Journal of Natural Disaster Science, Volume 27, Number 2, 2005, pp49-58

Study on Effective Operations Strategy of Emergency Fire Response Teams After the Great Minami Kanto Earthquake Disaster

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(Received for 27 May., 2005 and in revised from 6 Jan., 2006)

ABSTRACT

The Emergency Fire Response Team is a combining of fire brigades covering the entire country after a large-scale disaster performing fire fighting activities in the stricken area. It is necessary to track the number of required fire brigades corresponding to the scale of disaster for an effective operations strategy, as the number of brigades is limited. In this research, various experiments were conducted, revealing a quantitative understanding and effective operations strategy on the use of Emergency Fire Support Teams.

1. INTRODUCTION

1.1 Background on Research

Emergency Response Fire Teams are ready to respond to the imminent threat of large-scale earthquake disasters[1)]. There are also support operations beyond the boundaries of local prefectural governments based on the orders and requests of the Fire Commissioner in the event it is difficult for fire fighting organizations acting as municipal fire fighters throughout Japan at normal times to respond to large-scale earthquake disasters when these fire fighting organizations are the only groups dealing with the affected disaster area. This system consists of 2,800 fire brigades registered across Japan, covering roughly 15% of all fire brigades nationwide (as of 2004).

However, it is difficult to demonstrate the effectiveness in lessening the maximum level of damage through the dispatch of a limited number of brigades because prefectures dispatching personnel, the number of brigades, and the operation area requiring rapid decision-making by the overseer (nation) are not tracked quantitatively in terms of operations that meet the scale and the conditions of the disaster, thus lacking clarity with respect to effective action policies for Emergency Fire Response Teams.

Moreover, while much research has been conducted on fire fighting activities for multiple fires occurring simultaneously due to an earthquake disaster, there is no research on the combining of response teams from prefectures across Japan from the 2,800 registered brigades.

1.2 Purpose of Research

The purpose of this research is to respond to the scale and conditions of fires occurring simultaneously due to a disaster caused by a large-scale earthquake, develop tools to track quantitatively those prefectures offering assistance, response teams, response locations as ordered and requested by the Emergency Fire Response Teams for Japan, the overseer of operations, and implement sensitivity analysis and policy experiments using these, to propose effective action plans for Emergency Fire Response Teams in the case that a large-scale earthquake disaster occurs in the Minami Kanto Region of Japan.

2. Overview of Research

This research targets the number of open fires that local fire fighting organizations find it difficult to respond to, among the fires that occur due to a large-scale earthquake disaster. We tracked the quantitative operations of Emergency Fire Response Teams and uncovered effective action plans using the following methods.

* Developing Unit Operation Tools for calculating assistance methods (prefectures that are mobilizing, the number of dispatched brigades) using linear programming, in order to minimize the burned-out areas according to fire damage conditions (number of fires) for response teams throughout Japan
* Implementing sensitivity analysis on traffic speed, the number of open fires and disruptions of expressways
* Implementing policy experiments on operation methods of Emergency Fire Response Teams incorporating the support operation restrictions of neighboring prefectures and the reinforcement of brigades to specific locations with the Minami Kanto Region being the affected disaster area.

Tracking the efficacy of policies gained from the results of policy experiments, and proposing action plans for Emergency Fire Response Teams.

3. Development of Unit Operation Tools

3.1 Overview of Unit Operation Tools

Unit Operation Tools are used to calculate the shortest time

KEY WORDS: Emergency Fire Response Team, Unit Operation Tool, Earthquake Disaster

from the main hubs of prefectures responding to the main hubs of the affected prefecture using the Dijkstra method to enter affected prefectures, highway travel speeds, national highways travel speeds, mobilization restrictions, and the number of open fires. The number of response teams needed is calculated from the number of open fires in the disaster area using the spreading rate method (*Tokyo Fire Department Techniques 2003*[13)]). Then, the mobilization method (prefectures responding, number of response teams, prefectures to mobilize) to minimize the total burned-out area is calculated from both of these results using linear programming, and the burned-out area is calculated from these results.

3.2 Creating a Roadway Network Needed for Response

Emergency Fire Response Teams assemble primarily at highway interchanges and move to the disaster area. Thus network connection nodes based on actual roadways are created by establishing departure point main hubs one by one from the highway interchanges throughout Japan to each prefecture, and extracting 155 points, including main prefectural hubs as nodes in order to calculate the transit time to the disaster area. **Figure 1** shows part of this network. The roadways used for the network are the national expressways and national highways (designated zones on national highways).

3.3 Setting Time Needed to Respond

In this paper, response teams follow the roadway network, and the time to arrival at the disaster area was set as the lead time to request a mobilization, the time to organize response teams, travel time on highways & national highways, refueling time and the total time to deploy operations after arrival

a) Lead Time until Request for Mobilization

After a large-scale disaster, the government dispatches advance investigators to gather disaster information, then the time until the prefectural governor or mayor requests and directs Emergency Fire Response Teams is set as the lead time. In this paper, the lead time was set at 60 minutes based on the operations of the Disaster Headquarters of the Fire and Disaster Management Agency for the Nigata Earthquake.

b) Time to Organize Response Teams

The time for response teams organized by each prefecture was set. The time to organize the response teams was set based on the area of the prefecture. The setting method was treated as a circle for prefectures, fire brigades were deployed in uniform densities internally and the average arrival time that these brigades assembled at the center of the circle was set as the time to organize the response teams. The travel speed at that time was set at 30 km/h.

c) Highway/Designated National Highway Travel Time

The travel time for fire brigades using the route with the shortest time was calculated for set nodes (between main prefectural hubs). The calculation method gives weight to the time to set links, and calculates the time using the Dijkstra method.

d) Refueling Time

The refueling time is the time to refuel so that travel and support operations are performed as the response teams are heading to the disaster area. The time is set at 30 minutes each time all prefectures responding refuel at least once then a refueling time (30 minutes) for 1 time is added to each 500 km increase in the distance traveled for each prefecture.

e) Time to Deploy Operations after Arrival

The time to deploy operations after arrival is the time from when the Emergency Fire Response Teams arrive at the mustering site (main prefectural hubs) of the disaster area to when they move to the area of the actual fires within the disaster area (urban areas). For this, calculated values are used as substitutes for the affected prefecture making the request in b) Time to Organize Response Teams

3.4 Setting the Number of Brigades Needed for Affected Prefecture

The number of brigades needed based on the scale of the disaster (the number of open fires) is computed for the affected prefecture. In terms of the steps for computing, a spreading area func-

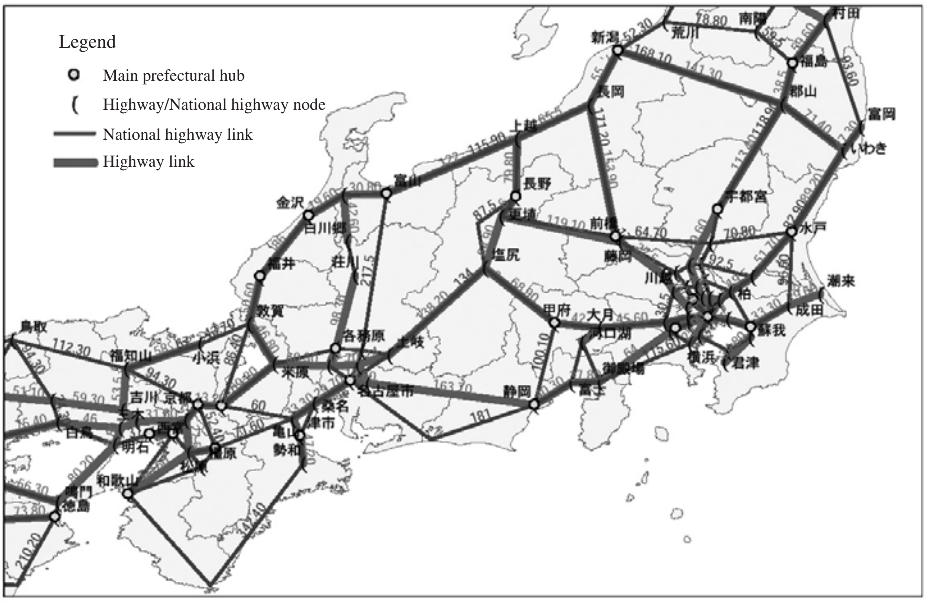

Fig. 1 Roadway Network (Partial Excerpt, Values Are Distance (km))

tion expressed with function time t (minutes) for the burned-out area of one open fire is set, then the number of fire brigades needed to contain the area from the spreading area function is similarly expressed with the time t (minutes) function. Multiplying the number of open fires to this gives the number of brigades needed based on the time t (minutes) for the affected prefecture.

a) Defining the Number of Open Fires

In many prefectures, assumed earthquake damaged is classified into 3 stages: a *full fire outbreak* expressing all fires, an *erupting fire* that cannot be extinguished by residents or voluntary disaster prevention organizations, and an *open fire* that cannot be extinguished by local or prefectural fire brigades. This paper uses the stage *open fire*. *Open fires* are set as occurring in DID regions in each prefecture based on the assumption that they occur in densely populated areas.

b) Setting Spreading Area Functions

Spreading rate functions are set in order to express the time course and the level of increasing damage.

First, weather data (humidity, wind speed) for the past 10 years for Otemachi in Chiyoda Ward, and average values for conditions in the urban area of Tokyo's 23 wards in the Tokyo Urban Area Conditions Study (Rate based on building structures, number of buildings by building structure, open space ratio, road ratio) were assigned to the Tokyo Fire Department System 2001[13)], and the spreading rate was calculated at random times.

Then, the distance integrating the spreading rate obtained with time t (minutes) was set at length, and double the distance integrating the spreading rate with time t when the wind speed is set at 0 was set at breadth, and the spreading area was obtained by an elliptic approximation. Furthermore, the relationship between the elliptic approximated spreading area and time was approximated using a root curve, and this was set as the spreading area function.

As a result of this approximation, the spreading rate was set at *S*(*t*), expressed as follows.

$$S(t) = 0.563\, t^{1.9932} \quad (\mathrm{m}^2) \qquad [1]$$

c) Computing the Number of Required Brigades

First, for the number of brigades required per open fire at the stage where response teams have not arrived, the spreading conditions were treated as a circle in order to simplify the spreading area shown in Equation [1], and the length of the circumference (set as the fire area perimeter) was set at a value to fully contain the fire. Then, the circumference that Fire Brigade 1 can oversee (fire defense) was set at 30 m, the number of brigades required for one open fire was set at N(t), resulting in the following when expressed using S(t).

$$N(t) = \frac{2\sqrt{\pi S(t)}}{30} = \frac{2\sqrt{\pi \times 0.563 t^{1.9932}}}{30} \quad \text{(brigades)} \quad [2]$$

Furthermore, the time required to arrive from prefectures nationwide to the affected prefecture was shown as 3(3), thus if Xi brigade can arrive at the fire in the affected prefecture after the prefectures responding i in time ti, this means that the ratio of the central angle expressed in $X_i/N(t_i)$ for the corresponding fire will be contained by the response teams assembling from these prefectures. It is necessary here for the conditions for $X_1, X_2, \ldots, X_n$ brigades to arrive after prefectures 1, 2, ..., n are at times $t_1, t_2, \ldots, t_n$

$$\sum_{i=1}^{n} \frac{X_i}{N(t_i)} = 1 \qquad [3]$$

while the number of response teams b(t) is as follows.

$$b(t) = \sum_{i=1}^{n} X_i \quad \text{(brigades)} \quad [4]$$

If the number of open fires is set at F, then the number of all required brigades *B*(*t*) is as follows (a non-overlapping spreading area is assumed).

$$B(t) = F \times \sum_{i=1}^{n} X_i \quad \text{(brigades)} \quad [5]$$

and fully contain the fire to be as shown below.

For the actual calculation, time $t_1, t_2, \ldots, t_n$ required to arrive for 1,2,...,n prefectures responding is already known, thus it is back calculated to satisfy the conditions of Equation [3], and the number of required brigades $X_1, X_2, \ldots, X_n$ is calculated. In addition, when used with the Unit Operation Tool, values rounded up with integers are used for the calculation. **Figure** 2 shows a simple image of the envelopment by the response teams and the spreading conditions.

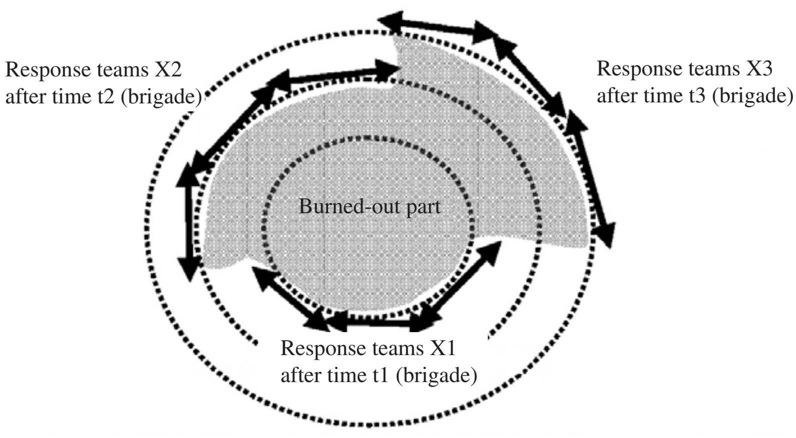

Fig. 2 Image of Envelopment by Response Teams and Spreading Conditions

3.5 Calculating Total Burned-out Area

A method to calculate the burned-out area of this fire using a solution derived as the optimal solution for response by the Unit Operation Tool is shown. Upon the breakout of a fire, X_1, X_2, X_3, ..., X_n brigades of response teams arrive after times t_1, t_2, t_3, ..., t_n, and when the fire is fully contained, the burned-out area of the fire is as follows.

$$\text{Burned-out area } = \sum_{i=1}^{n} S(t_i) \times \frac{Xi}{N(t_i)} (m^2) \quad [6]$$

Or, it can be expressed as follows if N(ti) is deleted

$$\text{Burned-out area } = \frac{30}{2\pi} \sum_{i=1}^{n} X_i \sqrt{S(t_i)} (m^2) \quad [7]$$

Thus the total burned-out area of the affected prefecture where F fire has occurred can be expressed as follows.

$$\text{Burned-out area } = \frac{30F}{2\pi} \sum_{i=1}^{n} X_i \sqrt{S(t_i)} (m^2) \quad [8]$$

3.6 Calculating the Optimal Response Method Using Linear Programming

The time required to head to the disaster areas by prefecture obtained in (3) and (4), the number of required brigades for the affected prefecture and information on the number of registered Emergency Fire Response Teams for each prefecture is used to calculate the optimal response method. The secondary operations of the fire brigades at this time is that all fire brigades the affected prefecture has can put out the open fires that occurred within their prefecture 180 minutes after the fires started.

In this paper, the number of registered brigades in the prefecture, the transit time and the constraints are clearly presented. The purpose is to minimize the burned-out area, which is expressed using each linear equation, thus linear programming is used in the development of the Unit Operation Tool.

a) Setting Constraints

The following are settings for constraints.

・0≦the number of response teams of each prefecture≦ number of registered brigades

・Satisfying the required number of brigades

b) Objective Conditions

・Minimize total burned-out area

Thus the Unit Operation tool outputs the following 5 items: the prefectures mobilizing a response, the prefecture to which they are responding, the number of response teams by prefecture, the burned-out area by affected prefectures, and the total burned-out area.

4. Sensitivity Analysis

Sensitivity analysis is performed to track the *number of open fires, the travel speed* of response teams, the total burned-out area due to changes whereby the *highways are blocked or not* near the disaster area, and the effect on the number of response teams, which are the non-policy variables whereby operations cannot be performed technically when a large-scale earthquake disaster occurs, by using the developed Unit Operation Tool.

4.1 Overview of Sensitivity Analysis

For the implementation method of sensitivity analysis, only 1 item was changed for the items input to the developed Unit Operation Tool (number of open fires, highway travel speed, blocked highway), and other items were set and calculated. Moreover, only Tokyo was considered as the disaster area.

4.2 Analysis Patterns

Conditions for sensitivity analysis are shown in order from a) to c) below.

a) Sensitivity Analysis on the Number of Open Fires (8 Patterns)
b) Sensitivity Analysis on Travel Speed (4 Patterns)
c) Sensitivity Analysis on Blocked Highway (2 Patterns)

The blocked highway here is where a highway cannot be used within 30 km from the disaster area, and this zone is set as the standard for national highway traffic, which flows at 20 km/h.

4.3 Analysis Results

a) Number of Open Fires

Table 4 shows the results of sensitivity analysis on the number of open fires, and **Figure 3** expresses this graphically.

Based on these results, with increases in the number of open

Table 1. Analysis Patter on Open Fires

Parameters	Set/Variable	Range
Disaster area	Set	Tokyo
Number of open fires	Variable	30 to 65 incidents(by 5)
Expressway travel speed	Set	60 km/h
Blocked highway	Set	No

Table 2. Analysis Patterns on Travel Speed

Parameters	Set/Variable	Range
Disaster area	Set	Tokyo
Number of open fires	Set	55 incidents
Expressway travel speed	Variable	40, 60, 80, 100 km/h
Blocked highway	Set	No

Table 3. Analysis Patterns on Blocked Highway

Parameters	Set/Variable	Range
Disaster area	Set	Tokyo
Number of open fires	Set	55 incidents
Expressway travel speed	Set	60 km/h
Blocked highway	Variable	Yes/No

Table 4. Sensitivity Analysis Results on the Number of Open Fires

Number of Open Fires (Incidents)	Burned-out Area (m2)	Number of Response Teams (Brigades)
30	520,130	467
35	604,776	543
40	691,650	621
45	792,430	705
50	929,158	802
55	1,270,387	955
60	2,374,913	1,233
65	5,755,066	1,692

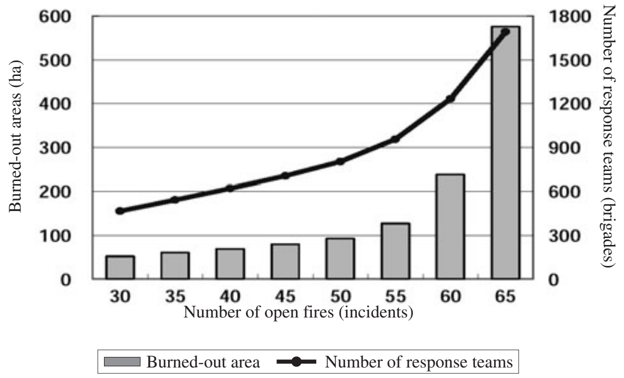

Fig. 3 Relationship between the Number of Open Fires, the Number of Response Teams and Burned-out Areas

Table 5. Sensitivity Analysis Results on Highway Travel Speed

Travel Speed	Burned-out Area (m2)	Number of Response Teams (Brigades)
100 km/h	1,126,580	918
80 km/h	1,175,236	932
60 km/h	1,270,387	955
40 km/h	1,593,119	1015

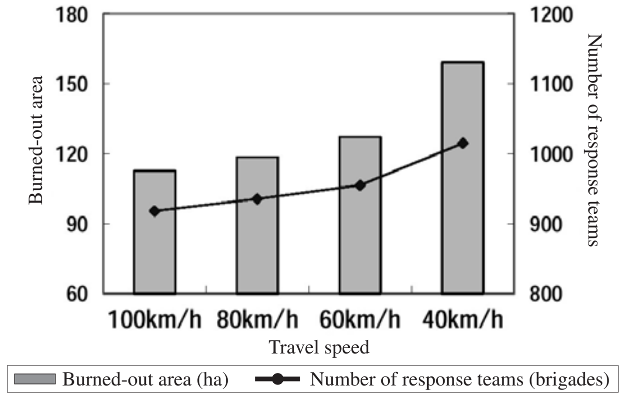

Fig. 4 Relationship between Travel Speed, Burned-out Area and the Number of Response Teams

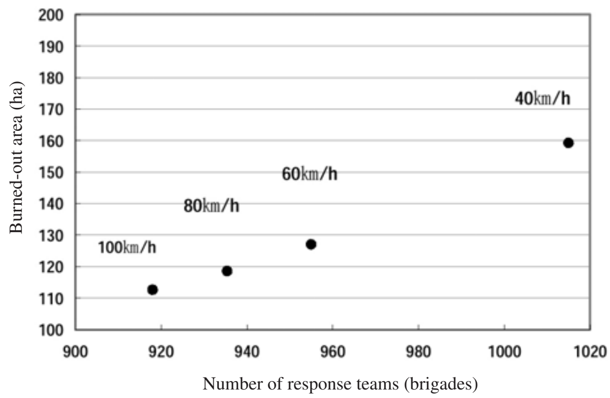

Fig. 5 Relationship between the Number of Response Teams and Burned-out Area by Travel Speed

Table 6. Sensitivity Analysis Results on Blocked Highway

Blocked HighwayArea	Burned-out (m2)	Number of Response Teams (Brigades)
No	1,270,387	955
Yes	2,491,406	1,157

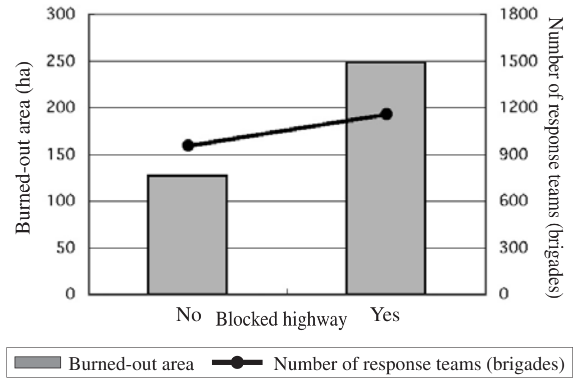

Fig. 6 Relationship between Blocked Highways, Burned-out Areas and the Number of Response Teams

fires comes moderate increases in the number of response teams required, showing that the burned-out areas on 55 open fire incidents increased rapidly.

b) Travel Speed

Table 5 shows the sensitivity analysis results on the travel speed on the highway for response teams, and **Figure 4** expresses this graphically.

Based on these results, with the drop in travel speed at a range of over 60 km/h, the number of response teams and the burned-out area increase linearly, and when the speed drops to 40 km/h, the rate of increase of the burned-out area increases slightly.

Figure 5 shows the relationship between the number of response teams and the burned-out area

From **Figure 5**, the values at 40 km/h are compared to others, and both the number of response teams and the burned-out area show large values, and 60 km/h to 100 km/h results in a fairly low position.

c) Sensitivity Analysis Results on Blocked Highways

Table 6 shows the sensitivity analysis results on blocked highways on which response teams are traveling, and **Figure 6** expresses this graphically.

These results show that, in comparison to the effect on the number of required response teams, the presence of blocked highways greatly affected burned-out areas.

5. Policy Experiments on Minami Kanto Region

5.1 Overview of Policy Experiments

In policy experiments, a large-scale earthquake on the Tokyo/Saitama border in the Minami Kanto Region was assumed to have occurred, and the scale of damage was set at a maximum value within the range of existing solutions using linear programming based on the results of sensitivity analysis on items input to the Unit Operation Tool, then, for internal data used for the calculations, mobilization restrictions of neighboring prefectures and percentage of mobilization of a simultaneous shift (refer to (3) in this Section) were changed and calculated to be used as policy variables. Fixed values based on the sensitivity analysis results are as follows.

・Number of open fires: 45 in Tokyo, 27 in Saitama
・Highway travel speed: 60 km/h
・Blocked highways: Yes

5.2 Policy Experiment 1: Mobilization Restriction of Neighboring Prefectures

When a large-scale earthquake disaster occurs in a region, there will be damage in prefectures neighboring the disaster area, thus there may be hesitation in responding to another prefecture. In this experiment, experiments on the reduction effect in burned-out areas brought about by response mobilization from neighboring prefectures to the disaster area are conducted in order to establish these judged materials.

a) Experiment Patten (2 Patterns)

No restrictions is a policy for mobilizing all registered brigades in neighboring prefectures, while all restricted is a policy whereby brigades in neighboring prefectures are not mobilized and the mobilization response comes from prefectures beyond the neighboring prefectures.

b) Experiment Results

Table 8 shows Policy Experiment 1 and **Figure 7** expresses this graphically.

The burned-out area where all mobilization of neighboring prefectures is restricted in this experiment mushroomed to near 2.5x that when mobilized from neighboring prefectures without restrictions.

Figure 8 shows the situation of responding prefectures when there are no restrictions, and **Figure 9** shows the situation of responding prefectures when all mobilization is restricted.

Figures 8 and **9** show that response requests when neighboring prefectures mobilize without hesitating are restricted to the partial range of the Kanto Koshinetsu and the Tohoku Region, yet when there is no mobilization response from neighboring prefectures, support from Hokkaido to part of Kyushu and support from all across Japan is needed.

Table 7. Experiment Pattern for Policy Experiment 1

Parameters	Set/Variable	Range
Disaster area	Set	Saitama/Tokyo
Highway travel Speed	Set	60 km/h
Number of open fires	Set	27 in Saitama, 45 in Tokyo
Mobilization restrictions of neighboring prefectures	Variable	No restrictions/ All restricted
Blocked highway	Set	Yes

Table 8. Experiment Results on Policy Experiment 1

Mobilization Restrictions	Burned-out Area (m2)			Number of Response Teams (Brigades)
	Saitama	Tokyo	Total	
No restrictions	1,379,841	821,415	2,201,256	1,321
restricted All	3,288,089	2,258,584	5,546,673	1,672

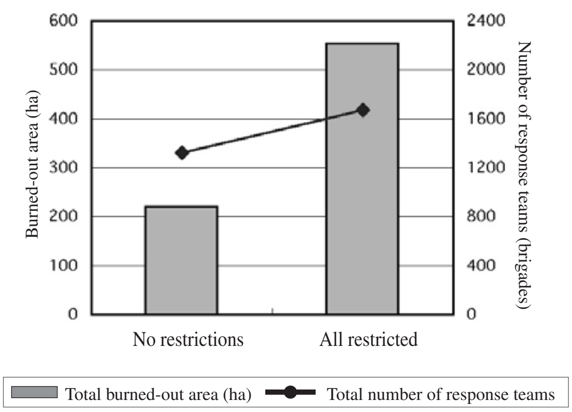

Fig. 7 Difference in Burned-out Area Due to Mobilization Restrictions of Neighboring Prefectures

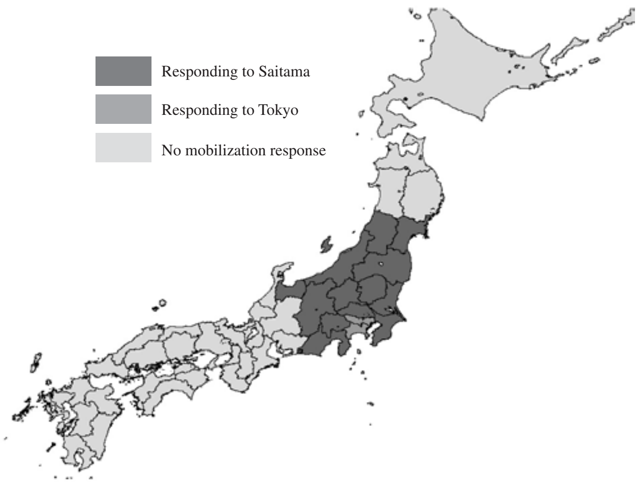

Fig. 8 Range of Response Request when There Are No Mobilization Restrictions

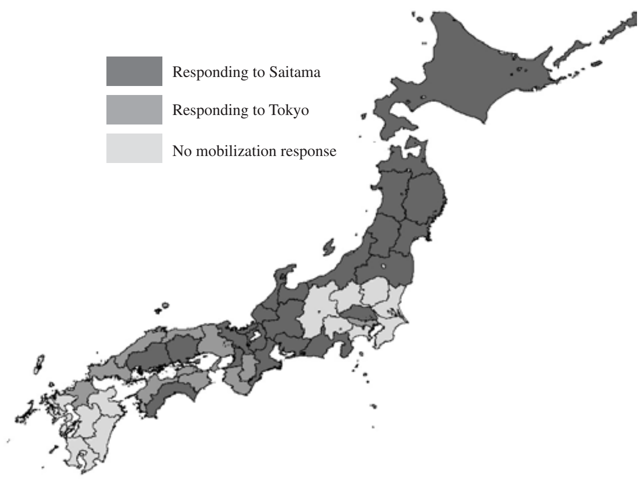

Fig. 9 Range of Response Request when There Are Mobilization Restrictions

5.3 Policy Experiment 2: Implementing Response Mobilization Using Simultaneous Shift System

Policy Experiment 1 shows the importance of mobilizing neighboring prefectures. Policy Experiment 2 uses a method (hereinafter referred to as a simultaneous shift) whereby neighboring prefectures mobilize a response to the disaster area beyond the number of registered brigades, and fire brigades from across Japan move in tandem to the neighboring prefectures in order to supplement the voids that occur in their fire fighting capabilities; i.e. a large number of brigades are sent into the disaster area in a short period of time. Moreover, only neighboring prefectures mobilize a response to the disaster area in this policy experiment, and other prefectures mobilize to supplement the fire fighting capability of the neighboring prefectures.

a) Experiment Pattern (3 Patterns)

Table 9 shows the policy experiment patterns of the simultaneous shift system. The ratio of simultaneous shift in **Table 9** is the rate as per the number of brigades the corresponding prefectures possess for mobilization, in addition to the number of registered brigades.

Table 9. Experiment Patterns in Policy Experiment 2

Parameters	Set/Variable	Range
Disaster area	Set	Saitama/Tokyo
Expressway travel speed	Set	60 km/h
Number of open fires	Set	27 in Saitama, 45 in Tokyo
Simultaneous shift rate	Variable	Number of registered brigades + remaining 20%, 30%, 50%
Blocked highway	Set	Yes

Table 10. Experiment Results of Policy Experiment 2

Simultaneous Shift Mobilization Ratio	Burned-out Area (m2)		
	Saitama	Tokyo	Total
20%	793,927	821,415	1,613,695
30%	758,708	819,768	1,580,123
50%	709,343	819,768	1,530,758

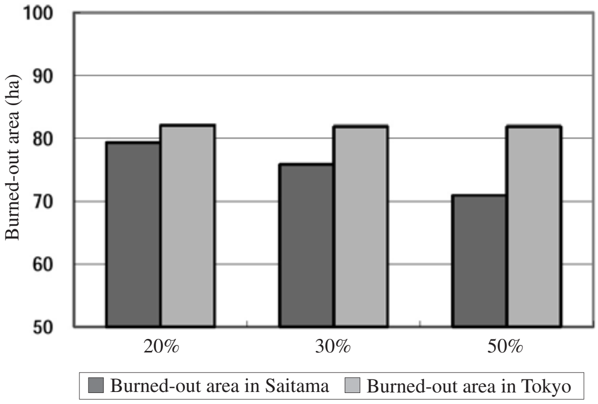

Fig. 10 Relationship between Simultaneous Shift Mobilization Ratio

Table 10 shows the results of Policy Experiment 2, and **Figure 10** expresses this graphically.

The experimental results show that when the mobilization ratio using the simultaneous shift increased from 20% to 30%, the burned-out area decreases approximately 330,000 m^2, and from 30% to 50%, it decreases approximately 50,000 m^2. In addition, from **Figure 10**, we learned that the reduction rate of the burned-out area in Saitama is larger than the reduction rate of the burned-out area in Tokyo. **Figure 11** shows these results expressed in the burned-out area per open fire.

This figure shows that the burned-out area per open fire in Tokyo is suppressed less than in Saitama, regardless of the simultaneous shift mobilization ratio.

5.4 Comparing Policy Experiment 1 and Policy Experiment 2

Figure 1 shows the results when there are no mobilization restrictions in Policy Experiment 1 as compared to Policy Experiment 2, in order to verify the effect of the simultaneous shift.

Figure 12 shows that a burned-out area less than 600,000 m^2 is suppressed more than when there are no restrictions implemented in Policy Experiment 1 in all patterns where a simultaneous shift is carried out, and that, when the mobilization ratio using the simultaneous shift increases, the depression effect of the burned-out area increases even with the same number of open fires, and

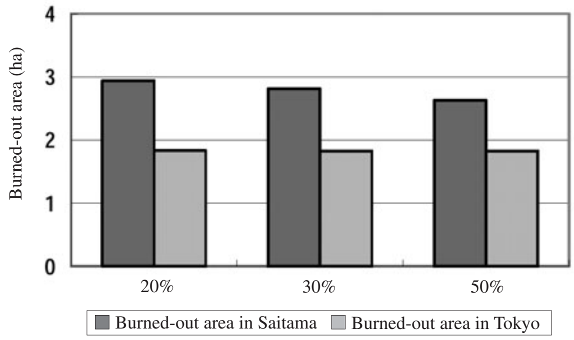

Fig. 11 Simultaneous Shift Mobilization Ratio and Burned-out Area per Incident

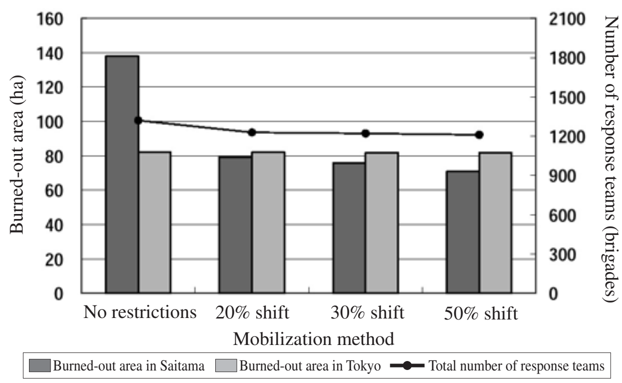

Fig. 12 Comparison of Policy Experiment 1 and Policy Experiment 2

the number of required brigades is controlled.

6. Results of This Study and Future Issues

6.1 Results of This Study

a) Development of Unit Operation Tool

We extracted the main prefectural hubs, highway nodes/links, national highway nodes/links from across Japan, expressed the roadway network in relation to time and distance to calculate the shortest (time) route from each prefecture to a disaster area, then we assigned the number of response teams and neighboring prefecture data derived from spreading area functions and performed linear programming calculations to develop a Unit Operation Tool for calculating solutions that minimize the burned-out area.

This tool outputs the prefectures responding, the number of response teams, the response mobilization destination and the burned-out areas from inputs of affected prefecture, travel speeds of response teams, mobilization restrictions of neighboring prefectures and the number of open fires, which can be utilized for disaster areas nationwide.

b) Sensitivity Analysis on Non-Policy Variables

This study assumed that a disaster occurred in Tokyo , the response was mobilized from across Japan, and sensitivity analysis was performed on the effect each parameter for the number of open fires, travel speeds, blocked highways, and non-policy variables has on the burned-out area and the number of response teams.

(A) Sensitivity Analysis on the Number of Open Fires

The number of open fires was increased 5 at a time from 30 to 65 incidents in the sensitivity analysis on the number of open fires, and we tracked the situation where there was an increase in the burned-out area. The result was that, when the number of open fires surpassed 55 incidents, the burned-out area appeared to increase rapidly. The cause of this is that, based on the geographical conditions of Tokyo, it was easy to assemble up to the number of required brigades (farthest prefecture was Shizuoka) to respond to these fires, and when the number of open fires exceeded this, brigades had to be assembled from places farther away to obtain the required number of brigades, as the required brigades assembled only from northern and western Japan. Furthermore, when the neighboring prefectures were compared to the remote prefectures, the area burned out even in the same supervised fire area perimeter increased because of the difference in arrival times. The combination of these 2 factors was accompanied by an increase in the number of open fires, and may have led to the appearance of locations where burned-out areas increased rapidly.

(B) Sensitivity Analysis on Travel Speed

We changed the highway travel speeds in this analysis to 100 km/h, 80 km/h, 60 km/h and 40 km/h then performed our analysis. From the analysis results, we were able to track the increase in the burned-out areas and the number of required brigades according to the drop in speed, yet, when compared to the sensitivity analysis of the number of open fires, we found nothing that rapidly increased the burned-out areas as the increases can be linear. Although, when comparing burned-out areas, an approximately 1.4x difference between 100 km/h and 40 km/h exists, the increase is only approximately 1.1x between 100 km/h and 60 km/h. It may be that there is little effect on increases in the burned-out areas if a travel speed of 60 km/h can be maintained.

(C) Sensitivity Analysis on the Presence of Blocked Highways

We performed sensitivity analysis in this paper assuming blocked highways located within a radius of 30 km from the disaster area. The analysis results showed that when we compare the effect that blocked highways have on the number of response teams and the burned-out areas, while the increase in the number of response teams was from 955 brigades to 1,157 brigades, standing at around 20%, due to the blockage, the burned-out areas increased approximately 2x from 137 ha to 249 ha. The cause for the great increase in the burned-out area is mainly that the 30 km distance to the disaster area was traveled at 20 km/h, and due to the extra time it takes at over 60 minutes regardless of the prefecture, and may greatly affect the increase in the burned-out area as a result. Compared to the burned-out area, the fact that the level of increase in the number of response teams required can be extrapolated to be that Tokyo has a secondary operational effect due to the 2 fire engines it has. When the number of response teams from places other than Tokyo is calculated, 668 brigades are deducted respectively from the number of response teams of the analysis results, an increase of 1.70x at 287 brigades and 489 brigades. Thus, the results in this case may be particular to Tokyo, and an increase in the number of response teams at the same level as the increases in the burned-out area are expected in other prefectures.

c) Policy Experiments for Minami Kanto Region

In our policy experiments, Tokyo and Saitama are damaged, response mobilization for Tokyo and Saitama from across Japan are assumed, and policy experiments were conducted on the effect the mobilization restrictions of neighboring prefectures that have policy variables and mobilization ratios using the simultaneous shift have on burned-out areas and the number of response teams. The conclusions for each are as follows.

(A) Presence of Mobilization Restrictions in Neighboring Prefectures

The policy experiments on response mobilization of neighboring prefectures indicate that when there are no mobilization restrictions, and when there are restrictions, the burned-out areas are 220 ha and 555 ha respectively, creating a tremendous gap of approximately 2.5x.

These policy experiments revealed the tremendous effect that brigades from neighboring prefectures have on suppressing the burned-out areas, the need to mobilize more response teams from neighboring prefectures to reduce the burned-out areas and the total number of response teams.

(B) Implementing a Simultaneous Shift

Fire brigades from across Japan moved concurrently to neighboring prefectures in the direction of the disaster area. The policy experiments on rapid response mobilization of large numbers of brigades from neighboring prefectures in a short period revealed that there would be a great impact compared to when there were no mobilization restrictions in neighboring prefectures, even when a simultaneous shift ratio of 20% was set. In addition, when the burned-out area with respect to the mobilization ratio using the simultaneous shift is compared, while a tremendous change was not really apparent in the burned-out area as compared to the increase in the ratio, this shows that 20% is a sufficient response in this case.

Furthermore, by comparing the burned-out areas of Tokyo and

Saitama, we demonstrated that the effect of containing the burned-out area using the simultaneous shift affects the number of fire brigades the affected prefectures has.

d) Conclusions

We limited the damage to multiple fires that occur when a large-scale earthquake occurs, and we performed sensitivity analysis and policy experiments in order to propose effective operation measures for Emergency Fire Response Teams.

The sensitivity analysis showed that there are upper limits to the number of open fires that can be responded to, and that blocked highways and traffic congestion are tremendous stumbling blocks to the mobilization of a response by Emergency Fire Response Teams to multiple fires. Under these conditions, the policy experiments indicated the need to have prefectures neighboring the disaster area mobilize a response, and for brigades to mobilize a response, and not be fully restricted even when there are mobilization restrictions, in order to minimize the burned-out area of the disaster area. In addition, it became clear that mobilization using a simultaneous shift has a strong effect if the depression effect is raised further.

6.2 Future Issues

The following issues require future study.

a) Improving the Calculation Accuracy of Unit Operation Tools

(A) Setting Departure Points/Destinations

Although 1 main hub was established with prefectures in this study, and a mustering area for response teams was established, when there is uneven distribution of locations for registered brigades within the prefectures, designating multiple mustering areas helps shorten the time to assemble. It is important to make improvements in establishing multiple main prefectural hubs.

(B) Examining the Travel Speeds of Response Teams

In this paper, the travel speeds of the Emergency Fire Response Teams were set to 60 km/h and 40 km/h respectively for highways and national highways when there were no blocked highways, and to 60 km/h and 20 km/h respectively when there were blocked highways. However, there is no basis for these settings, and, based on hearings we conducted on traveling in the left-most lane when on the highway, lining vehicles up in a column and traveling on the highway, and refueling in tandem along the way on the interchange, these are values set based on ballpark estimates. It is necessary to perform detailed investigations on the travel speed based on past examples, etc. and reset these travel speeds in order to create a tool with a higher accuracy than the current Unit Operation Tool.

(C) Roadways Used

Concerning roadways used by Emergency Fire Response Teams, we established only national expressways, highways and national highways (designated zones on national highways). For this, although we narrowed down the target roadways in order to simplify the calculations, the roadways used to mobilize Emergency Fire Response Teams are primarily prefectural and municipal roads in order to arrive at the disaster site, not limiting the response to highways or national highways. When establishing roads to be used, it is necessary to examine all roadways using factors such as road widths and cities linked together by these roadways, in order to create a Unit Operation Tool with better accuracy that the one currently available.

(D) Weather Data

For wide-ranging objective functions to be adequately limited for earthquake disasters, average values over the past 10 years were set for wind speed. However, it may be necessary to use these as non-policy variables in order to create a tool with better accuracy.

b) Using Linear Programming

Linear programming was used in this paper for calculating the response method to minimize the burned-out area in the development of a Unit Operation Tool. The reasons for this were to clearly present constraints based on the number of registered brigades from prefectures and the transit times, the objective of clearly minimizing burned-out areas, to be able to simplify calculations in short periods of time in comparison to replicated experiments, by using a simulation model.

It may be necessary to calculate the response method using both linear programming and simulations in order to gain solutions for such things as the number of fires fully contained, the number of fires not extinguished, and the burned-out areas from fires that have burned out, and in order to raise the reliability of this study, when experiments are conducted using a simulation model.

c) Policy Experiments on Simultaneous Shift Systems

Calculations for mobilizing a response to a disaster area beyond the registered number of brigades were performed where there was definitely a supplement of fire brigades mobilizing to respond from remote locations to neighboring prefectures of the affected prefecture in Policy Experiment 2. However, there are no proposals for an implementation method (prefectures responding, mobilization destination, number of brigades) for a simultaneous shift. Thus, to make specific proposals for mobilizing a response using a simultaneous shift, it is necessary to develop a means of calculating an implementation method for an effective simultaneous shift from a remote location to a neighboring prefecture based on the distance between each prefecture and coordinates. In addition, although we verified that carrying out mobilization using a simultaneous shift raises the depression effect of the burned-out area, in reality, it is also important to consider the tremendous risks borne by prefectures mobilizing response teams. This may be because aftershocks are occurring immediately after response mobilization. Implementing a simultaneous shift from the initial earthquake for earthquakes that are likely to occur in conjunction primarily with Higashi Nankai and Nankai earthquakes creates conditions whereby there is a lack of fire fighting capabilities vis-_-vis the required number in prefectures where response teams are mobilizing, and, secondly, where damage from disasters at normal times that occur in prefectures that have haphazardly implemented response mobilization increased as a result of mobilizing response teams, even when there is no correlation to other earthquakes such as those in the policy experiments of this study.

The following items must be considered in order to perform operations.

* Each prefecture must set plans in advance that determine the destination and the number of response teams, in order to start moving in tandem to the prefectures neighboring the affected prefecture.
* It is difficult to determine the use of a simultaneous shift as it is difficult to track information on region-wide damage immediately after a disaster has struck.
* It is difficult to direct response teams from other prefectures

that have different operation systems.

* It is necessary to rotate personnel who have performed fire-fighting operations at the site of response mobilization for a long period of time.
* It is necessary to alter the deployment of brigades at the stage where information on actual damage comes in.

This paper is based on a dissertation (thesis) compiled by the principal authors, and is unrelated to the specifics of their work in their current posts.

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