Development of Easy-to-use Simulation System of Earthquake Induced Urban Spreading Fire with Presentation through 3D Animation

O. Tsujihara & H. Gawa
Wakayama National College of Technology, Japan

H. Hayashi
Applied Technology Co., Ltd., Japan

SUMMARY:
Spreading fire analysis is effective for the fire-fighting actives, the preparation of regional disaster prevention plan and the promotion of people's awareness, since earthquake-induced urban spreading fires occur simultaneously and bring serious damage.   Modeling of the target area required in the simulation often costs us tremendous labor and time.   In order to promote the use of the simulation, it is important that the system is non-intrusive and the results of the analysis can be illustrated by the realistic presentation.   In this study, the simulation system is developed based on the Petri-net algorithm, in which easy operation can be realized in the modeling of the target area for the simulation and analytical results can be presented by realistic 3-D animation.

Keywords: earthquake, spreading fire, simulation, Petri-net, 3-D animation

1. INTRODUCTION

Multiple fires possibly occur simultaneously in a big earthquake.   They bring heavy damages especially in the overcrowded residential areas.   The need of spreading fire analysis is growing for the means not only to predict and reduce the damage but also to increase people's awareness of disaster prevention.

Macro-simulation of spreading fire between grids (for example each grid is 5km×5km mesh) over the urban area had generally been performed based on such information as the building coverage ratio. The improvement of the accuracy in the formula of spreading fire and development of GIS (Geographic Information System) enabled *micro-simulation* of spreading fire between houses. Some researches on the *micro-simulation* of spreading fire in urban areas have been done.   For example, Yano, *et al*. (1996) applied their original formula of spreading velocity of fire to the simulation of the fire in Kobe in 1995 Hyogo-ken Nanbu Earthquake. Sekizawa, *et al*. (2000) utilized digital residential map for modeling the paths of spreading fire and they developed the system to perform the simulations with given wind velocity, wind direction and origin of fire.   Tsujihara, *et al*. (2003, 2004) also proposed the system to simulate urban fire in an earthquake in which digital residential map was used.   Later, Tsujihara, *et al*. (2005) modified the system by introducing the Perti-net (: e.g. Reising (1992)), which was one of the graph algorithms and was defined in 1962 by Carl Adam Petri, so that it could be applied to the simulation of the simultaneous occurrences of fires. Tsujihara, *et al*. (2006) confirmed the validity of the system through the simulation in the burnt area in Hyogo-ken Nanbu Earthquake.

However, there are some difficulties to promote the use of such the conventional simulation schemes. In the simulation of urban spreading fire, it is required to build the analytical model of the target area. The modeling often costs us tremendous labor and time.

In this study, an easy-to-use simulation system of earthquake induced urban spreading fire is proposed based on the study by Tsujihara, *et al.* (2005), in which the operation through the modelling of target area for the simulation to the presentation of the simulated results by 3-D animation can be carried out in semi-automatic manner.　Almost all the data except the attribute data of houses, which are necessary for the simulation of earthquake induced urban spreading fire, are built automatically by just assigning the target area in the map.　And Google Earth is used to show the movements of fires by 3-D animation.

2. OUTLINE OF SIMULATION METHOD

2.1. Modeling by Petri-net

A house is modeled with some places as shown in Figure 1.　A couple of places are connected by input arc, transition and output arc as shown in Figure 2.　Each place can hold tokens.　The distribution of tokens represents the state of the system.　An arc may have the weight which is shown by the number of arrows or accompanying integral number.　The transition ignites when the number of tokens held in the input place is as same as the weight of the connecting input arc.　Then, the tokens in the input place are consumed and the tokens, the number of which is specified by the weight of the output arc, are generated in the output place.　The spreading time of fire, which can be calculated by the TFD (Tokyo Fire Department) formula, is allocated to the weight of each input arc. Figure 3 shows an example of the Petri-net modeling.　All of the weights of output arcs are 1. The arcs between the places which belong to the different houses are also prepared with those weight calculated by the TFD formula.　The outline of TFD formula of spreading velocity used in this study is mentioned in the followings.

The formula of the spreading velocity of fire 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 usage of building 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 the combinations of types of constructions.

2.2. Rules of Analysis by Petri-net

The rules developed for the analysis of spreading fire is based on the colored Petri-net in which every
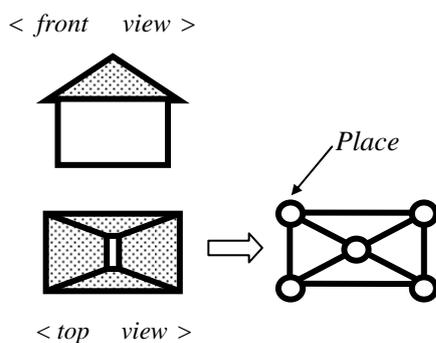
Figure 1. Modeling of a house
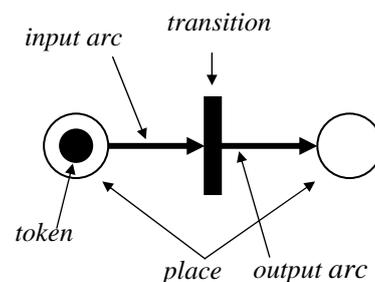
Figure 2. Base elements of Petri-net

<Front view>

<Top view>

<Petri-net model>

← ; arc inside houses
← ; arc inter houses
▮ ; transition inside houses
▨ ; transition inter houses
◯ ; place
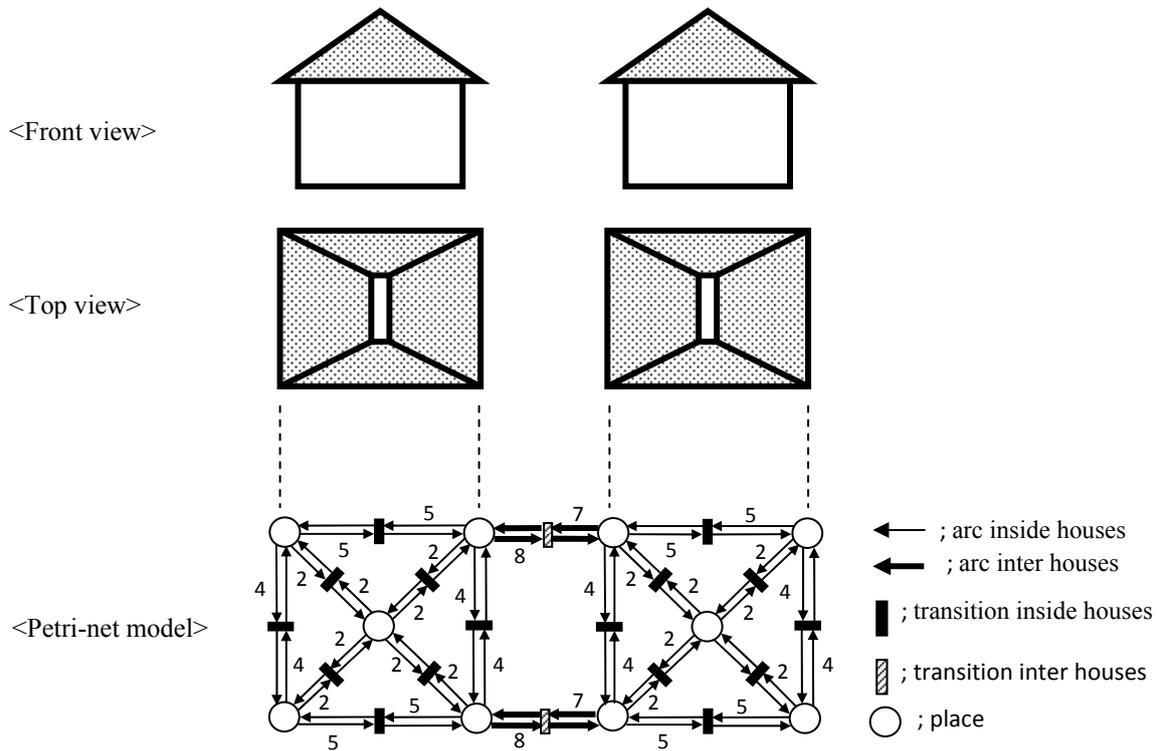
Figure 3 Petri-net modeling for simulation of spreading fire

(a) step0   (b) step1   (c) step2   (d) step3   (e) step3'
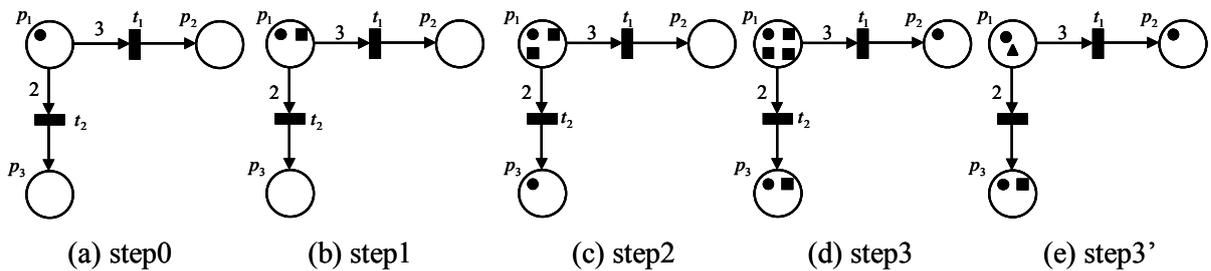
Figure 4 Marking in colored Petri-net

Table 1. Types of token and the roles

Shape	Name	Role
●	A	indicate burning
■	B	counter for *firing*
▲	C	indicate finishing *firing* from connected transitions

token has the type.   Three types of tokens in Table 1 are used.   Let us explain the rule and the flow with Figure 4.   The Petri-net model in Figure 4 has 3 places ($P=\{p_1,p_2,p_3\}$) and 2 transitions ($T=\{t_1,t_2\}$) and arcs.   The initial marking is shown in Figure 4 (a), which indicates that p_1 is the place of initially burning.   Token A is placed in p_1.   The place which holds token A generates token B in one (analytical) step as shown Figure 4 (b).   One step corresponds to, for example, one minute.   Place p_1 holds two tokens B after two steps as shown in Figure 4 (c).   Then since the number of tokens B in p_1 equals to the weights of the arc to the transition t_2, the copy of token A moves to p_3, but not consuming the tokens in p_1.   Place p_3 is to start burning after two steps; i.e., two minutes.   After three steps, another token B is generated in p_1, and the number of token B in it

equals to the weights of the arc to the transition t_1. Then the copy of token A moves to p_3 as shown in Figure 4 (d). A token B is generated also in p_3. In the step 3, all the output places from p_1 hold the token A, and p_1 generates a token C consuming the tokens B in it as shown in Figure 4 (e). Once a place holds a token C, it does not generate any more tokens, nor does it accept them. By memorizing the analytical step number when each place get first the token A, time to catch fire for each place is figured out. And by memorizing the number of place which sends a copy of token A, the paths of spreading fire can be identified.

3. AUTOMATIC DATA CREATION OF ANALYTICAL MODEL

In the system proposed by Tsujihara *et al.* (2005), each house in the computer display should be mouse-clicked to create the data of its analytical model. These operations are troublesome and time-consuming labor as the area of the simulation becomes large. Tsujihara *et al.* (2008) modified the system, so that the arrangement of places, arcs and transitions could be done automatically in the assigned urban area. The only operation required to create the data is to assign the area by mouse-clicking in the computer display, though the attribute data such as the type, number of stories are separately to be given to each house.

Figure 5 shows a part of the residential map. The target for the simulation of spreading fire is shown by the shaded area in Figure 6. The area can be assigned by mouse-clicking on its vertices. Figure 7 shows the automatically created analytical models in the area. Though the arrows of the arcs and transitions are not shown in the figure, the lines connecting the places denote two-way arcs and the transitions exist in between the places. The weights of the arcs are calculated by the TFD formula.

Figure 5. Residential map
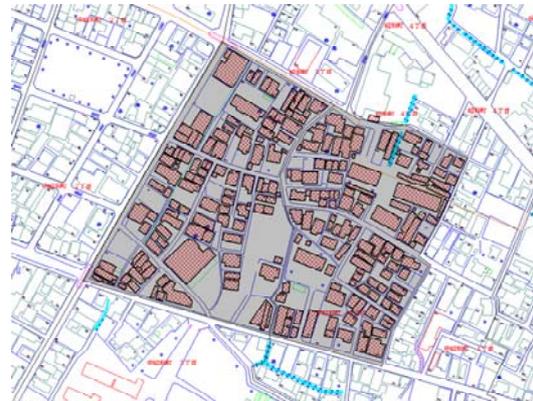
Figure 6. Assignment of analytical area
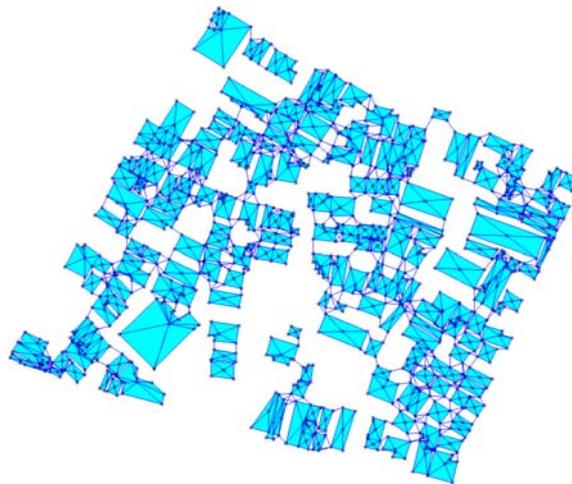
Figure 7. Analytical model by Petri-net

4. SIMULATION SYSTEM

The flow of procedures through the creation of data to the display of movements of fires is illustrated in Figure 8, in which the related data files are also shown.   Data such as the coordinates of longitude and latitude of the places, the attribute of arcs and houses are created automatically by just assigning the analytical area in the map of computer display.   The output data are obtained in Microsoft Excel format.   With these data and supposed wind velocity, wind direction and seismic intensity, the weights of arcs are calculated by the TFD formula.   Table 2 shows the obtained data file of the weights of input arcs in Microsoft Excel format.   "Type" denotes the type of arc in the table.   It is distinguished by the number of 1 and 2, which denote the arc inside a house and between houses,
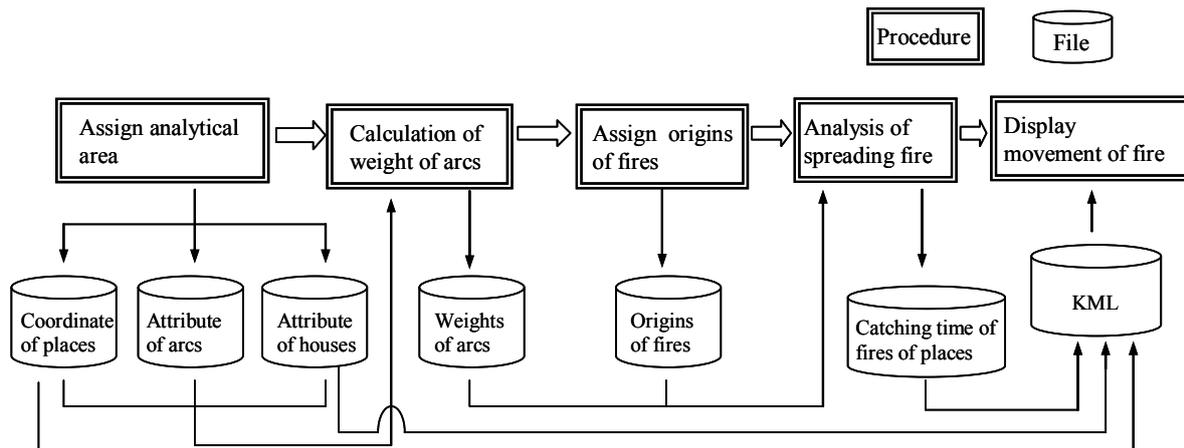
Figure 8. Procedure and related files in simulation system of earthquake-induced urban spreading fire

Table 2 Example of data file of weights of input arcs

No.	No. of Input Place	No. of Output Place	Type	Distance (m)	Spreading Time (minute)
1	1	2	1	6.01	6.92
2459	2	1	1	6.01	6.92
2	2	3	1	13.69	15.77
2460	3	2	1	13.69	15.77
3	3	4	1	1.07	1.23
2461	4	3	1	1.07	1.23
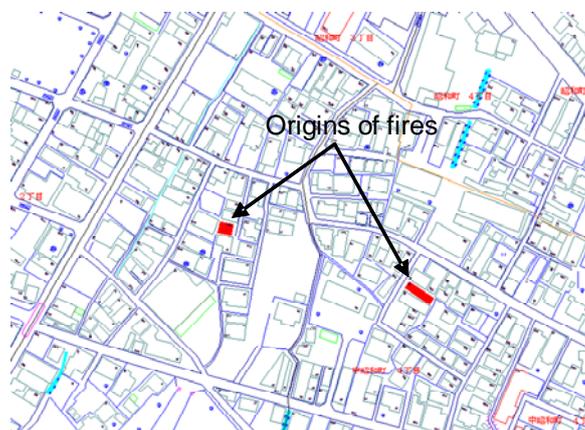
Figure 9. Origins of fires assigned by mouse-clicking

respectively.   The supposed origins of fires can be selected by mouse-clicking arbitrary houses as shown in Figure 9, and the related data file is created.   Thus all the data required for the spreading fire analysis are prepared.   In the next step, the analysis of spreading fire is carried out and the file of the results is obtained in which the number of places and the corresponding time to catch fire is written.

5. DISPLAY OF MOVEMENTS OF FIRES

In the previous study by Tsujihara (2005), movements of fires were shown by 2-D still image. Considering the promotion of the use of the simulation system, 3-D dynamic presentation of the analytical results is desirable.   In this system, a KML (Keyhole Markup Language) file is created with some data files in Figure 8 to realize 3-D dynamic expression of movements of fires on the platform of Google Earth.   KML is a file format used to display geographic data in an Earth browser, such as Google Earth and Google Maps.   KML files are created to pinpoint locations, add image overlays, and expose rich data in new ways.

Figure 10 shows the sheet which is developed with Microsoft Excel macro to create KML files. Appropriate file names and supposed date and time of breakout of fires are to be given to the yellow-shaded cells.   3-D dynamic expression of movements of fires can be seen by just double-clicking on the created KML file, if the environment for the usage of Google Earth is set up.

As an example, the spreading fire analysis for the shaded area shown in Figure 6 is carried out.   The same area is shown in Figure 11.   Blue-shaded houses in Figure 11 are the target houses.   The origins of fires are shown in Figure 9.   Other conditions in the analysis are as follows.
(1) Wind speed is 4m/sec from east to west.
(2) Seismic intensity is 6 weak in JMA (Japan Meteorological Agency) intensity scale.
(3) All of the houses are two-storied wooden.

	A	B
1	File name of Attribute of houses	Attri_House.xls
2	File name of Coordinates of places	Coord_Places.xls
3	File name of Catching time of fire of places	Cat_Fire_Time.xls
4	File name of KML	KML.kml
5		
6	Date and time Fires breaks out	
7	Year	2011
8	Month	1
9	Create KML File Day	22
10	Hour	15
11	Minute	0

Figure 10. Microsoft Excel sheet to create KML files
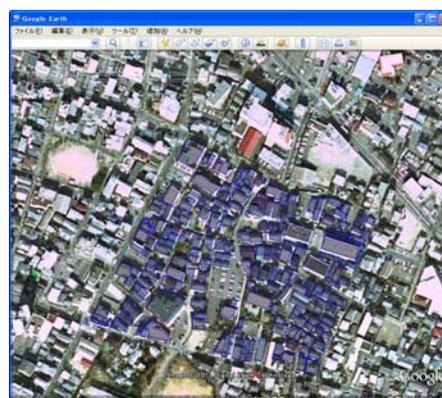
Figure 11. Target area of simulation
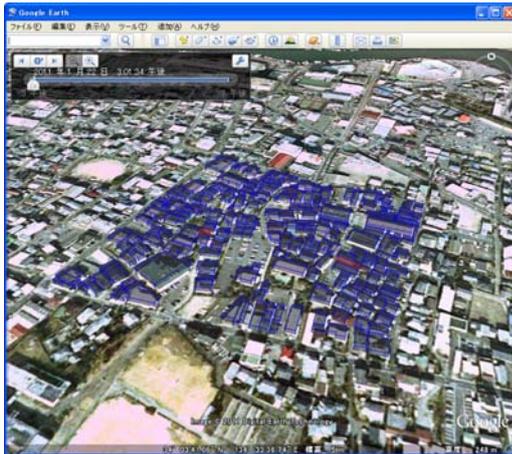
(a) Initial state just after fires break out
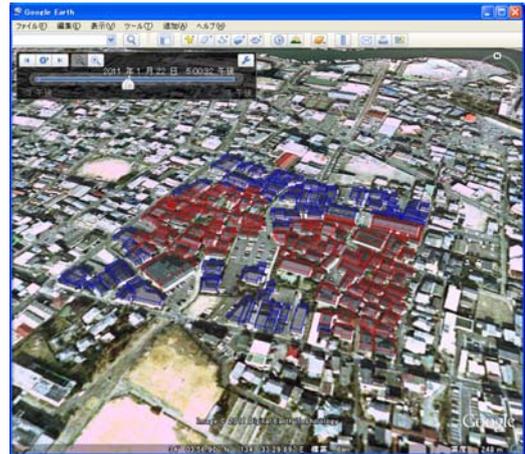
(c) State after 120 minutes
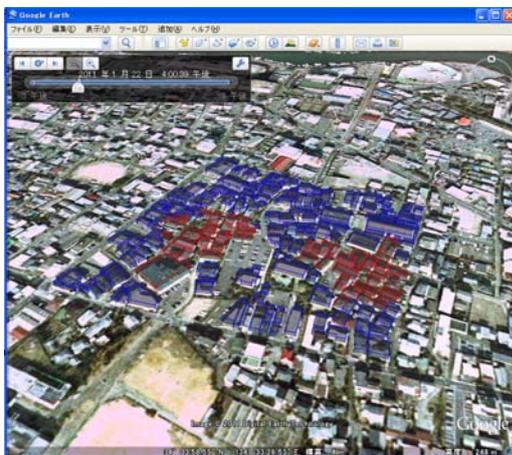
(b) State after 90 minutes
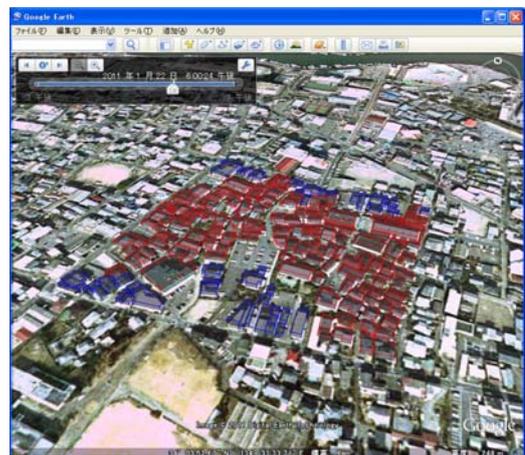
(d) State after 180 minutes

Figure 12. 3-D dynamic states of spreading fires on the platform of Google Earth

Figure 12 (a) shows the initial state in which the origins of fires are located. The states at 90, 120, 180 minutes after fires break out are shown in (b), (c) and (d) in Figure 12, respectively. The functions of Google Earth such as the movement of viewpoint can be used while the animation is played. Figure 13 shows the scene from the different viewpoint. The different type of expression is also available with the flame model as shown in Figure 14 in order to increase the reality.

CONCLUSIONS

In this study, an easy-to-use simulation system of earthquake induced urban spreading fire is proposed. Most of the required data for the simulation are created by a simple procedure. And the results of analysis can be illustrated in the comprehensible expression.

The major results are as follows.
1) The operation to create most of the data required in the simulation is just to assign the target area by mouse-clicking in the computer display. The attribute data such as the type, number of stories are separately to be given to each house.
2) The analysis of spreading fire is carried out by the method based on Petri-net with TFD formula.
3) KML file is created by the application built with Microsoft Excel macro to illustrate the results of the analysis in 3-D dynamic expression. Movements of fires can be seen in animated images on the platform of Google Earth.
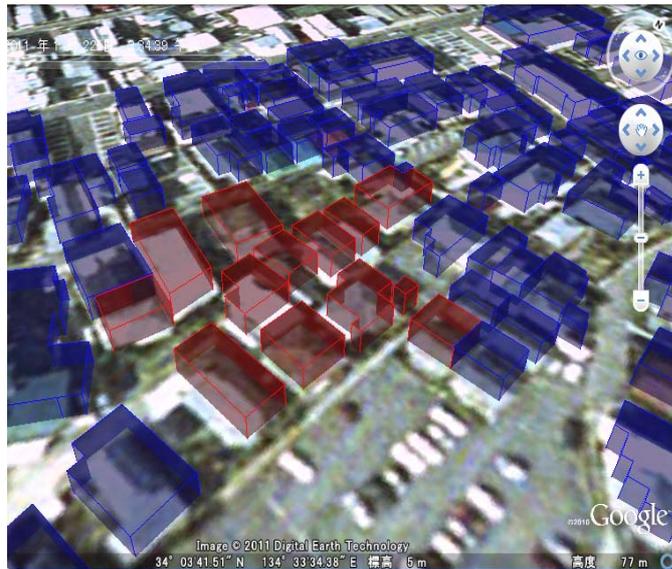
Figure 13. Example of viewpoint movement
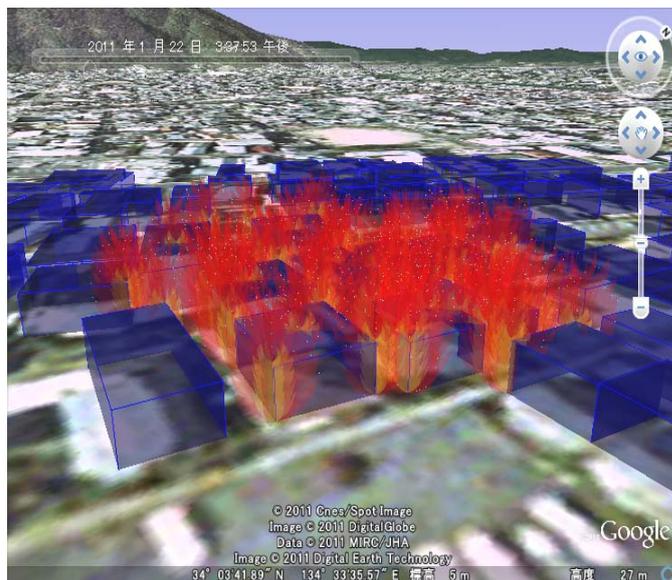
Figure 14. Expression by flame model

REFERENCES

Google, Inc. Developers Home (2012). Keyhole Markup Language. *https://developers.google.com/kml/*.

Google, Inc. (2012). Google Earth. *http://www.google.com/earth/index.html*.

Reising, W. (1992), *A Primer in Petri Net Design*, Springer-Verlag2.

Sekizawa, A., Takahashi, K., Endo, M., Zama, S., Yanase, T., Shinohara, H. and Sasaki, K. (2000). Information system for supporting fire-fighting activities based on real time fire spread simulation. *Proceedings of Institute of Social Safety Science*. No.11: 117-120 (in Japanese).

Tsujihara, O., Fushimi, Y., Kubori, T., Sawada, T. (2003). Construction of convenient simulation system of spreading fire at an earthquake using digital residential maps. *Journal of Applied Computing in Civil Engineering*. **Vol 12**: 237-244 (in Japanese).

Tsujihara, O., Fushimi, Y., Kubori, T., Sawada, T. and Mitsuiwa, Y. (2004). Simulation system of spreading fire in an earthquake using digital residential maps. *Proceedings of 13th World Conference on Earthquake Engineering*. Paper No. 3386: 1-12.

Tsujihara, O., Terada, K, Sawada, T. (2005). Development of simulation system of spreading fire occurring simultaneously in many places in an earthquake using Petri-net. *Journal of Applied Computing in Civil Engineering*. **Vol 14**: 129-136 (in Japanese).

Tsujihara, O., Terada, K, Sawada, T. (2006). GIS based simulation system of urban spreading fire in earthquake applying Petri net. *Proceedings of The International Symposium on Management System for Disaster Prevention*, 1-8 (in CD-ROM).

Tsujihara, O., Terada, K, Sawada, T. (2008). Development of simulation system of urban spreading fire in an earthquake and its application to decision of extinguishing priority order. *Proceedings of 14th World Conference on Earthquake Engineering*. Paper No. 3386: 1-8.

Yano, K., Matsui, T., Takaki, H., Bouike, M. and Uemura, Y. (1996). Study on simulation model of large fires spread caused by Kobe Earthquake. *Proceedings of Infrastructure Planning*. No.19(2): 39-42 (in Japanese).