a number of case studies were carried out by using the evacuation model. In the case studies, the effects of several fire safety measures were evaluated from two points of view: building safety features in relation to the spread of smoke and the evacuation risk to the occupants.

2. DESCRIPTION OF THE EVACUATION MODEL

The evacuation model is a deterministic simulation program implemented by the object-oriented computer language, Smalltalk [6]. It is more sophisticated than the previous version [7]. The model comprises three sub-models; the space model, smoke model and human model. The simulation process corresponds to information exchange between the sub-models. The object-oriented approach allows us to improve the model easily, because the sub-models are constructed as separate objects identified in the object-oriented approach. Evacuation behavior is determined from the response to a change in the local environmental conditions. Psychological factors influencing evacuation behavior are not considered. The advantages of this model are: 1) to handle the evacuation of persons with mixed abilities including rescuers, 2) to change egress routes in accordance with environmental conditions and 3) to handle contra-flows which typically occur between occupants and rescuers.

2.1 Space Model

The space model deals with modeling space of a building. Currently, the model can only encompass one floor having a fire. Floors, rooms and doors are also defined as separate objects. A floor is assumed to be a set of rooms and a room is defined by a list of walls and doors which contains data about the X-Y positions. Doors have information about connections between rooms. Persons can move freely in a room by handling space information in a geometrical manner. The space model can set a guide light in a room to provide information about the egress direction for ambulatory occupants. This model plays a role as an information exchange unit between other sub-models.

2.2 Smoke Model

The smoke model play a role in transferring data about the spread of smoke to the space model. To predict the spread of smoke, the two-layer zone model is employed [8]. Using the results of smoke simulation, physiological impact of smoke at time *t*, *S(t)*, is calculated for each room. *S(t)* is given by the following equation:

$$S(t) = \sum_{ts}^{t} (\Delta T)^2 \delta t \tag{1}$$

where δt is time interval for simulation (in this study, 1 second), *ts* is the smoke-exposure starting time, and ΔT is the temperature rise in the smoke layer. *ts* is defined as the time when the smoke layer interface reaches below the head of an evacuee (1.8 m). If *S(t)* in a room *i* becomes over 4,000, the room *i* is assumed to reach the critical egress time [9], *te*, when any persons in the room *i* are assumed to become victims. After falling under *te*, the room is blocked due to smoke and anyone cannot enter there. Data of *te* for each room is transffered to space model as input. Although *S(t)* is calculated based on temperature, the standard is determined considering impact of smoke production on the evacuees [9]. In this model, the influence of people's movement on smoke movement cannot be considered because the two-layer zone model is separated from the evacuation model.

2.3 Human Model

The human model deals with the decision making process for determining the evacuation route and the position of a person. In the model, three types of people are modeled; an ambulatory occupant, a non-ambulatory occupant and a rescuer. Rescuers play a role in assisting non-ambulatory occupants. Non-ambulatory occupants are classified into two categories in accordance with their mobility: those who need assistance with 1) a wheelchair and 2) a stretcher. In the model, all people are modeled in circles individually considering spatial requirement of each persons including an appliance. It is important factor in predicting interactions between peoples, for example, congestion or contra-flows.

The decision making process of occupants and rescuers is defined as shown in Figure 1. At first, they select two types of targets: a short term target and a long term target. The short term target indicates a place which people should pass through (for example, a door). The long term target indicates a place to which people finally escape (for example, a vestibule or a balcony). People continue evacuation until they reach a long term target.

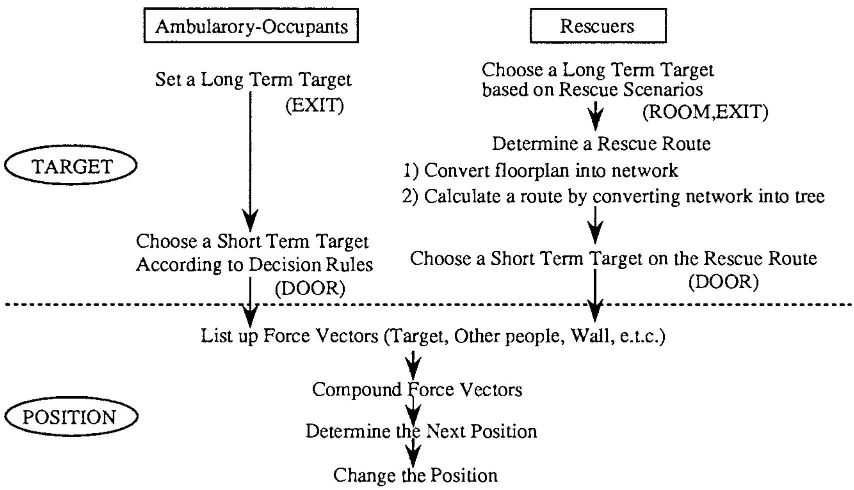


FIGURE 1. Decision Making Process of the Human Model

Rules governing the decisions occupants make when choosing a target are: 1) if there is at least one exit, choose the closest exit, 2) if there is a guide light, choose the closest door in the direction indicated by the guide light, 3) if no information is available, choose the closest door. If there are someone at a door or an exit, a person stays in front of it until they finish passing through. It enables the model to take into account congestion. Rescuers can change long term targets in accordance with the rescue scenarios to determine the order of the rooms for rescue. It enables rescuers to repeat the rescue of non-ambulatory occupants. To find a rescue path, a tree is constructed which links the room in question with the long term target using the network description of a building. After that, the rescue route is calculated. In this model, network information is available only to calculate rescue routes. Kostreva et al. [10] proposed a calculation method of an evacuation route using multiple criteria; length of a route, cost or time. An algorithm for dynamic optimal path finding involves many problems for future studies. To make it simple, this model accounts for only the number of nodes from the current room to the long term target in determining the optimal egress route.

In determining the position of a person, several objects are assumed to have an influence on a person. They include the escape target (a door or an exit), wall, smoke and other persons. The effects of the physical objects on the person are represented by force vectors which can be attractive or repulsive. The moving direction of a person is determined by calculating the force vectors applied by these physical objects. The magnitude of the force vectors is calculated by a function of the distance between physical objects and the person. From the direction of the compounded vectors and the travel speed initially defined for each person, the position at the next step is determined. Many studies have been done on modeling the walking speed of people in a crowd. For example, Predtechenskii and Milinskii indicated that the walking speed was influenced by the density of a crowd [11]. However, in this model, it is assumed to be kept constant. That is because the density of people is not so high in the care facilities which are the main targets of the current version of the model.

3. EVALUATION PROCESS FOR EVACUATION SAFETY

Figure 2 shows the evaluation process for evacuation safety using the proposed model. Data regarding building features which include size of rooms or doors and a connection between rooms are used for both simulation models. Conditions pertaining to fire protection provisions are considered in the two-layer zone model; for example, the heat release rate at the fire origin and the door opening scenario. Conversely, conditions pertaining to management profiles are considered in the evacuation model; for example, the number of rescuers, rescue scenarios and the initial location of the occupants.

As inputs of the simulation model, two kinds of emergency scenarios should be assumed; fire scenarios and evacuation scenarios. Fire scenarios are dealt with by the two-layer zone model and handle the room where the fire originated and the time history of the heat release rate etc. Evacuation scenarios are dealt with by the evacuation model and handle the starting time of egress and rescue, rescue priorities etc.

Especially, in the evacuation of disabled occupants, certain behavior essential to providing assistance greatly influences the total evacuation time. In this model, horizontal speed, preparation time, elapsed time though a door and spatial requirements are taken into account as the simulation parameters for evacuation capability. Preparation time means elapsed time to remove a non-ambulatory occupant to an appliance. Table 1 presents the simulation parameters for the evacuation behavior, which are determined from the results of a survey conducted by the Tokyo Fire Department [12]. Hall has conducted a similar survey for patients in hospitals [13] and the results is a little different from those in Table 1. In this study, data in Table 1 is employed because the survey by the Tokyo Fire Department was conducted for the heavily disabled occupants in care facilities for the elderly. Parameters for rescuers change to ones for non-ambulatory occupants during rescue.

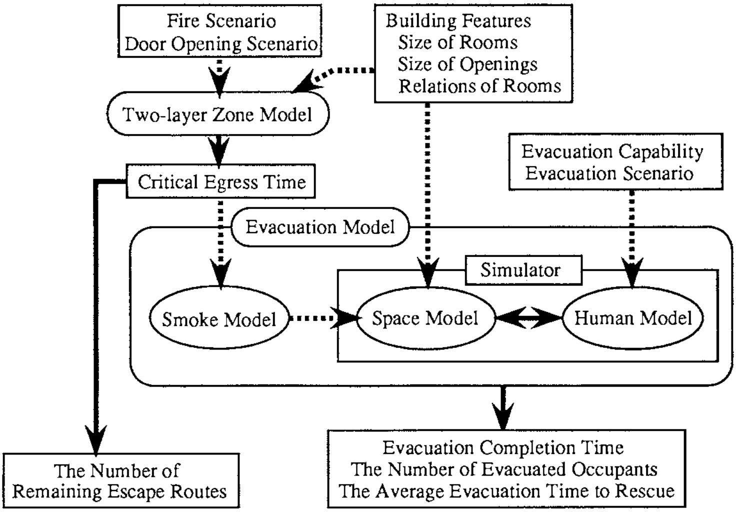


FIGURE 2. Evacuation Safety Evaluation Process Using the Model

TABLE 1. Simulation Parameters for Evacuation Behavior

	Horizontal Walking Speed	Preparation Time	Elasped Time though a Door	Spatial Requirement (diameter of the circle)
Ambulatory Occupants	0.5 m/sec.	---	---	0.5 m
Non-Ambulatory Occupants (Wheelchair-bound)	[1.5 m/sec.]	[15 sec.]	[9 sec.]	0.5 m [0.7 m]
Non-Ambulatory Occupants (Stretcher-bound)	[1.5 m/sec.]	[25 sec.]	[9 sec.]	0.5 m [1.0 m]
Rescuers	2.0 m/sec.	---	---	0.5 m

Values in parentheses are ones for rescuing non-ambulatory occupants.

Evacuation safety was evaluated from two points of view; the spread of smoke and evacuation risk. The spread of smoke was evaluated by the number of remaining escape routes to an indoor temporary safety zone. The index expresses building features for preventing the spread of smoke and depends almost entirely on the kinds of fire protection provisions. That is calculated by using the critical egress time for each room derived from the two-layer zone model. Evacuation risk was evaluated by evacuation completion time, the number of evacuated occupants and the average evacuation time required for rescue derived from the evacuation model.

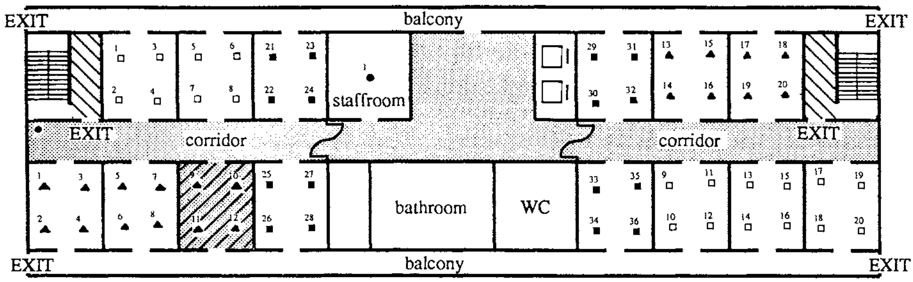
4. CASE STUDIES

Case studies are conducted by using the evacuation model. Two types of facilities are chosen for the case studies. They are hypothetical facilities with different types of floor plans: a center-corridor type and a rectangular type (Figure 3). They are modeled to compare the effect of the floor planning. In each facility, there are twenty ambulatory occupants, twenty requiring wheelchairs and sixteen needing stretchers. The occupant's ratio in mobility is an average for care facilities in Tokyo and it is derived from the results of a survey on care facilities for the elderly conducted by the Toyo Fire Department [12].

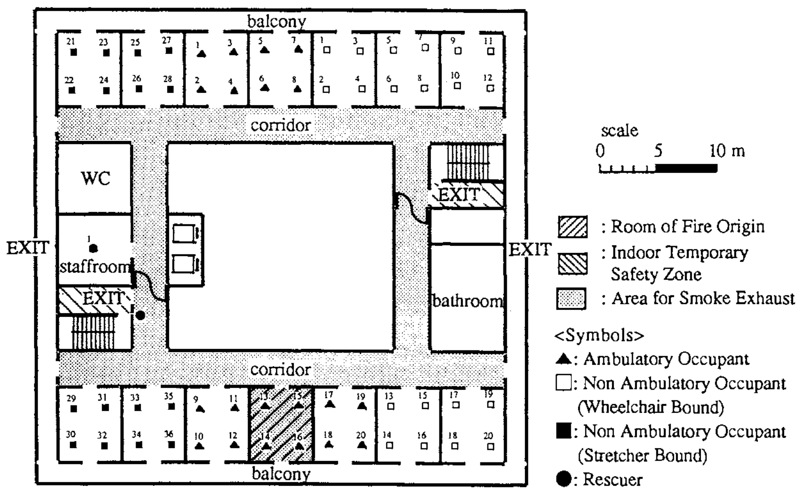
In the case studies, only the floor having a fire is evaluated. Temporary safety zones are located at the vestibules of the staircases and at each side of the balcony. If an evacuee reaches a temporary safety zone, he is assumed to have completed the evacuation. Table 2 shows the conditions in the case studies pertaining to fire safety measures. To compare the effect of the spread of smoke, the cases without any spread of smoke are also examined.

4.1 Initial Conditions

In the case studies, two initial locations are assumed for occupants: 1) grouped with those having the same mobility and 2) randomly. Rescuers on the fire floor are located in the staff room. Rescuers who come from the other floors are considered to be near the vestibules because this model can only encompass one floor having a fire. However, a delay time in reaching the fire floor is incorporated by delaying the starting time of the staff.



(a) Center-Corridor Type



(b) Rectangular Type

FIGURE 3. Floor Plans of Example Facilities in the Case where Occupants with the Same Mobility are Located as Groups

TABLE 2. Conditions in Case Studies

Floor Type		Spread of Smoke	Fire Protection Provisions			Management Profiles	
C	R		Sprinkler	Horizontal Compartment	Smoke Exhaust	Number of Staff	Initial Location
Case A1	Case B1	---	---	---	---	3	G
Case A2	Case B2	---	---	---	---	6	G
Case A3	Case B3	---	---	---	---	9	G
Case A4	Case B4	O	---	---	---	3	G
Case A5	Case B5	O	---	---	---	6	G
Case A6	Case B6	O	---	---	---	9	G
Case A7	Case B7	O	---	---	---	3	R
Case A8	Case B8	O	O	---	---	---	---
Case A9	Case B9	O	---	O	---	---	---
Case A10	Case B10	O	---	---	O	---	---
Case A11	Case B11	O	---	O	O	---	---

O; Considered,---; Not Considered Floor Type: C; Center-corridor, R; Rectangular
Initial Location: G; Grouped, R; Random

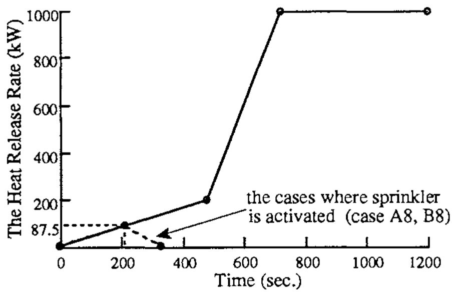


FIGURE 4. Heat Release Rate at the Fire Origin

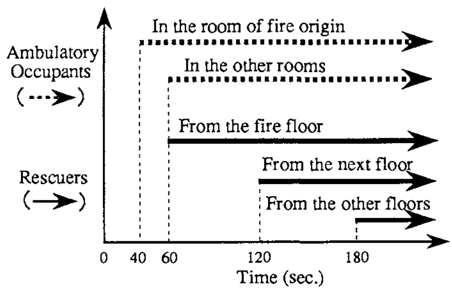


FIGURE 5. Evacuation and Rescue Scenarios

A fire is assumed to occur in a bedroom, reference to which is made from the statistics of the previous fire accidents in Tokyo [12]. The statistics indicates that 16 % of fires originated in bedrooms (1982-91). The heat release rate at the fire origin is determined in accordance with the standard fire origin for a bedroom in a hospital (Figure 4) [9].

Evacuation and rescue scenarios are determined as shown in Figure 5. A fire alarm is assumed to go off at the time when the depth of the smoke layer in the room where the fire originated exceeds 10 cm. In this study, it was determined by the two-layer zone model to be 30 seconds from ignition. 10 seconds after the fire alarm was activated, ambulatory occupants in the fire room start to egress. The egress starting time of the ambulatory occupants depends on the initial location. The evacuation starting time of the non-ambulatory occupants is contingent on the rescue scenarios involving the staff members. The rescue starting times are determined from the response delay lapse time in relation to the initial location. In this study, indoor temporary safety zones (vestibules) are given priority for evacuation. Physically disabled evacuees are rescued from rooms nearest to the fire origin.

4.2 Evaluation Parameters

In the case studies, fire protection provisions and management profiles are considered to be the parameters for evaluating the effects on evacuation safety. The conditions regarding fire protection provisions are dealt with in the two-layer zone model. The effect of activation of a sprinkler system is expressed by the heat release rate at the fire origin (Figure 4). A horizontal compartment which is a subdivision of the corridor works to prevent smoke from spreading by closing the fire doors and enables disabled occupants to egress horizontally. A natural smoke exhaust system is assumed to be installed in the bedroom and corridor. The operation time for each fire protection provision is defined as follows:

1) Sprinkler system is assumed to activate when the average temperature in the smoke layer exceeds eighty degrees derived from the two-layer zone model (in this study, 210 sec.). After it works, the heat release rate is assumed to become 0 kW in two minutes.
2) Horizontal compartmentation is assumed to work when the smoke spreads to the next space of the compartment.
3) A natural smoke exhaust system is assumed to work when the facility staff from the non-fire floor reaches the floor having the fire. Smoke was exhausted by opening the windows in the fire room and the corridor.

In the facility, it is assumed that there are certain facility staff members; one on the fire floor, one each from the floors next to the fire floor, and six on the other floors. In order to evaluate the number of facility staff members, three different cases are considered: 1) three staff members from the fire floor and adjacent floors, 2) six staff members including those from other floors, and 3) nine staff members. The results of a recent survey on care facilities in Tokyo [12] indicated that the ratio of non-ambulatory occupants to one facility staff was about twelve to one on average at night. Therefore, a total of three staff members represents an average for facilities in Tokyo.

The number of assistants required for a non-ambulatory occupant is considered to be one for the wheelchair-bound and two for the stretcher-bound. The team combination of assistants for each case is shown in Table 3. It cannot be changed during the simulation. To compare the effect of the number of staff, the ratio of assistants between wheelchairs and stretchers is kept constant.

TABLE 3. Team Combination of Rescuers for Non-ambulatory Occupants

	Three Rescuers	Six Rescuers	Nine Rescuers
Wheelchair	1 (1)	2 (2)	3 (3)
Stretcher	2 (1)	4 (2)	6 (3)
Total	3 (2)	6 (4)	9 (6)

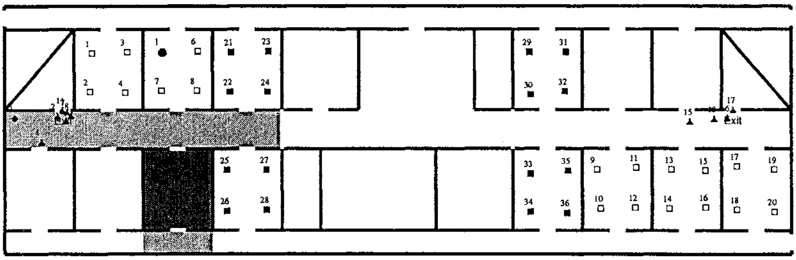
Non-ambulatory occupants using stretcher are assisted by two staff.
Number in parentheses expresses the number of rescue teams.

5. RESULTS AND DISCUSSION

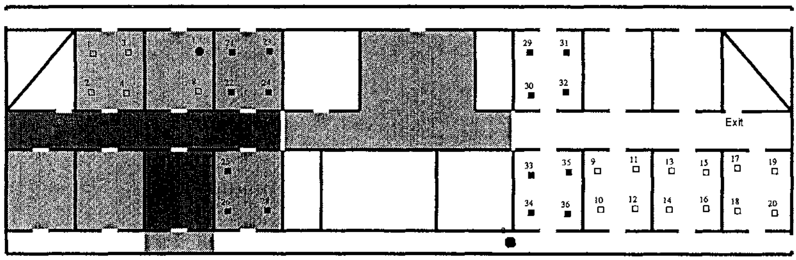
Figure 6 illustrates example outputs of the evacuation model (case A4). At 90 seconds after ignition of the fire, ambulatory occupants are escaping to the indoor exits and congestion occurs in front of both exits. Since the indoor egress route near the fire origin is obstructed by smoke at 210 seconds, the balconies are used for evacuation by a rescuer. Based on these kinds of outputs, the results concerning evacuation behavior are given as shown in Figure 7.

5.1 Effect of Fire Protection Provisions

Figure 8 shows the relationship between the time and the number of bedrooms from which people can evacuate to indoor temporary safety zones. If any indoor egress routes from a bedroom are obstructed by smoke, the evacuees must use the balcony to egress. Figure 8 indicates that both floor plans demonstrate similar smoke spread characteristics when fire protection provisions exist. This may be so because the spread of smoke is limited if the fire protection provisions work.

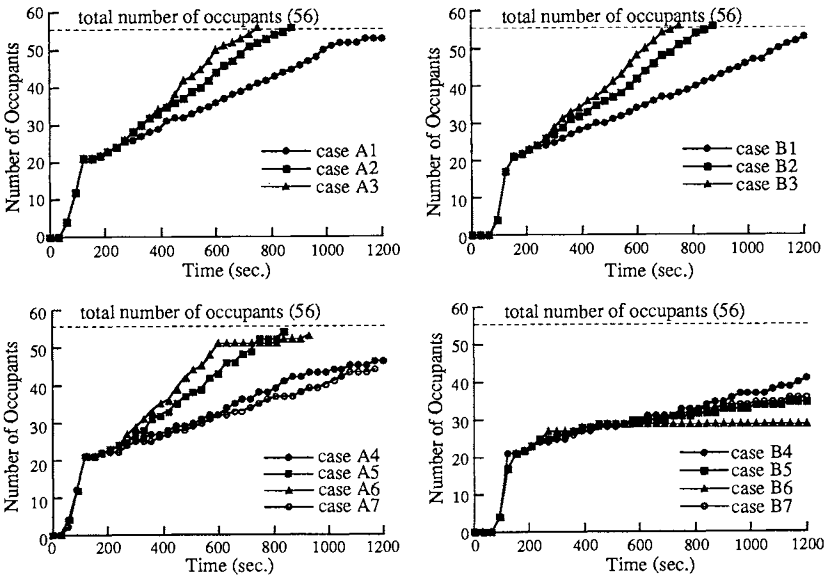


(a) at 90 seconds after ignition of a fire



(b) at 210 seconds after ignition of a fire

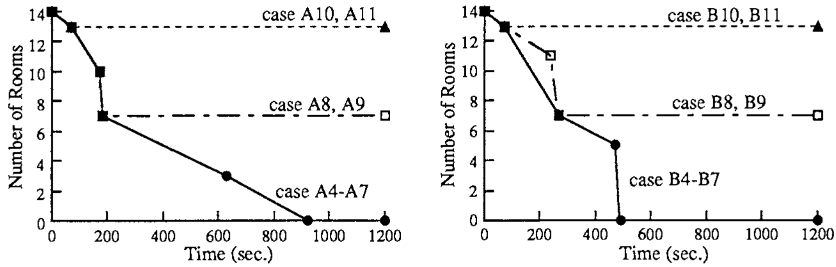
FIGURE 6. Example Outputs of the Evacuation Simulation (case A4): Area in light gray is one for spreading smoke and area in dark gray is one for falling under the critical egress time.



(a) Center-Corridor Type

(b) Rectangular Type

FIGURE 7. Relationship between Time and Number of Evacuated Occupants



(a) Center-Corridor Type (b) Rectangular Type

FIGURE 8. Relationship between Time and Number of Bedrooms from which People Can Evacuate to Indoor Temporary Safety Zones.

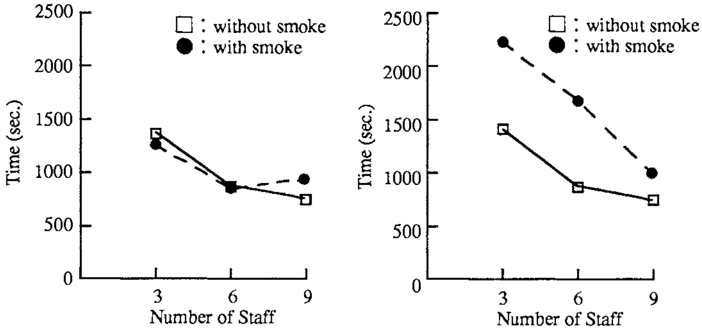
In cases without fire protection provisions, it is clear that most of the egress routes become obstructed in the early stage of the fire. In these cases, floor plans may influence the spread of smoke. In activating automatic sprinklers, some egress routes near the fire origin fall under the critical egress time because of the delay to operate. Although a horizontal compartmentation makes a non-fire zone safer, it makes the fire zone more dangerous than in the case where no fire protection equipment exists. That is because it encloses smoke within the fire zone. If it exists together with the smoke exhaust system, it may be safe enough to evacuate non-ambulatory occupants to the non-fire compartment on the same floor.

5.2 Effect of Management Profiles

Figure 9 shows evacuation completion time in the cases without fire protection provisions. In the center-corridor type, evacuation completion time in the cases with the spread of smoke is not so different from in those without it. Conversely, in the rectangular type, the spread of smoke clearly influences evacuation completion time especially with fewer facility staff members. The difference in the results may be caused by the early spread of smoke in the rectangular type as shown in Figure 8.

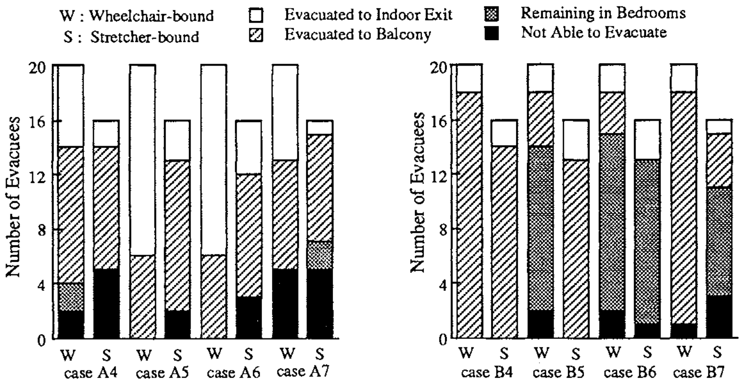
Figure 10 shows the results of evacuation for non-ambulatory occupants classified by their mobility. All the ambulatory occupants are evacuated safely by using the indoor egress routes. Conversely, most of the non-ambulatory occupants are evacuated to the balconies. Evacuation to the balconies indicates that evacuation routes were changed in accordance with a change in the environmental conditions because indoor egress routes are given priority for evacuation in this study. In order to evacuate non-ambulatory occupants safely, balconies which are available for escape may be needed. A smaller number of staff members or random occupant locations creates a more dangerous situation for non-ambulatory occupants. In the rectangular type cases, staff are obstructed by smoke during evacuation because of congestion near indoor exits. Therefore, many non-ambulatory occupants have to remain in the bedrooms when staff cannot continue rescue operations. Giving priority to the balconies for evacuation seems to put non-ambulatory occupants and facility staff in less danger.

Figure 11 shows the average time to evacuate a non-ambulatory occupant in the case where the spread of smoke is not considered. More time is required in the case of a larger number of staff members because contra-flows in the corridors or congestion near the door or the exit easily occur. Especially, contra-flows will have great influence in these kinds of facilities because they often occur in the escape routes between evacuees and rescuers. The floor plans do not have so much influence on the average evacuation time for a non-ambulatory occupant in these cases. In the cases where the spread of smoke is considered, it is difficult to compare the efficiency of evacuation with one another, because some staff are obstructed by smoke during evacuation in the several cases.



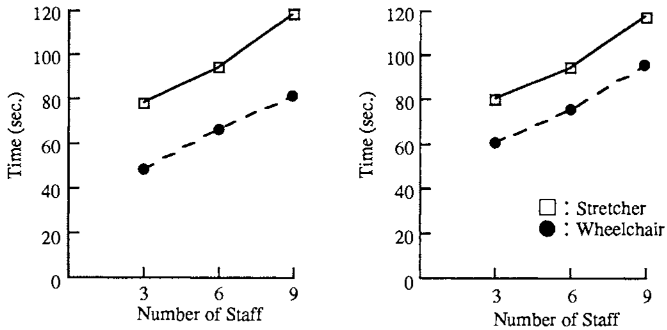
(a) Center-Corridor Type (b) Rectangular Type

FIGURE 9. Relationship between Number of Staff and Evacuation Completion Time



(a) Center-Corridor Type (b) Rectangular Type

FIGURE 10. Results of the Evacuation Simulation for Non-ambulatory Occupants



(a) Center-Corridor Type (b) Rectangular Type

FIGURE 11. Average Evacuation Time for a Non-ambulatory Occupant in the Cases where the Spread of Smoke is not Considered (case A1-A3, B1-B3)

6. CONCLUSIONS

By using the developed evacuation model, the effects of fire safety measures were evaluated comparing with the results of the case studies. The important advantage of the model is to accept fire safety measures as inputs. In the case studies, giving priority to indoor egress routes seems to influence the conclusions. Furthermore it is necessary to compare the effects of means of egress, for example, horizontal evacuation to other compartments, vertical evacuation by elevator etc. The evacuation simulation provides a quantitative evaluation method for fire safety measures to aid building designers. The evacuation model now under development can possibly be applied to the performance based design of a building. It will be needed to verify the validity of the model's simulation results in relation to actual fire accidents. The object-oriented approach allows us to improve the model easily. It is very important so that new findings from the future research be incorporated into the model.

To advance research, future studies should be undertaken in three areas: 1) evaluation of psychological factors that affect perception and egress activities, 2) appropriate optimal path finding methods based on the recollections and experience of people and 3) establishment of valid scenarios. To evaluate the effects of fire safety measures appropriately, the fire and evacuation scenarios should be determined in reference to previous fire accidents. For example, the work of Lerup et al. [14] will be instructive in this field of research.

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REFERENCES

1. for example, BS 5588 Part 8, Means f Escape for Disabled People, British Standards Institution, 1988, HMSO.
2 Archea, J.:"The Evacuation of Non-Ambulatory Patients from Hospital and Nursing Home Fires: A Framework for A Model," NBSIR 79-1906, 1979
3. Shields, T.J. and Dunlop K.E.:"Emergency Egress Models and the Disabled," Conference Proceedings of the sixth International Interflam Conference, 143-150, 1993
4. Alvord, D.M.:"The Escape and Rescue Model: A Simulation Model for the Emergency Evacuation of Board and Care Homes," NBS-GCR 83-453, NBS, 1983
5. Stahl, F.I.:"BFIRES-II: A Behavior Based Computer Simulation of Emergency Egress During Fires," Fire Technology, 18, 49-55, 1982
6. Pinson, L.J. and Wiener, R.S.: An introduction to object-oriented programming and Smalltalk, Addison-Wesley Publishing Company Inc., 1988
7. Ebihara, M., Ohtsuki, A. and Iwaki H.:"A model for simulating human behavior during emergency evacuation based on classificatory reasoning and certainty value handling," Microcomputer in Civil Engineering, 7: 1, 63-71, 1992
8. Tanaka, T:"A model of multiroom fire spread," NBSIR 83-2718, NBS, 1983
9. Ministry of Construction in Japan: Report on fire safety design methods for buildings (in Japanese), 1988.
10. Kostreva, M.M., Wiecek M.M. and Getachew T.:"Optimization Models in Fire Egress Analysis for Residential Buildings," Proceedings of the third international symposium on fire safety science, 1992
11. Predtechenskii, V.M. and Milinskii, A,I.:"Planning for Foot Traffic Flow in Buildings," Amerind Publishing Company Inc., New Delhi, 1978
12. Fire Prevention Conference hosted by the Tokyo Fire Department:"Report on the appropriate fire safety measures in facilities for the disabled (in Japanese)," 1993.
13. Hall J.:"Patient Evacuation in Hospitals," Fires and Human Behaviour, pp. 205-225, John Wiley & Sons Ltd., 1980
14. Lerup L., Cronrath D. and Liu J.K.C.:"Fires in Nursing Facilities," Fires and Human Behaviour, pp. 155-180, John Wiley & Sons Ltd., 1980