Ohgai, A., Y. Gohnai, S. Ikaruga, M. Murakami, and K. Watanabe, 2004, Toyohashi University of Technology, Toyohashi, Japan Cellular Automata Modeling for Fire Spreading as a Tool to Aid Community-Based Planning for Disaster Mitigation, In: Van Leeuwen, J.P. and H.J.P. Timmermans (eds.) *Recent Advances in Design & Decision Support Systems in Architecture and Urban Planning*, Dordrecht: Kluwer Academic Publishers, ISBN: 1-4020-2408-8, p. 193-209.

Cellular Automata Modeling for Fire Spreading as a Tool to Aid Community-Based Planning for Disaster Mitigation

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Keywords: Community-Based Planning for Disaster Mitigation, Fire Spreading, Fire Fighting Activity, Cellular Automata Modeling, Planning Support Tool.

Abstract: As a tool to support collaboration in community-based planning for disaster mitigation in Japanese old wooden built-up areas, we attempt to develop a fire spreading simulation model incorporated a fire fighting activity using Cellular Automata (CA). The proposed model can deal with the process of fire spreading in a building that traditional models can not represent. Whether or not fire can spread is based on a stochastic calculation process to reproduce uncertain fire spreading. The errors caused by the stochastic factor are analyzed by carrying out simulation two or more times under the same condition. Moreover, the reproductivity of the model is examined by comparing simulation results with actual fire records.

1. INTRODUCTION

There are a lot of old wooden built-up areas in Japan. When the Hanshin-Awaji (Kobe) earthquake occurred in 1997, those areas were badly damaged by building collapse and fire spreading. Compared to other areas, some of the badly damaged areas could be reconstructed rapidly due to the existence of community-based planning practices in such areas. This situation clearly emphasizes the importance of a planning strategy that collaborates with residents to achieve effective disaster mitigation. In general, the planning process requires the enhancement of residents' tendencies to participate in the planning process through their heightened awareness of the disaster risk and the need for improvement of the local environment. This enhancement leads to increased and improved collaboration in planning between residents and planning authorities. In order to increase disaster mitigation, an alternative plan based on residents' consensus is required. Due to the difficulty of achieving this enhanced state, as well as in achieving consensus among participants, consensus-building tools are required. In this regard the development of planning support tools in Japan has received widespread attention.

In old wooden built-up areas, the damage caused by the spread of fire may increase significantly. Therefore, it is important to improve fire prevention performance by limiting the spread of fire as much as possible.

Through the comparison of virtual conditions of fire spreading (speed, direction, range, etc.) based on the assumption of certain fire prevention measures (widening of road, establishment of disaster prevention plaza, etc.) district improvement can be visually illustrated to participants and compared to existing circumstances of the specific districts. Participants are then able to confirm for themselves the effect of proposed improvement projects on limiting the spread of fire. Additionally, this could also serve as and effective source of information to educate residents on the hazard of fire. To achieve this, a model that can visually and dynamically simulates the spread of fire based on various assumptions about improvement projects is required.

The previous model focused the reproductively regarding fire spreading. In other words, there is no useful model to serve as a tool for collaboration in community-based planning for disaster mitigation.

From the above-mentioned background, we attempt to develop a fire spreading simulation model, which can plainly offer residents the information on the effect of increase in disaster mitigation performance by improvement of the local environment as well as enlighten them on the disaster risk and the need of the improvement.

2. FIRE SPREADING MODEL AND CA

CA can reproduce a complicated phenomenon by setting up simple rules into lattice space. Many researches by use of this technology have been advancing in some fields; such as transportation, economy, and chemistry. In the field of city planning, CA is used to understand dynamic and complicated urban phenomenon and to predict urbanization and land use change (Batty and Xie, 1994; White and Engelen, 1993; White and Engelen, 1997; Li and Yeh, 2000).

Fire spreading in built-up areas is not natural but a physical phenomenon. In the phenomenon, various factors about circumstances of built-up areas are intricately related. But, by using the technique of CA, the phenomenon must be reproduced by constructing some appropriate rules. Though simulation models of forest fire have been studied using CA (Resnick, 1995), there is little city fire spreading simulation model using CA, but Yamada, Takizawa, et al (1999) and Xie, Sakamoto, et al (2001) are trying to develop the model using CA.

On the other hand, many researchers have been studying about city fire spreading simulation model and a lot of good results have been found in Japan. Because these researches basically use ‘building’ as a unit of output about whether or not burning occurs in simulation, it is difficult for these models to realistically express the fire spreading process. For example, they cannot deal with gradually spreading in a building with large area. Moreover, they may not provide enough the information on the likely effect of increase in disaster mitigation performance by improvement of the local environment. In this research, by using the results of previous researches regarding fire spreading simulation model and the characteristics of CA, we attempt to develop a model that can simulate fire spreading by using a smaller unit than the ones of the previous researches, which can visually show detailed fire spreading process in built-up areas with wooden buildings.

3. FIRE SPREADING MODELLING

This chapter explains a fire spreading modelling by use of CA, parameters used in the model and the process of simulation.

3.1 Cell size

Naturally, if the size of cell that is a basic unit of fire spreading model is smaller, more detailed spreading simulation becomes possible. However, when the size of cell is too small, the explosive increase in the calculation time and the volume of data occurs. As the purpose of a simulation model proposed here is to show the appearance of fire spreading, the size of cell needs not be small so much. Then, in this research, the size of cell is set at 3 by 3 meters using the following equation representing spread speed to leeward proposed by Hamada (Jirou and Kobayashi, 1997).

$$D = 1.15(5 + 0.5v) \quad (1)$$

where v is a wind velocity meter per second [m/sec] and D is the limit of distance which fire can spread [m].

3.2 Attribute of cell

From previous researches on fire spreading models in built-up areas, the following three factors of fire spreading are defined: building condition, weather condition and characteristics of built-up area (Murosaki, Ohnishi, et al, 1984). The building condition is composed of building material, floor area, opening area and height that represent the characteristics of building. These attributes relate to the possibility of building burning. The weather condition is composed of wind velocity and direction. These relates to the direction, the range, and the possibility of spreading. The characteristics of built-up area consist of vacant land, pitch of building, and road. These attributes are used as factors relating to the spreading control.

3.3 Neighbourhood

Based on the idea of the limit of distance that fire can spread, which has been brought out by previous researches (Jirou and Kobayashi, 1997), the neighbourhood type of the model is set as shown in *Figure 1*, changing according to wind velocity. Cell *kl* is a causing one of the fire spreading and cell *ij* is a received one in the neighbourhood.

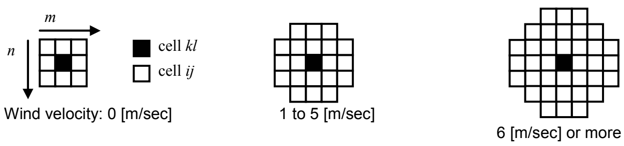


Figure 1. Neighbourhood used in the model

3.4 State of cell

Transition of cell state is set as shown in *Table 1*. The cell with state [1] is not burning yet, but has the possibility of burning. Once the cell catches fire, the state of the cell changes to state [2]. And then, according to the elapsed time after outbreak of fire, the state of the cell changes from state [2] to [4]. But the cell with state [0] is unburnable and never changes during the simulation period.

Table 1. State of a cell

Expression	Explanation
[0]	$n_{mn} = 0$: Unburnable; Having nothing burning.
[1]	$n_{mn} = 1$: No burning yet; Having the possibility of burning.
[2]	$n_{mn} = 2$: Catching fire; Just catching fire, but having no ability to cause fire spreading.
[3]	$n_{mn} = 3$: On fire; Having the ability to cause fire spreading.
[4]	$n_{mn} = 4$: Extinction

3.5 Fire spreading probability

The fire spreading judgment, that is whether or not cell *ij* changes from state [1] to state [2], is done by using the fire spreading probability of cell *ij* and the stochastic calculation process in section 3.6. The probability is given by the fire spreading judgment index F_{ij}. This is calculated for all cells *ij* within the neighbourhood of cell *kl* and defined by equation (2).

$$F_{ij} = \alpha \cdot (S_{ij} \cdot P_{ij}) \cdot W_{ij}^{\ \beta} \cdot p(t_{ckl}) \qquad (2)$$

where, S_{ij} is a building structure parameter, P_{ij} is the ratio of the area occupied by wooden or fire preventive wooden building in cell *ij*, W_{ij} is a parameter decided by wind velocity and direction and $p(t_{ckl})$ is the ability of cell *kl* causing fire spreading. These values range from 0 to 1. α is a coefficient to tune the degree of slowdown in spreading caused by the condition except wind velocity ($0 < \alpha \le 1$), and β is a coefficient to adjust the range and direction of spreading, that is $0 < \beta$.

S_{ij} and P_{ij} are parameters representing combustibility of cell *ij* itself. The value of S_{ij} is given as follows; wooden=1.0, fire preventive wooden=0.6, and fireproof=0.0. P_{ij} plays the role of controlling combustibility by adjusting the value of S_{ij} according to the area of wooden or fire preventive wooden building in cell *ij*. The parameter W_{ij} relates to spreading speed and direction, the value of which is set subject to the distance and direction from cell *kl* to cell *ij*. As shown in *Figure 1*, the number of cells *ij* that is an object of fire spreading judgment increases as wind velocity becomes higher. When wind velocity externally given in the model is 0 to 1 [m/sec], the parameter value of cell *ij* adjacent to cell *kl* is set at 0.5. Other cells are set at 0.3. When wind velocity is more than 1[m/sec], the parameter values variously change as influenced by wind velocity and wind direction. For example, as shown *Figure 2*, in the case of west wind, the value of cell *ij* on the east side of cell *kl* is set at higher than the west side. Moreover, as wind velocity is higher, cell *ij* adjacent to cell *kl* takes a higher value and other cells take a lower value subject to the distance from cell *kl*. Consequently, the possibility of fire spreading becomes higher on the leeward than windward and in the higher wind velocity.

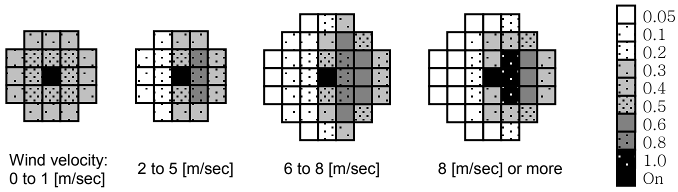


Figure 2. W_{ij} in the case of a west wind

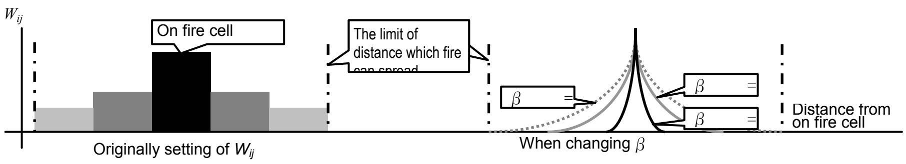


Figure 3. Image of W_{ij} changing by tuning β

In general, the actual area devastated by a fire per unit time varies significantly depending on the whole of condition related to the spreading. For instance, in case of fires at Hanshin-Awaji earthquake, combustion and fire spreading slowed down because the building collapse restricted the supply of air. As a result, the areas devastated by the fires per unit time were smaller than the past fire records. In order to consider the situations such as the above that can not be represented by parameters used in F_{ij}, α is incorporated.

W_{ij} is set so as to decrease linearly subject to the distance from cell *kl* to cell *ij* as shown in *Figure 2*. Thus, by tuning the value of β, a sharp or gradual decrease in the value of W_{ij} is expressible as shown in *Figure 3*. In other words, the coefficient β plays the role of controlling the possibility and range of spreading.

The parameter $p(t_{ckl})$ is set by equation (3) using the indoor temperature standard curve of wooden house at fire as referenced to the literature (Wakamatsu, 1978).

$$p(t_{ckl}) = \begin{cases} \dfrac{4.0}{t_2 - t_1} \cdot t_{ckl} + \dfrac{0.2 \cdot t_2 - 4.2 \cdot t_1}{t_2 - t_1} & \left[t_1 \le t_{ckl} \le \dfrac{t_2 - t_1}{5} + t_1 \right] \\ \dfrac{5}{4 \cdot (t_2 - t_1)} \cdot (-t_{ckl} + t_2) & \left[\dfrac{t_2 - t_1}{5} + t_1 \le t_{ckl} \le t_2 \right] \end{cases} \tag{3}$$

The time t_1 until cell *kl* becomes having the ability to cause fire spreading after catching fire is set at 2 [min]. The reason is below. Horiuchi (Yasuno and Nanba, 1999) proposed the equation as follows.

$$t_x = (3 + 3a/8 + 8d/D)/(1 + 0.1v) \tag{4}$$

where, a is a length of average of a side in building [m], d is a pitch of building [m] and D is the limit of distance which fire can spread [m].

This equation shows the time until an adjacent house to the point of fire origin ignites after catching fire in the origin (Yasuno and Nanba, 1999). In this research, the time t_x was considered as the time until a building becomes having the ability to cause fire spreading after catching fire. But it is by building and thus can not be used in the model simulating by cell. Then, the examination of the value of the time t_1 used in the model was carried out by calculating t_x changing the values of d and v but fixed a at 3 meters. This leads to setting t_1 at 2 minutes.

The time t_2 until cell *kl* burns out after catching fire is defined as follows.

$$t_y = (w/5.5)/(A_w\sqrt{H}/A_f) \tag{5}$$

where, w is a fire load [kg/m^2], A_w is a opening area [m^2], A_f is a floor area [m^2] and H is a height [m].

This equation approximately represents the continuation time of fire as assuming wooden building and constant combustion speed (Sugawara and Naruse, 1997). In this research, we consider the value calculated by this equation as the time until a building burns out after catching fire. However, as t_y is the value by building, unrealistic results can be outputted when carrying out a simulation using the value, for example all cells within a building with large area remain on fire more than a likely burning out time. The reason is because a floor area A_f critically influences the value of t_y. Then, t_2 is set at 10 minutes as a result of calculating t_y by considering a cell as a building of 9 square meters.

The value of W_{ij} depends on the position of cell *ij* within the neighbourhood and a given wind velocity and direction. $p(t_{ckl})$ depends on an elapsed time after outbreak of fire in cell *kl*. Therefore, F_{ij} is not constant in cell *ij* but changes according to W_{ij} and $p(t_{ckl})$.

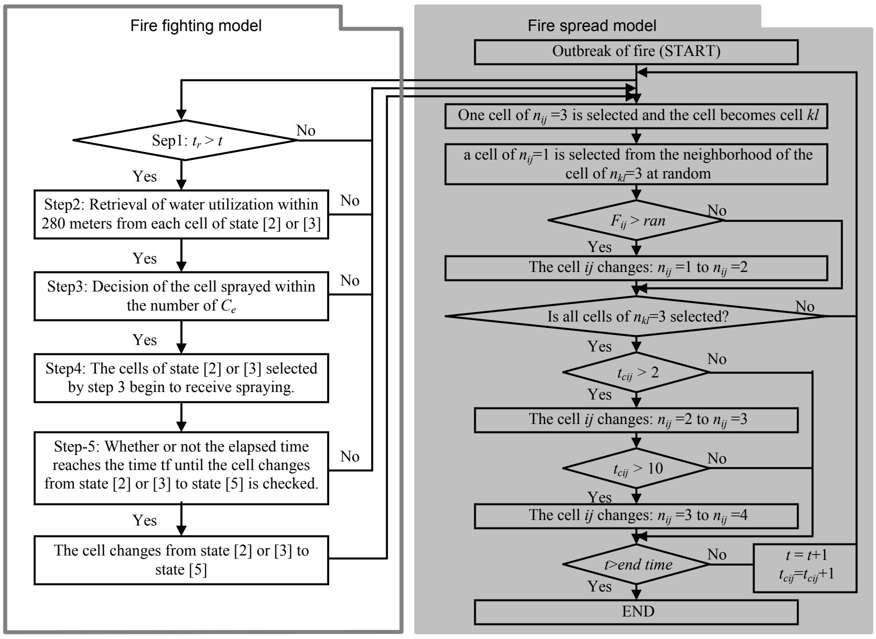
3.6 Process of the fire spreading model

Figure 4 shows the flow of a fire spreading model proposed here in addition to a fire fighting model described later.

- Step 1: First of all, one cell *kl* of n_{kl} =3 is selected.
- Step 2: One cell *ij* of n_{ij} =1 is selected at random from the neighbourhood defined by a wind direction and a wind velocity externally given when simulation starting.
- Step 3: Fire spreading judgment index F_{ij} of a selected cell *ij* is calculated. If F_{ij} is satisfied with the following requirements, the sate of cell *ij* becomes n_{ij} =2 (Catching fire).

$$If\ \ n_{ij}(t) = 1\ \ and\ \ F_{ij} > ran\ \ then\ \ n_{ij}(t+1) = 2 \tag{6}$$

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



t : The simulation time [min], t_{cij} : The elapsed time of after outbreak of fire [min], *end time* : The end time of simulation [min], F_{ij}: The fire spread judgment index of cell *ij*, *ran*: The random number given within the range from the maximum to the minimum of *Fij* value, t_r: The time until the nearest fire brigade rushes to the fire site and then begins to spray water [min], C_e: The number of cells of which the fire can be extinguished with a water utilization [cell]

Figure 4. The flow of the model

Note that t_{cij} is an elapsed time after 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 satisfied with equation (6). Step 2 and 3 are iterated for all cells *ij* within the neighbourhood of cell *kl*. Further, the process regarding cell *kl* is executed for all cells of state [3].

– Step 4: The state of cell *ij* after catching fire changes according to the elapsed time after outbreak of fire t_{cij}. In other words, if the value of t_{cij} takes more than t_1=2[min], cell *ij* changes from state [2] to [3]. Namely, n_{ij} =3. Moreover, if the value of t_{cij} takes more than t_2=10[min], cell *ij* changes from state [3] to [4]. Namely, n_{ij} =4.
– Step 5: The simulation ends when the time *t* [min] becomes the end time externally given in the model. The time *t* is counted from the simulation start to the end. When the time *t* does not reach *end time*, 1 is added to t_{cij} and *t*, and then the process returns to Step 1.

4. FIRE SPREADING SIMULATION IN JAPANESE HISTORICAL BUILT-UP AREA

4.1 Subject area

The subject area is located at Futagawa district, the east part of Toyohashi city, Aichi Prefecture, that is a typical historical built-up area with Futagawa-Honjin museum. The size of the area is 400 meters at the north-south and west-east direction (see *Figure 5*). In this area, there are old stores called Nishikomaya, Higasikomaya, and Kurebayashi-Syohyu. And there is a road that was called the Tohkai highway in the Edo era. But, old wooden houses are densely built up and there are many roads of which the width is not so wide with 4-5 meters in this district.

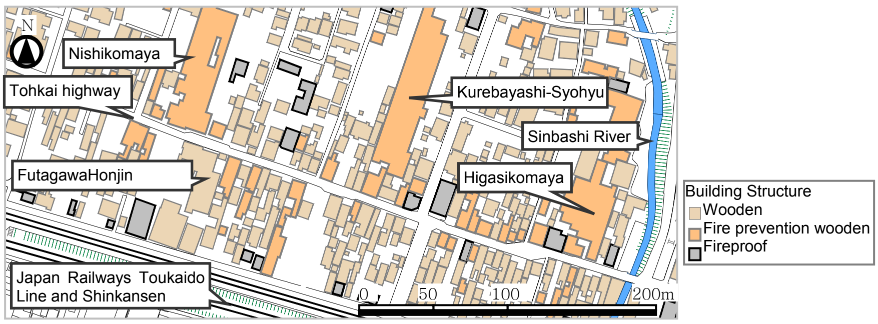


Figure 5. Subject area

4.2 Data arrangement

The date about building attributes was first arranged by building in the subject area. In order to carry out the simulation using a CA model developed here, it is necessary to identify the data by building with cell. The method is as follows. First, the layer of grid cell (3 by 3 meters) is overlaied on the city map representing buildings, roads and land use. Second, The attributes of building in a cell were defined on the supposition that the type of building occupying the largest area among all types in the cell is the type of the cell used in the model. But, the building data is not set to the cell where the building does not exist. Weather condition is given at the start time of a simulation.

4.3 Fire spreading simulation

Figure 6. Two simulation results by the model

The model developed here was applied to the subject area. The probabilistic calculation process is built into this model. Therefore, even if simulation is executed two times at most by a setting of parameters, weather condition and the point of fire origin, one result is different from another. Then, a simulation was carried out one hundred times supposing the point of fire origin as shown in *Figure 6*, α =1 β=1, wind velocity of 3 [m/sec] and the west wind. The simulation end time was set at 180 minutes. The calculation time of the simulation for one hundred is about 26 minutes by the personal computer of CPU: Pentium-M 1.4GHz and Memory: 1GB. The number of cells with each state in each simulation time is outputted. Two simulation results are visually shown in *Figure 6*.

This figure indicates that fire spreading has the tendency to extend to the leeward side of the origin of a fire. Each range of spreading after 180 minutes was about 200 meters on the leeward side. But there is the little difference in detailed process of spreading. Moreover, two examples are different in the number of cells with each state.

5. ANALYSIS OF SIMULATION RESULTS

5.1 The errors analysis

As mentioned above, simulations by the same condition are even different in the results of spreading. Therefore, in the scene of collaboration in community-based planning for disaster mitigation, it may be difficult to examine the effect of improvement in local environment by using one simulation result of this model. However, as you know, from the characteristics of the model with a probabilistic calculation process, the number of cells with each state is converged to a certain value when infinitely iterating simulation by the same condition. Accordingly, it must be more suitable to use a probabilistic expression as a way of offering the information to the participant. Then, first of all, all of the numbers of extinction cells acquired by one hundred simulation samples are prepared. Second, the mean and the standard deviation in each of 20 cases of 5, 10, … , 100 samples were calculated.

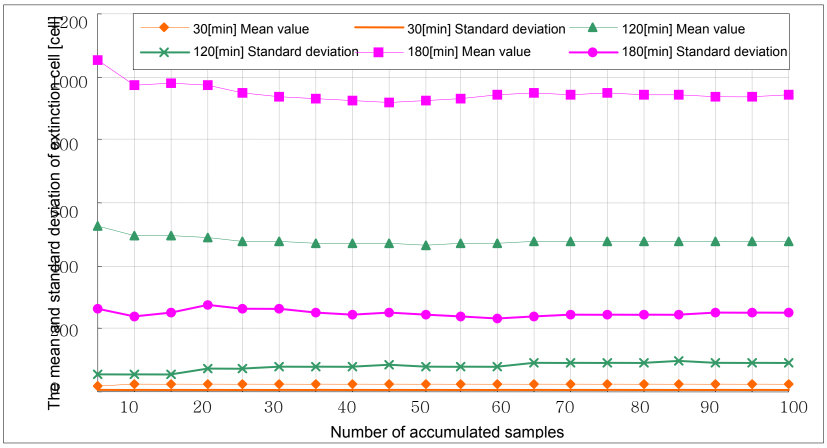


Figure 7. The mean and the standard deviation by simulation results

The following can be confirmed from *Figure 7*. There is increase or decrease in the mean and the standard deviation at each simulation time according to the increase of samples until 30 samples. But, in 50 or more samples, the amplitude of the mean and standard deviation becomes smaller than less than 50 samples. As a result, it is found that the number of extinction cells becomes stable in 50 samples at most. Therefore, hereafter in the analysis of simulation result, 50 samples are used.

5.2 Visualizing probability of cells changing

Figure 8 shows the probability that cells change to extinction at the simulation time of 180 minutes. This result is based on the 50 simulations at α =1, β=1 and wind velocity of 0 [m/sec]. From this figure, it is confirmed that the cells that burn out with the probability of more than 60 percent exists linearly in the southeast direction from the point of fire origin.

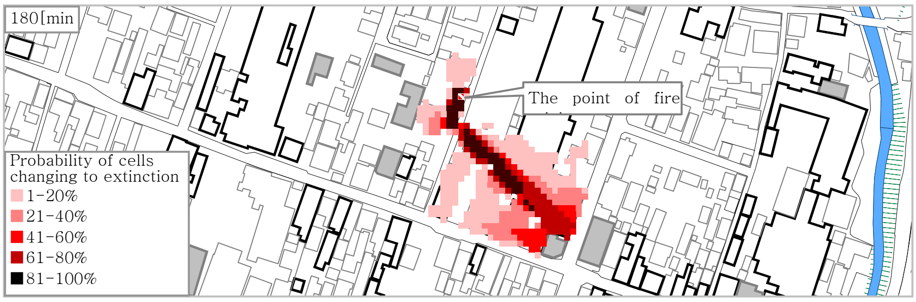


Figure 8. Probability of cells changing to extinction

In the scene of collaboration in the planning, for example using such a visual presentation of probable result must be useful for participants to discuss some concrete improvement projects such as widening of road, rebuilding from wooden to fireproof.

5.3 Comparison between actual fire records and simulation results

Figure 9 shows the relation between the number of extinction cells and the spreading time based on the following three kinds of actual records adding to simulation results; First type of actual record is one at Nagata district of Kobe City in Hanshin-Awaji earthquake (Matsubara and Suzuki, 1996). The district is an old wooden built-up area comparatively similar to the subject area. The gray and thick line is based on regression analysis using those records. Second type expressed with a triangle mark, is calculated by applying the data of wind velocity and fire spreading speed of Hanshin-Awaji earthquake to an oval model of Hamada (Jirou and Kobayashi, 1997). Third type is calculated from the record of fire in the subject area, which had occurred in April, 2003. The blue line is based on the means of 50 samples in each simulation time at α=1 β=1. On the other hand, the red line is based on the means at α=0.7 β=1.

From *figure 9*, it is found that the number of extinction cells of the first type of record is about 70 percent of the estimated number of those cells in simulation at α=1 β=1. This reduction can be considered as the slowdown of the spreading because of the restriction of air supply by building collapse. The simulation result at α =0.7 β =1 can approximately reproduce the situation of Hanshin-Awaji earthquake. Therefore, we can see that α plays the role of expressing the uncertain situation like the above. The number of extinction cells based on the records in the subject area (third type) is less than that of others because of a fire fighting.

As there is the difference in the circumstance of district, weather condition, situation of the earthquake damage, etc., the appearance of spreading actually has a wide range. According to the record of past conflagration, the fire spreading speed is with the wide range of 100 to 1,300[m/h] but depending on the velocity of the wind (Jirou and Kobayashi, 1997). In other words, the spreading scale considerably depends on the circumstances. Therefore, it seems to be able to explain the error of each simulation result and the variety of range of fire spreading to some degree caused by stochastic calculation process used in the model.

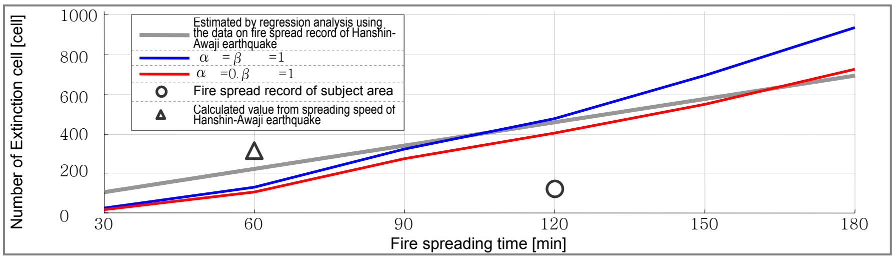


Figure 9. Comparison between the actual fire record and simulation results

6. FIRE FIGHTING SUBMODEL CONCEPT AND STRUCTURE

In chapters 4 and 5, we constructed a fire spreading model, analyzed simulation results of the non-interference model and carried out calibration. But, in the collaboration, a discussion must be necessarily done that how the fire spreading changes by fire fighting activity besides non-interference spreading. Therefore, to make the model more useful as a support tool, the incorporation of a fire fighting activity into our model proposed in previous chapter is significant.

In this research, the following fire fighting process was modelled; a fire brigade rushes to the site, the brigade sprays water on burning buildings, and the fire of the building is extinguished.

To support the collaboration, offering the information on the spreading interference by the fire fighting activity seems to be important. Then, state [5] (=cell of which the fire is extinguished not naturally but by fire fighting activity) is defined additionally. The following describes the concept and the parameter of a fire fighting model proposed here.

6.1 The time until the fire brigade rushes to the fire site

In this sub-model, the time t_r [min] is assumed to be the time until the nearest fire brigade rushes to the fire site and then begins to spray water. The value of this parameter can be optionally set and externally given in the model. A non-interference fire can be then reproduced by setting t_r at the time longer than the simulation time t. Introducing t_r enables the model to provide participants with whether or not the fire brigade can put down the spreading when a certain time t_r.

6.2 The number of cells of which the fire can be extinguished with water utilization for fire fighting

The number of cells of which the fire can be extinguished with water utilization, C_e, is given by equation (7). This is based on the assumption that one nozzle continues spraying water to a cell of state [2] and [3] until extinction of the cell.

$$C_e = \left\{ V_w / (C_w \cdot t_f) \right\} \cdot R_w \tag{7}$$

where, V_w is the capacity of a water utilization for fire fighting [m^3], C_w is the water volume that a nozzle consumes every a minute [m^3/min], t_f is the time until the cell sprayed changes from state [2] or [3] to state [5] [min] and R_w is the range of a nozzle spraying water [cell]. Referring to the previous research (Sekizawa and Endou, 2003) and hearing the fire department of local government in Japan, the values of C_w, t_f and R_w are set at 0.5, 20 and 3 respectively. The value of V_w can be optionally set and externally given within the range of 40 to 100 [m^3] which is based on the Japanese standard of establishing the water utilization. Therefore, the number of cells of which the fire can be extinguished by fire fighting depends on only the capacity and number of water utilizations located at the subject area in the model.

6.3 Process of the fire fighting sub-model

The flow of the fire fighting sub-model is constructed based on the above mentioned and the previous research (Sekizawa and Endou, 2003). The flow of the model is shown in *Figure 4*.

– Step 1: Whether or not the time t in the simulation reaches the time t_r until the fire brigade rushes to the fire site is checked.
  The following steps are iterated for all cells.

– Step 2: If the time *t* reaches the time t_r, water utilizations within 280 meters from each cell of state [2] or [3] are retrieved. If not so, the following steps are skipped.
– Step 3: The cell sprayed is decided within the number of C_e, subject to the priority of spraying to the cell decreasing according to the distance from the cells to a water utilization retrieved in step 2.
– Step 4: The cells of state [2] or [3] selected by step 3 begin to receive spraying. The elapsed time after spraying by the cell starts to be counted at the same time.
– Step 5: Whether or not the elapsed time reaches the time t_f until the cell changes from state [2] or [3] to state [5] is checked, and then the state of the cell changes when reaching the time t_f.

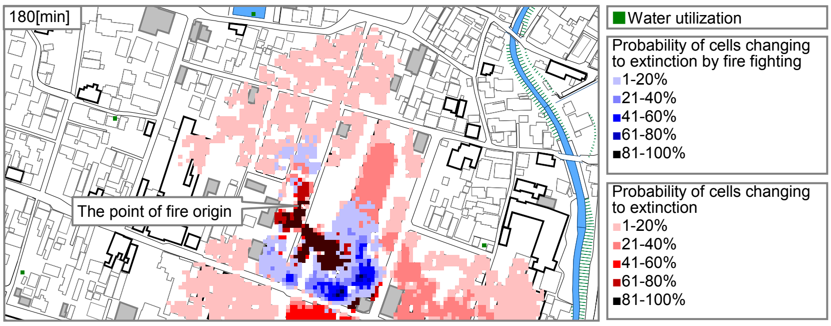


Figure 10. Probability of changing to natural extinction and extinction by fire fighting

7. SIMULATION RESULTS OF THE MODEL INCORPORATED FIRE FIGHTING ACTIVITY

Here, to analyze the behaviour of the fire fighting sub-model, two types of simulation with fire fighting activity (t_r =5 and t_r =60) were carried out 50 times respectively. The value of V_w of 4 water utilizations is set at 40 [m^3]. The location of these utilizations is shown in *Figure 10*. Other parameters and conditions externally given is the same as ones used in chapter 4.

There was no cell that changes from state [2] or [3] to state [4] in all of 50 simulations at t_r =5. As a result, we can see that the fire brigade rushing at 5 minutes can absolutely extinguish the fire in all cells burning. This result seems to be reasonable compared to actual fire fighting generally stated.

Figure 10 visually shows two types of the probability of cells in 50 simulation results at t_r =60. First type is one that cells change to state [4] and second is that cells change to state [5]. The followings can be seen from this figure. Cells changing to state [4] at the probability of 80 percent or more are distributed around the point of fire origin. On the other hand, there are cells changing to state [5] at the probability of 80 percent or more in the outside. From this, it is found that fire spreading is obstructed to some degree by the fire fighting.

8. CONCLUSION

In this paper we have attempted to develop a fire spreading simulation model using CA in order to provide the participants with the useful information in collaboration for the community-based planning for disaster mitigation. The conclusion is as follows.

Using CA enables the model to visually represent the fire spreading in detail. The proposed model can deal with the process of fire spreading in a building that traditional models can not represent. The actual fire spreading varies dramatically according to the circumstance of district, weather condition, situation of the earthquake damage, etc. The fire spreading judgement of the model can be done considering those conditions by using operational parameters. Although the full investigation of parameters by sensitivity analysis still remains, it was shown that simulation results can reproduce the actual fire spreading records approximately.

Though the model is based on a stochastic calculation process to reproduce uncertain fire spreading, we are sure that the use of the probable expression makes it useful for examining the effect of improvement in collaboration. Visual presentation of simulation results shown in this paper may help participants discuss about the improvement projects and enlighten them on the disaster risk and the needs of improvement. However, computational time takes over 10 minutes in order to get a stable simulation result in the present model. Shortening the calculation time is significant in order to enhance the usefulness of the model for really aiding the collaboration. Moreover, in our future work, we are going to develop a support tool of community-based planning for disaster mitigation, devising a visual and effective display of fire spreading process to participants, and incorporating the revised model into GIS.

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