Evaluation of Time Delay of Coping Behaviors with Evacuation Simulator

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Abstract. In this paper, we analyzed the influence of time required to begin coping behaviors of managers in chemical terrorism. In order to calculate the damage of chemical attacks in a major rail station, our network model-based pedestrian simulator was applied with hazard prediction systems of indoor gas diffusion. Our analysis was used for enlightening the managers of the rail station in a tabletop exercise held by Kitakyushu City Fire and Disaster Management Department.

1 Introduction

CBR terrorisms caused by chemical(C) and biological(B) agents and radioactive(R) materials are nonselective attacks on crowds in urban areas. These hazardous materials might be sprinkled, vaporized, or spread with an explosion. A first responder of these accidents, such as a fire protection and police agencies of municipalities, has to prepare practical plans of coping behaviors against CBR terrorism, but they do not have much experience and knowledge of CBR terrorism. Therefore, useful tools supporting to make plans is required to estimate and illustrate the damage done by CBR attacks.

To meet their needs, Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT) ordered research consortium of Tokyo University, Advanced Industrial Science and Technology (AIST), Mitsubishi Heavy Industries (MHI) and Advancesoft to develop a new evacuation planning assist system for CBR attack. The work in this paper is supported as the national project for urban safety commenced from 2007 by MEXT. Our evacuation planning assist system consists of three components; a pedestrian simulator constructed by AIST, a prediction system of outdoor gas diffusion by MHI, and a prediction system of indoor gas diffusion by Advancesoft.

With our evacuation planning assist system, a user can estimate the damage caused by CBR terrorism. These disasters, which are likely to be caused in urban areas, have many characteristics different from natural disasters. These disasters are caused intentionally, which means we must prepare for the worst; there are still few case that CBR terrorism were actually conducted, which means we still know little about what damage will be caused by such terrorism; unlike natural disasters, these disasters are not always harmful to some of the urban infrastructure, which means that they could be utilized for more efficient evacuation.

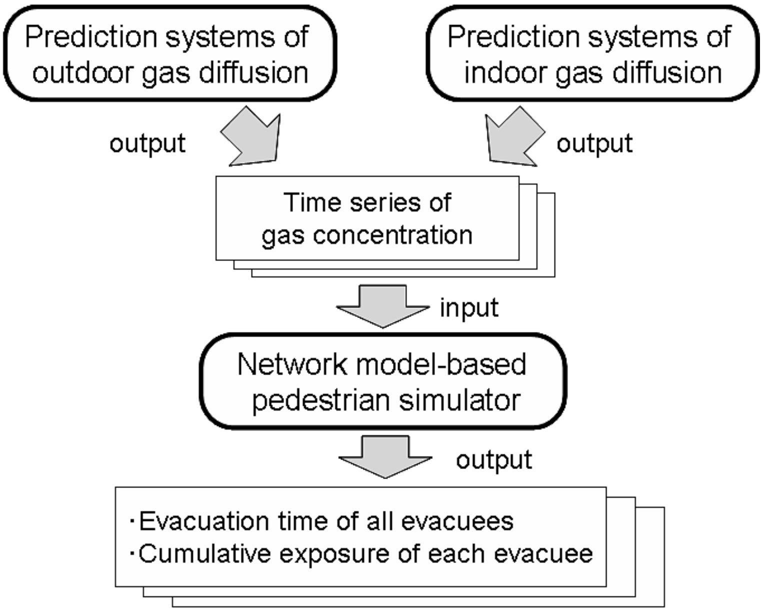


Fig. 1. Outline of dataflow of the evacuation planning assist system

In this paper, we have built a network model-based pedestrian simulator as a part of the evacuation planning assist system. Compared to previous grid based and continuous space based models which took hours to conduct simulations with less than thousands of evacuators, our network model are designed to conduct simulations much faster, taking less than few minutes for simulation with ten thousands of evacuators. Our pedestrian simulator is designed to be working with hazard prediction systems of outdoor and indoor gas diffusion, which calculates how fast and concentrated harmful gases spread. Using data provided from hazard prediction systems, our pedestrian simulator can be used to estimate how much damage will be done, for various evacuation scenarios. These results could be used to make and evaluate evacuation plans against CBR terrorism.

In this paper, we explain our evacuation planning assist system, and share with an example of practical use of our system. We dealt with coping behaviors against chemical attack in a major rail station because of a request from the Fire and Disaster Management Department of Kitakyushu City. In our simulation, we revealed the relationship between the time required to begin coping behaviors of the managers and the damage of passengers. Our analysis was used for enlightening the managers of the rail station in a tabletop exercise held by the Fire and Disaster Management Department of Kitakyushu City.

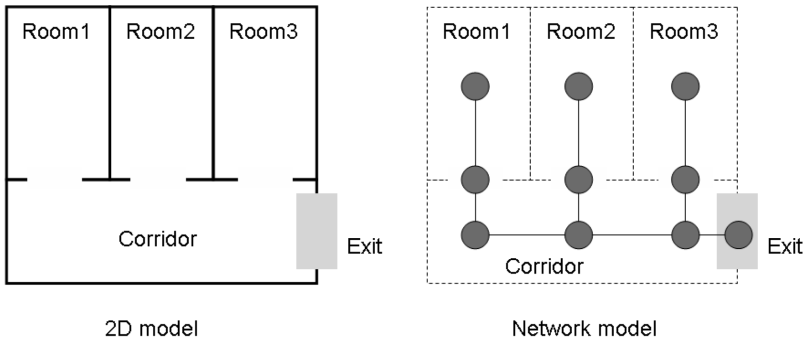


Fig. 2. 2D model and network model

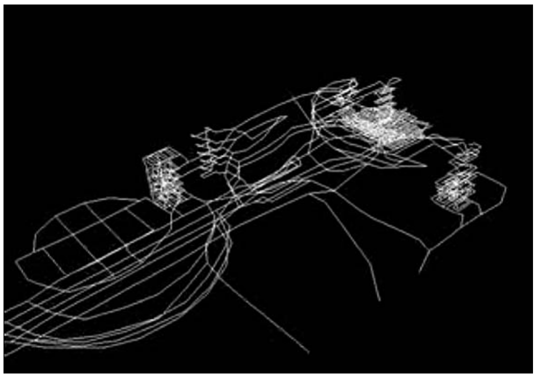
2 Evacuation Planning Assist System

Our evacuation planning assist system consists of three components; a pedestrian simulator and prediction systems of indoor and outdoor gas diffusion. At first, the prediction systems of indoor and outdoor gas diffusion calculate concentration of hazardous gases. The output of these systems is time series of gas concentration in designated areas. Then, the pedestrian simulator calculates evacuation time of all evacuees and cumulative exposure of each evacuee with time series of gas concentration. Outline of dataflow of the evacuation planning assist system is shown in Fig. 1.

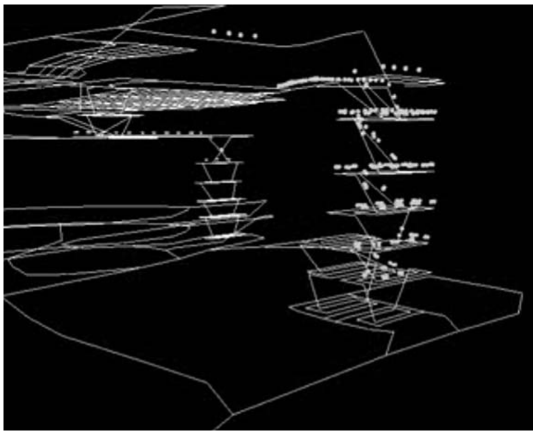
2.1 Pedestrian simulator

Various kinds of pedestrian simulators have been developed for various purposes. Pan roughly classified them into three categories; fluid and particle systems, matrix-based systems, and emergent systems [5]. However, all of these systems are two dimensional systems, which allow pedestrians to move around two dimensionally. Unlike other pedestrian simulators, our simulator simplifies traffic lines by representing it with a graph model - a model with links and nodes (Fig. 2). The paths where the pedestrians move around are represented as links, and these links are connected at nodes. As the pedestrians could move only along the links, our model is more one dimensional than two dimensional.

This approach has often been used in traffic simulators [1], but not for pedestrian simulators. We chose the network based-model for our simulator, as we need a high speed simulator dealing with evacuation behaviors of many evacuees on the macroscopic side. Network based-model is not suitable for simulating many pedestrians evacuating large space precisely, but could be used to reveal bottlenecks and evocation time quickly as well as to compare a lot of evacuation plans. Appearance of a network-based pedestrian simulator are shown in Fig. 3.



(a)



(b)

Fig. 3. 3D view of our network-based model pedestrian simulator

The speed of a pedestrian The speed of a pedestrian is calculated from the density of the crowd on the link. Each link has a width and a length, which is used to calculate the area of the link. Then, the density of the crowd on the link could be calculated from the number of the pedestrians on the link. Speed V_i of the pedestrian on link i is calculated from the following formula;

$$V_i = \begin{cases} V_f, & d_i < 1 \\ d_i^{-0.7945} V_f, & 1 \leq d_i \leq 4 \\ 0, & d_i > 4 \end{cases} \tag{1}$$

where V_f represents free flow speed of the pedestrians, which is the speed of the pedestrian when not in a crowd, and d_i represents the density of the pedestrians on link i.

Fig. 4 shows the relationship the speed of pedestrian and the density of the link. The exception to this formula is the pedestrian on the head of a crowd on the link. For this pedestrian, V_f is used regardless of how the link is crowded. Note that when the density of a link exceeds 4 pedestrians/m^2, all the pedestrian on the link cannot move except for the one who is on the head of the crowd.

Confluence Confluences - where two or more paths meet together - slow down the speed of pedestrian. To illustrate slow-down by confluence, we used a simple model of limiting the number of the pedestrian who could enter a link. The maximum number of the pedestrian entering link l_{out} shown in Fig. 5 is determined from the width of the link. When there are pedestrians on l_{out} already, the number of the pedestrians that could enter l_{out} is decreased at some ratio. When there are more than two links where the pedestrians are trying to enter l_{out}, this number is divided among the links depending on the number of the pedestrians trying to enter l_{out}. Also, in this case, the total number of the pedestrians able to enter l_{out} is also reduced.

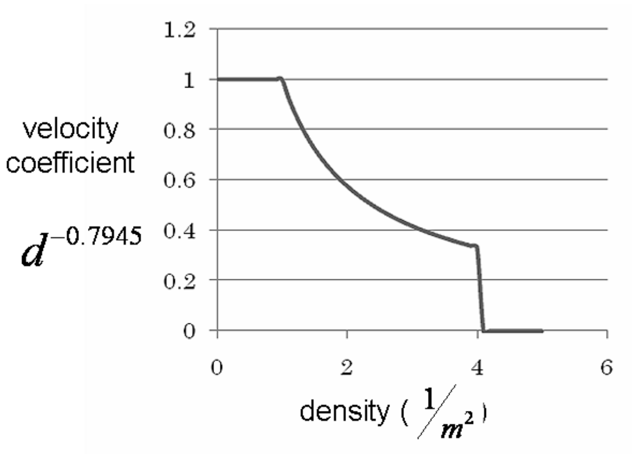


Fig. 4. The coefficient of the speed and the density of the pedestrians

2.2 Prediction systems of indoor gas diffusion

Recently, more subways, shopping malls, and high-rise buildings have large-scaled and intricate passages. Accordingly, the casualties on CBR attacks or fires there increase more disastrously. For prevention or reduction of these disasters, a hazard prediction systems of indoor gas diffusion "EVE SAYFA" (Enhanced Virtual Environment Simulator for Aimed and Yielded Fatal Accident) has been

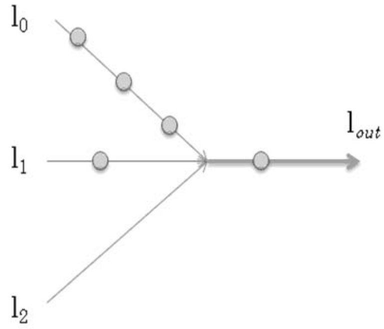


Fig. 5. Modeling confluence

developed to aid their anticipation and the evaluation of the safety [2, 7]. EVE SAYFA has two simulation models; one is EVE SAYFA 3D with highly accurate 3-dimensional model. The other is EVE SAYFA 1D with high-speed calculating 1-dimensional network model.

Using EVE SAYFA 3D, the simulation of diffusion of hazardous and noxious substances is carried out by Computational Fluid Dynamics (CFD) software based on Large eddy simulation (LES), which is a numerical technique used to solve the partial differential equations governing turbulent fluid flow.

Using EVE SAYFA 1D, the macro-model is expressed in differential equations or algebraic equations in the whole of the large-scaled structures which consist of some elements corresponding to, e.g., rooms, corridors, stairs, walls, windows, etc. The total computing time can be reduced by saving the result of air movement simulation in database and reusing for diffusion simulation.

2.3 Prediction systems of outdoor gas diffusion

A hazard prediction system has been developed for CBR attacks in urban areas with the use of the mesoscale meteorological model, RAMS and its dispersion model HYPACT.

RAMS is equipped with an optional scheme to simulate airflow around buildings based on the volume fraction of the buildings within each grid cell. The HYPACT (HYbrid PArticle and Concentration Transport) code is an atmospheric diffusion code that can be coupled to RAMS. This code is based on a Lagrangian particle model that satisfies mass conservation in complex airflow and can adopt the finite difference method at large distances downwind to reduce computational time.

The developed simulation system, called MEASURES, consists of HYPACT, RAMS and an airflow database [3, 4]. Meteorological data can be loaded onto the system by the user directly or through the Internet. A time series of airflow is generated for the location of interest. In this procedure, the 3-dimensional

Table 1. The influence of exposure of chloropicrin

amount of exposure ($mg \cdot min/m^3$)	1	200	1,000	2,000	20,000
Influence on behavior	pain in the eye & throat	nausea & headache	breathing trouble	lethal dose 50%	lethal dose 100%
Implementation in pedestrian simulation	decrease in speed (-40%)	decrease in speed (-90%)	stop	stop	stop
damage level	mild	moderate	severe	severe	severe

wind data from the database of 48 atmospheric conditions are interpolated at each time step for the wind direction and the atmospheric stability observed at the location at that time step.

3 Simulation

With our evacuation planning assist system, we dealt with an chemical attack in a major rail station because of a request from the Fire and Disaster Management Department of Kitakyushu City. In our simulation, for enlightening the managers of the rail station, we revealed the relationship between the time required to begin coping behaviors of the managers and the damage of passengers.

3.1 Simulation settings

In our simulations, the chemical attack with chloropicrin is set to be taken place in the station yard of the conventional line. Gas diffusion in the station yard is calculated with the prediction systems of indoor gas diffusion. The move and the damage of about 9000 passengers is calculated with our pedestrian simulator. The amount of exposure of chloropicrin of the passenger is calculated as product of the concentration of chloropicrin and the time spent in the area. The influence of exposure of chloropicrin [6, 8] on the passenger's behavior is described in table. 1.

This rail station is a complex facility. There are 4 kinds of facilities; a conventional line, a new bullet train line, a monorail, and a hotel. Each facility has a manager. We assume following 10 coping behaviors of the managers and the times required to begin these coping behaviors described in table 2. The times required to begin these coping behaviors has a influence on the damage of the passengers because the beginning of evacuation of the passengers is delayed if the beginning of these coping behaviors is delayed. The sequence of the coping behaviors is shown in Fig. 6.

For example, the manager of the conventional line has 4 coping behaviors; (1) detecting chemical attack, (2) reporting to the fire station and the other managers of the new bullet train line, monorail, and the hotel, (3) shutting down the conventional trains, and (4) ordering an evacuation to the passengers

Table 2. Coping behaviors of the managers and the times required for them

Manager		Coping behavior	Time required to begin(min) quick	Time required to begin(min) slow
Conventional line	1	detecting chemical attack	5	10
	2	reporting to the fire department and the other managers	3	6
	3	shutting down the trains	3	6
	4	ordering an evacuation to the passengers	3	6
New bullet train line	5	ordering an evacuation to the passengers	3	6
	6	shutting down the trains	3	6
Monorail station	7	ordering an evacuation to the passengers	5	6
	8	shutting down the trains	3	6
Hotel	9	ordering an evacuation to the guests	3	6
Fire and Disaster Management Department	10	rescuing insured passengers	20	30

of the conventional line. Each coping behavior is set to have two kinds of the time required. For example, if coping behavior 4 (ordering an evacuation to passengers) is begun quickly, the time required to begin is 3 minutes. Otherwise (begun slowly), the time required is 6 minutes.

The number of all evacuation scenarios is 1024 because the number of combination of the times required to begin 10 coping behaviors is 2^{10} (=1024). We calculate the damage of about 9000 passengers in 1024 evacuation scenarios is calculated with our pedestrian simulator. In our pedestrian simulation, each passenger walks around normally, from/to outside of the station from/to platforms, until the attack is detected and alarm is given. After ordering an evacuation to the passengers, the passengers evacuate through the route directed by station staffs.

To assign sequential serial number to each scenario whether 10 coping behavior are begun quickly or slowly, we use a ten-digit number in the binary system. For example, if coping behavior 1 (detecting chemical attack) is begun quickly, the first bit of the ten-digit number is set as 0. If all coping behaviors are begun quickly, this scenario is represented as 0000000000 in the binary system. Then, the ten-digit number in the binary system is transferred to a serial number in the decimal system. The scenario represented as 0000000000 in the binary system is assigned serial number 0 in the decimal system, and the scenario represented as 1111111111 is assigned serial number 1023.

3.2 Simulation result

The result of our simulation is shown in Figs. 7∼9.

In Fig. 7, the graph shows the number of the severe victims in 1024 scenarios. Based on the number of the severe victims, there are 5 characteristic clusters. In

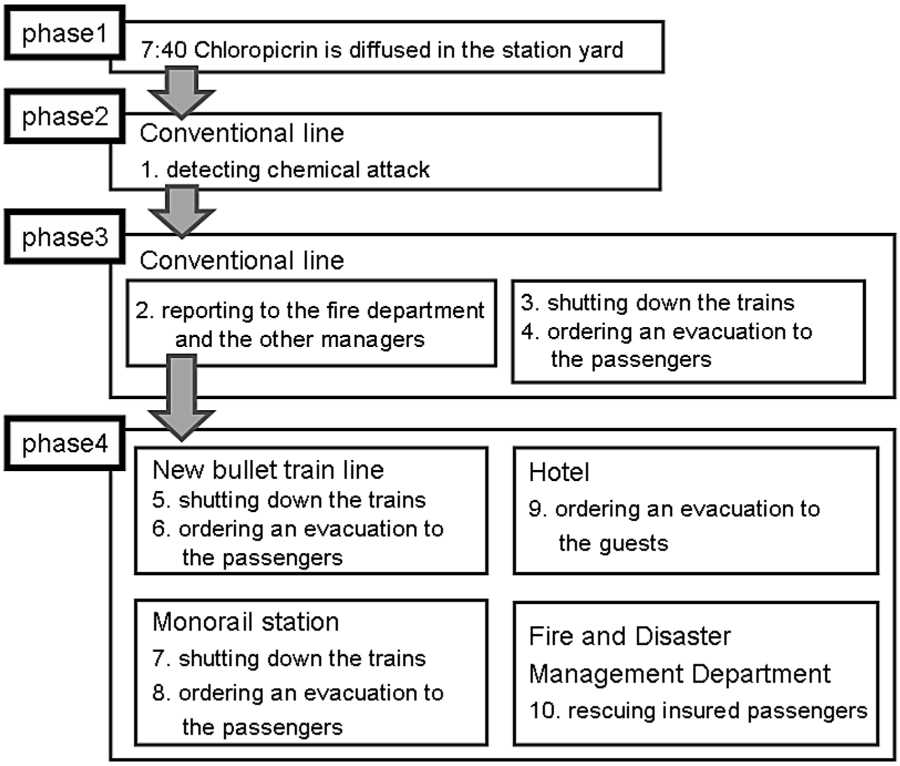


Fig. 6. The sequence of the coping behaviors

each cluster, the scenarios has the same tendency of coping behavior 1 and 4. In the scenarios of cluster 1-1, both (1) detecting chemical attack and (4) ordering an evacuation to passengers of the conventional line are begun quickly. In the scenarios of cluster 1-2, (1) detecting is begun quickly, and (4) ordering an evacuation is begun slowly. In the scenarios of cluster 1-3a and 1-3b, (1) detecting is begun slowly, and (4) ordering an evacuation is begun quickly. The difference between cluster 1-3a and 1-3b is coping behavior 10. In the scenarios in cluster 1-3a, (10) rescuing insured passengers by Fire and Disaster Management Department is begun slowly. On the other hand, in the scenarios in cluster 1-3b, (10) rescuing is begun quickly. In the scenarios of cluster 1-4, both (1) detecting and (4) ordering an evacuation are begun slowly. Therefore, it is confirmed that both (1) detecting, (4) ordering an evacuation, and (10) rescuing insured passengers are more important to decrease the severe victims.

In Fig. 8, the graph shows the number of the moderate victims in 1024 scenarios. Based on the number of the severe victims, there are 4 characteristic clusters. The number of victims in cluster 2-1 is less than that of other clusters. There is not so much difference among the number of the victims of cluster 2-1, 2-2, and 2-3. Therefore, it is confirmed that (1) detecting and (4) ordering an evacuation are more important to decrease the moderate victims.

In Fig. 9, the graph shows the number of the mild victims in 1024 scenarios. Based on the number of the severe victims, there are 4 clusters. The number of mild victims in cluster 3-1 is more than that in cluster 3-2. However, the amount of all victims in cluster 1-1, 2-1, and 3-1 is equal to that in cluster 1-2, 2-2, and 3-2. Therefore, Therefore, it is confirmed that (1) detecting is important to decrease the damage of the passengers.

As a result of comparison of the damage in 1024 scenarios, we confirm that the most effective coping behaviors for decreasing the damage of the passengers are i) detecting chemical attack and ii) ordering an evacuation to passengers of the conventional line. In a tabletop exercise held by Fire and Disaster Management Department of Kitakyushu City, our simulation result was shared with for enlightening the managers of the rail station.

4 Conclusion

In this paper, we explained our evacuation planning assist system consisting of a pedestrian simulator constructed, a prediction system of indoor gas diffusion, and a prediction system of outdoor gas diffusion. Chemical attack in a major rail station in Japan is taken up as an example of practical use of our system because of a request from the Fire and Disaster Management Department of Kitakyushu City. In our simulation, we revealed the relationship between the time required to begin coping behaviors of the managers and the damage of passengers. As a result of comparison of the damage in 1024 scenarios, it is confirmed that, to decreasing the damage of the passengers, it is important to begin coping behaviors quickly; i) detecting chemical attack and ii) ordering an evacuation to passengers.

5 Acknowledgment

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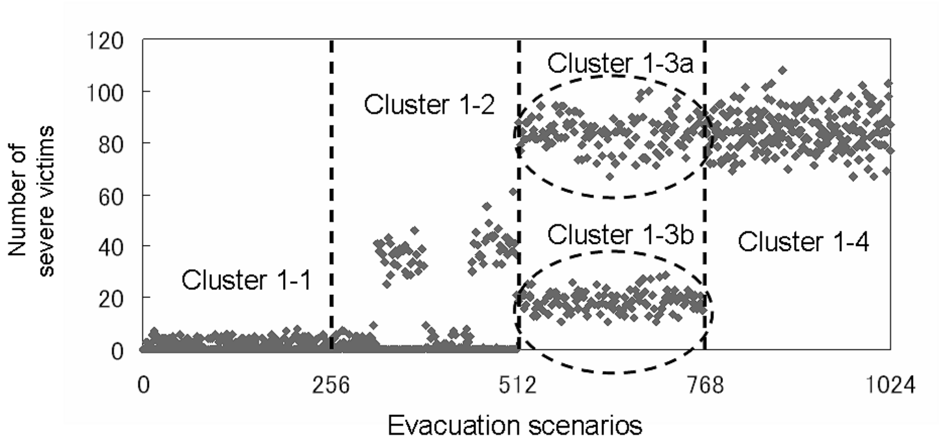

Fig. 7. The number of the severe victims

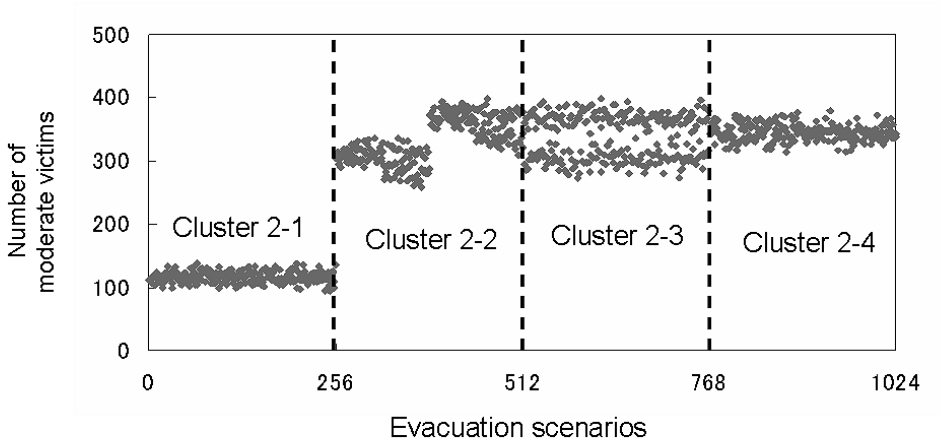

Fig. 8. The number of the moderate victims

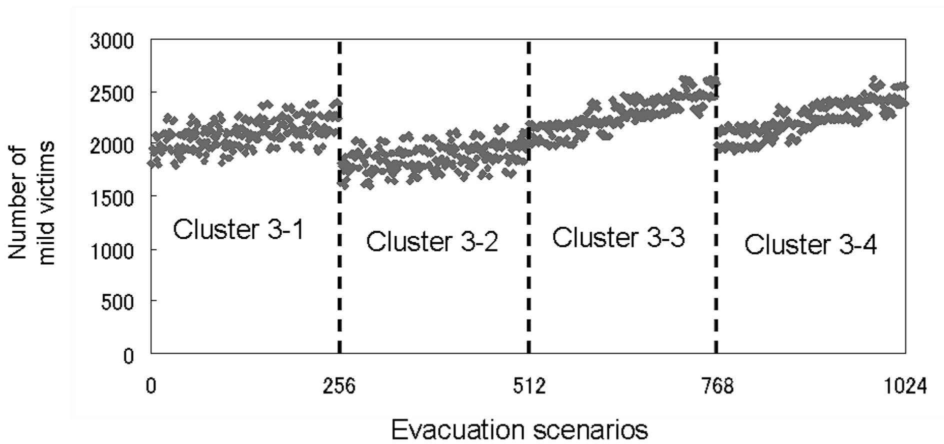

Fig. 9. The number of the mild victims