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ESTIMATION OF TRAFFIC DEMAND OWING TO THE CONSTRAINED LIFE OF EARTHQUAKE DISASTER IN TOKYO

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SUMMARY

To mitigate severe traffic confusion in the aftermath of an earthquake, the transportation management through the use of computer aided system is needful for government's measures. Thus, a evaluation system based on the GIS and road network database has been developing in Tokyo Metropolitan Government. The system, which employs the flow dependent traffic assignment, estimates the maximum road network capacity with variable demand (namely, elastic demand) under any damaged network. Several categories of information, which are obtained from the system, can offer the efficient methods for transportation management.

On the other hand, input data for practical system, such as generation and attraction demand whose volume and characteristics, have not been fully studying as yet. This study analyzed the traffic demand, which is supposed to be produced by the pressure of necessity under the disaster, on the basis of the Earthquake Disaster Scenario in Tokyo. These traffic demand on the earthquake day, at the 2 days later and at the 7 days later are estimated to be 10%, 7% and 21% of usual traffic demand, respectively.

INTRODUCTION

Management toward road transportation system is recently regarded as one of efficient measures against severe traffic confusion in aftermath of an earthquake. It is to be very needful for the management that characteristics of trip after a disaster, such as its purpose, category and volume are recognized in advance. However, even comprehension of its total volume is mostly difficult. We suppose that one of those reasons is a difficulty in accurate or pertinent estimation of traffic demand under highly uncertain situation.

On the other hand, to appraise traffic demand after disaster has significant for not only estimation of damage in government's task but also project to efficient strategies of reconstruction. Besides, it is to be important that a process to recognize the image of damage is indispensable for strategies of restoration.

We have been developing the Disaster Assessment System Against Near Earthquake in Tokyo, which is structured with the GIS and road database. A functional disorder within road transportation system caused by ground disaster such as liquefaction can be evaluated by employing hypocenter and magnitude as a given condition. Road network flow much affected by disaster is assessed by Maximum Road Network Capacity Estimation Method. This method, in short, can evaluate a capable volume to flow in damaged network with variable traffic demand. Integrated model which is combined a deterministic user equilibrium traffic assignment model with a elastic distribution demand estimation model is employed for the system. This procedure to assess a network flow is to be very promising because of two reasons as follows:

(1) It must be considered that consequences of disaster affect generation and distribution of traffic (namely, induced traffic).

(2) Excess demand, which cannot reach its destination, will occur owing to obstructing and/or stopping link.

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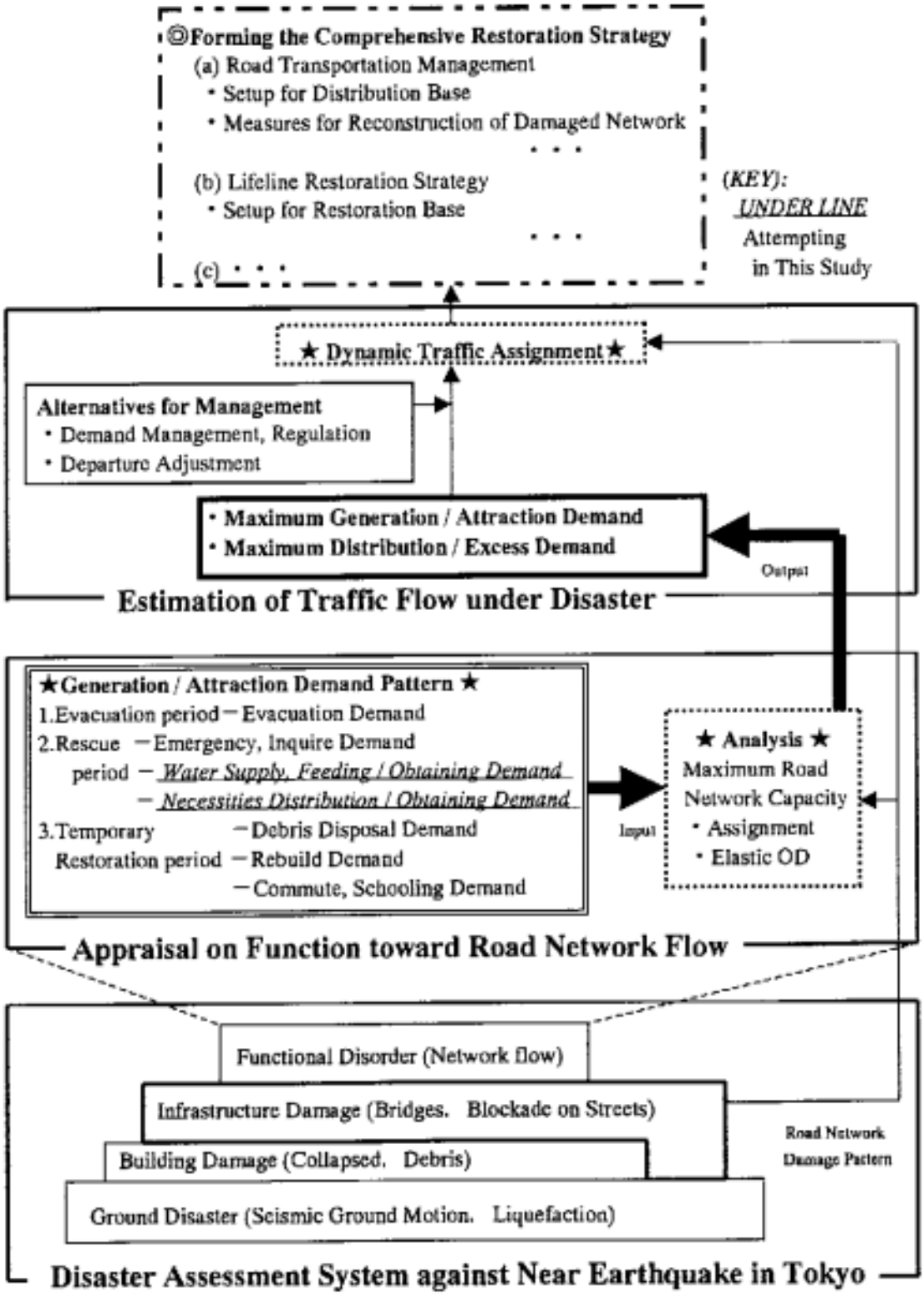

Maximum network flow characterized by maximum generation and/or attraction volume, maximum distribution volume and excess volume is derived from the system. With some alternatives for transportation management and application of a dynamic traffic assignment model, maximum network flow are highly utilized in comprehensive strategies for earthquake disaster. The outline of the system is illustrated in Figure-1. This study estimates the traffic demand as a basic data for the system.

PRESUPPOSITION

Object and Method

The traffic demand of Tokyo-23-ward is estimated on the basis of the Disaster Scenario [Tokyo Metropolitan Government Earthquake Disaster Prevention Committee, 1991(a)] of earthquake which is the same scale as the Kanto Earthquake. The analysis takes damage to water treatment system, shortage of food and insufficiency of the necessities of life into account as the constrained life. This study treats traffic demand caused not only by water service activities and feeding activities but also by activities to obtain food and the necessities of life by dwellers who still live in malfunction houses.

The analysis estimates those demand on the day of earthquake, at the two days later and at the seven days later, respectively.

Estimation method focuses on the number of victims, base unit of several kinds of demand for victims, its commodity weight and carload. The number of victims and base unit of demand are derived from the Disaster Scenario [Committee, 1991(a)]. Commodity weight is counted on several kinds of handbooks. The number of carloads is calculated by employing each the commodity weigh and its base unit on the supposition of transportation channels. Finally, generation / attraction traffic volume are developed from the estimated number of carloads.

Assumption of Victims and Whereabouts

Victims are composed of three categories and every whereabouts of those is composed of four types. Victims and those whereabouts are defined as shown in Table-1. Victims are classified as follows: (1) the poor in commuting; (2) inhabitants in collapsed houses; and (3) dwellers in malfunction houses. Each whereabouts of victims is considered as follows: (a) safety evacuation areas; (b) shelters; (c) outside of stricken area; and (d) own houses.

Tokyo Metropolitan Government coordinates the two-stages-refuge system as a refuge strategy [Tokyo Metropolitan Government Earthquake Disaster Prevention Committee, 1991(b)]. The first stage of this system is that victims temporally evacuate safety evacuation areas. And the second stage is that victims earnestly evacuate shelters with the suitable conduct under confirmation of lower risk against the aftershock. Safety evacuation areas are places where victims temporally take refuge in site on the day of earthquake, and that are managed by Tokyo Metropolitan Government. Shelters are, public schools / community centers, regular evacuation sites on and after the two later days.

The poor in commuting are assumed that the people who are, workers, students and shoppers, supposed not to be able to get home on foot in nine hours on the day of earthquake. Because substitutive transportation means should be only on foot so that usual commuter channels have been damaged by the disaster. It is defined that those whereabouts on the day of earthquake, at the two days later and the seven days later are safety evacuation areas, outside of stricken area and outside of stricken area, respectively. We term those “evacuees” in this study.

Inhabitants of collapsed houses are defined that the people suffered by collapsed and / or burned-out his own houses. They can also not live in own houses. Whereabouts of those may be composed of two types: (1) the one is that whereabouts on the day of earthquake, at the two days later and at the seven days later are safety evacuation areas, outside of stricken area and outside of stricken area, respectively; (2) the other is that on the day of earthquake, at the two days later and the seven days later are safety evacuation areas, shelters and shelters, respectively. This analysis terms, the former “evacuees”, the latter “refugees”.

Dwellers in malfunction houses are defined that the people still live in own houses but suffered by damage to water treatment system/electric power system, by shortage of food and by insufficiency of the necessities of life. Whereabouts of those may be composed of three categories on the basis of questionnaire [Committee, 1991(a)] as to refuge-behavior, which is shown in Table-2: (1) the one is that whereabouts on the day of earthquake, at the two days later and the seven days later are safety evacuation areas, outside of stricken area and outside of stricken area, respectively; (2) the second is that whereabouts on the day of earthquake, at the two days later and the seven days later are safety evacuation areas, shelters and shelters, respectively; (3) the third is that whereabouts are his own houses from the day of earthquake to the seven later days. We call “evacuees”, “refugees” and “non-refugees”, respectively.

Table-1: Definition of Victims and Whereabouts

Categories of Victims	Definition of Terms	Whereabouts		
		On the Day	2 Days Later	7 Days Later
The Poor in Commuting	Evacuees	Safety Evacuation Areas	Outside of Stricken Area	Outside of Stricken Area
Inhabitants in Collapsed Houses	Evacuees	Safety Evacuation Areas	Outside of Stricken Area	Outside of Stricken Area
	Refugees	Safety Evacuation Areas	Shelters	Shelters
Dwellers in Malfunction Houses	Evacuees	Safety Evacuation Areas	Outside of Stricken Area	Outside of Stricken Area
	Refugees	Safety Evacuation Areas	Shelters	Shelters
	Non-Refugees	Own Houses	Own Houses	Own Houses

Table-2: Reply to Questionnaire about Refuge Behavior *

Suspension Patterns of Supply Equipment	Continue to Living in Own Houses	Refuge at Several Weeks After	Refuge at A Week After	Reuge at 2 / 3 Days After	Refuge Immediately After
	(%)	(%)	(%)	(%)	(%)
Water Treatment System Only	25	7	14	37	17
Electric Power System Only	30	8	19	33	10
Both	22	2	9	23	44

* : Source) [Tokyo Metropolitan Earthquake Disaster Prevention Committee,(1991)].

TRAFFIC DEMAND CAUSED BY DAMAGE TO WATER TREATMENT SYSTEM

Water Service toward Refuges

Tokyo Metropolitan Government prepares both forty-two emergency water tanks and six setup-to-be interim water tanks somewhere among one hundred safety evacuation areas [Committee, 1991(b)]. Besides, all the city wards intends to prepare public water tanks at shelters. This study presumes that victims will not be guided into shelters, which are being suspended water supply on and after the two later days. Namely, all refugees will evacuate shelters, which have no difficulties of water service. It is to be assumed that water service activities for victims staying in a certain refuge site will carry out toward both safety evacuation areas without emergency water tank and shelters, which will be prepared water tanks on the earthquake day. The number of population is derived from a rate of the number of prospective refugees to capacity at each safety evacuation area. The estimated population for water service is shown in Table-3.

The base unit of water demand at safety evacuation areas on earthquake day may be defined as 23 *l*/person/day (3 *l* for drinking water plus 20 *l* for miscellaneous use). Since Tokyo Metropolitan Government expects that general channel of water service will originate in either filtration plants (also stations) or water supply stations via water wagons as well as portable tanks / mobile square tanks (water service equipment). So this study assumed that water service activities toward safety evacuation areas without emergency water tank are used by water service equipment, whose unit of carload is either 2 m^3 or 4 m^3 (via water service equipment) and 1 t-volume truck. While activities toward temporary water tanks are supposed to be used by water wagons, whose unit of carload is $2m^3$. Therefore, each of the estimated number of carloads is developed into either generation traffic volume or attraction traffic volume.

Water Service Activities toward Non-Refugees

This analysis focuses on either non-refugees or rear medical facilities as subject of water service activities toward outside refuges.

The number of non-refugees is derived from nighttime population except refugees and evacuees. The base unit of water demand may be defined two types as follows: (1) 60 *l*/person/day (3 *l* for drinking plus 57 *l* for cooking work) except average storage water in common household on earthquake day; (2) 132 *l*/person/day (3 *l* for drinking water, 57 *l* for cooking work, 20 *l* for housework and 52 *l* for miscellaneous use) on and after the two later days. Major channels of water service activities, which are supposed to generate vehicle-trips, are from water filtration plants by water wagons / water service equipment.

The results of questionnaire after the Great-Hanshin earthquake disaster for victims in Ashiya, Hyogo prefecture, conducted by Okumura and Yoshida et al. [Okumura and Yoshida, 1997], is shown in Table-5. Proportion of channels via water wagons for non-refugees' drinking and cooking water is thought of being approximate 10 % on the earthquake day. At the two days later, for drinking and cooking work is thought of being approximate 22 %, for housework is approximate 33 % and for miscellaneous use is approximate 23 %. Similarly, at the seven days later, these are approximate 64 %, 65 %, and 42 %, respectively. This study defined that ratios of major means to obtain water via water wagons by non-refugees are the same as above, and the rest of ratios are through the use of water service equipment. In developing the number of carloads into attraction traffic volume, the analysis defined that channels used by water wagons are 2 m^3 volume truck, and channels used by water service equipment may be composed of three types: volume of 2m^3; volume of 4 m^3; 1 t-volume truck. The estimation results are showing as Table-4.

Table-3: The Number of Victims

Categories of Constrained Life	Victims (also Medical Facilities)	Estimation Period		
		On the Day (persons)	2 Days Later (persons)	7 Days Lat (persor
Damage to Water Treatment System	Refugees *	3,929,609	1,605,021	1,100,03
	Non-Refugees *, **	101,092	147,920	66,78
	Rear Medical Facilities	16,874	24,777	34,49
	Local Hospital	8,446	10,744	15,20
Sub-total		4,056,021	1,788,462	1,216,51
Shortage of Food	Refugees *	3,929,609	1,605,021	1,100,03
	Non-Refugees *	6,275,083	6,722,830	7,227,82
Sub-total		10,204,692	8,327,851	8,327,85
Insufficiency of the Necessities of Life	Refugees *	3,929,609	1,605,021	1,100,03
	Non-Refugees ***	2,765,639	2,975,512	3,205,85
Sub-total		6,695,248	4,580,533	4,305,88

KEY) * : Those are not include evacuees.
** : Those are constrained by damage to water treatment system.
*** : Those are estimated from non-storage ratio of the necessities of life.

Water Service Activities toward Rear Medical Facilities

There are twenty-two approved facilities in city wards of Tokyo. The number of population to have to serve water in rear medical facilities is derived as follows: (1) Average daily inpatients and average daily outpatients in each rear medical facility are calculated from both its number of sickbeds and the total number of sickbeds as well as the number of daily inpatients and daily outpatients within the secondary health medical bloc.; (2) The number of doctors, nurses and other staff are estimated from the number of patients as above (i.e. inpatients and outpatients in each facilities) under Medical law, the 21-th article.; (3) The number of seriously injured patients who are directly transported into rear medical facilities on the earthquake day is estimated from the total number of prospective seriously injured patients and sickbeds within the secondary health medical bloc.; (4) It is likely that seriously injured patients in local hospital, who cannot receive suitable medical treatment owing to damage against water treatment system, are brought into rear medical facilities. Therefore, this study assumes that all seriously injured patients except those who are brought into rear medical facilities are transported on and after the two later days. Daily ratios of transport-to-be patients are defined that at the two days later is 50 %, and the rest is transported during seven days from the earthquake day.

Also, outpatient-ratios in rear medical facilities on usual day to on the earthquake day, to the two days later and to the seven days later are 10 %, 50 % and 100 %, respectively. The number of population in rear medical facilities is estimated in Table-3.

The base unit of water demand for rear medical facilities is defined as constant through the period concerned of this analysis. Each quantity of water is that for inpatients is 75 *l*/person/day by way of

Table-4: Traffic Demand Caused by Damage to Water Treatment System

Categories of Major Channels to Serve / Obtain Water	Unit of Carload (t)	Estimation Period		
		On the Day (vehicles)	2 Days Later (vehicles)	7 Days Later (vehicles)
Water Filtration Plant to Safety Evacuation Area * (Into Temporary Water Tank)	2	198	0	0
Water Filtration Plant to Safety Evacuation Area * (Without Emergency Water Tank)	2	2,181	0	0
	4	262	0	0
	1	3,484	0	0
Water Filtration Plant to Shelter *	4	0	646	1,038
Non-Refugees **	1	1,784	3,080	3,455
Water Filtration Plant to Water Wagon *	2	309	1,953	2,128
Water Filtration Plant to Portable Tank * (Water Service Equipment)	2	1,268	2,891	13,447
	4	174	395	1,766
	1	2,204	5,063	24,845
Water Filtration Plant to Rear Medical Facilities *	4	355	425	517
Local Hospital **	1	656	560	682
Total		12,875	15,013	47,878

KEY) * : Trip Attraction
** : Trip Generation

drinking, household affairs and miscellaneous use, for seriously injured patients is 153 *l*/person/day by way of medical treatment use and drinking, for outpatients is half of 55 *l*/person/day by way of drinking and miscellaneous use. Tokyo Metropolitan Government both plans to put water service activities into practice with request from rear medical facilities and expects that those activities use water wagons or water service equipment via water filtration plants. Considering the number of rear medical facilities and base unit of water demand, this study assumes that all of water service activities are carried out by 4 m^3 water wagons, whose the number of carloads is developed into attraction traffic volume. The estimation results are shown in Table-4.

Table-5: Major Channel Rates to Obtain Water for Non-Refugees

Categories of Major Channels	Usage : Base unit of Demand ** (liter)	On the Day rate	2 Days Later rate	7 Days Later rate
Total Demand of Water ***	Drinking and Cooking : (3+57)	1.00	0.87	0.98
	Housework : 20	0.60	0.75	0.77
	Miscellaneous Use : 52	0.87	0.82	0.72
Water Wagon	Drinking and Cooking : (3+57)	0.10	0.22	0.64
	Housework : 20	0.00	0.33	0.65
	Miscellaneous Use : 52	0.00	0.23	0.42
Water Service Equipment	Drinking and Cooking : (3+57)	0.90	0.78	0.36
	Housework : 20	1.00	0.67	0.35
	Miscellaneous Use : 52	1.00	0.77	0.58

KEY) * : This is derived from [Okumura et al.,(1997)]
** : Those are usual water demand in Tokyo
*** : Those are not include well water.

Table-6: Average Daily Trip-Rates and Vehicle-Trip Rates ***

Average Daily Trip-Rates / Categories		On the Day	2 Days Later	7 Days Later
Damage to Water Treatment System *	(trips/person/day)	0.230	0.347	0.880
Shortage of Food *	(trips/person/day)	0.210	0.217	0.530
Insufficiency of the Necessities of Life *	(trips/person/day)	0.080	0.137	0.222
Vehicle-Trip Rates **	(rate)	0.339	0.254	0.255

KEY) * : Those are non-Refugees'.
** : People who have auto-ownership and vehicle is treated
*** : This is derived from [Kato et al.,(1997)] and [Odani et al.,(1997)]

Activities to Obtain Water by Non-Refugees

It is to be supposed that major channels of activities to obtain water through the use of auto by non-refugees are either from water service bases (i.e. water filtration plants, emergency water tanks and public water tanks) or from water service terminals (i.e. water service equipment). Considering the results of questionnaire after the Great-Hanshin earthquake disaster conducted by Kato et al. [Kato, Ajisawa, Ieda and Hayashi, 1997] and by Odani et al. [Odani, Matsumoto, Sako and Imai, 1997], average daily trip-rates to obtain water by non-refugees are to be regarded as showing in Table-6. Average daily trip-rates multiplied by vehicle-trip rates makes average daily trips used by car. Hence, average daily trips multiplied by the number of non-refugees can yield total number of trips to obtain water. Also, non-refugees, living in Tokyo, have auto-ownership and vehicle. The estimation results are shown in Table-4.

Activities to Obtain Water by Local Hospital

The victims in need of water in local hospital are estimated as same as above process of rear medical facilities. Since only seriously injured patients in local hospital are supposed to be transported into rear medical facilities on and after the two later days, this study deduced the number of transport-to-be patients from the prospective population. The results are shown in Table-3.

The base unit of water demand for those people is the same as the case of rear medical facilities. Channels to obtain water are, as the same case of non-refugees, defined as via water service bases and water service terminals. Taking account of being medical facilities, it is to be supposed that all the trips for demands is used by either auto or truck. This study develops the number of carloads into generation traffic volume under the assumption of that every trip is used by 1 m^3-volume truck. The estimation results are shown in Table-4.

TRAFFIC DEMAND CAUSED BY SHORTAGE OF FOODS

Feeding Activities for refugees

The standard feeding activities for refugees till the two later days is to release his emergency food being stored by city wards. Tokyo Metropolitan Government either intends to distribute his own storing food or to procure food from traders by contract in case of insufficiency of a certain city ward's storing food. Tokyo Metropolitan

Government coordinates to distribute boiled rice foods, side dishes and perishable foods (also including procurement foods from the traders) for refugees after the three later days. As more than 12,660 thousand meals are secured by all city wards and Tokyo Metropolitan Government, these are equivalent to two-day supply provided that refugees are estimated as 2,110 thousand. This study evaluates traffic demand as to transportation of rice, side dishes and perishable foods after the three later days as well as transportation of emergency foods and procurement foods till the two later days of the earthquake day. The number of population to be distributed is shown in Table-3.

Major channels of those activities are composed of four types as follows: these are (1) from storehouses (managed by city wards) to shelters; (2) from warehouses (managed by Tokyo) to safety evacuation areas; (3) from traders to shelters (also safety evacuation areas); (4) from outside of stricken area to shelters (also safety evacuation areas). Each channel, except from storehouses to shelters, are needed to transship several kinds of food at inner transportation stations, goods bases and transportation bases (distribution bases). This study treats channels (1) to (3). The number of carloads is estimated on the basis of the number of refugees, base unit of demand for food and each weight. The number of carloads also means the total flow volume. Taking account of that safety evacuation areas (also shelters) will be destination of transportation, terminal transportation (trip-end is refuge sites) is assumed to being used by 1 t volume truck. Storage facilities into distribution bases (trip-end is a distribution bases) are assumed to being used by 4 t volume truck. The results are shown in Table-7.

Non-refugees' activities to obtain foods

According to the questionnaire about storing food for common household in Tokyo, the number of self-supportable days with storage food is approximate 5.3 days. To allow the results, it is to be supposed that traffic demand caused by obtaining food by non-refugees will not occur or little. However, it is to be unlikely that the situation like this will rarely come into existence after severe disaster. It is highly proper that whatever sufficient storage food non-refugees have, they will not be able to cook with lifeline damaged. So this study focuses on non-refugees' activities. The subject of population is derived from nighttime population except refugees and evacuees. The analysis, defined those traffic demand as same as demand to obtain water, estimated traffic demand to obtain food by non-refugees on the basis of both the number of average daily trip-rates and vehicle-trip rates (which are also shown in Table-6). The estimated results are shown in Table-7.

Table-7: Traffic Demand Caused by Shortage of Food

Categories of Major Channels of Feeding Activities / to Obtain Food	Unit of Carload (t)	Estimation Period		
		On the Day (vehicles)	2 Days Later (vehicles)	7 Days Later (vehicles)
Storehouse to Safety Evacuation Area *	1	260	0	0
to Shelter *	1	0	167	18
Warehouse to Distribution Base *	4	73	42	12
The Traders to Distribution Base *	4	106	70	544
Distribution Base to Safety Evacuation Areas *	1	553	0	0
to Shelter *	1	0	331	1,823
Non-Refugees **	1	102,430	74,376	223,130
Total		103,422	74,986	225,527

KEY) * : Trip Attraction
** : Trip Generation

Table-8: Traffic Demand Caused by Insufficiency of the Necessities of Life

Categories of Major Channels to Distribute / Obtain the Necessities of Life	Unit of Carload (t)	Estimation Period		
		On the Day (vehicles)	2 Days Later (vehicles)	7 Days Later (vehicles)
Storehouse to Safety Evacuation Area *	1	1,442	0	0
to Shelter *	1	0	51	28
Warehouse to Distribution Base *	4	1,310	28	25
The Traders to Distribution Base *	4	6,146	1,878	297
Distribution Base to Safety Evacuation Areas *	1	29,150	0	0
to Shelter *	1	0	7,084	845
Non-Refugees **	1	17,784	24,535	42,857
Total		55,832	33,576	44,052

KEY) * : Trip Attraction
** : Trip Generation

TRAFFIC DEMAND CAUSED BY INSUFFICIENCY OF THE NECESSITIES OF LIFE

Distribution of the necessities of life toward refuges

The standard distribution of the necessities of life to refuges is provided by city ward. They release their own storing necessities as the same case of feeding activities. Tokyo Metropolitan Government designs either to release or to procure necessities with the request of a certain city ward under the case of insufficiency. The number of population to be distributed is shown in Table-3.

Transportation channels are the same case of feeding activities. The number of carloads as the total flow volume is estimated on the basis of the base unit of demand, its weight and the number of population. In developing the number of carloads into attraction traffic volume, it is to be assumed as the same process of food distribution that the terminal transportation is used by 1 t-volume truck and transportation toward distribution bases is used by 4 t-volume truck. The results are shown in Table-8.

Non-refugees' activities to obtain the necessities of life

Tokyo Metropolitan Government Earthquake Disaster Prevention Committee executed questionnaire about circumstances of storing the necessities of life to common household in Tokyo. These results (non-stock rate of the necessities of life) are employed in estimating the number of constrained population (which is shown in Table-3). Generation traffic volume is estimated as the same process of demand to obtain water caused by non-refugees. The results are shown in Table-8.

CONCLUSION

Estimated total traffic demand is shown in Tabel-9. Results of this analysis are summarized as follows:

Table-9: Total Demand Caused by Constrained Life

Categories of Constrained Life	Estimation Period		
	On the Day	2 Days Later	7 Days Later
	(vehicles)	(vehicles)	(vehicles)
Damage to Water Treatment System	12,875	15,013	47,878
Shortage of Food	103,422	74,986	225,527
Insufficiency of the Necessities of Life	55,832	33,576	44,052
Total	172,129	123,575	317,457

(1) Total traffic demand owing to the constrained life on the day of earthquake, at the two days later and at the seven days later are 170,000 vehicles / day, 120,000 vehicles / day and 310,000 vehicles / day, respectively.

(2) The traffic demand caused by damage to water treatment system is on upward trend form the day of earthquake to the seven days later. The traffic demand owing to shortage of food and insufficiency of the necessities of life decrease at the two days later. Then the later is on upward trend.

(3) Approximate 60 % of estimated the total traffic demand is caused by food obtaining activity. This activity is derived from non-refugees.

(4) The demand on the day of earthquake, at the two days later and at the seven days later are respectively equivalent to 10 %, 7 % and 21 % of the usual OD traffic demand on the assumption of that those traffic demand are round-trips.

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