13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 636

SIMULATION ON RESCUE IN CASE OF EARTHQUAKE DISASTER BY MULTI-AGENT SYSTEM

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SUMMARY

In this paper, a simulation system on rescue is developed and proposed. This system can predict earthquake disaster spatially and temporally by using intelligent systems such as cellular automata and multi-agent system. The proposed system consists of two parts, i.e.; prediction of direct damages from an earthquake by using empirical equations and simulations of rescue activities in accordance with direct damages. In this system, persons and rescue teams are assumed as agents and can act autonomously based on their own rules. The effectiveness of proposed system is verified and discussed by using simulation results.

INTRODUCTION

In the Hyogoken Nanbu Earthquake occurred at Jan. 17, 1995, there is a fact that various rescue operations in the first stage can not be performed effectively because direct damage information caused by the earthquake can not gather (Hyogo Prefecture [1]). When a large earthquake occurs in a large modern city, it is difficult to avoid to suffer certain damages. Therefore, in order to suppress expansion of damages caused by the earthquake to the minimum, it is required to predict and measure damages caused by the earthquake before the earthquake occurrence. After the Hyogoken Nanbu Earthquake, researches on real time disaster prevention systems (Kanamori [2]) are performed in order to plan effective disaster prevention system and perform effective rescue operations just after a large earthquake in the future. The real time disaster prevention systems generally consist of early earthquake detection system and real time information system on disaster (Kanamori et. al. [3]). Recently, many real time disaster prevention systems are introduced such as Phoenix system in Hyogo prefecture, Japan [4]. In this paper, a simulation system on rescue is developed and proposed. This system can predict earthquake disaster spatially and temporally by using intelligent systems such as cellular automata and multi-agent system (Weis [5]). Proposed system is developed aiming to gather various information in real time when

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earthquake disasters are occurred and to support rescue operation smoothly. In this paper, rescue operations in earthquake disasters are simulated by using proposed system and the ability of disaster prevention is discussed and clarified. In addition, RFID (Radio Frequency Identification) [6] is introduced as a brand-new technique in various fields. In Japan, the proof experiment is already started for the application to the construction industries (Arai et. al. [7]). RFID is considered to be a handy information gathering device and in great disasters, information on constructions such as structural members, construction materials and information of peoples who have RFID cards can be gathered by sending the radio waves. In this paper, applicability of RFID is also proposed and discussed.

The proposed system (Yamamura et. al. [8] and [9]) consists of two parts. In the first part, predictions of direct damages from an earthquake are performed by using empirical equations. Here, judgment whether buildings are collapsed, the ratio that people are trapped in the wreckage and so on are estimated. The virtual city model is defined as a two-dimensional plane which is divided into cells. In the second part, rescue activities are simulated in accordance with direct damages predicted in the first part. Here, the transition of the earthquake human disaster in the urban area by rescue operation can be simulated in consideration with the change in a time disaster situation. In this system, rescue operations are assumed to be performed by the family of trapped persons and rescue teams. Persons and rescue teams are assumed as agents and can act autonomously based on their own rules. As for a target city, Takarazuka City, a middle city in Hyogo Prefecture, Japan is employed and is mapped as digital data to 10m mesh.

Some case studies are carried out. It becomes possible to compare human damages for time and the effective acceleration on the ground became possible by proposed system. The transition processes of human damage are obtained and discussed spatially and timewise. Finally, the effectiveness of proposed system is verified and discussed by using simulation results.

OUTLINE of SIMULATION

Flowchart of Simulation System

Fig.1 shows a flowchart of proposed simulation system. At first, damages of houses are predicted by using empirical equations immediately after the earthquake occurrence. In the next step, humans alive in collapsed buildings and situations of human suffering are determined. Based on results of damage prediction, rescue works are simulated in accordance with changes of disaster situations by time progress.

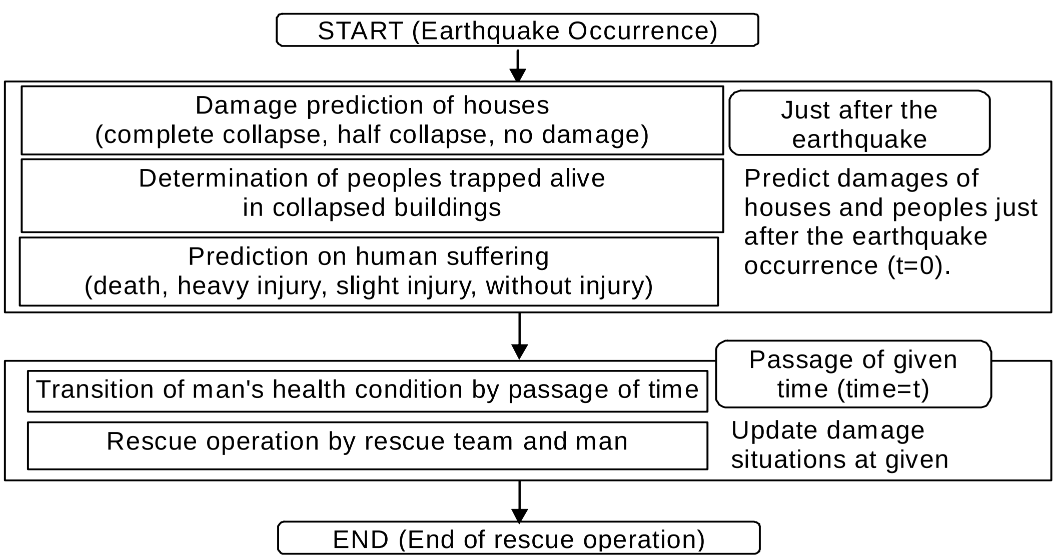


Fig.1 Flowchart of simulation system (Yamamura et. al. [9])

Modeling of virtual city

In this paper, it is assumed that a target city of this simulation consist of multiple cells as shown in Fig.2. These cells represent houses, fire departments and roads. Citizens and rescue teams are assumed to live in this virtual city. Citizens are assumed to live in houses, and rescue teams assumed to belong to fire departments. In this paper, it is assumed that only houses are damaged by the earthquake.

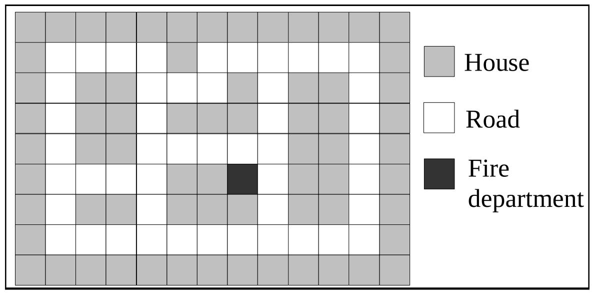


Fig.2 Model of virtual city

DAMAGE PREDICTION

In this paper, both damages of houses and human sufferings are predicted immediately after the earthquake occurrence.

Prediction of damages of houses

In this paper, indexes such as complete collapse ratio and half collapse ratio are employed and these indexes are estimated by Eqs.(1)-(3) (Nojima et. al. [10]). Eqs.(1) and (2) are functions of effective acceleration and summation of complete and half collapse ratio may exceed 100% when assumed effective acceleration is large. In such case, half collapse ration is assumed to be determined by Eq. (4). By using these equations, damages of houses are classified following three categories; ‘Complete collapse’, ‘Half collapse’ and ‘No damage’.

$$Y_{CC} = 100/\{1 + 2300 \cdot \exp(-0.01 \cdot x)\} \quad (1),$$
$$Y_{D} = 100/\{1 + 1700 \cdot \exp(-0.012 \cdot x)\} \quad (2),$$
$$Y_{HC} = 2(Y_{D} - Y_{CC}),\ Y_{TC} + Y_{HC} \leq 100\% \quad (3),$$
$$Y_{HC} = 1 - Y_{CC},\ Y_{CC} + Y_{HC} > 100\% \quad (4)$$

Here, Y_{CC} : Complete Collapse Ratio (%), Y_{D} : Damage Ratio (%),
Y_{HC} : Half Collapse Ratio (%), x : Effective accerelation on the ground (gal).

Prediction of human sufferings

Judgments whether humans are trapped in collapse houses or not are performed based on probabilities in accordance with damage situations of houses as shown in Table 1 (Murakami et. al. [11]). Human sufferings caused by the earthquake are also determined based on probabilities in accordance with damage situations of houses as shown in Table 2 (Murakami et. al. [11]).

Table 1 Probabilities trapped in collapse houses

	No damage	Half collapse	Complete collapse
Trapped ratio in collapse houses	10%	17%	35%
Ratio of escape for oneself	90%	83%	65%

Table 2 Probabilities of human sufferings

	No damage	Half collapse	Complete collapse
Death	0.01%	5.88%	8.58%
Heavy injury	9.09%	11.76%	20.00%
Slight injury	81.81%	64.71%	54.71%
Without injury	9.09%	17.65%	25.71%

Transition of Health Conditions of Trapped People

Health conditions of humans trapped in collapse houses assumed to change with time. In this paper, death of trapped humans is judged based on characteristic values of life-expectancy (Ohta et. al. [12]). Characteristic values of life-expectancy are estimated by characteristic functions of life-expectancy defined as shown in Eqs. (5)-(7). When characteristic values of life-expectancy become less than 0.01 in accordance with time, it is assumed that a trapped human is dead.

$$W_{HI} = \exp\left\{-\left(t/3.324\right)^{3.71}\right\} \quad (5),$$
$$W_{SI} = \exp\left\{-\left(t/26.59\right)^{3.71}\right\} \quad (6),$$
$$W_{WI} = \exp\left\{-\left(t/66.48\right)^{3.71}\right\} \quad (7)$$

Here, W_{HI}: Characteristic function on life-expectancy for heavy injury, W_{SI}: Characteristic function on life-expectancy for slight injury, W_{HI}: Characteristic function on life-expectancy for heavy injury, and t: Time (hour) .

RESCUE OPERATION

In this paper, two kinds of agent are assumed such as rescue teams and peoples. These agents assumed to perform rescue operations. If health conditions of rescued peoples are slight or no injury, rescued peoples are assumed to join in rescue operations. Rescue operations are assumed to terminate when trapped peoples in a target house are rescued.

Rescue Operation by Rescue Team

Rescue teams are assumed to perform rescue operations by following three actions as ‘Move’, ‘Search’ and ‘Rescue’. Rescue teams are assumed to belong to each fire department and a starting point of a rescue team is assumed to be a cell in abutment with each fire department.

Action ‘Move’

Action rules of rescue teams are shown in Fig.3. Rescue teams go straight along a road until an intersection. In the intersection, rescue teams stop and determine a next traveling direction. After that, rescue teams go straight again. In the intersection, the traveling direction where the frequency of the passage of the team is small is selected. In this paper, action ‘Move’ is assumed to be performed every second.

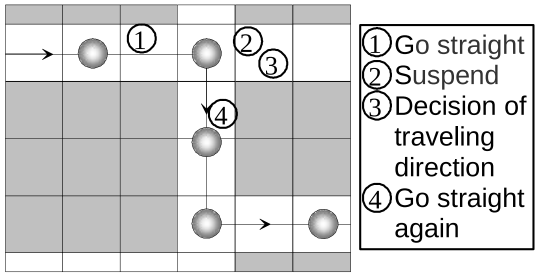


Fig.3 Movement of Rescue Team

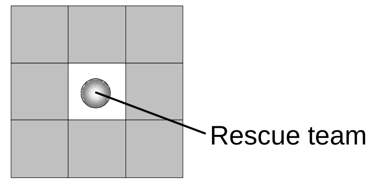


Fig.4 Search Area

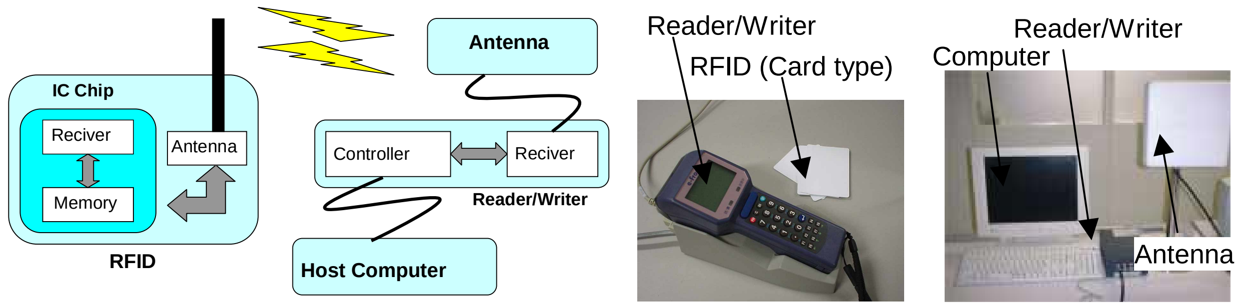
Action 'Search'
The rescue team searches for the rescue site in parallel with moving action. Search areas are assumed to be 8 cells surrounding current position of the rescue team as shown in Fig.4. If there are peoples trapped in a collapsed house within the search area, that cell is determined as a rescue site and rescue operations are started. When there are multiple corresponding places, a rescue site is selected randomly.

Action 'Rescue'
As for the rescue operations by rescue team, a certain interval when a rescue team can remove on rubbles in the rescue site is assumed parametrically. In this simulation, transportation of rescued peoples to medical institutions is not considered.

Rescue Operation by People
As for the rescue operations by peoples, it is assumed that peoples perform rescue operations only when their families are trapped in a collapse houses. Peoples are also assumed to stop rescue operations and evacuate to the safe place when rescue operations for their families are completed. A certain interval when a people can remove on rubbles in the rescue site is also assumed parametrically.

APPLICABILITY of RFID to REAL TIME DISASTER PREVENTION SYSTEM

In the modern cities, disaster information on houses, buildings and another structures can be obtained by cellular phones, PDA and/or mobile computers easily to search damaged areas. However, detailed information such as size, length and/or strength of structural members, what kinds of construction materials are used as interiors can not be gathered by visual observation. Usually, to gather required information, it is necessary to check drawings and specifications. If RFID devices are set up to structural members and/or construction materials, required information can easily gather by sending radio waves. In the rescue operations, rescue teams and/or rescue peoples can identify what kinds of rubbles are there over trapped peoples. Such information is useful to plan rescue works and to prevent second disaster by rubbles which contains harmful matters. As for the information of trapped peoples in collapse houses, rescue teams and/or peoples can search trapped peoples by sending radio waves if peoples put on RFID devices such as IC cards. At this time, power of RFID is small, so it is difficult to identify information in a long range. In near future, zone of radio waves are planed to transfer UHF bands in Japan, and power of RFID becomes strong, RFID is considered to be effective for real time disaster prevention system. Fig.5 shows an outline of RFID system. In Fig.5 (a), information flow of RFID is shown. As for RFID system, portable and stationary types are developed and are used properly according to the purposes of those usages as shown in Figs.5 (b) and (c).



(a) Information Flow of RFID (b) Portable Type (c) Stationary Type

Fig.5 Outline of RFID System

EXECUTION of SIMULATION

As for a target city, Takarazuka City, a middle city in Hyogo Prefecture, Japan is employed. Geographic information such as roads and town blocks of Takarazuka City is mapped as digital data to 10m mesh. Assumptions of simulation Case 0 are shown in Table 3. In this case, numbers fire departments and rescue team in each fire department are fixed. Removing speeds of rubbles by rescue teams and peoples are also assumed to be constant. In Cases 1 to 4, number of rescue teams, speed of removing rubbles by peoples and rescue teams and number of fire departments are changed. In these cases, running time is assumed to be 400 hours and another basis assumptions of the target city are same as those in Case 0. Figs.6 to 9 show simulation results in Case 0. Figs. 10 to 12 also show simulation results in Cases 1 to 3. Fig.13 shows the comparison of rescued area in Case 3.

Table 3 Assumptions of Case 0

Running Time	120hours
Effective Accelerelation on the Ground	400-1000gal
Number of Data	100
Number of Fire Department	5
Number of Rescue Team in One Fire Department	10
Number of Houses	19596
Number of Men who Live in One House	4
Population of Virtual City	78384
Speed of removing rubbles by people	one rubble/1hours
Speed of removing rubbles by rescue team	one rubble/1 minite

Table 4 Assumptions of Cases 1, 2 and 3

	Case1 Change the number of rescue teams	**Case2** Change the speed of removing rubbles by the rescue team	**Case3** Change the number of fire department in virtual city
Number of fire department in city	5		5, 6
Speed of removing rubbles by people	one rubble/5 hours		
Number of rescue teams that belong to fire station	1,5,10,20,25,30 teams	10 teams	
Speed of removing rubbles by rescue team	one rubble/1 minite	one rubbles／1,2,3minites	

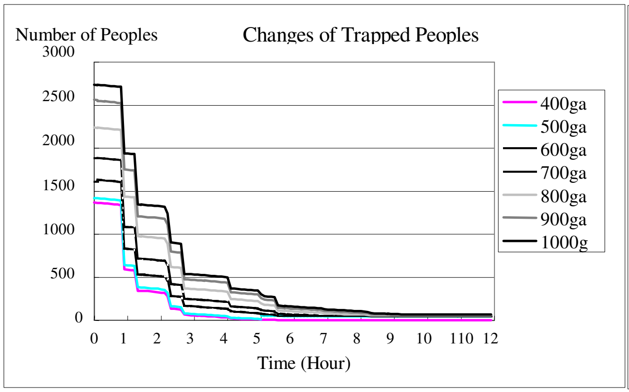


Fig.6 Changes of Trapped Peoples (Case 0)

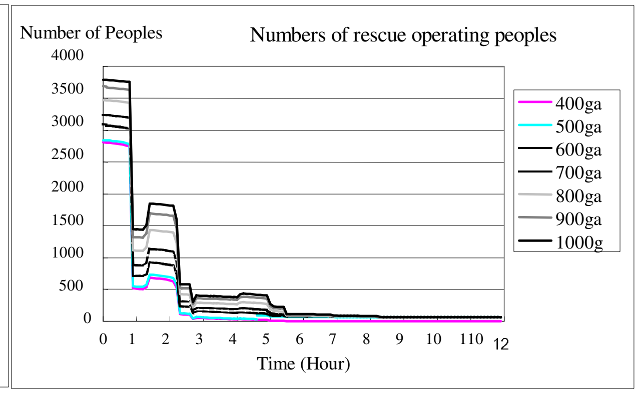


Fig.7 Number of Rescue Operating Peoples (Case 0)

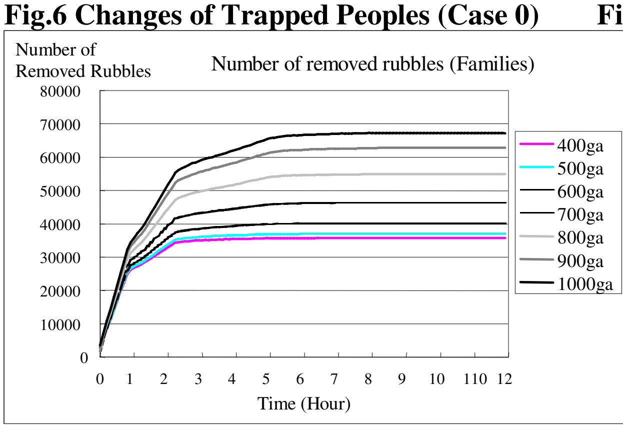


Fig.8 Number of Removed Rubbles (Case 0)

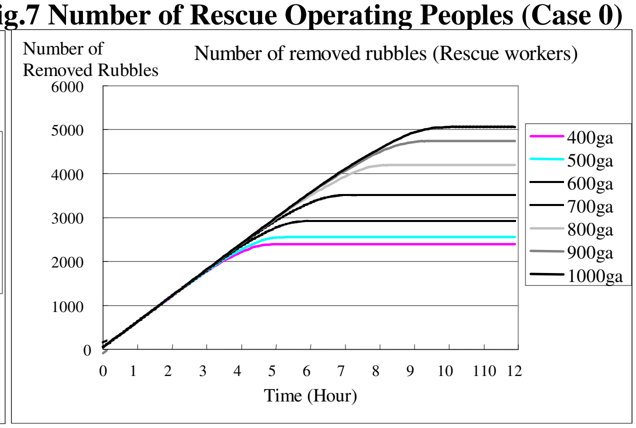
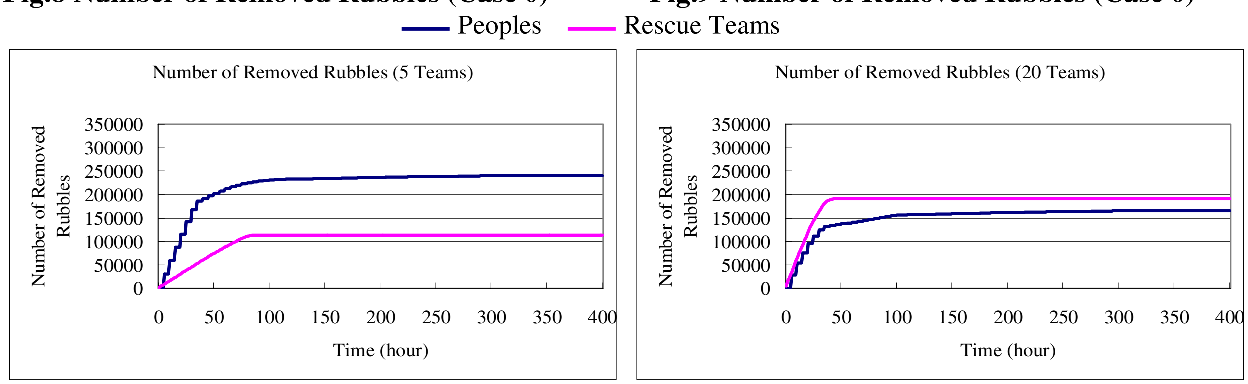
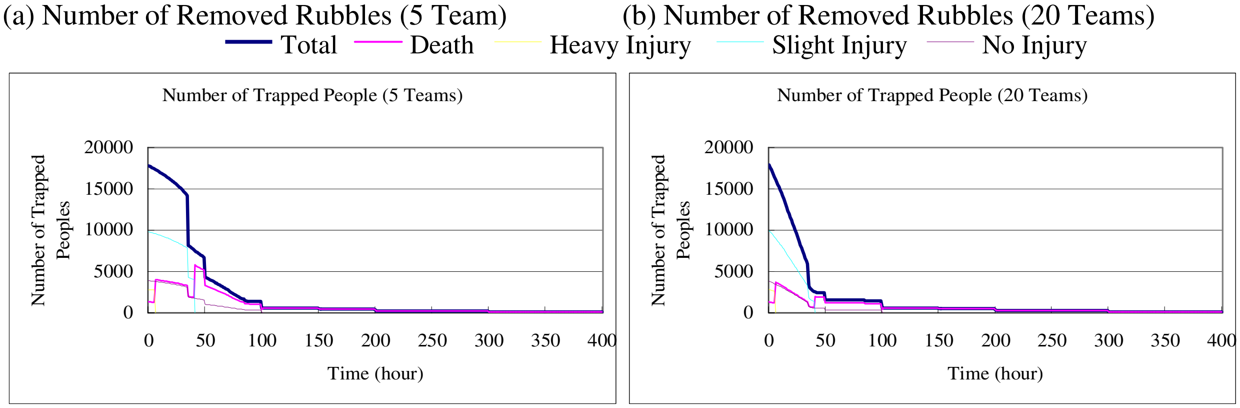


Fig.9 Number of Removed Rubbles (Case 0)

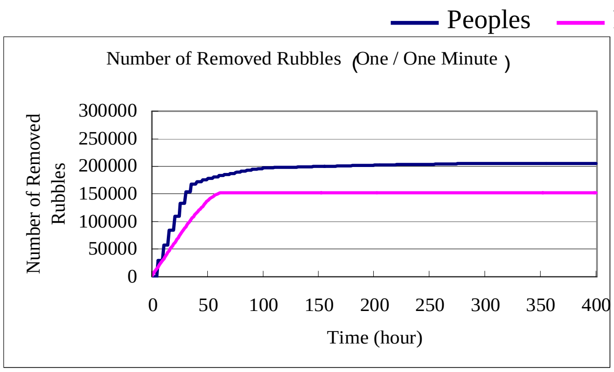


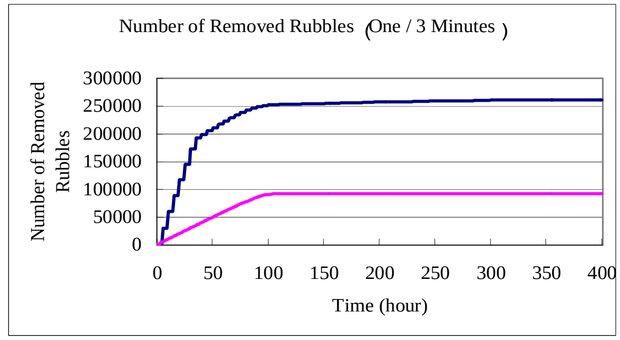
(a) Number of Removed Rubbles (5 Team) (b) Number of Removed Rubbles (20 Teams)



(c) Number of Trapped Peoples (5 Teams) (d) Number of Trapped Peoples (20 Teams)

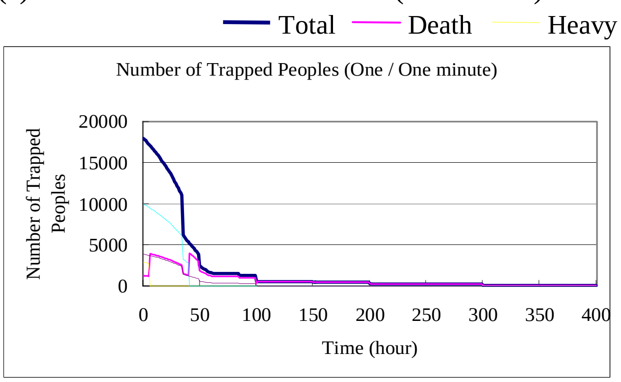
Fig.10 Results of Simulation (Case 1)

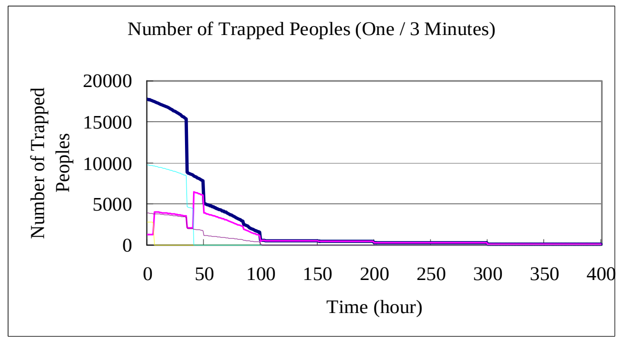




(a) Number of Removed Rubbles (1/1 Minute)

(b) Number of Removed Rubbles (1/3Minutes)

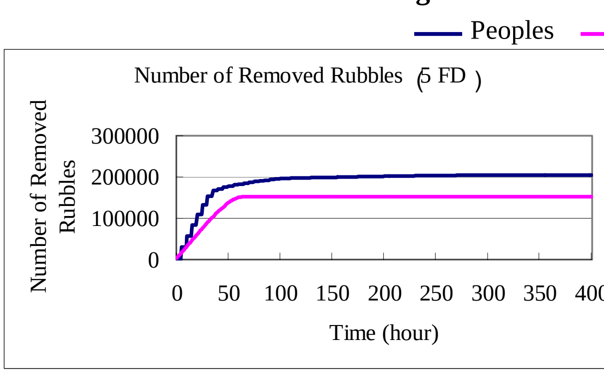


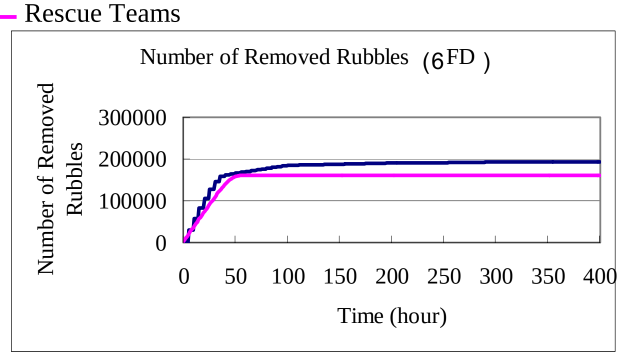


(c) Number of Trapped Peoples (1/1 Minute)

(d) Number of Trapped Peoples (1/3Minutes)

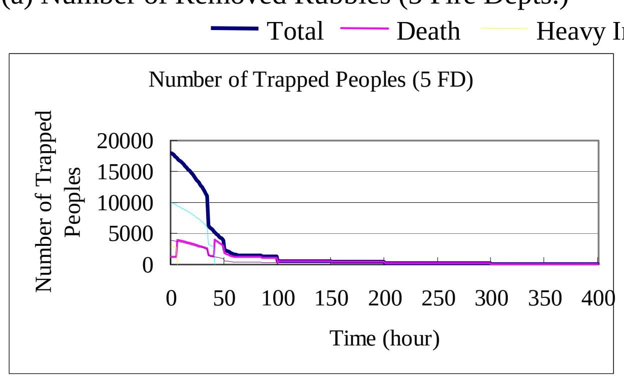
Fig.11 Results of Simulation (Case 2)

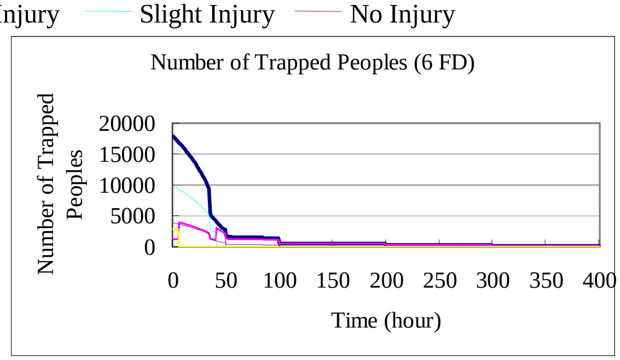




(a) Number of Removed Rubbles (5 Fire Depts.)

(b) Number of Removed Rubbles (6 Fire Depts.)

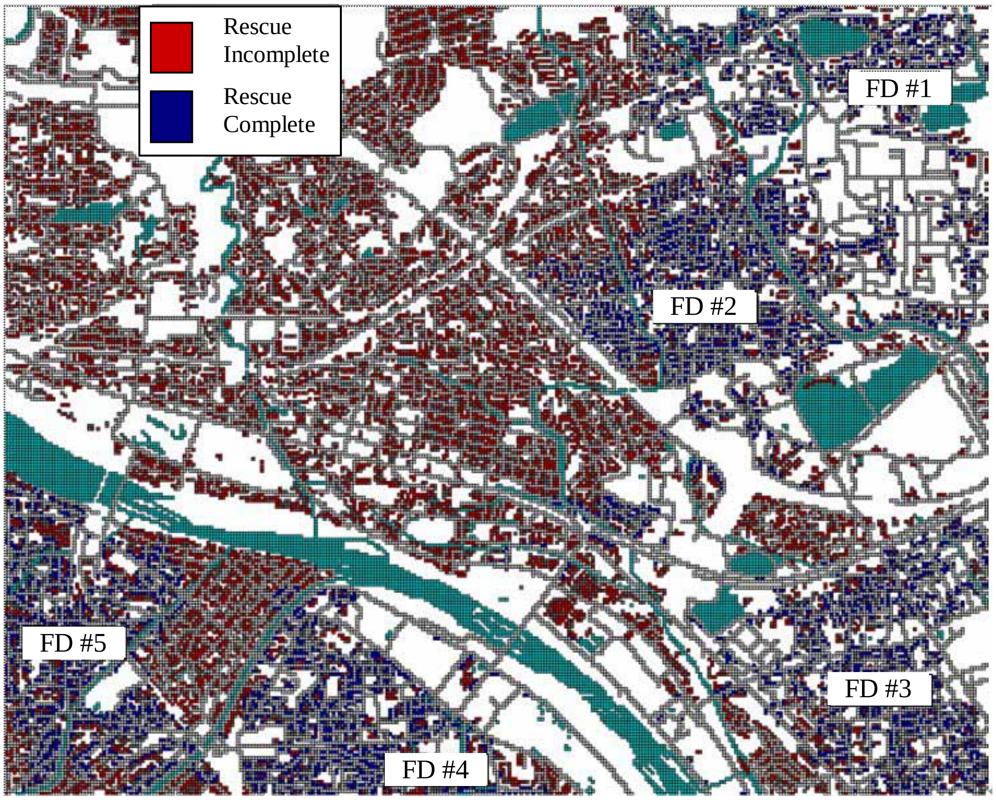




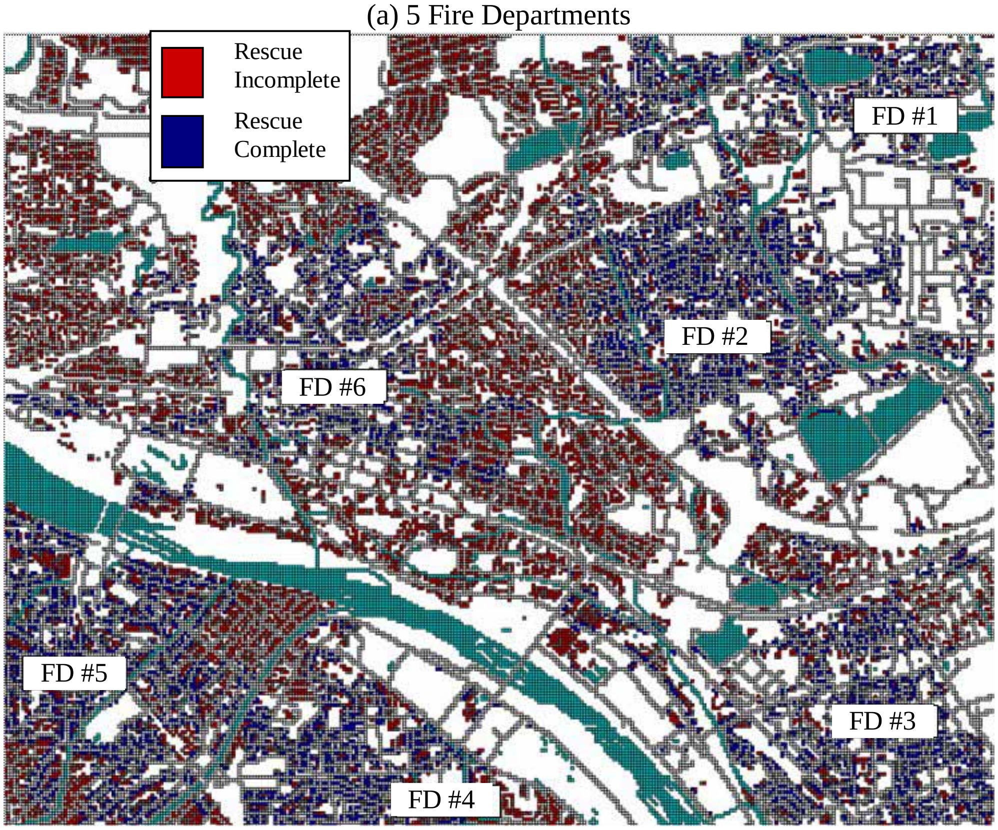
(c) Number of Trapped Peoples (5 Fire Depts.)

(d) Number of Trapped Peoples (6 Fire Depts.)

Fig.12 Results of Simulation (Case 3)



(a) 5 Fire Departments



(b) 6 Fire Departments

Fig. 13 Rescue Situation after 30 hours (Case 3)

DISCUSSIONS

Simulation Case 0

In Fig.5, the numbers of trapped peoples are decreased largely after 9, 13 and 23 hours at the earthquake occurrence. In Case 0, when only peoples perform rescue operations, one people can be rescued by three peoples by 8 hours. So, in this case, it is considered that there are many people to be rescued by their families. In Fig.6, after 9 and 23 hours at the earthquake occurrence, numbers of peoples who join rescue operations are decreased greatly because peoples who join rescue operations are excluded after completion of rescue operations. This also shows that there are many people to be rescued by their families. Same conditions after 23 hours are also as the same reason. In Fig.7, numbers of rubbles removed by peoples is in population to time and gradients are changed in four steps. This means that numbers of peoples who join rescue operations are roughly divided into four steps. In Fig.8, relations between numbers of rubbles removed by rescue teams and time have different characteristics. Numbers of rubbles removed by peoples is in population to time and gradients are changed in two steps. This is because peoples are excluded after completion of rescue operation, but rescue teams are assumed to join rescue operation during all simulation time.

Simulation Cases 1

In Fig.9 (a), increments of numbers of removed rubbles by rescue teams and peoples are ended about 50 hours and 270 hours respectively. In Case 1, speeds of removing one rubble over trapped peoples are assumed to be 1 minute by rescue teams and 5 hours by peoples. In case that peoples started rescue operations for their families before a rescue team arrived at rescue site, rescue operations are assumed to perform only by peoples. So, these differences are considered to depend on time required to rescue a trapped people. In Fig.9 (a), the total number of removed rubbles by peoples is larger than that by rescue teams. In case of 20 rescue teams, rescue teams can remove larger rubbles than peoples as shown in Fig.9 (b). In Fig.9 (c), the total numbers of trapped peoples are decrease stepwise after about 35 and 50 hours in case of 5 rescue teams. These rescue operations are considered to be performed by peoples. However, in case of 20 rescue teams, the total numbers of trapped people are decrease continuously before 50 hours. In this case, rescue operations are considered to be performed by both rescue teams and peoples. In this simulation, differences of time transition curves of total numbers of trapped peoples become small, so it is considered that required rescue teams in the target city is up to 20 teams in assumed equivalent earthquake acceleration on the ground.

Simulation Case 2

In this simulation, speeds of removing one rubble by rescue teams are changed. In case that removing speed is assumed to be 1 minute, the total numbers of removed rubbles are nearly and increase of removed rubbles are ended before about 60 hours by rescue teams as shown in Fig.10 (a). On the other hand, in case that removing speed is assumed to be 3 minute, the total numbers of removed rubbles by rescue teams are less than those by peoples and increase of removed rubbles are ended after about 100 hours as shown in Fig.10 (b). In this case, peoples remove rubbles 2.5 times larger than those by rescue teams. The total numbers of trapped people are decreased rapidly when the speed of removing one rubble become faster.

Simulation Case3

In this simulation, numbers of fire departments in the target city are changed. In this case, the number of rescue teams in each fire department is assumed to be 10, numbers of removed rubbles become large when the number of fire department is assumed to be 6 as shown in Figs.12 (a9 and (b). Total numbers of trapped peoples are decreased rapidly after 35 hours in case that the number of fire department is assumed to be 6 as shown in Figs.12 (c) and (d). In this case, a new fire department FD#6 is assumed to be located at north-west area in the target city as shown in Fig.13 (b). In case that the number of fire departments is 5, rescue operations in this area is late because there is no fire department located around this area as shown in Fig.13 (a). Therefore, proposed simulation system is considered to be effective to arrange locations of fire departments in the target cities because rescue operations are considered to perform around each fire department.

Applicability of RFID System

At present, RFID system has not introduced to real time earthquake disaster prevention system yet. However, when output power of RFID system becomes large, it is considered that RFID is effective at disaster sites. If trapped peoples have RFID, rescue teams can judge weather there are tapped people or not easily. If RFID is set to structural members and/or construction materials in collapse houses, rescue teams can also identify which kinds of material are used and how many rubbles are there over trapped peoples because reader of RFID can read multiple data at the same time. Furthermore, if RFID system can be used not only rescue teams but also peoples, RFID system is considered to be more effective in the disaster site. If RFID system is combined with another information tools such as cellular phones, PDA and/or mobile internet tool, various information at disaster sites can be gathered easily in a short time. As shown in Case 2, the speed of removing rubbles by rescue teams is considered to depend on the identification of kinds of rubbles. Therefore, RFID is effective for the identification of kinds and/or numbers of rubbles and the removing speed is considered to be short.

CONCLUSION

In this paper, examinations on the disaster prevention power of a modern a city are performed by the proposed simulation systems. In digital simulations, in order to discuss and clarify the disaster prevention power, numbers of rescue teams, arrangements of fire departments, and so on are changed variously, and many digital simulations are performed. Results of digital simulations shows effectiveness of rescue operations by rescue teams are clarified and the layout planning of fire departments are also discussed. It is proved that that proposed system is effective for rescue simulations and the estimation of disaster prevention power prior to large earthquake disasters in the future. Furthermore, applicability of RFID to real time disaster prevention system is also discussed. To perform more effective and realistic simulations, it is necessary to perform further improvements of proposed system.

ACKNOWLEDGEMENTS

This research is supported by the Japan Society for the Promotion of Science (2004 Grants-in-Aid for Scientific Research, Scientific Research (A)(1), No.14205087: System Design for Architecture, Urban and Social Systems Adapting to Human and Environment by Complexity Science), and supported in part by the Twenty-First Century Center of Excellence (COE) Program "Design Strategy towards Safety and Symbiosis of Urban Space" awarded to Graduate School of Science and Technology, Kobe University. The Ministry of Education, Culture, Sports, Science and Technology of Japan sponsors the Program. This research is also supported by Research Center for Urban Safety and Security (RCUSS), Kobe University, Japan. The authors acknowledge to Dr. Akihiko Hokugo, Associate Professor of RCUSS, Kobe University who is a member of our research project supported by RCUSS for his advice and discussion.

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