CONSTRUCTION OF CONVENIENT SIMULATION SYSTEM OF SPREADING FIRE IN AN EARTHQUAKE USING DIGITAL RESIDENTIAL MAPS

Osamu Tsujihara[1], Yu-ki Fushimi[2], Takayoshi Kubori[3] and Tsutomu Sawada[4]

Abstract: The objective of this study is to develop the convenient simulation system of the spreading fires at an earthquake. Generally, it requires a tremendous labor to make the data which are used for this kind of simulation. This system needs some attribute data and the coordinate of each residence which can be picked up with a digital residential map in a simple manner besides the data about the wind direction, wind velocity and seismic intensity. A work file is produced with the basic data and the simulation of the spreading fire is formulated as the shortest route problem, which is solved by the Dijkstra's algorithm. The results of the simulation can be shown on the digital residential map of computer display.

Keywords **:** simulation system of spreading fires, earthquake, digital residential map, shortest route problem

1. INTRODUCTION

1) Present Situation and Problem of Earthquake Disaster Prevention Information System

After the 1995 Hyogo-ken Nanbu Earthquake, It was recognized again that there is the earthquake which brings locally the heavy damage even if its magnitude is relatively small. The local public bodies are expected to estimate the damage and to form the disaster prevention plan in the future earthquakes which are supposed to occur in each area. Early Estimation System for Earthquake Disaster (EES[1)]) has been operated by National Land Agency since April in 1996 to support the local public bodies in the estimation of the damage. Although this system can be applied to every local public body, the damage is estimated by mesh and the detailed setup can not be performed. On the other hand, some local public bodies have their original disaster prevention information systems. In for example, Yokohama-shi, the advanced system (Real-time assessment of earthquake disaster in Yokohama; READY[2)]) is built in which the real-time estimation of the damage in an earthquake can be performed with the dense seismograph network and GIS(geographic information system). However, it is almost impossible to apply the same system to another local public body because of the economical reason.

Thus several earthquake disaster prevention information systems have been developed and some of them are put into practical use. But in reality most of the small-to-medium sized local public bodies do not have any systems. It is expected to develop the system which is convenient, functional and not expensive, so that many local public bodies can introduce it. Considering the heavy damage by the fire in the 1995 Hyogo-ken Nanbu Earthquake, the function of simulation of spreading fire is to be added to the system. The function of estimation of the damage in a future earthquake and real-time estimation right after the occurrence of an earthquake can be realized in the identical system. The system is considered to be most useful in which the information of every house and building can be managed in the area covered by the local public body. In recent years, the digital residential map produced by such a company as Zenrin Co.Ltd[3)] has been available in Japan. It made it possible to develop the disaster information system based on GIS in which every house and building is a target of risk

1) Member of JSCE, Ph.D., Associate Professor, Wakayama National College of Technology
(77, Noshima,Nada-cho, Gobo-shi, Wakayama-ken 644-0023, JAPAN, E-mail: tsujihara@ wakayama-nct.ac.jp)
2) Student, Wakayama National College of Technology
3) Member of JSCE, Student, Tokushima University
4) Member of JSCE, Ph.D., Professor, Tokushima University

analysis.

2) Previous Study on Spreading Fire in Urban Area

The study on the analysis of spreading fire in an earthquake can be classified into the construction of the analytical model and the application of the model to urban areas. The velocity of spreading fire inside the building and between the buildings is formulated through the experiment and the investigation at the damaged area. The formula of spreading velocity of fire by Hamada has been used in Japan. This formula was built for wooden houses. Later, it was modified and it is also applicable to the wooden preventive and fire-resistive types of houses. On the other side, the accuracy of spreading velocity of fire has been improved through the experience of damage in Hyogo-ken Nanbu Earthquake and various experiments. The formula of spreading velocity of fire inside the house and between the houses proposed by TFD (Tokyo Fire Department)[4] is one of the most reliable formulas. Some researches on spreading fire in an urban area (for example, Yano, *et al.*[5], XIE, *et al.*[6] and SEKIZAWA, *et al.*[7]) have been done following the development of these formulas.

3) Objective and Feature of this Study

In this study a convenient simulation system of spreading fire based on GIS using the formula of TFD in an earthquake is proposed. The feature of this system is as follows.

1) The data necessary for the analysis can be prepared by a simple operation with little efforts.
2) The algorithm is simple enough to be combined into the existing disaster prevention information system.
3) The calculating time of spreading fire is short enough to be used on real time in an earthquake.

2. METHOD OF ANALYSIS

The formula of the spreading velocity of fire proposed by TFD is given to the wooden, wooden fire-preventive, quasi-fire-resistive and fire-resistive types of houses and buildings. Moreover the collapsed and partly collapsed houses can be considered. The spreading velocity of fire inside the wooden and wooden fire-preventive types is 52.1m/h and 42.8m/h, respectively. As to the quasi-fire-resistive and fire-resistive types, they are classified into 3 levels according to the building use and each spreading velocity is defined as the function of the size of building and the damage rate. The damage rate is related to the seismic intensity. The spreading velocity of fire between the houses or buildings is represented as the function of such parameters as seismic intensity and wind velocity. It varies with combination of the types of construction. The results of calculation of radiant heat are also referred to build the formula of spreading velocity of fire between the houses or buildings.

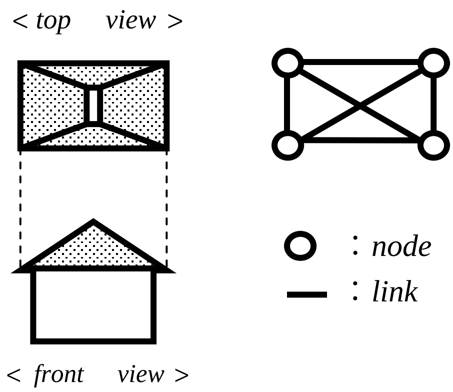
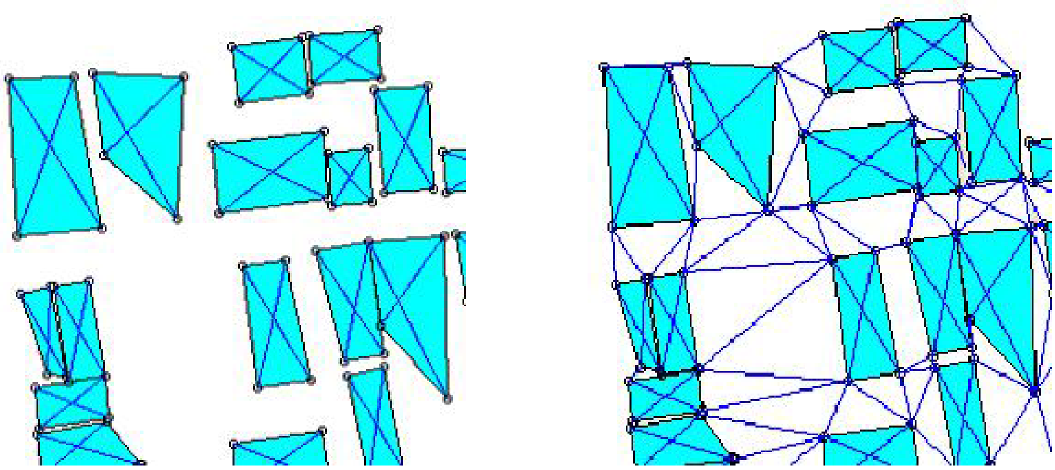


Fig.1 Modeling of a house

In order to apply the formula mentioned above to the urban fire, the method is proposed in which a house or building is modeled by 4 nodes and 6 links shown in Figure 1. Spreading time of fire that is calculated with the spreading velocity and the length of link is allocated to each link. Links connecting the nodes of different houses are also set up. Spreading time of fire for the inter-house link is allocated in the same way. These jobs can be carried out by the computer system as is mentioned in the following section. Thus an urban area is modeled as a network that consists of nodes and links shown in Figure 2. The problem of spreading fire from the origin of fire is solved as the shortest route problem. It is shown schematically in Figure 3. The circle denotes a node and its number is shown inside it. The number with under line denotes the time required for passing the link. Let us estimate the shortest route and time to node 5, assuming that the node 1 is the origin of fire. Three proposed routes are shown below.

Route1 : Node 1 => Node 2 => Node 5: 10 minutes
Route2 : Node 1 => Node 4 => Node 5: 9 minutes
Route3 : Node 1 => Node 3 => Node 4 => Node 5 : 8 minutes

Route 3 is the shortest route among the three. In practice the shortest route is searched with Dijkstra's algorithm[8]. In the simulator of spreading fire mentioned in the following section, the allocation of



(a) Links inside houses **(b) Links inside and inter houses**

Fig. 2 Network model of the part of a city

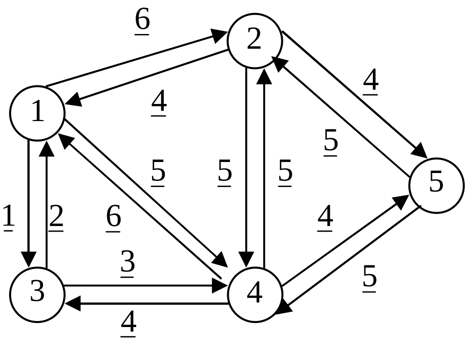


Fig.3 Schematic diagram of the shortest route problem

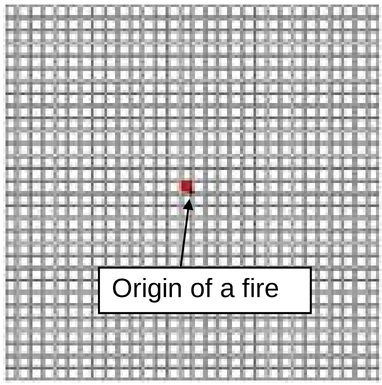


Fig.4 Virtual city and origin of a fire

spreading time of fire and the searching of shortest route is performed by each subsystem.

The results of numerical experiment are shown below. The virtual city that consists of 30x30 houses is supposed (see Figure 4). The origin of fire is around center of the city. First the simulation is carried out to illustrate the influence of wind. All the houses are assumed to be wooden and single-story. Other conditions are as follows.

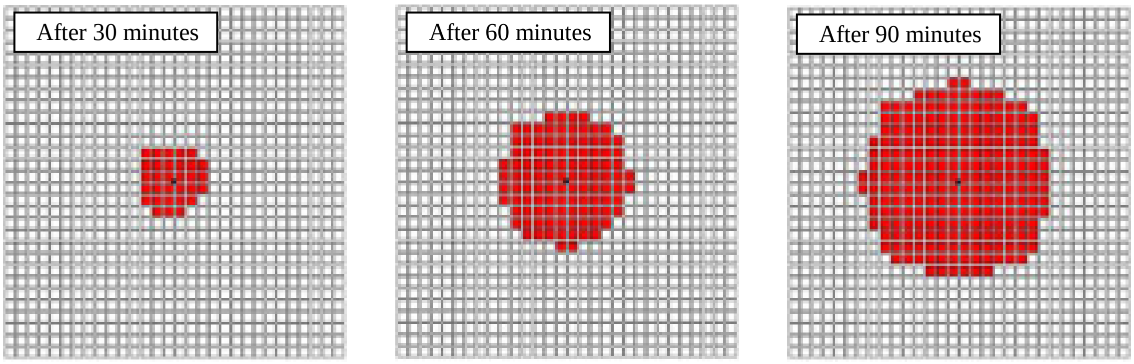
1) The plane shape of the house is square. The side length is 5m. The distance between the neighboring houses is 1m.
2) The wind direction is from west to east.
3) The wind velocity is 0m/sec or 10m/sec.
4) The seismic intensity scale by JMA (Japan Meteorological Agency) is 6 lower. In this scale, less earthquake-resistant houses occasionally collapse and even walls and pillars of highly earthquake-resistant houses are damaged.

The movements of spreading fire after 30, 60 and 90 minutes are shown in Figure 5. The colored cells denote the houses that catche fire. In the case of no wind, it is shown that the fire are spreading radially from the origin. In the case of wind of 10m/sec, the fire is spreading in the direction of wind.

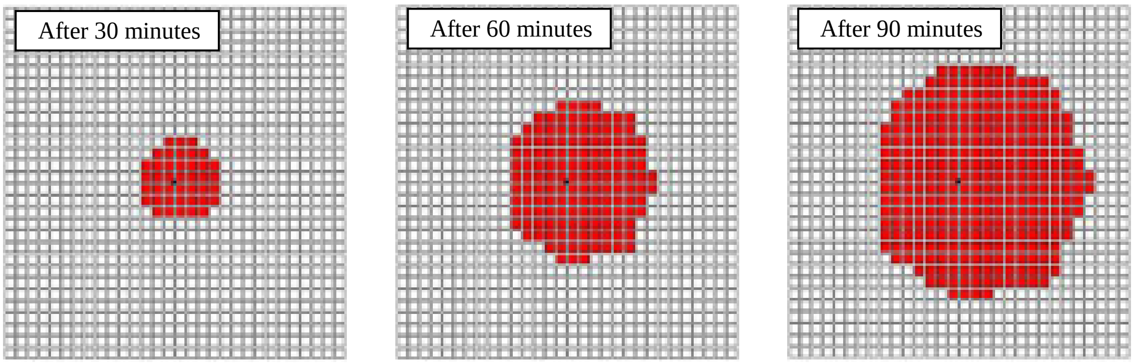
Secondly the simulation is carried out to illustrate the difference according to the type of house. The results are shown in Figure 6. The simulation is performed on the same condition with the wind of 10m/sec. In the figure, the state of fire after 90 minutes from the ignition is shown for the wooden, wooden fire-preventive, quasi-fire-resistive and fire-resistive types of houses. The fire for the wooden type spreads fastest. It is 3 to 4 times as fast as that for the fire-resistive type.

3. SIMULATOR OF SPREADING FIRE AND PREPARATION OF DATA

The components of database and the subsystems of the simulator are shown in Figure 7. The files of

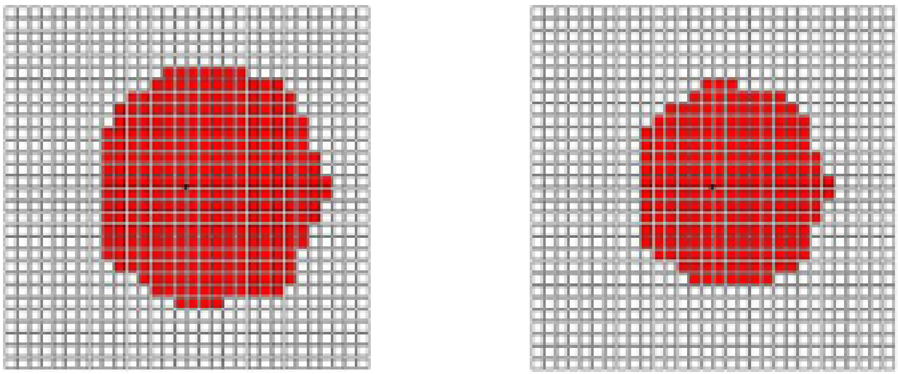


(a) In the case of no wind

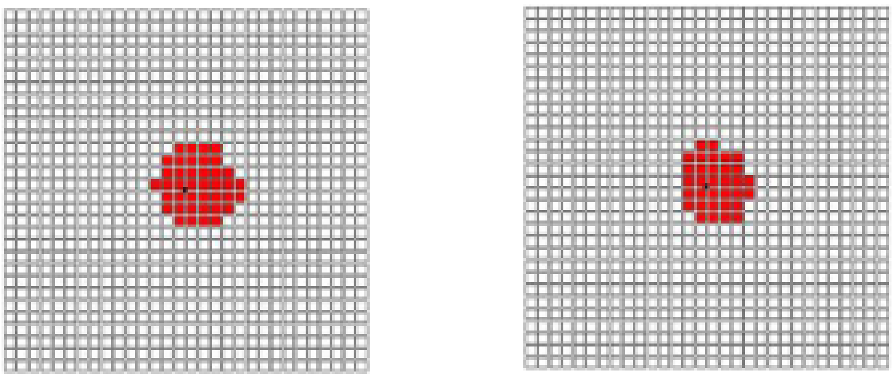


(b) In the case of 10m/sec wind

Fig.5 Movement of spreading fires in a virtual city in the case of no wind and 10m/sec wind



(a) wooden **(b) wooden fire-preventive**



(c) quasi-fire-resistive (Level 3) **(d) fire-resistive (Level 3)**

Fig.6 State of fire after 90 minutes from the ignition for 4 types of houses

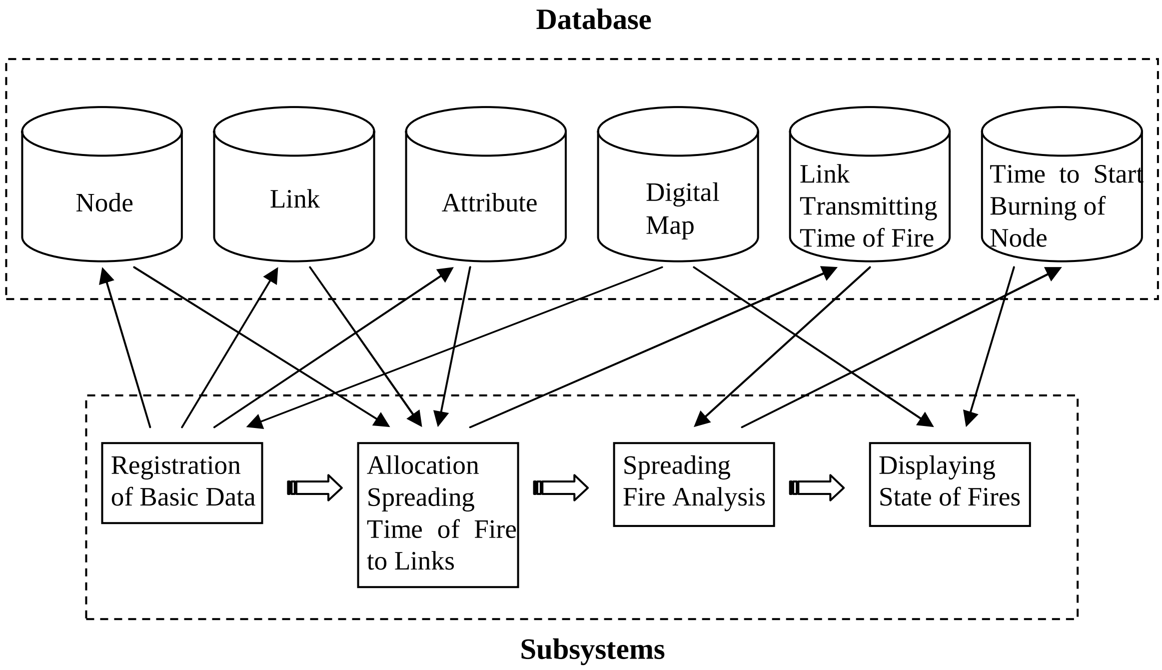


Fig. 7 Components of database and subsystems of simulator to predict spreading fire

nodes and links as well as attribute of houses and buildings are necessary as the basic data files. These files can be prepared with the help of subsystem "Registration of Basic Data". You can register such data as the coordinate of nodes and the node number of both ends of each link inside a house or building using the residential map (Zmap Town 2 of Zenrin Co.Ltd). Active Map Pro[9] is used as the engine to show the map on the computer display. Since these files are saved by the format of Microsoft Excel, you can also register the basic data directly without help of the subsystem. A sample of "Node" file is shown in Table 1. The X and Y coordinates denote the distances from the reference point in the X-Y plane, respectively. The data of "coordinate system", "number of figure" and "number of attribute" are necessary when the results of simulation are illustrated on the residential map. They are also registered automatically when the coordinate of node is registered with the help of subsystem "Registration of Basic Data". If the number of vertices of the polygon that expresses a house or building is over 5, it is approximated by a rectangular polygon. A sample of "Link" file is shown in Table 2. Using the subsystem, the 6 links of the house clicked on the computer display are prepared, and the nodal numbers of both ends of each link are written on the file as well as the type of the link. The type is either 1 or 2 which denotes the link inside a house or inter house, respectively. The inter-house link is registered when the arbitrary two nodes that belong to the different houses are clicked continuously on the computer display and its data are added on the file "Link". All the links have two ways. A sample of "Attribute" file is shown in Table 3. Number of the 4 nodes that belong to the house clicked on the computer display as well as the type of house, fire-resistive level and stories are written on the file. The wooden, wooden fire-preventive, quasi-fire-resistive and fire-resistive types are denoted by 1, 2, 3 and 4, respectively. The fire-resistive level is set only for the quasi-fire-resistive and fire-resistive types.

Next the spreading time of fire is allocated to each link with the subsystem "Allocation Spreading Time of Fire to Links". The output is written on the file "Link Transmitting Time of Fire" by the format of Microsoft Excel. Using these data, the shortest route problem from an ignition node is solved with the subsystem "Spreading Fire Analysis" and the time to start burning for each node is written on the file "Time to Start Burning of Node" by the format of Microsoft Excel as well. A sample file is shown in Table 4. Finally the computed movements of spreading fire are shown on the residential map with the subsystem "Displaying State of Fire". The state at every moment after the fire starts can be illustrated. This simulator is programmed with Microsoft Visual Basic.

Table 1 File of Node

No	X-coordinate	Y-coordinate	coordinate system	number of figure	number of attribute
1	2555.12	7098.03	6	11927698	50
2	2555.81	7104.62	6	11927698	50
3	2564.61	7101.09	6	11927698	50
4	2562.51	7095.71	6	11927698	50
5	2563.22	7094.75	6	11927698	76
6	2564.92	7089.37	6	11927698	76
7	2567.69	7090.12	6	11927698	76
8	2567.25	7094.75	6	11927698	76
9	2565.41	7095.25	6	11927698	37
10	2567.25	7100.16	6	11927698	37

Table 2 File of Link

No	Node 1	Node 2	Type
1	1	2	1
2	1	3	1
3	1	4	1
4	2	3	1
5	2	4	1
6	3	4	1
7	5	6	1
8	5	7	1
9	5	8	1

Table 3 File of Attribute

Node 1	Node 2	Nod 3	Node 4	Type	Level	Stories
1	2	3	4	2		2
5	6	7	8	2		2
9	10	11	12	2		2
13	14	15	16	2		2
17	18	19	20	2		2
21	22	23	24	1		2
25	26	27	28	3	1	2
29	30	31	32	3	2	2
33	34	35	36	1		2
37	38	39	40	1		2
41	42	43	44	1		2

Table 4 Time to Start Burning of Node

Node No.	Time(minute)	coordinate system	number of figure	number of attribute
77	106.6	6	11927698	142
78	105.8	6	11927698	142
79	92.8	6	11927698	142
80	99.4	6	11927698	142
81	0.0	6	11927698	301
82	15.3	6	11927698	301
83	22.0	6	11927698	301
84	17.6	6	11927698	301

4. SIMULATION

An analysis of spreading fire is demonstrated with the simulator proposed in this study. The result is shown Figure 8. In this simulation the wind of 10m/sec from south to north and the seismic intensity scale of 6 lower by JMA is assumed. The five origins of fire are given on the map. They are represented as the colored (red) houses. The state of fire right after the ignition is illustrated on the map of upper left hand side in Figure 8. The states of fire at 30, 60 and 90 minutes after the ignition are also illustrated in the figure. It is simulated that the colored houses grow as the time proceeds.

5. CONCLUSIONS

A system based on GIS to simulate the spreading fire caused by an earthquake is developed. An urban area is modeled as a network that consists of nodes and links, and the problem of spreading fire is formulated as the shortest route problem. This simulation system

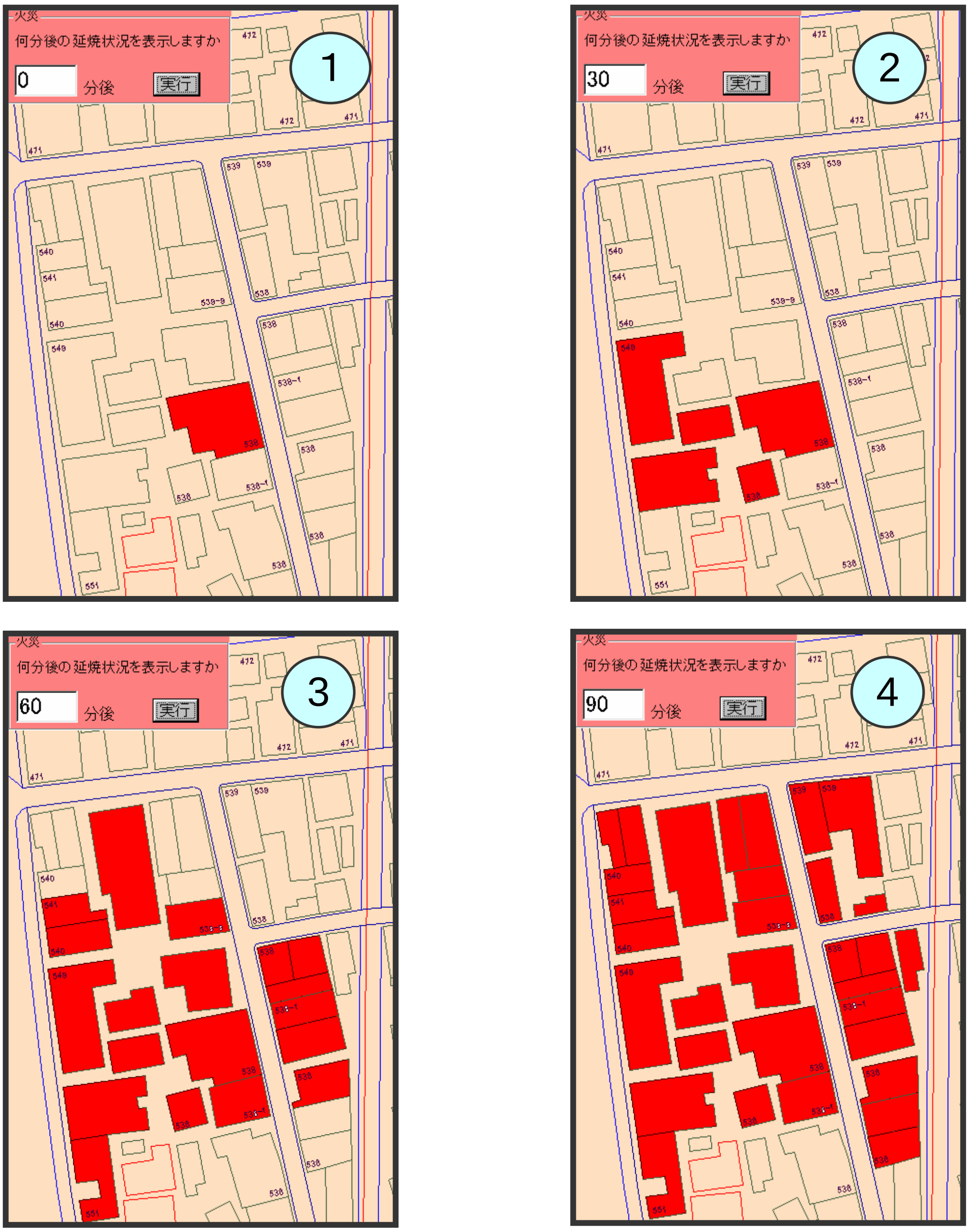


Fig.8 Movements of spreading fire

consists of four subsystems such as preparing basic data, allocating the spreading time of fire to each link, calculating the time to start burning at each node and illustrating the state of spreading fire on the residential map. The formula of spreading velocity of fire is used in this system which is proposed by Tokyo Fire Department. Using this system, the simulation of spreading fire in the part of a city was performed. The states of fire at some stages were shown.

The major results are as follows.

(1) The basic data can be easily prepared and saved as the Microsoft Excel files. This system is easy to be incorporated as a subsystem of simulating fire into other full-scale disaster prevention systems that had already been developed.

(2) The algorithm used in this system is helpful to reduce the calculating time, which is short enough to be used in the real-time estimation of spreading fire.

ACKNOWLEDGEMENTS

The advice from Dr. Hideaki Takimoto (Tokyo Fire Department) on the application of the formula of spreading velocity of fire was very helpful. This advice is gratefully acknowledged.

REFERENCES

1) http://www.bousai.go.jp/jishin/,2003.2(in Japanese).
2) http://www.city.yokohama.jp/me/bousai/jisin.html, 2003.2 (in Japanese).
3) http://www.zenrin.co.jp/english, 2003.2.
4) http://www.tfd.metro.tokyo.jp/eng/index.html, 2003.2.
5) Koichi YANO, Takeshi MATSUI, Hiroyuki TAKAI, Michiaki BOUIKE and Yuji UEMURA, "Study on simulation model of large fires spread caused by Kobe Earthquake", Proceedings of Infrastructure Planning, No.19(2), pp.39-42, 1996 (in Japanese).
6) Mengchun XIE, Naotsugu SAKAMOTO and Katsushi FUJITA, "Proposal of the middle cell in the simulation of spreads of fire on a city site using Cellular Automaton", Proceedings of the 63-th National Convention of Information Processing Society of Japan, Vol.1, pp.171-172, 2001 (in Japanese).
7) Ai SEKIZAWA, Ken-ich TAKANASHI, Makoto ENDO, Shinsaku ZAMA, Toshiro YANASE, Hideaki SHINOHARA and Katsunori SASAKI, "Information system for supporting Fire-fighting Activities based on real time fire spread simulation", Proceedings of Institute of Social Safety Science, No.11, pp.117-120,200 (in Japanese).
8) Dijkstra, E. W., "Notes on structured programming", In O. Dahl, E. Dijkstra, and C. Hoare, editors, Structured Programming, number 8 in A.P.I.C. Studies in Data Processing, chapter 1, pp.1-82, Academic Press, 1971.
9) http://www.kernel-map.co.jp, 2003.5(in Japanese).