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SIMULATION OF CONDUCT OF EVACUEES CONSIDERING THE REACTION OF EVACUEES' CONDUCT TO GUIDE'S INSTRUCTION IN AN EMERGENCY

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ABSTRACT

People who gather in complex spaces such as underground shopping centers or department stores would face great danger in emergency situations such as earthquake and / or fire. It is very important that owners or salesclerks who are responsible for safety in such places know how to lead evacuees to exits safely and quickly. In order to simulate the behavior of evacuees and guides under such a situation, we developed a computational model by using genetic codes used in genetic algorithm. This model simulates not only the behavior of guides and evacuees but also the interaction between evacuees' to guide's instructions. Furthermore, we applied this simulation model to the underground shopping center in Tokyo to determine number of evacuees who could be killed, the actual time of complete evacuation altered by the changes in the percentage of evacuees who know the way to the exits and the number of guides. As a result, we found that evacuees can evacuate more quickly with a guide's instruction.

KEYWORDS

human evacuation behavior, guide's instructions, information transmission, computational simulation, fire

INTRODUCTION

There are many complexes and enclosed areas such as shopping centers, offices, underpasses and subway stations in big cities, which are characteristics of urbanization. These places where many people gather could be dangerous in emergency situations such as earthquakes and / or fires. It is very important that owners or salesclerks serving as guides in such places know how to lead evacuees to exit safely and quickly. In order to achieve this, the conduct of evacuees in an emergency should be understood. And what is more important, it should be considered that these guides relay vital information about evacuation to evacuees when they come in contact with evacuees. It is impossible to study the conduct of people experimentally in building structures, such as buildings, where an actual earthquake occurs. Therefore, many simulation models of evacuees' conduct in emergency situations have been proposed by using computers (Iki,1983, Ohtsuki, 1991, Yokoyama *et al.*,1993). These simulation models, however, are focused only on evacuees' conduct. The simulation method should take into account the role of guides, because the time to complete the evacuation depends not only on the quick reaction of evacuees but also on better instructions given by guides. In order to simulate the conduct of evacuees and guides in a situation of fire preceded by an earthquake, we developed a simulation model by applying genetic codes used in genetic algorithm. In this study, the model simulates not only the conduct of guides and evacuees but also the reaction of evacuees' conduct to guide's instructions.

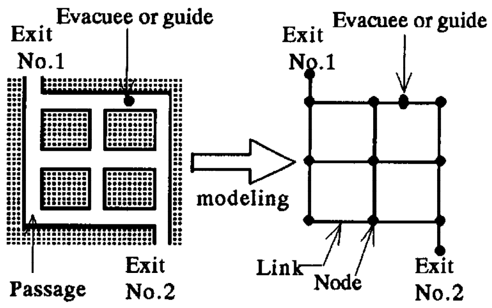


Fig.1. Floor model.

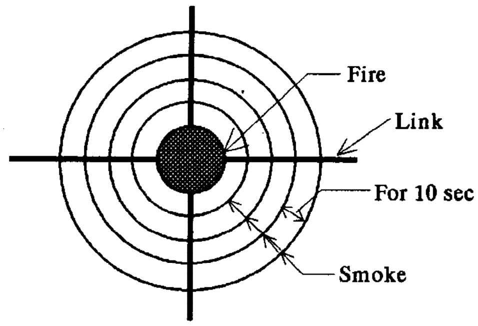


Fig.2. Fire model.

SIMULATION MODEL

The simulation model which we propose consists of a floor, fire and human models. Each content of the modeling is described bellow.

Floor Model

It is difficult and complex to represent space for places such as underground shopping centers etc. in a computational model. So for the floor modeling, the spaces where people move such as passages and crossings are simply represented with a network of nodes connected by links (Ohtsuki, 1991). An example of the floor model is shown in Fig.1. Nodes and links indicate crossings and passages, respectively. Dots represent the human model which can move on these links.

Fire Model

Spreading of fire and smoke is a very complex phenomenon. Therefore, for the fire model, we assumed that the fire can only breaks out on a node and smoke simply spreads in coaxial circles as shown in Fig.2. Smoke is considered harmless at first as it diffuses at the velocity of 0.5 m/s and then it becomes poisonous as it spreads to see after the break out of fire. In this model, the fire does not break out in numerous places simultaneously right after an earthquake but in specific area.

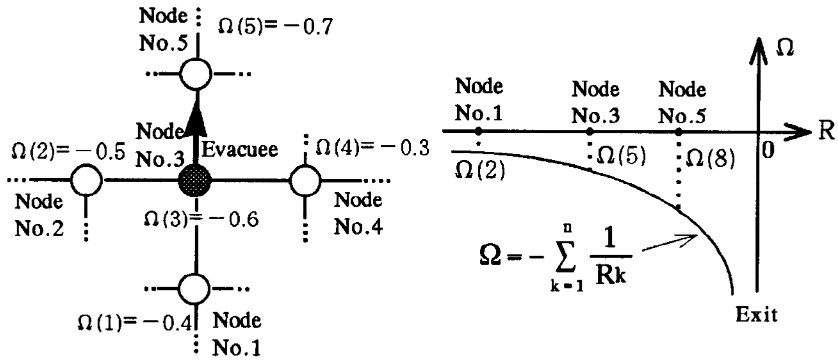
Human Model

There are two types of human model. One is the evacuee model and the other is the guide model which represents an owner or a salesclerk. Each model is described bellow.

Evacuee Model. Some people stroll through the underground shopping center often and others seldom do. So for the evacuee model, we propose two typical models of evacuee due to their different reaction in an emergency, namely, one could know routes to all exits and the other would not know any route to exit at all. The way of determining evacuees' conduct is as follows:

(1) Evacuees move in accordance with potential value Ω given by random number before a fire breaks out in an earthquake. This means that evacuees walk randomly at the velocity of 1.3 m/s.

(2) After a fire breaks out, potential value at the point where the fire breaks out, Ω, is assumed to be zero and



(a) Human motion and potential values at nodes.　　(b) Potential curve.

Fig.3. Rule for determining the direction of motion based on the potential value.

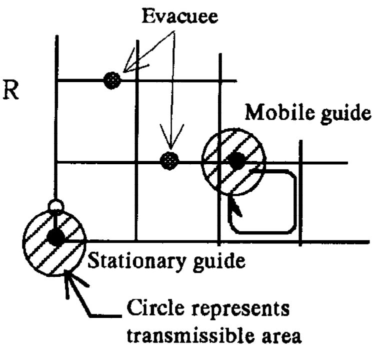


Fig.4. Two kinds of guides, Stationary guide and Mobile guide.

the area of potential value 0 spreading in coaxial circular manner represents smoke. Evacuees cannot approach this area of fire because the potential values in this area are greater than the rest of the area.

(3) The evacuees who are familiar with the place move in the direction is determined by the potential Ω given in eq.(1).

$$\Omega = -\sum_{k=1}^{n} \frac{1}{R_k} \tag{1}$$

where R_k denotes a distance from the position of evacuee under consideration to exit k. An example how an evacuee determines the direction is illustrated in Fig.3. In this case,an evacuee at node No.3 compares the potential value of his node with those of other joint nodes which are obtained by eq.(1) and he moves in the direction of node No.5 because it was the lowest potential value. Whenever the evacuee reaches the next node in a new position, the potential values Ω are calculated.

(4) Some of the evacuees continue to walk randomly if they are confused and forget the exit routes or they are not familiar with the place.

(5) When evacuees get caught in a fire, they could die of suffocation within 90 seconds.

(6) If evacuees gather in front of an exit, they can pass through the exit without stopping by an arch action.

Guide Model. Guides give evacuees information about the way to the nearest exit when the former encounters the latter. We introduce two kinds of guide. One is the stationary guide who gives evacuees information about the way to the nearest exit and the other is the mobil guide who give information to evacuees during his patrol in the area.

(1) Stationary guides are stationed at the node where they can see at least one exit and on the circumference of the floor model.

(2) Mobil guides patrol clockwise along rectangular links.(Fig.4)

(3) The velocity of guides' movement is at 2.0 m/s.

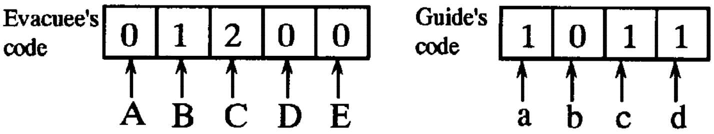
(4) Guides give the evacuees information about the route to the nearest exit when the evacuee is within 5m. Then the evacuee's speed of movement changes from 1.3 m/s to 2.3 m/s.

(5) Guides stop giving evacuees information and starts to escape by taking the route to the nearest exit when the guides enter in the smoke area.

Code of Information About Condition of Evacuees and Guides

The situation and character of the evacuees and guides are described in genetic codes as a row of numbers (Kitano, 1993). Contents of these codes are shown in Fig.5. The evacuees have five codes from A to E and the guide have four codes from a to d.

They are summarized in Table1.



Code :

A: whether the evacuee has met guides or not.
B: whether the evacuee saw a fire or not.
C: how long the evacuee stayed in fire.
D: whether the evacuee arrives at exit or not.
E: whether the evacuee has information about the routes to exits or not.

Code :

a: kind of guides.
b: whether guide should begin to evacuate or not.
c: choice of routes to exits.
d: whether the guide has information about routes to exits or not.

Fig.5. Composition of the codes.

Table 1. The summary of the codes.

Evacuees	
A	Yes : 1, No : 0
B	Yes : 1, No : 0
C	0 sec : 0 0-29 sec : 1 30-59 sec : 2 60-89 sec : 3 90 sec : 4
D	Yes : 1, No : 0
E	Yes : 1, No : 0

Guides	
a	Stationary guide : 0 Mobil guide : 1
b	Yes : 1, No : 0
c	Number of route
d	Yes : 1

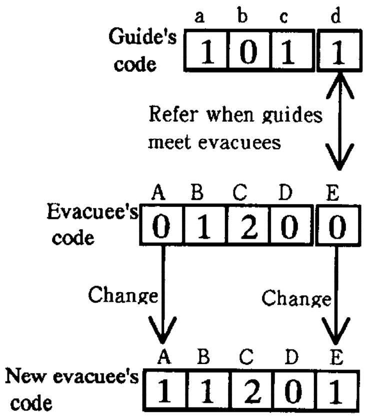
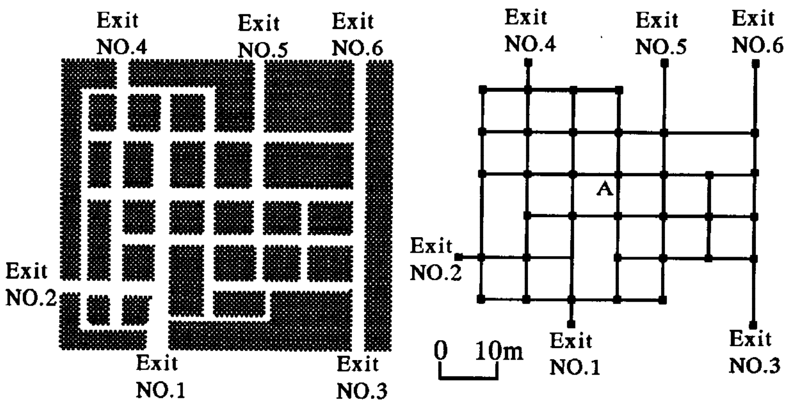


Fig.6. Example of the transmition of information.



(a) Bird's eye view of an actual underground shopping center.

(b) Simulation model.

Fig.7. Model analized.

For example, the evacuee in Fig.5 has not met a guide yet, saw a fire, stayed in the area of fire from 30 to 59 seconds, has not arrived at an exit yet and has not obtained any information from a guide. The guide in Fig.5 is a mobile guide, does not begin to evacuate yet, plans his escape on route number 1 and has information about routes to exits.

TRANSMITTING GUIDES' INFORMATION TO EVACUEES

When a guide sees evacuees after the fire breaks out, he give evacuees his instruction to the nearest exit. The way of conveying the information is shown in Fig.6. At that moment, the guide's code d which indicates information about the route to the exit replaces the corresponding evacuee's code E resulting in the evacuee's new knowledge. Then the evacuee's code A changes from 0 to 1 by getting new information.

SIMULATION CONDITION

We applied this simulation model to an actual underground shopping center in Tokyo. The model is shown in Fig.7. The condition of the simulation are summarized as follows:

(1) The number of evacuees is 50.

(2) Fire breaks out at point A in Fig.7 30 sec after the beginning of simulation.

(3) As soon as fire breaks out, evacuees begin to evacuate and guides start to assist evacuees.
(4) Simulation stops when the last evacuee succeeded in evacuating or failed to evacuate resulting in death from fire or smoke inhalation.
(5) The time for complete evacuation is defined as the time when the very last evacuee reaches an exit.

We calculated the number of evacuees who could be killed and the actual time of complete evacuation altered by changes in the percentage of evacuees who know the way to the exits and the number of guides. The percentage and number are listed in Table 2.

Table 2. Simulation cases.

		Percentage of evacuees who know the way to exits (%)		
		0	50	100
Number of guides	0	——	——	——
	2	ST / MO	ST / MO	ST / MO
	4	ST / MO	ST / MO	ST / MO
	6	ST / MO	ST / MO	ST / MO
	8	ST / MO	ST / MO	ST / MO
	10	ST / MO	ST / MO	ST / MO

ST : A case of tationary guide
MO: A case of mobile guide

RESULT OF THE SIMULATION

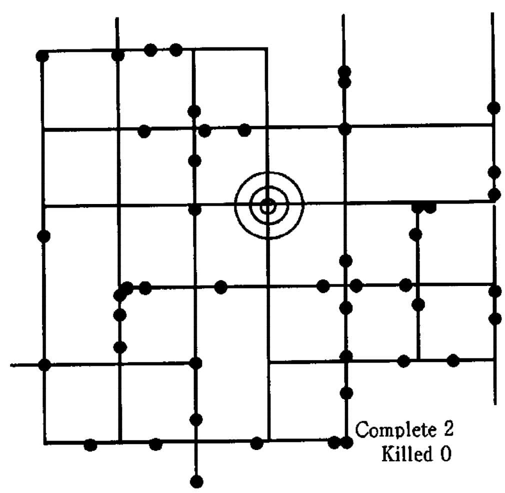
The situations of evacuees after 50 and 150 seconds of the beginning of simulation are shown in Figs.8 and 9. Figure 8 shows the situations without guide and Fig.9 with 10 mobil guides. In both cases, the percentage of evacuees who know the route to exits is 50 %. Symbols ● and ○ represent evacuees and guides respectively, and smoke and fire are shown in coaxial colorless or gray circles in these figures. It can be seen that evacuees can evacuate more quickly in Fig.9 than in Fig.8 in the same simulation time due to the aid of the guides.

Figure 10 shows the relation between the number of success in evacuation and the time to complete the evacuation by changing the number of guides. Figure 10(a) is the result from the cases with stationary guides and (b) with mobil guides. The percentage of evacuees who know the route to exits is 50 % in the same condition as in Fig.8 and Fig.9. It is found that with more guide's assistance, more evacuees can complete evacuation, and a mobile guide is more effective than a stationary guide.

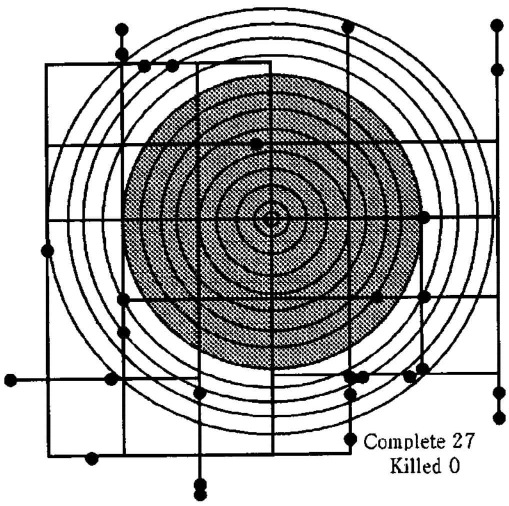
Figure 11 illustrates the difference in the number of evacuees killed with the changes in the number of guides and evacuees who know the way to the exits. Figure11(a) is the case of a stationary guide and Fig.11(b) is the case of a mobile guide. From both figures, it can be seen that the more the guides assist evacuees, the higher the percentage of evacuees who could know the route to the exits, and the more evacuees could complete evaçuation. Moreover, it is found that a mobile guide is more effective than a stationary guide in terms of reducing the death rate.

The difference in time span to complete evacuation with the changes in the number of guides and evacuees who know the way to the exits is shown in Fig.12 . Figure 12(a) is the case of a stationary guide and Fig.12(b) is the case of a mobile guide. These figures indicate that the higher the rate of evacuees who know the route to the exits, the more quickly the evacuation is completed. When the number of guides is zero and the percentage of evacuees who know the way to exits is low, the time to complete evacuation decreases contrary to our expectation in these figures. This is only because the time to complete evacuation here is defined as the time when the very last evacuee reaches an exit. By no means is this an effective evacuation but a rather poor one because evacuees are mostly killed most as shown in Fig.11(b).

Finally, Fig.13 shows a plot of the changes in the time to complete evacuation and the percentage of evacuees killed under the condition that the ratio of guides and evacuees is kept constant at 1 to 10 with the changes in the number of guides from 10 to 2. It is found that the percentage of evacuees killed and the time to complete evacuation tend to increase with decreasing number of guides even if the ratio is kept constant.

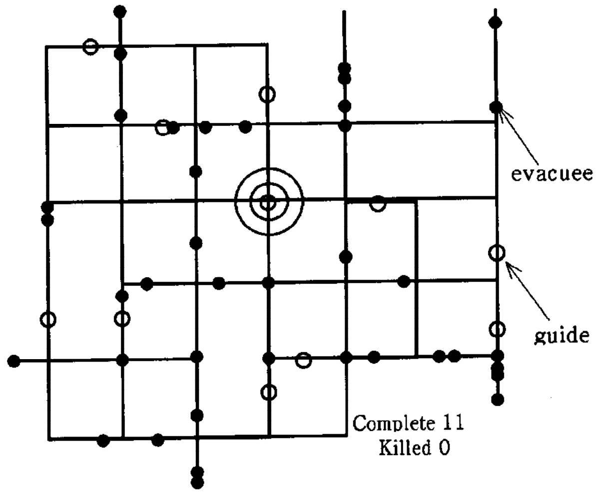


(a) Situation at 50 sec

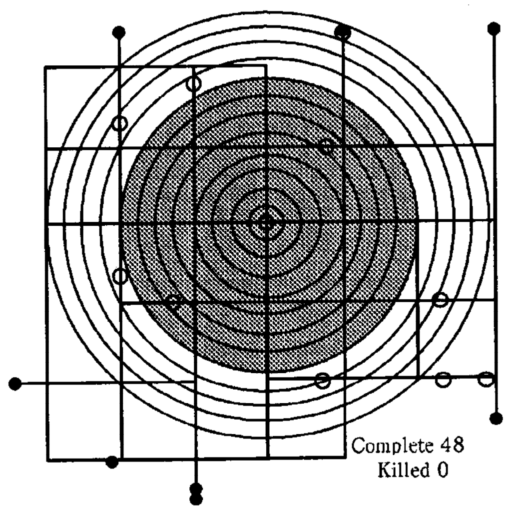


(b) Situation at 150 sec

Fig.8 Situation of evacuees whitout guide.

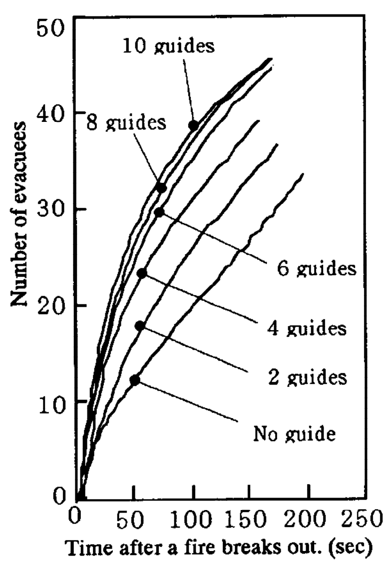


(a) Situation at 50 sec

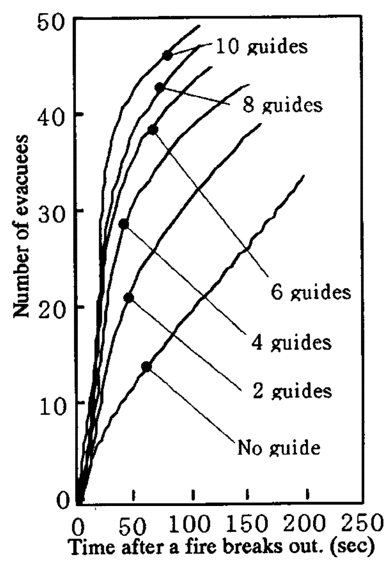


(b) Situation at 150 sec

Fig.9 Situation of evacuees with 10 mobil guide.

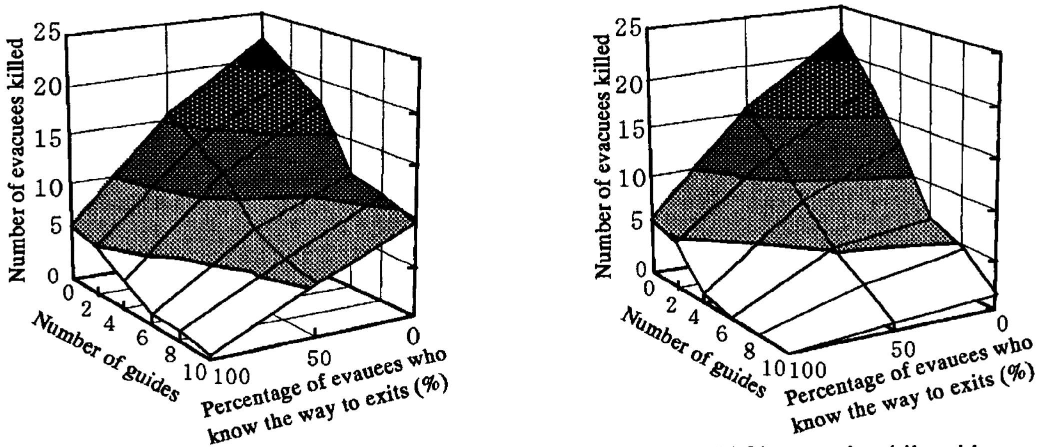


(a) In case of stationary guide



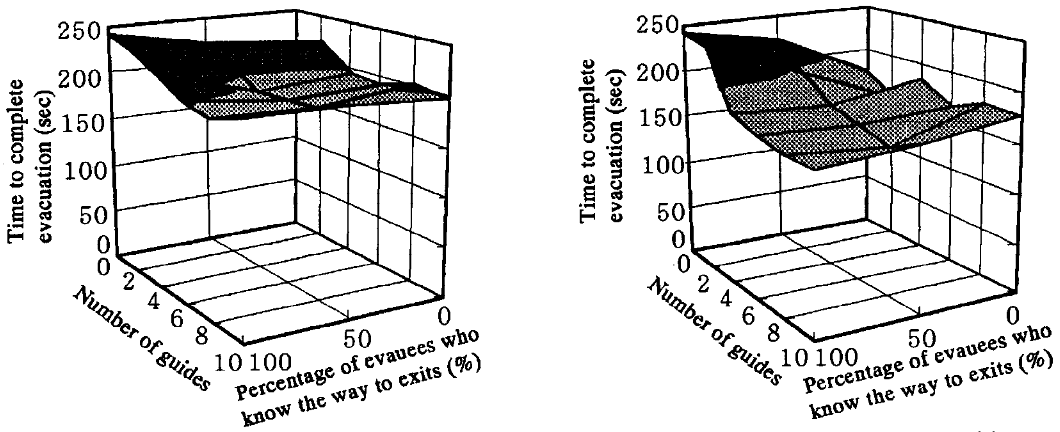
(b) In case of mobile guide

Fig.10 Comparison of the number of evacuees who completed the evacuation.



(a) A case of stationary guides (b) IA case of mobile guides

Fig.11. Difference in the number of evacuees who are killed with guides' assistance.



(a) An case of stationary guides (b) An case of mobile guides

Fig.12. Difference in time span to complete evacuation with guides' assistance.

CONCLUSIONS

In this paper, we first developed a computational simulation model at the reaction of evacuees to guide's instruction. Then we also tried to apply this simulation model to the actual underground shopping center in Tokyo and met with the following results.

(1) It was found that the more guides assist, the more evacuees could evacuate.

(2) Instructions provided by a mobile guide is more effective than that of a stationary guide.

(3) There is an influence on safe evacuation based on the number of guides even if the percentage of guides and evacuees is the same.

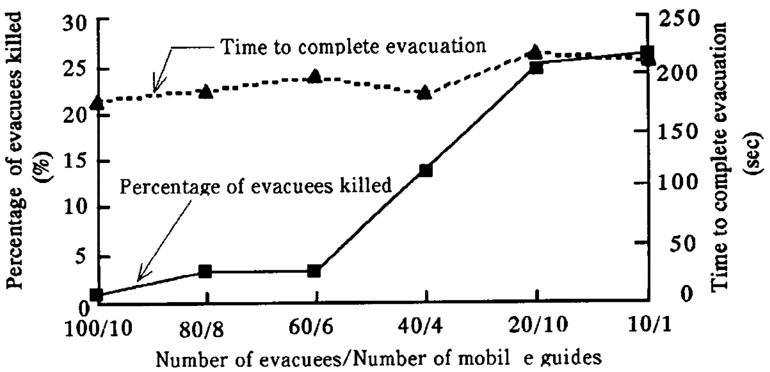


Fig.13. Changes in time to complete evacuation and the percentage of evacuees killed under the condition in that the ratio of the guides and evacuees is kept content as 1 to 10.

From this study, we think that it is very important for a guide to instruct evacuees the evacuation route when an earthquake occurs. Therefore, owners should consider the emergency management for guide's instructions and the education of disaster prevention for guides when they draw up a plan or devise disaster prevention plans.

ACKNOWLEDGEMENTS

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REFERENCES

Ohtsuki, A. (1991). Simulation for human Behavior at Emergency Evacuation in Underground Structure by Using Object Oriented Language. *Computer Simulation*, **Vol.2-4**, 78-83 (in Japanese).

Kiyo, K. (1983). Simulation Model for Human Behavior at Emergency Evacuation - Proposal of Model Considering Fire Condition and Mental State -. *Journal of Archit. Plann. Environ. Engng. AIJ*, **No.325**, 125-132 (in Japanese).

Yokoyama, H., K. Meguro and T. Katayama (1993). Simulation Method of Human Behavior at the Underground Shopping Center. *Papers of the Annual Conference of the Institute of Social Safety Science*, **No.3**, 161-164 (in japanese).

Kitano, A. (1993). In: Genetic Algorithm (in Japanese).

Matsushita, S. and S. Okazaki (1991). A Study of Simulation Model for Wayfinding Behavior by Experiments in Mazes. *Journal of Archit. Plann. Environ. Engng. AIJ*, **No.429**, 51-59 (in Japanese).

Murozaki, Y. (1993). *Modern Construction*, pp.36(in Japanese).