Scenario of the Restoration Process Associated with Critical Infrastructure and its Interdependency due to a Seismic Disaster －A Case Study for the Anticipated North Tokyo Bay Earthquake－

Gaku SHOJI [1] and Ayumi Toyota[2]

[1] Department of Engineering Mechanics and Energy, Graduate School of Systems and Information Engineering, University of Tsukuba

[2] Department of Risk Engineering, Graduate School of Systems and Information Engineering, University of Tsukuba

Abstract: In this paper, the scenario of the restoration process associated with critical infrastructure such as electric power supply systems, gas supply systems, water treatments, communication networks and road ones due to a seismic disaster is clarified. The North Tokyo Bay Earthquake is anticipated for the analysis. First, the scenario of the restoration process is developed by analyzing the operational plans for disaster prevention offered by the stakeholders associated with the subject critical infrastructure distributed in the Tokyo area. Second, the scenario is analyzed based on the DEMATEL theory, and the related interdependency is modeled by selecting the dominant events in the restoration process and idealizing them as a directed graph.

Key Words: *critical infrastructure, restoration process, interdependency, seismic disaster*

1. Introduction

Our economical and societal activities strongly depend on the function of critical infrastructure such as electric power supply systems, gas supply systems, water treatments, communication networks, transport facilities and so on. Hence, shutdowns and functional impairment induced in the infrastructure due to a seismic disaster cause severe damage to above activities.

There are two types of countermeasures to prepare the system failure and functional impairment. First is to improve the physical reliability and second is to improve the reliability of software management. Former examples are the seismic retrofit of the related facilities and the development of redundant networks. Latter examples are the preparation of an effective operational plan by involved stakeholders. Both types of countermeasures are necessary to maintain the reliability of critical infrastructure. In Japan, Central Disaster Prevention Council and local governments make plans against the anticipated earthquakes such as the Tokyo Metropolitan Earthquake, the Tokai-Tonankai-Nankai Earthquake and so forth, and they take the countermeasures for the improvement of the physical reliability of critical infrastructure. However countermeasures and related researches to improve the software reliability are not sufficiently enough. Efficiency of the restoration process during a disaster is especially required to be improved, because it influences the economical and societal activities extensively.

In addition to improve the efficiency of the restoration management, the interdependencies associated with critical infrastructure should be considered. For instance, the restoration processes of gas suppliers, water suppliers and sewage suppliers become complicated when they repair the pipelines under the ground and they should take account into the road restoration process to proceed their own restoration. The interdependencies occurred in the past disasters such as the 1995 Kobe Earthquake and the 2004 Niigata-ken Chuetsu Earthquake. They might be anticipated in the mega cities where the economical and societal activities depend on critical infrastructure.

There are many studies associated with the restoration of critical infrastructure. Hoshiya and Miyazaki[1)] developed a model to predict the restoration process of water pipelines based on probabilistic approach. Sato and Ichii[2)] proposed the optimization scheme of the restoration process of lifeline networks using Genetic Algorithms. Noda and Nishimura[3)] revealed the structure of the problems in the restoration of water treatments from the questionnaire survey

to workers involved in the restoration activities in the 1995 Kobe Earthquake. Hada and Meguro[4] clarified the dependency of the restoration process of water treatments and gas supply systems upon the damage of road networks and houses from the damage assessment in the Kobe Earthquake. Nojima and Kameda[5] proposed a method by probabilistic approach to evaluate the seismic risk of urban lifeline network systems with emphasis on the aspect of system interactions, discussing the outline of interaction-related problems in lifelines due to a seismic disaster. Okuyama et al.[6] investigated the issues regarding interdependency analyses by interviewing the related researchers and the users. Eusgeld and Kröger[7] reviewed the analytical methods associated with the interdependency of lifeline systems and classified those into 8 groups, referring to their merits and demerits.

Results of most studies above associated with the restoration of critical infrastructure propose the methodologies such as the analytical methods to improve the efficiency and how to allocate the related human resources and materials optimally for specific infrastructure. However, the research associated with the interdependency of the restoration process has not been sufficiently enough.

From the reasons above, in this study, the scenario of the restoration process associated with critical infrastructure and its interdependency due to a seismic disaster is analyzed. Six systems of critical infrastructure are selected; electric power supply systems, gas supply systems, water treatments, communication networks and road ones. Operational plans for disaster prevention offered by the suppliers and managers associated with subject critical infrastructure are analyzed, and the model associated with the restoration process of the infrastructure and its interdependency is developed from qualitative and quantitative analysis based on graph theory. The related stakeholders who are described in operational plans are selected. Since the critical infrastructure is distributed widely and concentrately in the Tokyo area, the anticipated North Tokyo Bay Earthquake is subjected because.

2. Subject seismic disaster and its damage of critical infrastructure

Central Disaster Prevention Council and Tokyo metropolitan government assume 18 types of seismic ground motions for the Tokyo Metropolitan Earthquake and the damage due to those ones. Table 1 shows the damage resulted from the most severe grand motion; the North Tokyo Bay Earthquake. The number of fatalities is assumed to be 6,500 to 7,800 people and 470,000 to 530,000 buildings are completely failed in the Tokyo area. Economical loss arises 112 trillion yen[8] and it exceeds 10 times the case of the Kobe Earthquake. In terms of the damage of critical infrastructure in the Tokyo area, Central Disaster Prevention Council and Tokyo metropolitan government use different indexes to measure the damage. For instance, by Tokyo metropolitan government, rate of power failure reaches 16.9% and 6 days are required to repair. The supply stop rate of gas, suspension of the water supply rate, the damage rate of sewage pipelines and interrupted rate of communication networks become 17.9%, 34.8%, 22.3% and 10.1% immediately after the event, respectively. 53 days, 30 days, 30days and 14 days are required to repair gas supply systems, water treatments and communication networks.

Table 1 Anticipated damage due to the seismic disaster in the Tokyo area

		Central Disaster Prevention Council[8),9)]		Tokyo metropolitan government[10)]	
Condition		wind velocity 15m/s, occurs at 6 p.m.		wind velocity 15m/s, occurs at 6 p.m.	
	Numbers of fatalities	7,800 people		6,413 people	
	Numbers of completely destroyed buildings	530,000 buildings		471,586 buildings	
Condition		Wind velocity 15m/s, occurs at 6 p.m.		Wind velocity 6m/s, occurs at 6 p.m.	
	Electric power supply	Numbers of affected houses	1.1 million houses	Rate of power failure	16.9%
		Restoration period	6 days	Restoration period	6 days
	Gas supply	Numbers of affected houses	1.1 million houses	Supply stop rate	17.9%
		Restoration period	55 days	Restoration period	53 days
	Water supply	Numbers of affected people	3.9 million people	Supply stop rate	34.8%
		Restoration period	30 days	Restoration period	30 days
	Sewage	Numbers of affected people	0.13 million people	Damage rate of pipelines	22.3%
		Restoration period	—	Restoration period	30 days
	Communication networks	Numbers of interrupted lines	0.74 million lines	Interrupted rate	10.1%
		Restoration period	14 days	Restoration period	14 days

3. Analysis of restoration process of critical infrastructure

(1) Analytical framework

A restoration process in time series is classified into 4 phases[13]; emergency response phase, temporary restoration phase, recovering phase and reconstruction phase. In this study, the process of emergency response phase and temporary restoration phase are focused on, and the 2 processes are defined as to prevent the secondary damage and to secure the temporary supply of electric power supply systems, gas supply systems and water treatments, and to maintain the function of communication and road networks. Thus these phases correspond to ones from the immediately after the event to 72 hours after the event.

In the analysis, the disaster prevention plan offered by Tokyo metropolitan government[12] and the operational plans for disaster prevention by suppliers[13),14),15),16),17),18)] are referred. Stakeholders associated with the restoration process of critical infrastructure are selected and relationships among their activities in the process are clarified.

Figure 1 shows the framework to analyze the scenario. A column denotes the activities of stakeholders from immediately after the event to 72 hours. In the cases that the phase of the activities is not exactly detected from the references, it is assumed to be suitable phase by considering their features. Relationships among the activities are clarified into 3 types; exchange of the information, the related human resources and materials with the restoration process.

	Sector A	Sector B	Sector C	Sector D
event				
～1hour		◂Form headquarters		◂Confirm safety of staffs
	◂Collect information *←Sector B		◂Confirm safety of staffs	◂Confirm stock
				◂Request materials *→Sector B
～24hours	◂Press release	◂Send materials *→Sector D		
			◂Dispatch staffs *→Sector D	◂Request human resources *→Sector C
～72hours				
72hours～				

→ exchange of the information associated with the charateristics of earthquake and induced damage

→ exchange of the human resources associated with the restration process and related information

→ exchange of the materialas associated with the restration process and related information

Figure 1 Framework of the scenario

(2) Scenario of restoration process of electric power supply systems

Figure 2 shows a part of the scenario of the restoration process of electric power supply systems. The electric power supplier in the Kanto area is the Tokyo Electric Power Company, Inc. In the case that seismic intensity becomes 6 lower, the third emergency operation is formed automatically and all staffs gather to their own sections. During the gather of staffs, 24 hours-working operators in nuclear power stations, thermal power stations, transmission offices and load dispatching offices start emergency responses. In this process, automatic restoration system begins to work and the operators check the damage of the facilities, switch over the normal equipments to emergency ones and shutdown the affected equipments. At the same phase, central load dispatching office starts systematic emergency responses such as to collect the information of the damage of the related facilities and to instruct the operators in the facilities how to respond. Corresponding to these activities, the sections of disaster countermeasures are formed in the head office and all other offices, and the section of the head office makes the decision and plays central roles in the restoration activities. In the 1 hour from the event, branch offices start to check the damage of their facilities, confirm the stock of the materials and the safety of staffs. The information associated with the damage of facilities and the blackouts is informed from all offices to restoration section and information one in the headquarters of disaster countermeasures in the head office, and the 2 sections inform the related information to other sections of the head office. The power operational section that instructs central load dispatching office, and the restoration section check the efficiency of the

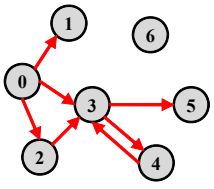
Figure 2　A part of the scenario of restoration process of electric power supply systems

	Tokyo Electric Power Company, Inc															
	Head office								Branch office	Nuclear powr station	Thermal power office	Construction office	Thermal power station	Transmission office	Remote control & maintenance office	Central load dispatching office
	Chief	Information Section	Public Info Section	Restoraion Section	Power Operational Section	Logistics Section	Welfare Section	General affairs Section								
event	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation	◂3rd emergency operation
	◂Start to gather	◂Staffs start to gather	◂Staffs start to gather	◂Staffs start to gather	◂Staffs start to gather	◂Staffs start to gather	◂Staffs start to gather	◂Staffs start to gather	◂Staffs start to gather	◂Staffs start to gather	◂Staffs start to gather	◂Staffs start to gather	◂Staffs start to gather	◂Staffs start to gather	◂Staffs start to gather	◂Staffs start to gather
										◂Automatic restoration system			◂Automatic restoration system	◂Automatic restoration system	◂Automatic restoration system	◂Automatic restoration system
		◂Section of disaster measures is formed	◂Section of disaster measures is formed	◂Section of disaster measures is formed	◂Section of disaster measures is formed	◂Section of disaster measures is formed	◂Section of disaster measures is formed	◂Section of disaster measures is formed	◂Section of disaster measures is formed	◂Section of disaster measures is formed	◂Section of disaster measures is formed	◂Section of disaster measures is formed	◂Section of disaster measures is formed	◂Section of disaster measures is formed	◂Section of disaster measures is formed	◂Section of disaster measures is formed
										◂Operators check the damage of facilities *←Central load dispatch office			◂Operators check the damage of facilities *←Central load dispatch office	◂Operators check the damage of facilities *→load dispatch offices	◂Operators check the damage of facilities *→load dispatch offices	◂Operators check the damage of facilities *←power stations, load dispatch offices
										◂Emergency responses ・Switch over normal to emergency equipments ・Shutdown the damaged equipment *←Central load dispatch offices			◂Emergency responses ・Switch over normal to emergency equipments ・Shutdown the damaged equipment *←Central load dispatch offices	◂Emergency responses ・Switch over normal to emergency equipments ・Shutdown the damaged equipment *←load dispatch offices	◂Emergency responses ・Switch over normal to emergency equipments ・Shutdown the damaged equipment *←load dispatch offices	◂Emergency responses *⇔power stations, load dispatch offices
																◂Confirm system failure *→Electric power system council
1hour	◂Collect information ・disaster characteristics *← Information Section, press	◂Collect & inform information ・disaster characteristics *←Cabinet office, Tokyo metropolitan gov, Ministry of Economy, Trade and Industry, Tokyo fire department, Metropolitan police, press, Japan meteorological agency, Branch offices *→sections, Chief	◂Collect & inform information ・disaster characteristics *← Information Section, press	◂Collect information ・disaster characteristics *← Information Section, press	◂Collect information ・disaster characteristics *← Information Section, press, Central load dispatching office	◂Collect information ・disaster characteristics *← Information Section, press	◂Collect information ・disaster characteristics *← Information Section, press	◂Collect information ・disaster characteristics *← Information Section, press	◂Collect & inform information ・disaster characteristics *←local governments, press, fire stations, police stations *→ Information Section, Sub offices	◂Collect information ・disaster characteristics *← Information Section, press	◂Collect information ・disaster characteristics *← Information Section, press	◂Collect information ・disaster characteristics *← Information Section, press	◂Collect information ・disaster characteristics *← Information Section, press	◂Collect information ・disaster characteristics *← Information Section, press	◂Collect information ・disaster characteristics *← Information Section, press	◂Collect information ・disaster characteristics *←Information Section, Operation Section, press
	・damage & restoration *← Information Section	・damage & restoration *←sections, offices *→Cabinet office, Tokyo metropolitan gov, Ministry of Economy, Trade and Industry, Tokyo fire department, Metropolitan police, press, Japan meteorological agency, Branch offices	・damage & restoration *← Information Section	・damage & restoration *←Nuclear powr station, Nuclear powr station, Branch office, Construction office *→ Information Section	・damage & restoration *←load dispatch offices *→ Information Section	・damage & restoration *← Information Section *→ Information Section	・damage & restoration *← Information Section *→ Information Section	・damage & restoration *← Information Section *→ Information Section	・damage & restoration *←Sub offices,Branch offices of the load dispatch *→Sub offices, Information Section	・damage & restoration *→Operation Section	・damage & restoration *→Operation Section	・damage & restoration *→Operation Section	・damage & restoration *→Central load dispatch offices, Thermal power offices	・damage & restoration *→load dispatch offices, Sub offices	・damage & restoration *→load dispatch offices, Sub offices	・damage & restoration *←Power system Section *→Power system Section
		◂Confirm the safety of staffs *→Welfare Section	◂Confirm the safety of staffs *→Welfare Section	◂Confirm the safety of staffs *→Welfare Section	◂Confirm the safety of staffs *→Welfare Section	◂Confirm the safety of staffs *→Welfare Section	◂Confirm the safety of all staffs	◂Confirm the safety of staffs *→Welfare Section	◂Confirm the safety of staffs *→Welfare Section, Operation Section	◂Confirm the safety of staffs *→Welfare Section, Operation Section	◂Confirm the safety of staffs *→Welfare Section, Operation Section	◂Confirm the safety of staffs *→Welfare Section, Operation Section	◂Confirm the safety of staffs *→Thermal power offices	◂Confirm the safety of staffs *→Sub offices	◂Confirm the safety of staffs *→Sub offices	◂Confirm the safety of staffs *→Power system Section
		◂Confirm the stock *→Logistics Section	◂Confirm the stock *→Logistics Section	◂Confirm the stock *→Logistics Section	◂Confirm the stock *→Logistics Section	◂Confirm all stock	◂Confirm the stock *→Logistics Section	◂Confirm the stock *→Logistics Section	◂Confirm the stock *→Logistics Section, Operation Section	◂Confirm the stock *→Logistics Section, Operation Section	◂Confirm the stock *→Logistics Section, Operation Section	◂Confirm the stock *→Logistics Section, Operation Section	◂Confirm the stock *→Thermal power offices	◂Confirm the stock *→Sub offices	◂Confirm the stock *→Sub offices	◂Confirm the stock *→Power system Section
		◂Check the damage of office buildings *→General Affairs Section	◂Check the damage of office buildings *→General Affairs Section	◂Check the damage of office buildings *→General Affairs Section ◂Pless release *→press	◂Check the damage of office buildings *→General Affairs Section	◂Check the damage of office buildings *→General Affairs Section	◂Check the damage of office buildings *→General Affairs Section	◂Check the damage of all office buildings	◂Check the damage of office buildings *→General Affairs Section ◂Pless release *→press	◂Check the damage of office buildings *→General Affairs Section	◂Check the damage of office buildings *→General Affairs Section	◂Check the damage of office buildings *→General Affairs Section	◂Check the damage of office buildings *→Thermal power Office	◂Check the damage of office buildings *→Sub offices	◂Check the damage of office buildings *→Sub offices	◂Check the damage of office buildings *→Power system Section
⋮ 72hour	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

restoration process, make the restoration plan for the affected facilities, and instruct the power plans, transmission offices, branch offices to carry out the plans. The information associated with the shortage of materials and human resources is reported from the offices to the restoration section in the sector of disaster countermeasures in the head office. The logistics section, welfare section and general affairs section request the materials and human resources to the headquarters of disaster countermeasures in Tokyo metropolitan government, related industry associations, other electric power companies and affiliated companies. In the 24 hours from the event, temporary restoration activities are carried out in the power stations, transmission offices, power system offices and remote control offices. Corresponding to the activities, operators switch over from damaged systems to safety ones in the load dispatching offices. After the 24 hours, the restoration of damaged distribution facilities such as cables and utility poles is started in the branch offices and the operators in the load dispatching offices systematically switch over the transmission lines to alternative ones up to the temporary restoration process.

(3) Quantitative model of scenario

A quantitative model of the restoration process is developed based on Decision Making Trial & Evaluation Laboratory (DEMATEL) theory[19),20)] and the feature of the process is analyzed. Adopting the DEMATEL theory, 3 procedures are carried out; 1) abstraction of dominant factors in the frame of a subject problem, 2) clarification of relationships among the factors, 3) development of the adjacent matrix. Figure 3 shows an example of the adjacent matrix. The adjacent matrix is constructed by idealizing a factor as a node and a relationship among the factors as a link. In the case that there is a link from node i to node j, the number of 1 is set in the (i,j) component in the adjacent matrix, and in the case that there is no link from node i to node j, the number of 0 is set in the (i,j) component. Now, the sum of row in the adjacent matrix is set as D and the sum of column as R. D_i means the total number of links that are summed up from node i to others, and R_i means the total number of links that are summed up from others to node i. Then, (D_i+R_i) denotes the index to describe the related level of node i and (D_i-R_i) denotes the influence level of node i on a subject matrix.



j

i	0	1	2	3	4	5	6	D
0	0	1	1	1	0	0	0	3
1	0	0	0	0	0	0	0	0
2	0	0	0	1	0	0	0	1
3	0	0	0	0	1	1	0	2
4	0	0	0	1	0	0	0	1
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
R	0	1	1	3	1	1	0	

Figure 3 Development of the adjacent matrix

In this study, an item in the scenario, which describes the activity in the restoration process, is assumed to be a factor in the DEMATEL theory and the factors abstracted from the scenario are idealized as nodes. In addition, relationships among the factors are categorized into 3 ones; exchange of the related information, human resources and materials associated with the restoration process. The relationships are idealized as links. Figure 4 and Table 2 shows a quantitative model of the scenario in the restoration process of electric power supply systems. Vertical and horizontal axes denote the related level and influence level, respectively. In addition, in Figure 4, the factor of which values of both related and influence levels become high is No.10 that is the development of the restoration plan by the restoration section. The restoration section instructs the branch offices how to manage the restoration process, requests the related materials and staffs to the logistics section, and communicates with power operation section concerning about how to decide the optimal order of the restoration process. The factors of which values of related level become high are No.22 (damage assessment of office buildings and office furnitures by general affairs section), No.18 (confirmation of the safety of staffs by welfare section), No.5 (collecting the related information with the damage of the facilities by information section), No.16 (requesting the materials associated with the restoration process for other electric

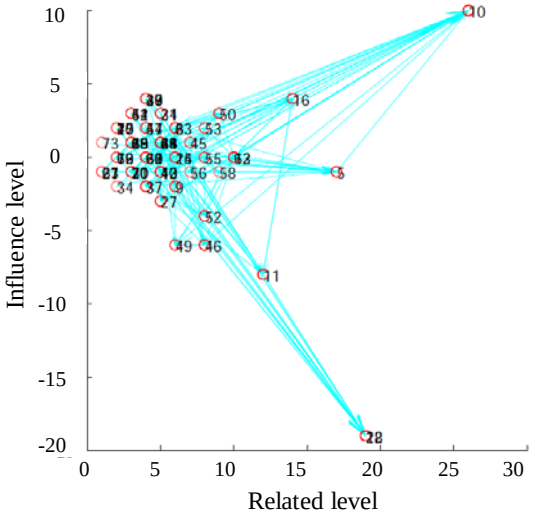


Figure 4 Quantitative model of the scenario in the restoration process of electric power supply systems

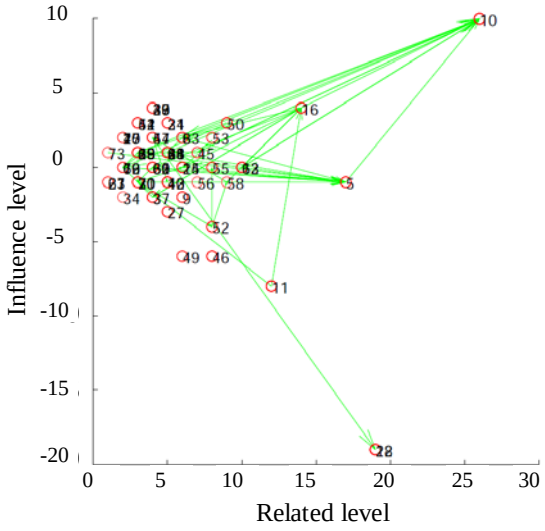


Figure 5 Simplified model

Table 2 Items in the scenario of the restoration of electric power supply systems

No.	Sectors		Activity	R	D	RL	IL
1	Head office	Chairman	Command on the restoration activities	2	1	3	1
2			Play role as an officer to get the related information from Tokyo metropolitan government	1	2	3	-1
3			Request to the self defense force	1	3	4	-2
4		Information Section	Confirm the safety (staffs, facilities)	2	0	2	2
5			Collect & inform the related information	8	9	17	-1
6			Correspond to customers requirments	3	2	5	1
7		Public Infomation Section	Confirm the safety (staffs, facilities)	2	0	2	2
8			Press release	4	2	6	2
9		Restoration Section	Confirm the safety (staffs, facilities)	2	4	6	-2
10			Makie restration plan of affected facilities	18	8	26	10
11			Manage human resources and materials associated with restoration	2	10	12	-8
12		Power operational Section	Confirm the safety (staffs, facilities)	2	3	5	-1
13			Make restration plan for dispatching system	5	5	10	0
14			Request the temporary electoric power supply	3	3	6	0
15		Logistics Section	Confirm the safety (staffs, facilities)	2	0	2	2
16			Request & arrange the materials associated with restoration	9	5	14	4
17		Welfare Section	Confirm the safety (staffs, facilities)	2	0	2	2
18			Confirm the safety (all staffs)	0	19	19	-19
19			Request & arrange the necessaries	1	1	2	0
20		General Affairs Section	Confirm the safety (staffs, facilities)	2	0	2	2
21			Management of heanquarters	0	1	1	-1
22			Check damage of facilities	0	19	19	-19
23			Telephone communication control	0	1	1	-1
24	Branch office		Confirm the safety (staffs, facilities)	4	1	5	3
25			Collect & inform the related information	3	3	6	0
26			Press release	3	2	5	1
27			Restoration of distribution facilities	1	4	5	-3
28	Nuclear powr station		Collect & inform the related information	2	1	3	1
29			Confirm the safety (staffs, facilities)	4	0	4	4
30			Restoration of nuclear power plants	1	2	3	-1
31	Thermal power office		Confirm the safety (staffs, facilities)	4	1	5	3
32			Restoration of thermal power plants	2	2	4	0
33	Construction office		Confirm the safety (staffs, facilities)	4	0	4	4
34			Restoration of facilities	0	2	2	-2
35	Thermal power station		Collect & inform the related information	2	1	3	1
36			Confirm the safety (staffs, facilities)	4	0	4	4
37			Restoration of thermal power plants	1	3	4	-2

No.	Sectors	Activity	R	D	RL	IL
38	Transmission office	Collect the information & emergency responses by operators	3	2	5	1
39		Confirm the safety (staffs, facilities)	4	0	4	4
40		Restoration of transmission offices	2	3	5	-1
41	Remote control & maintenance office	Collect the information & emergency responses by operators	3	2	5	1
42		Confirm the safety (staffs, facilities)	3	0	3	3
43		Restoration of remote control offices	2	3	5	-1
44	Sub office	Confirm the safety (staffs, facilities)	3	1	4	2
45		Customer services	4	3	7	1
46		Restoration of distribution facilities	1	7	8	-6
47	Customers center	Confirm the safety (staffs, facilities)	4	0	4	4
48		Customer services	3	2	5	1
49		Restoration of distribution facilities	0	6	6	-6
50	Central load dispatching office	Collect the information & emergency responses by operators	6	3	9	3
51		Confirm the safety (staffs, facilities)	3	0	3	3
52		Switching over transmission lines	2	6	8	-4
53	System load dispatching office	Collect the information & emergency responses by operators	5	3	8	2
54		Confirm the safety (staffs, facilities)	3	0	3	3
55		Switching over transmission lines	4	4	8	0
56	Branch office of the load dispatching	Collect the information & emergency responses by operators	3	4	7	-1
57		Confirm the safety (staffs, facilities)	3	1	4	2
58		Switching over transmission lines	4	5	9	-1
59	Electric power system council	Confirm system failures	2	1	3	1
60	Central electric power council	Request the human resources & materials associated with restoration activities to the electoric companies	2	2	4	0
61	Conference of the electoric power supply in East area		2	2	4	0
62	Other electric power companies	Dispatch the human resources & materials associated with restoration activities to the electoric companies	5	5	10	0
63	Affiliated companies		4	2	6	2
64	Self defense force		3	2	5	1
65	Headquarters for disaster	Collect and inform the information	2	2	4	0
66	countermeasures of Tokyo	Request to the self defense force	1	1	2	0
67	metropolitan government	Supply stockyard & bases	0	1	1	-1
68	Tokyo fire department	Collect & inform the related information	2	1	3	1
69	Metropolitan police		2	1	3	1
70	local governments		1	2	3	-1
71	Cabinet office, Government of Japan		1	2	3	-1
72	Ministry of Economy, Trade and Industry		1	1	2	0
73	Japan meteorological Agency		1	0	1	1

D : Sum of low, R : Sum of column, RL : Related level, IL: Influence level

companies and so on, and arranging them to the associated sections by logistics section), No.11 (communicating with the sections in which the related human resources and materials with the restoration process are lacked by restoration section). The values of the influence level of No.22 and No.18 become negative, because collecting the related information associated with the restoration process from other sections and branch offices is required to carry out the activities, and they depends strongly on other nodes. The activity of No.5 is frequently involved in exchanging the related information and to summary the situation associated with the damage of facilities and the restoration process. The reason that the values of related level of No.16 and No.11 become high is that the sections associated with No.16 and No.11 frequently exchange the related information with other sectors how to get the materials and how many materials are needed.

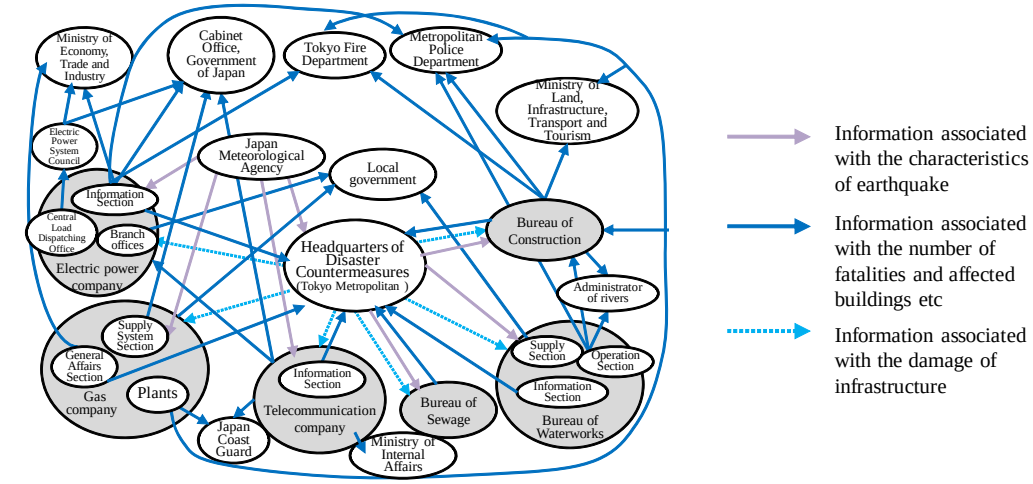
Figure 5 shows the simplified model of Figure 4. To simplify, 1) all combinations of links from node *i* to node *j* are detected, 2) the minimum path sets are detected among the combinations and 3) the number of path sets between the adjacent nodes is summed up and only links of which the number becomes more than 40 is selected. By the procedure, it means the selection of strong connectivity among the subject graph. From Figure 5, the links from No.52(switching over the transmission lines by central load dispatching office) to No.55(switching over by system load dispatching office) and No.58(switching over by branch office of the load dispatching) have strong connectivity in the subject graph. Focusing on the relation between the subject suppliers and other sectors, the links from No.71(collecting the information by Cabinet office, Government of Japan) and No.72(collecting the information by Ministry of Economy, Trade and Industry) to No.5(collecting the information by information section), and from No.70(collecting the information by local governments) to No.25(collecting the information by branch office) have strong connectivity.

4. Analysis of interdependencies in the restoration process of critical infrastructure

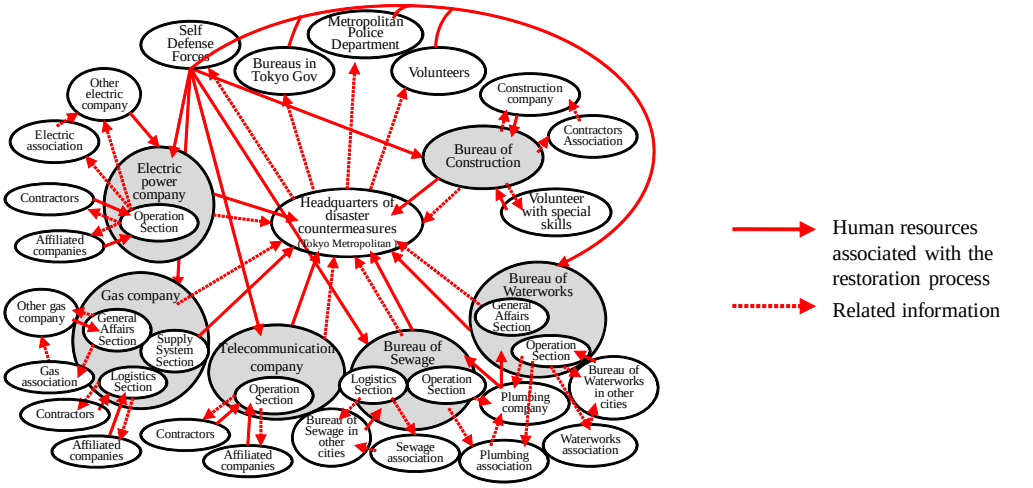
Based on the analysis in chapter 3, the model of interdependencies associated with the restoration process for subject infrastructure suppliers is developed as the qualitative network. In this study, the meanings of interdependencies are categorized into 3 types; competition and share with the related information, human resources and materials in the restoration process.

Figure 6(a) shows the interdependency of the information associated with the characteristics of the subject earthquake and the induced damage. From Figure 6(a), there are the differences in the structure of exchange of the information between private companies (such as electric suppliers, gas suppliers and communication networks suppliers) and public sectors (such as water suppliers, sewage suppliers and road networks managers). The feature of former is that the suppliers give the information associated with their own damage to the headquarters for disaster countermeasures in Tokyo metropolitan government(headquarters in Tokyo metropolitan government), and they receive the information associated with the damage of water treatments and road networks that the headquarters in Tokyo metropolitan government collects. The suppliers in the private companies exchange the information with the related ministries, the government of Japan and related local governments. The feature of latter is that the public sectors exchange the information with the related ministries through the headquarters in Tokyo metropolitan government. On the other hands, water suppliers and road networks managers communicate the information directly concerning about the restoration activities with the traffic administrators, administrators of rivers and the local governments. Electric power suppliers and communication networks suppliers communicate the information concerning about the restoration process of affected utility poles.

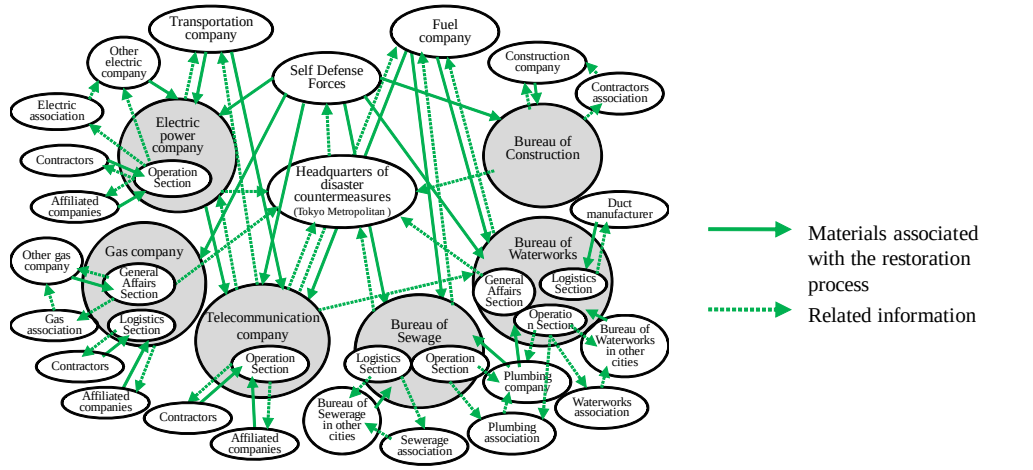
Figure 6(b) shows the interdependency of the human resources associated with the restoration activities and the related information. From Figure 6(b), both private companies and public sectors dispatch the officers to the headquarters in Tokyo metropolitan government. The role of the officers is to get the information associated with the restoration process of other infrastructure from the headquarters in Tokyo metropolitan government and inform their damage and restoration process to the headquarters. The restoration activity by all suppliers after the event is supported by the followed activity of the self defense force which for instance is the remove of debris on the road in an



(a) In terms of the information associated with restoration activities



(b) In terms of the human resources associated with restoration activities



(c) In terms of the materials associated with restoration activities

Figure 6 Interdependency associated with the restoration process

emergency stage. Therefore, the suppliers ask the headquarters in Tokyo metropolitan government to request the dispatch of the self defense force. In terms of the request of the human resources associated with the restoration activities, specific sections of all suppliers ask the related associations, affiliated companies and the contractors to

dispatch the staffs. Water suppliers and sewage suppliers ask the same contractors to dispatch the human resources associated with the restoration of affected ducts. In addition, water suppliers ask the headquarters in Tokyo metropolitan government to arrange the dispatch of the human resources from the bureaus of Tokyo metropolitan government, the metropolitan police department, the self defense force and volunteers registered in the system by Tokyo metropolitan government. The dispatched human resources are engaged in carrying out the temporary water service.

Figure 6(c) shows the interdependency of the materials associated with the restoration activities and the related information. As well as the reason that the suppliers ask the headquarters in Tokyo metropolitan government to request the dispatch of the self defense force, the suppliers ask the headquarters in Tokyo metropolitan government to request the delivery of the materials by the self defense force. Private companies (electric suppliers, gas suppliers and communication networks suppliers) ask the headquarters in Tokyo metropolitan government to secure the stockyard of the materials and the bases of restoration activities. In terms of the request of the materials, specific sections of all suppliers ask the related associations, affiliated companies and contractors to send the materials associated with the restoration activities. Water suppliers and sewage suppliers ask the same contractors to send the materials associated with the restoration of affected ducts as well as the case of the human resources. Electric power suppliers and communication networks suppliers overlap to rent the transportational ways such as tracks, helicopters and ships to bring the materials from the logistics companies. Water suppliers and communication networks suppliers overlap to request the fuels for the use of working the backup generators, to fuel companies. Communication networks suppliers requests to rent the backup generators from the electric power suppliers, and to get the cooling water for the use of working the generators from the water suppliers.

5. Conclusions

In this paper, the scenario of the restoration process associated with critical infrastructure such as electric power supply systems, gas supply systems, water treatments, communication networks and road ones due to a seismic disaster is analyzed. The North Tokyo Bay Earthquake is anticipated for the analysis.

First, the scenario of the restoration process is developed by analyzing the operational plans for disaster prevention offered by the stakeholders associated with subject critical infrastructure distributed in the Tokyo area. The scenario is analyzed based on the DEMATEL theory and modeled as a directed graph describing the related and influence levels. Based on the model of the subject restoration activities on whole restoration process for subject infrastructure, the dominant activities in the restoration process of electric power supply systems are reviewed and the relationship between the activities is classified into 3 categories; exchange of the information, the human resources and the materials associated with the restoration process.

Second, the related interdependency is modeled by selecting the dominant activities with the restoration process based on the simplified network model. In terms of the interdependency of the information associated with the characteristics of the subject earthquake and the induced damage, there are differences in the structure of exchange of the information between private companies and public sectors. In addition, water suppliers and road networks managers communicate the information directly concerning about the restoration activities with the traffic administrators, administrators of rivers and the local governments. Electric power suppliers and communication networks suppliers communicate the information concerning about the restoration process of affected utility poles. In terms of the interdependency of the human resources and materials, both private companies and public sectors dispatch the officers to the headquarters in Tokyo metropolitan government, who get the related information associated with their restoration process. All suppliers ask the headquarters in Tokyo metropolitan government to request the dispatch of the self defense force and to deliver the materials. In addition, private companies ask the headquarters in Tokyo metropolitan government to secure the stockyard of the materials and the bases of restoration activities. Specific sections of all suppliers ask the related associations, affiliated companies and the contractors to dispatch the human resources and materials associated with the

restoration activities. Water suppliers and sewage suppliers ask the same contractors to dispatch the human resources and materials associated with the restoration of affected ducts. Water suppliers ask the headquarters in Tokyo metropolitan government to arrange the dispatch of the human resources from the bureaus of Tokyo metropolitan government, the metropolitan police department, the self defense force and volunteers registered in the system by Tokyo metropolitan government, in order to carry out the temporary water supply. Electric power suppliers and communication networks suppliers overlap to rent the transportational ways and ships to bring the materials from the logistics companies. Water supplier and communication networks supplier overlap to request the fuels working the backup generators, to fuel companies. Communication networks suppliers requests to rent the backup generators from the electric power suppliers, and to get the cooling water for working the generators from the water suppliers.

Acknowledgements

This research was sponsored by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) under a grant as Special Funds for Disaster Prevention and Reduction associated with the anticipated Tokyo Metropolitan Earthquake (leader, Professor H. Hayashi at DPRI, Kyoto University and F. Yamazaki at Chiba University).

Refereces

1) Hoshiya, M. and Miyazaki, M. : Strategy and Prediction of Water Pipeline Restoration from Earthquake Disaster, *Journal of Structural Mechanics and Earthquake Engineering*, Vol.331, pp.45-54, 1983.3

2) Sato, T. and Ichii, K. : Optimization of Post-Earthquake Restoration of Lifeline Networks using Genetic Algorithms, *Journal of Structural Mechanics and Earthquake Engineering*, No.537/I-35, pp.245-256, 1996.4

3) Noda, S. and Nishimura, K. : Questionnaire-based Investigation for Restoration Activities and Earthquake Countermeasures of Lifelines, *Proceedings of the 24th JSCE Earthquake Engineering Symposium*, Vol.2, pp.1201-1204, 1997

4) Hada, Y. and Meguro, K. : Study for Restoration Activities of Lifeline systems in the Kobe Earthquake and the Influence of Obstacle Factors, *Proceedings of the 25th JSCE Earthquake Engineering Symposium*, Vol.2, pp.1077-1080, 1999

5) Nojima, N. and Kameda, H. : Seismic Risk Assessment of Urban Lifelines Under System Interactions, *Journal of Structural Mechanics and Earthquake Engineering*, No.507/I-30, pp.231-241, 1995

6) Okuyama, Y. , Horii, H. and Yamaguchi, K. : Interdependency Analysis: Trend and Issues, *Journal of Shakai-Gijutsu*, Vol.5, pp.197-205, 2008,

7) Eusgeld, I. and Kröger, W. : Comparative Evaluation of Modeling and Simulation Techniques for Interdependent Critical Infrastructures, *International Conference on Probabilistic Safety Assessment and Management*, PSAM9, Hong Kong, China, 2008

8) Expert Examination Committee on Measures for The Tokyo Metropolitan Earthquake, Central Disaster Prevention Council : http://www.bousai.go.jp/jishin/chubou/shutochokka/houkoku.pdf, 2005.7

9) Expert Examination Committee on Measures for The Tokyo Metropolitan Earthquake, Central Disaster Prevention Council : http://www.bousai.go.jp/jishin/chubou/shutochokka/15/shiryou2.pdf, 2005.2

10) The Disaster Prevention Conference, Tokyo Metropolitan Government : http://www.bousai.metro.tokyo.jp/japanese/knowledge/material_h.html, 2006.3

11) Japan Society For Natural Disaster Science : Dictionary of Disaster Terminology, Tsukiji Shokan , 2002

12) The Disaster Prevention Conference, Tokyo Metropolitan Government : Local plan for disaster prevention of Tokyo Metropolitan, 2007,

13) Tokyo Electric Power Company, Inc. : http://www.tepco.co.jp/cc/pressroom/bousai.pdf, 2006.7

14) Bureau of Waterworks Tokyo Metropolitan Government : http://www.waterworks.metro.tokyo.jp/press/h18/press060825.pdf, 2006.6

15) Bureau of Sewerage Tokyo Metropolitan Government : Manual for seismic disaster prevention (temporary restoration version), 1998.8

16) Bureau of Sewerage Tokyo Metropolitan Government : Manual for seismic disaster prevention (preparedness version), 1998.8

17) Tokyo Gas Company, Ltd. : http://www.tokyo-gas.co.jp/safety/bousai.pdf, 2008.4

18) Nippon Telegraph and Telephone Corporation Group : http://www.ntt-east.co.jp/saigai/taisaku/bousai.pdf, 2007.7

19) Terano, T. : Introduction of System Engineering, Kyoritsu Shuppan, 1985

20) R,J. Willson, translated by Nishizeki, T. and Nishizeki, Y. : Introduction of Graph Theory, Kindai Kagakusha, 2001