A simulation model development of firefighting activity by community residents against coseismic fire spread using multi-agent system

As a support tool for community-based disaster prevention planning

Y. Gohnai, A. Ohgai and K. Watanabe[1]
Toyohashi University of Technology, Toyohashi, Japan
[1]The University of Tokushima, Tokushima, Japan

Key words: Community-based Planning for Disaster Prevention, Planning Support System, Fire Spread Simulation, Firefighting simulation, Multi-agent system, Cellular Automata

Abstract: This paper attempted to develop a simulation model of residents' firefighting activity against coseismic fire spread using multi-agent system. The developed model was applied to a case study area. In the application, the simulations were carried out to the existing area and eleven cases of the assumption (virtual conditions) of the area where are implemented various non-physical and physical measures. As a result, the measures with only physical and haphazard multitude of measures did not show a remarked effect of disaster prevention performance. And, it is confirmed that the model can visually, dynamically and quantitatively output results. From these outputs, the possibility of contribution for enhancing residents' awareness and drafting a plan of disaster prevention was confirmed. However, there are still some problems to be solved for the practical use of the model.

1. INTRODUCTION

Japan has suffered various damages by many grate earthquakes. In particular, densely built-up area with decrepit wooden buildings and many narrow roads has sustained enormous damage by building collapse, fire spread and others each time. The high risk area still exists in substantial amounts nevertheless, where have a lot of serious problems such as uncertainty of safe evacuation, firefighting, rescue and threat of fire spread. For the solution to these problems and reduce the risk level in Japan, there is need for promotion of efforts to improve the local environment through cooperative consensus building between the residents and the administration of the areas.

To promote the efforts, enhancing residents' awareness and drafting a plan of disaster prevention are necessary. But, there is limit to change the residents' mind by the traditional method such as briefing and public information (newsletter, bulletin, etc.). Moreover, it is difficult for residents who do not have expertise to make concrete a plan. From these situations, the support technology development of community-based planning for disaster prevention has societal demand in Japan.

For the enhancing awareness and the drafting a plan, they have to deal various major difficulties from the point of view of disaster prevention. Especially in the densely built-up area, measures of fire spread prevention are generally addressed as a main theme because most of the area is structured by highly combustible building. Additionally the local administrative fire department cannot response to all the fires in case of multiple fires by massive earthquake. Therefore, firefighting activity of community residents is extremely important for minimizing damage of the area. Against such a background, if there were a tool that could provide the residents information on simulation results of fire spread and residents' firefighting activity in case of an existing circumstance and an improved circumstance, the tool would be useful for the enhancing awareness and the planning. For more effective providing information, a simulation model development which can accurately, visually and dynamically reproduce an actual phenomenon is required. As a one method for the model development, Multi-Agent System (MAS) which has potential for analysis and understanding of societal phenomena is brought to international attention in fields such as social science, economics and urban planning.

Based on the above, this paper attempted to develop a simulation model of firefighting activity by community residents against coseismic fire spread using multi-agent system as a support tool for community-based disaster prevention planning.

This study's approach is outlined as follows. Firstly, we tried to develop the model by reference to previous researches. Secondly, the developed model was applied to an existing case study area and the virtually-improved area. And, the effect of improvement were analysed and discussed using the simulation results. Finally, the usefulness and problems of the proposed model were discussed from outcome of this process.

2. FIREFIGHTING ACTIVITY BY RESIDENTS AND MULTI-AGENT SYSTEM

Multi-Agent System (MAS) is composed by multiple interacting intelligent agents and environments that are independent subjects. They have several characteristics such as attribute, algorithms and at al. They are additionally interdependent and influence each other (Ohuchi, Yamamoto and et al., 2007). MAS is not a monolithic system, it is intended to reproduce the actual situations as realistic as possible by modelling of unpredictable phenomena , for example natural phenomena, human society which contain wide variety of character, uncertainties, various factors and at al (Yamakage, 2007).

Previous research using this technology has been advancing in various fields including economics, social science, and engineering. In the field of urban planning, MAS is used to understand dynamic and complicated urban phenomena and to predict land use changes, pedestrian behavior and optimization of facility placement. The firefighting activity by residents against fire spread is a phenomenon, in which various factors related to the circumstances of built-up area, residents' attribute and ability are intricately related. From results of previous research, this phenomenon must be reproduced by constructing appropriate model using MAS.

For enhancing residents' awareness and planning to promote community-based disaster prevention activities, easy-to-understand and effective simulation outputs are required. Using MAS, it is possible to visually, quantitatively and dynamically provide information about the simulation results.

In the present study, using the results of previous research and the characteristics of MAS, we have developed model of a residents' firefighting activity against fire spread.

3. BASIC CONCEPT FOR MODEL DEVELOPMENT

In this paper, the overview flow of whole firefighting activity was set as shown in *Figure 1* based on previous research. The firefighting can be treated separately divided into "firefighting in an early stage" and "Fire spread prevention activity". The former is intended to extinguish origin of fire, and the letter's objective is block of fire spread to neighboring buildings for prevention the damage from spreading as a district. In case of the former, it is generally considered in Japanese firefighting circles that if residents can

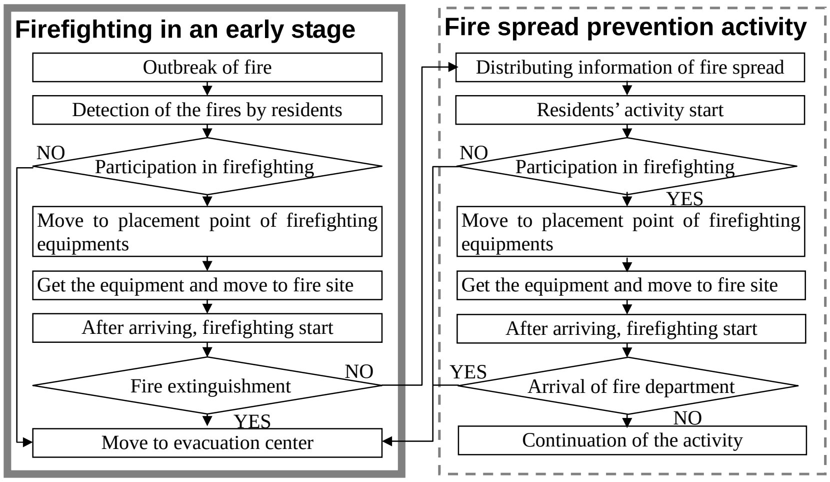


Figure 1. Overview flow of whole the firefighting activity

reach the fire site within ten minutes, there is a possibility of control a fire by firefighting using extinguishers (Kanai and Kaji, 2002). And, it is important to extinguish in an early stage for minimizing the damage, because of the stage is less ability to cause the fire spread and burning area is small.

From the above, this paper attempts to construct a model of the part of heavy gray line in *Figure 1* that is especially important in the firefighting.

4. MODEL DEVELOPMENT

For the development, agents and elements of environment were set as shown in *Table 1*. As mentioned above, this model development aims to output simulation results with realistic, and the model deals with early stage's firefighting that is a very short period of time. Therefore, the unit of the time is one second, and the space of the model was composed a lattice array of one by one meter cells. The model consists fire spread model and residents' firefighting model. These models are described below.

4.1 Fire Spread Model

Fire spread model of this paper use the achievements of the previous research (Ohgai, Gohnai and Watanabe, 2007). The outline of the model is described below. As for details, please refer to the paper.

Transitions in the cell state and types of neighborhoods used in the model are set as shown in *Table 2* and *Figure 2*.

Table 1. Agents and environment in the developed model

Category	Element	Content
Agent	a) Residents	It has parameters of movement speed and start position as exogenous attributes, and keeping state of firefighting equipments and participation or nonparticipation in firefighting as endogenously attributes. Residents basically move on roads and open spaces, but they can enter only burning buildings for firefighting.
	b) Fire (Fire spread)	It has state of catching fire, burning, naturally extinguished, and extinguished by firefighting as attribute.
Environment (Built-up area)	c) Building	It has parameters of structure (wooden, fire-prevention wooden and fireproof) and the ratio of the area occupied by wooden or fire-prevention wooden buildings in cell as exogenous attributes. And, it has parameters of state (catching fire, burning, naturally extinguished, and extinguished by firefighting) and the ability of fire spread.
	d) Road	Public and private roads. It has two situation of normal and blockage by building collapse.
	e) Open space	Open-air car parks, farmlands, unused land and etc.
	f) Extinguisher	Fire extinguisher of general type that is placed in built-up area of Japan.
	g) Storage of supplies and equipments for disasters	It is small building to storage various supplies for disasters. In this paper, it was assumed that portable fire pump is stored in the storage.
	h) Water tank for firefighting	It was assumed that the capacity of the tank is about forty cubic meters (it is in widespread use all of Japan)
	i) Evacuation Center	The assigned evacuation sites such as elementary schools, junior high schools, community centers and etc. by the municipality.

Table 2. State of a cell

Expression	Explanation
[0]	n_{mn} = 0: Unburnable; Having nothing burning.
[1]	n_{mn} = 1: Not burning yet; Having the possibility of burning.
[2]	n_{mn} = 2: Catching fire; Just catching fire, but having no ability to cause the spread of fire.
[3]	n_{mn} = 3: Burning; Having the ability to cause the spread of fire.
[4]	n_{mn} = 4: Extinguished (subsidence of fire); Not having the ability to cause the spread of fire.
[5]	n_{mn} = 5: Extinguished by firefighting；Not having the ability to cause the spread of fire.

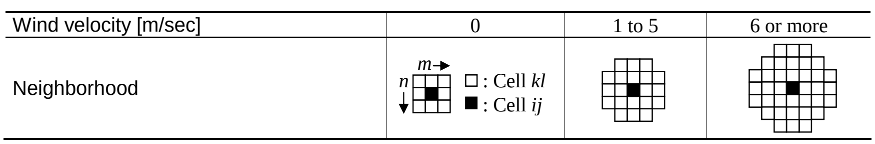


Figure 2. Neighborhoods used in the model

The fire spreading judgment, that is, whether or not cell *ij* changes from state [1] to state [2], is performed using the fire spreading probability of cell *ij*. The probability is given by the fire spreading judgment index F_{ij}. This is calculated for all *ij* cells within the neighborhood of cell *kl* and defined by equation (1).

$$F_{ij} = S_{ij} \cdot P_{ij} \cdot W_{ij} \cdot p(t_{ckl}) \qquad (1)$$

where S_{ij} is a building structure parameter, P_{ij} is the ratio of the area occupied by wooden or fire-prevention wooden buildings in cell *ij*, W_{ij} is a parameter determined by the wind velocity and direction, and $p(t_{ckl})$ is the ability of cell *kl* to cause the spread of fire. These values range from 0 to 1.

Figure 3 shows the flow of the fire spread model in addition to a residents' firefighting model described later.

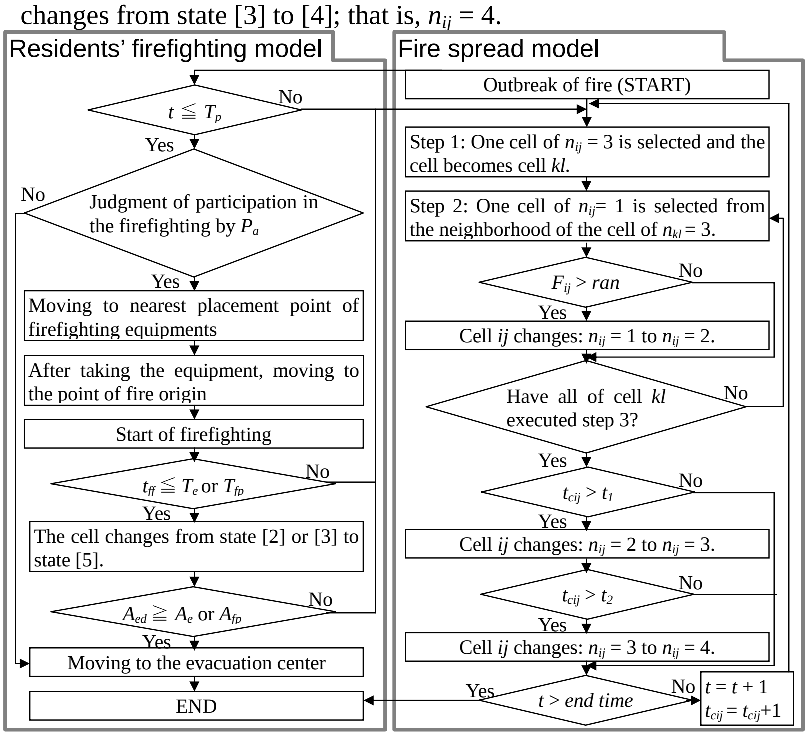
- Step 1: First, one cell *kl* of $n_{kl} = 3$ is selected.
- Step 2: One cell *ij* of $n_{ij} = 1$ is selected at random from the neighborhood defined by the wind direction and wind velocity externally given when starting the simulation.
- Step 3: The fire spreading judgment index F_{ij} of the selected cell *ij* is calculated. If F_{ij} satisfies the following requirements, the state of cell *ij* becomes $n_{ij} = 2$ (catching fire):

$$If \quad n_{ij}(t) = 1 \ \ and \ \ F_{ij} > ran \ \ then \ \ n_{ij}(t+1) = 2 \tag{2}$$

where $n_{ij}(t)$ is the state of cell *ij* at simulation time *t* and *ran* is a random number from 0 to 1.

Note that t_{cij} is the elapsed time after the outbreak of fire in cell *ij*. The time count of t_{cij} starts when the state of cell *ij* changes from state [1] to [2]; that is, when equation (2) is satisfied. Steps 2 and 3 are iterated for all cells *ij* within the neighborhood of cell *kl*. Further, the process regarding cell *kl* is executed for all cells in state [3].

– Step 4: The state of cell *ij* after catching fire changes according to the elapsed time after the outbreak of fire t_{cij}. In other words, if the value of t_{cij} is more than t_1 = 2 [min], cell *ij* changes from state [2] to [3]; that is, $n_{ij} = 3$.
– Step 5: Moreover, if the value of t_{cij} is more than t_2 = 10 [min], cell *ij* changes from state [3] to [4]; that is, $n_{ij} = 4$.



t: simulation time [sec], T_p: detection time of fire outbreak, P_a: percentage of firefighting participants[%],T_e: The time for control a fire by extinguisher [sec], T_{fp}: the time for control a fire by portable fire pump [sec], A_e: the number of extinguishable cell by an extinguisher[cell], A_{fp}: the number of extinguishable cell by portable fire pump[cell], t_{cij}: elapsed time after outbreak of fire [sec], t_1: The time until cell *kl* becomes able to cause the spread of fire after catching fire [sec], t_2: The time until cell *kl* burns out after catching fire [sec], *end time*: end time of simulation [sec], F_{ij}: fire spreading judgment index of cell *ij*, *ran*: random number given within the range from the maximum to the minimum value of F_{ij}, t_{ff}: The elapsed time from the start of firefighting in each cell [sec], A_{ed}: Number of the cell extinguished by firefighting [cell]

Figure 3. Flow of the model

– Step 6: The simulation ends when the time *t* [min] becomes the end time externally given in the model. The time *t* is counted from the start of the simulation to the end. When the time *t* does not reach the end time, 1 is added to t_{cij} of cell state [2] and *t*, and the process then returns to step 1.

4.2 Residents' Firefighting Model

The following firefighting process was modeled as bellow in this study.

After a lapse of detection time of fire outbreak T_p [sec], residents participate in the firefighting or move to the evacuation center. Whether or not residents participate the firefighting are set by percentage of firefighting participants P_a [%] that is randomly and endogenously given residents the rate at the start of simulation. Residents of participation in firefighting move to nearest placement point of extinguisher or portable fire pump according to the attribute of the usable equipments. After taking the equipment, they move to the point of fire origin at the movement speed S_r [m/sec] according to the situation of agents' keeping equipments and road blockage by building collapse. Resident keeping extinguisher or portable fire pump can change cells of state [2] and [3] (catching fire and burning) to state [5] (extinguished by firefighting) according to these equipments' performance. When resident used up the equipment, they move to the evacuation center.

The model flow of the residents' firefighting and fire spread are shown in *Figure 3*. Additionally, the detailed information about parameters and setting values of the resident's firefighting model are shown in *Table 3*.

The parameter values were set based on previous researches, but, for consideration of the subject area's condition, the developed model was incorporated control modules that can easily adjust the value.

5. APPLICATION OF THE DEVELOPED MODEL

As a case study, the developed method is applied to Akumi district, Japan (*Figure 4*). The district is located in the Japanese local cities of Toyohashi and is considered as having disaster prevention issues due to existence of many narrow roads and densely built-up area with old wooden structures (*Figure 5*). Furthermore, occurrences of big earthquakes are feared in the municipality. The Japanese government designated the municipality as focus area for earthquake disaster prevention measures in 2002. Therefore, the municipality in the case study district is seriously working on improvement projects for disaster prevention.

Table 3. Parameters and its contents of residents' firefighting model

Parameter	Contents and set values
Detection time T_p [sec]	T_p is required time for residents to dete[illegible] [illegible]erience in disaster drills for firefighting was three mi[illegible] [illegible]utes based on previous resea[illegible] (Kanai and Kaji, 2002).
Percent[illegible] firefighting [illegible] [%]	[illegible] percen[illegible]e of firefighting participants [illegible] subject area. The [illegible] set as follows with reference t[illegible] [illegible]i, Ohgai and et [illegible] exper[illegible] [illegible]s for firefighting is [illegible] the case; its value is 50%.
Movement speed S_r [m/sec]	[illegible] is [illegible] residents' movement speed, and the speed va[illegible] with circu[illegible] built-up area. The values were [illegible] as follows with reference to previous researches. - Movement on the normal road or op[illegible] spaces: 1.5[m/sec] (Fire institute of Japan, 1997) - Movement on the debris of the colla[illegible]d building and the burning building: 0.75[m/sec] (Watanabe, 2007 and Fire Institute of Japan, 1997) - Movement with portable fire pump: 0.5[m/sec] (Sekizawa and Endou, 2003)
Performance of extinguisher	A_e[cell] is the number of extinguishable cell by an extinguisher. The value was set one [cell] with reference to previous research (Kanai and Kaji, 2002). T_e[sec] is the time for control a fire, and the value was set 15[sec].
Performance of portable fire pump	A_{fp}[cell] is the number of extinguishable cell by portable fire pump. The value was set ten [cell] with reference to previous research (Sekizawa and Endou, 2003). T_{fp}[sec] is the time for control a fire, and the value was set 85[sec]. V_t[m^3] is the capacity of water tank for firefighting. V_n[m^3/min] is the volume of water that a nozzle consumes per minute. The value of V_t can be optionally set and externally given 40, which is based on the Japanese standard for [illegible] water tank for firefighting. With reference to the previous research, the value of V_n was set at 0.35. The spraying time by portable fire pump depends on the capacity and the amount of consumption. Firefighting using the pump needs two people for [illegible] power unit setting and spraying (Japan fire protection Association, 1997). Additionally, the preparation time spraying was set 200 [sec], including setting the pump's power unit at the water tank, carrying a hose to burning building and et al (Sekizawa, Kobayashi and at al., 2005).

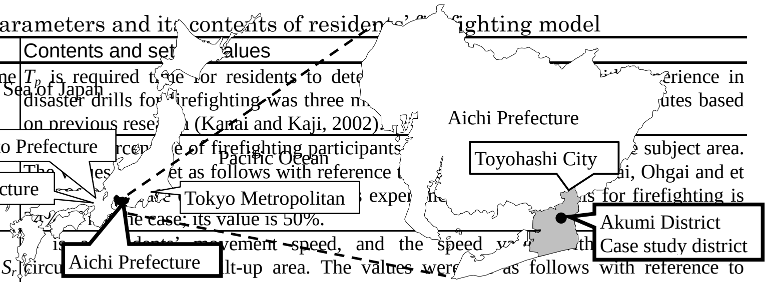
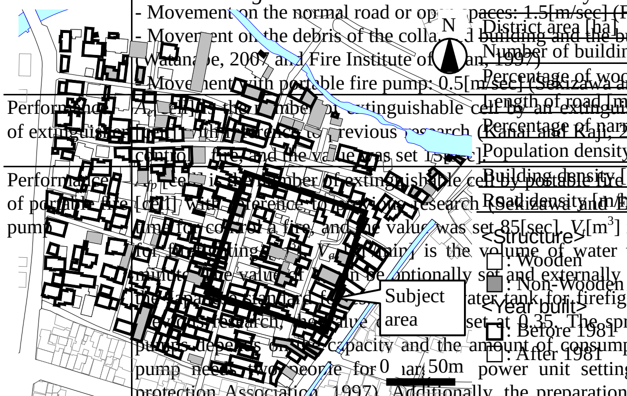


Figure 4. The location of the case study district



District area [ha]	7.47
Number of building	386
Percentage of wooden buildings [%]	85.8
Length of road [m]	2320
Percentage of narrow roads [%]	44.0
Population density [Person/hectares]	86.3
Building density [Building/hectares]	51.7
Road density [m/hectares]	298.5

Figure 5. The detail of the case study district and the subject area

5.1 The Case Study District and the Subject Area

Akumi district is a small-scale densely built-up area that has never encountered war damage. Additionally, this district was not involved in the improvement of urban infrastructure. Therefore, the area still has a lot of old wooden buildings, many narrow roads of 4-5 meters in width and dead-end street. And, designated evacuation sites by the municipality (such as elementary schools, junior high schools, community centers and et. al) and many open spaces or fire-proof buildings which can block fire spread are not within the district.

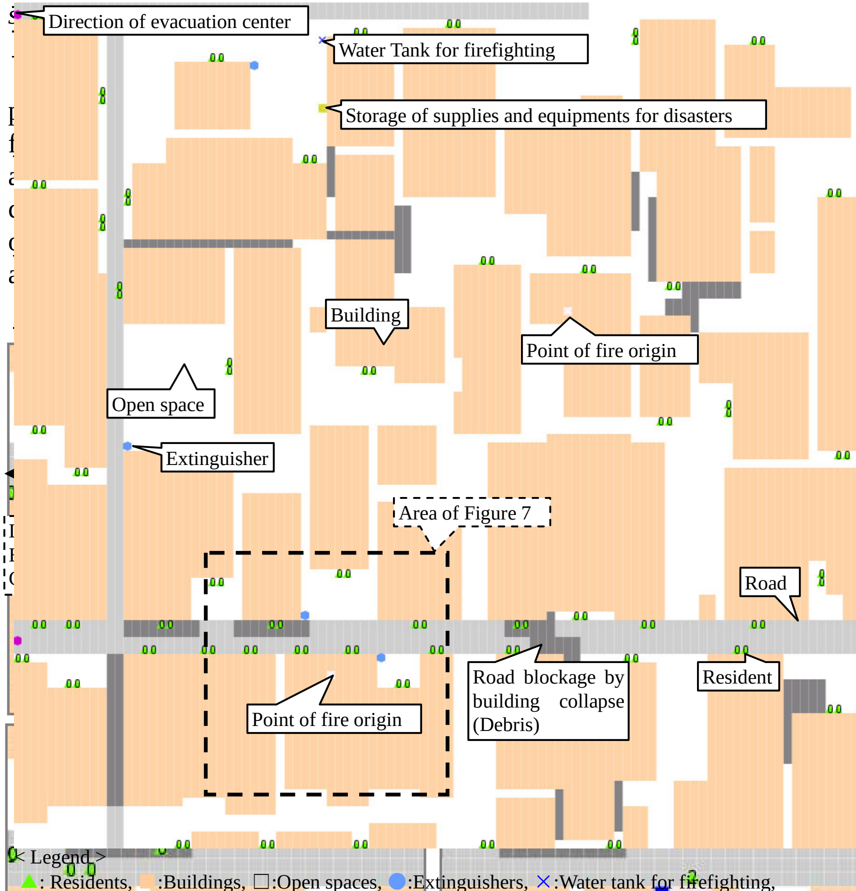
A part of the district has a particularly high risk of building collapse, road blockage, fire spread and difficulties during emergency response activities such as evacuation, fire fighting and rescue. The area was set as the subject area for the application. The size of the area is about one hundred square-meter patch of built-up area (see *Figure 5*).

The reproduced subject area by MAS is show in *Figure 6*. About one hundred residents are deployed on the area in consideration of population, number of households and stay-at-home percentage referenced by census data (Toyohashi city, 2007).

5.2 Setting of Simulation Cases

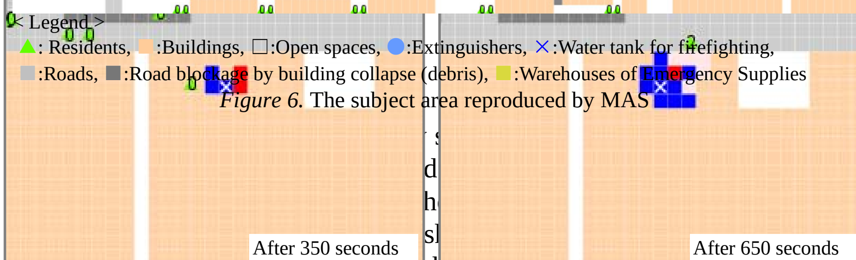
The simulations of the following four categories (eleven cases) ware carried out to confirm simulation results on the existing circumstances and the improvement effect by assumption (virtual conditions) of physical and non-physical measures. *Table 4* shows the detailed setting of simulation cases.

The non-physical measures are assumed improvement of human and community capabilities of disaster prevention by awareness enhancement, disaster drills and et al. And, the assumptions of physical measures are increasing in disaster prevention performance by improvement of the local environment such as antiseismic reinforcement of buildings, addition of firefighting equipments and et al. In the combinations of non-physical and physical measures, the following two cases were set; 1) the all measures of non-physical and physical (six measures), 2) the most effective one non-physical and one physical measures.



< Legend >
: Residents, :Buildings, :Open spaces, :Extinguishers, ×:Water tank for firefighting,
:Roads, :Road blockage by building collapse (debris), :Warehouses of Emergency Supplies

Figure 6. The subject area reproduced by MAS



Elapsed time after outbreak of the fire is shown on the bottom-right corner of each output
<Legend of the cell> : Catching fire, : Burning, : Extinguished by firefighting
<Legend of the resident's state> 0: Open-hand, 1: Keeping an extinguisher, 2: Keeping a portable fire pump, 3: Setting a power unit of portable fire pump

Figure 7. An example of simulation result by map representation

after 300 seconds of outbreak of the fire. The condition of resident's firefighting using portable fire pump at the elapsed time 650 seconds can also be seen in the figure. And, *Figure 8* quantitatively shows an example of simulation result by graph representation in real time. From this figure, it is possible to confirm the cell number of state of burning, extinguished cell by firefighting and naturally extinguished cell.

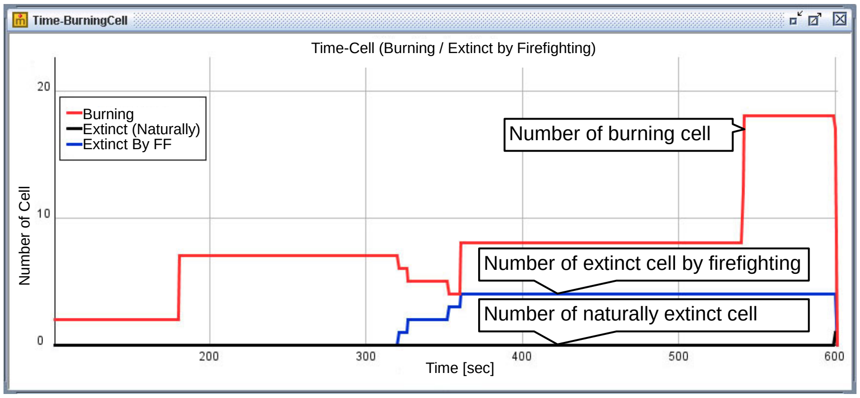


Figure 8. An example of simulation result by graph representation

It is considered that the above simulation results may be help residents in consensus building, enhancing awareness of the need for improvement of the local environment and decision making when planning for disaster prevention.

However, the actual time required for simulation calculation of the one case was about an hour using a personal computer with an Intel Core 2 Duo 1.6 GHz CPU and 1 GB memory (depending on the simulation conditions of each case).

5.3 Analysis and Discussion of Simulation Results

The simulation results of firefighting in an early stage that is ten minutes after fire breakout are analyzed and discussed the improvement effect of disaster prevention performance in the subject area using three indexes shown in *Table 5*. *Figure 9* shows simulation results of all cases by the index.

C-2 that is implemented two measures (one non-physical and one physical) has a high probability of extinguishment by residents' firefighting more than P-4 implemented three physical measures. From this fact, it is surmised that the only physical measures have only a limited effect. When compared to C-2 and C-1 that is implemented many different varieties of measures (six measures), C-1 is about twenty percent higher than C-2 in the probability of extinguishment by residents' firefighting more than C-2, however the number of burned cells is almost the same. From these results, it is conceivable that a haphazard implementation of many different varieties of measures can not achieve a significant effect of the improvement.

It is considered that the above results mean not merely need for multitude measures but the importance of measures by adequate investigation of the contents or balance between physical and non-physical measures.

Table 5. Use data for analysis and discussion of simulation results

Index name	Explanation
The number of burned cells	The sum of cell number of state [2], [3] and [4] (catching fire, burning and extinguished by naturally)
The number of extinguished cells by residents' firefighting	The cell number of state [5] (extinguished by residents' firefighting)
The probability of extinguishment by residents' firefighting	If there is not cell of state [2] or [3] (catching fire or burning) in the subject area at ten minutes after fire breakout, the samples are treated as the completely extinguishment samples. And, "The probability of extinguishment by residents' firefighting" is percentage of the completely extinguishment samples in the all samples (fifty simulation results)

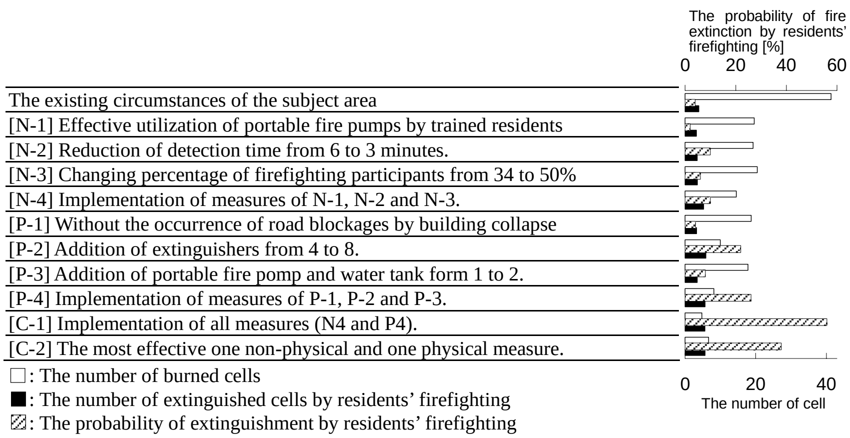


Figure 9. Comparison of simulation results of all cases

6. CONCLUSION

In this paper we have attempted to develop a simulation model of firefighting activity by community residents against coseismic fire spread using multi-agent system in order to provide useful information to residents in community-based planning for disaster prevention.

The developed model was applied to a case study area having disaster prevention issues in Japanese local city. In the application, the simulations were carried out to the existing area and eleven cases of the virtually-improved area where are implemented various non-physical and physical measures.

The simulation results of the all cases were analyzed and discussed the improvement effect of disaster prevention performance in the subject area using three indexes. As a result, the improvement of only physical measures combination and multitude measures did not show a remarked effect of disaster prevention performance. This finding suggests that the quality of measure is more important than the quantity.

In addition, it is confirmed that the developed model are able to output real-time animation on a digital map with behavior of fire spread and residents' firefighting activity, and graph of cell number (burned cells and extinguished cells by residents' firefighting). From these visual, dynamic and quantitative outputs, the possibility of contribution for enhancing residents' awareness and drafting a plan of disaster prevention is confirmed.

However, the proposed model is no more than an experimental development, the remaining problems for the practical use of the model are as follows; 1) shortening the calculation time, 2) incorporation of various factors related firefighting activity into the developed model for more realistic reproduction, 3) investigation of setting values of the parameters, 4) characteristics analysis of the developed model, 5) upgrading the expression of the simulation result more real and easily understood (ex; cooperation with WebGIS)

Moreover, in our future work we intend to address the above problems through experimentation in actual community participatory activities for disaster prevention.

7. ACKNOWLEDGEMENTS

This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Young Scientists Start-up, 19860038, 2007. And, we are grateful for the cooperation of KOZO KEIKAKU ENGINEERING Inc., who provides us Agent-Based Simulator "artisoc" for academic use.

8. REFERENCES

A. Sekizawa and S. Endou, 2003, "Information system for supporting firefighting based on real-time fire spreading forecast" in: S. Zama (eds.), *Research report concerning development of firefighting activity support system*, National Research Institute of Fire and Disaster of Japan, p.133-198 (in Japanese).

A. Sekizawa, M. Kobayashi and at al., 2005, "A Research on Suitable Operation of Community-based Firefighting" in: Tokyo National Research Institute for Earth Science and Disaster Prevention, Kogakuin University and at al. (eds.), *Annual Working Papers of Disaster Mitigation Measures for Risk Management by Information sharing Technology (by the Grant in Aid of Special Coordination Funds for Promoting Science and Technology)*, Science and Technology Promotion Bureau of Japan, p. 201-210 (in Japanese).

Fire Institute of Japan (eds.), 1997, *Fire Handbook (Third Edition)*, Kyoritsu Publishing Co., Ltd., Tokyo Japan (in Japanese).

Gohnai Y., Ohgai A. and et al, 2007, "An Attempt Quantification of Community Disaster Mitigation Capability Focusing on Neighbourhood Association and Activities", *Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan*, F-1, p. 349-352 (in Japanese).

Japan Fire Protection Association, 1997, *Leaflet of Community Disaster-prevention Activities; Utilization of Equipments and Materials for Disaster Prevention*, Gyousei Publishing Co., Ltd., Tokyo Japan (in Japanese).

Kanai A. and H. Kaji, 2002, "Evaluating system for the fire fighting ability of community organization for disaster prevention", *Journal of Architecture and Planning(Transactions of Architecture Institute of Japan)*, No. 552, p. 207-213 (in Japanese).

Ohgai A., Y. Gohnai and K. Watanabe, 2007, "Cellular Automata Modeling of Fire Spread in Build-up Areas; A Tool to Aid Community-Based Planning for Disaster Mitigation", *Computers, Environment and Urban Systems*, 31(4), p.441-460.

Ohuchi A., M. Yamamoto and H. Kawamura, 2007, *Theory and Application of Multi-agent Systems; Computing Paradigm form Complex Systems Engineering*, CORONA Publishing Co., Ltd., Tokyo Japan (in Japanese).

Toyohashi city, 2004, *Research Report of Seismic Damage Prediction in Toyohashi City*, Toyohashi City of Japan (in Japanese).

Toyohashi city, 2007, Statistical data of Toyohashi city, Toyohashi City of Japan (in Japanese).

Watanabe K., 2007, "Development of Planning Support Systems for Tsunami Disaster Mitigation Planning using Tsunami Evacuation Simulation Model and GIS", *Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan*, F-1, p. 587-588 (in Japanese).

Yamakage S., 2007, *Handbook of Construction Artificial Society; Primer of Multi-agent Simulation by Artisoc*, Hayayama Publishing Co., Ltd., Tokyo Japan (in Japanese).