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THE LOSS EVALUATION OF EMERGENCY MEDICAL TREATMENT FUNCTION AND NETWORK OF EMERGENCY HOSPITALS

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SUMMARY

It is necessary that future earthquake disaster mitigation plans depend upon the evaluation of the loss of urban functions that play an important roll for lives of residents in town. In other words, the paradigm changes from the evaluation of fragility of urban structures to the evaluation of fragility of urban functions for living in a urban community. The simulation analysis of the evaluation of the loss of medical treatment function during earthquake was presented to serve as an example to make clear the importance of the consideration of urban function. To simulate the loss of emergency medical treatment function, triage, treatment, and transportation of patients relation was modeled, considering the network of emergency hospitals.

INTRODUCTION

Earthquake research to date has focused on damage to buildings, civil engineering structures and utility lines. It has mainly consisted of evaluating physical damage to urban structures from earthquakes and related fires, and on using these evaluations to estimate financial losses and plan earthquake-proofing measures and other disaster prevention plans. However, viewed by the life of its citizens, a city is a structure made meaningful only by the functions derived from its physical structures and the active interactions among these functions. Before urban earthquake disaster prevention measures can be created, there is a need to clearly define the basic concepts of earthquake crisis management. These basic concepts should start with analysis of damage to city structures, and cover damage to the interactions between city functions ("damage modes"), and damage severity evaluations. There is a need for a paradigm shift away from evaluations of weaknesses in urban structures, toward evaluations of weaknesses in urban functions.
The following sections discuss the simulation we used to evaluate hypothetical earthquake damage to medical functions, and the analysis results generated by our simulation. We overview impairment to one city function (medical services) to examine the effects of earthquakes in cities. Through this discussions, the emergency and disaster medical treatment support system was proposed for mitigating the loss of medical treatment function to save residents from widely spread natural and social disasters.

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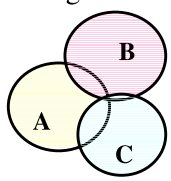
EVALUATING EARTHQUAKE DAMAGE TO MEDICAL FUNCTIONS; EMERGENCY MEDICAL NETWORKS

By disabling medical facilities, utility lines, and communication equipment, the Great Hanshin-Awaji Earthquake of 1995 caused major damage to the area's medical functions. Along with damage to medical facilities, interruptions in utilities such as water and power resulted in the shutdown of life-saving medical services such as Intensive Care Units, surgery and dialysis treatment. Figure 1 is a Venn diagram showing each type of damage.

$$\text{Damage to medical functions} = A \cup B \cup C, \qquad \text{---- (1)}$$

where A is damage to medical facilities, B is the interruption of power, and C is the interruption of water. Any one of these items can damage medical functions and interrupt the supply of medical services.



A : Damage of Medical Facilities
B : Damage of Electricity Supply
C : Damage of Water Supply
D : Loss of Medical Treatment Function
D = A U B U C

Figure 1. Venn Diagram of Loss of Medical Treatment

The severity of the damage to medical facilities in the disaster area cannot be evaluated just by considering item A, B or C alone. Since this paper examines damage to medical functions, damage to medical facilities must be broken down into damage to facilities for each function (such as surgery or dialysis). For example, disaster victims needing surgery must go to a hospital with an operating room, while those needing dialysis must go to a hospital with a kidney machine.

Figure 2 shows the flow of medical services during a disaster, when the three types of damage in Figure 1 have occurred. As shown, one of the major problems for emergency medical services is transportation of victims. In major earthquakes such as the Great Hanshin-Awaji Earthquake of 1995 and the Great Kanto Earthquake of 1923, cooperation among medical services within the affected area and surrounding areas is crucial. To achieve this cooperation, it is vital to create a network among emergency medical facilities, and a model to simulate the process of triage, treatment and transportation among network members. This model should be used to shed light on possible numbers of victims that will require treatment, and to create plans to deal with them.

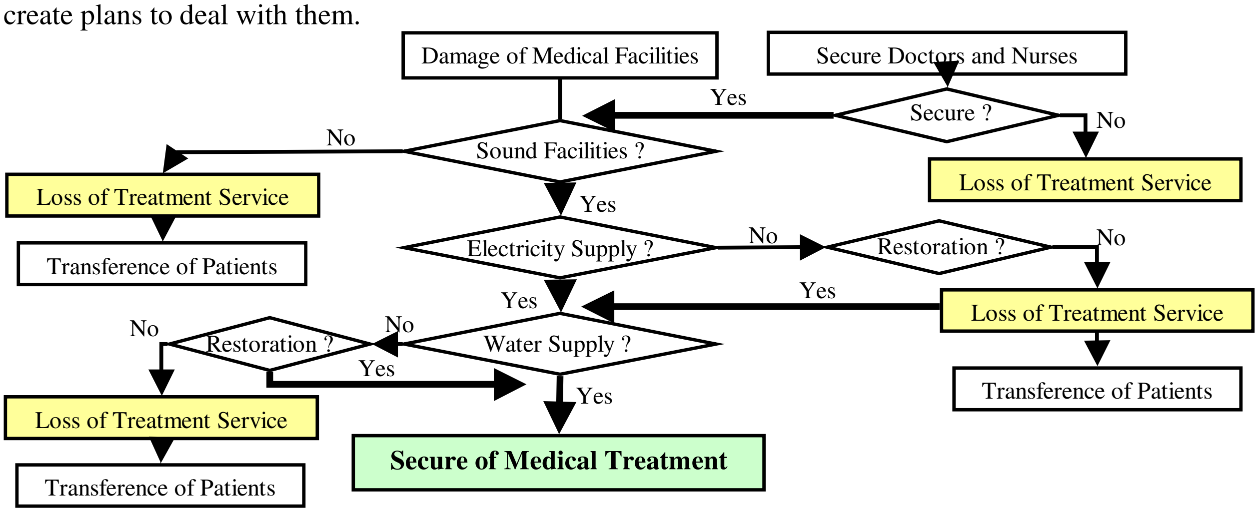


Figure 2. The Flow of Responses for the Loss of Medical Treatment

MODEL FOR EMERGENCY MEDICAL TREATMENT PROCESS-TRIAGE, TREATMENT AND TRANSPORTATION-

When the normal hospital network is damaged by an earthquake, the network of emergency medical treatment facilities must be rebuilt around the intact facilities. Figure 3 shows the conceptual model of this process. Included in this model is a No. 2 hospital with medical services interrupted for a limited amount of time directly after the earthquake, and restored when power or water was restored.

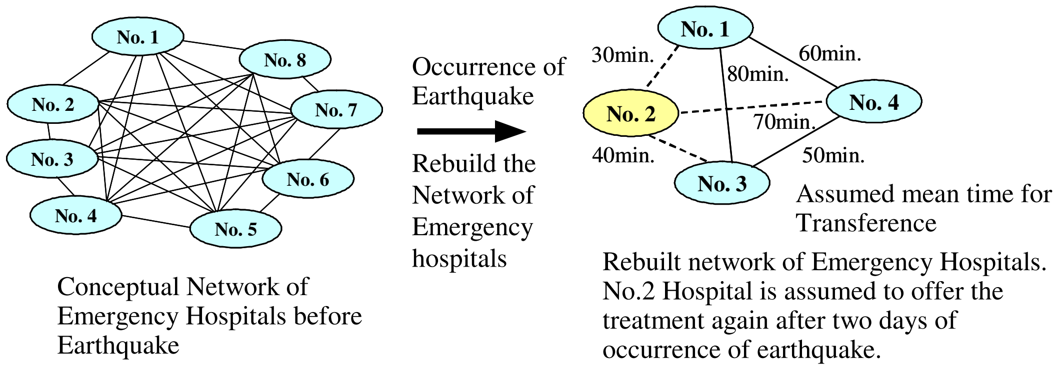


Figure 3. The General Idea of a Reconstruction of Network of Emergency hospitals for Patients after the Occurrence of Earthquake

In this model, facilities with supplies of emergency power or medical water that can maintain medical functions are treated as facilities with intact medical functions. In this example, three hospitals, No. 1, No. 3, and No. 4, have intact medical functions after the earthquake, while one hospital, No. 2, suffers damage to utility lines and has medical functions restored two days later. In the model we created, the condition of each hospital and each numerical value can be set to any value.

Figure 4 is a conceptual diagram illustrating the fundamental medical treatment process of each hospitals-triage, treatment and transportation of earthquake victims (the "3T model"). Our model incorporates five patient types: (1) critically injured patients (not needing surgery), (2) critically injured patients (needing surgery), (3) patients needing dialysis, (4) seriously ill patients, and (5) patients with minor injuries, according to the report on 1995 Hanshin Awaji Earthquake. But these patient types enable any number to be set. Each type of patient arrives at hospitals in each area at random, starting immediately after the earthquake.

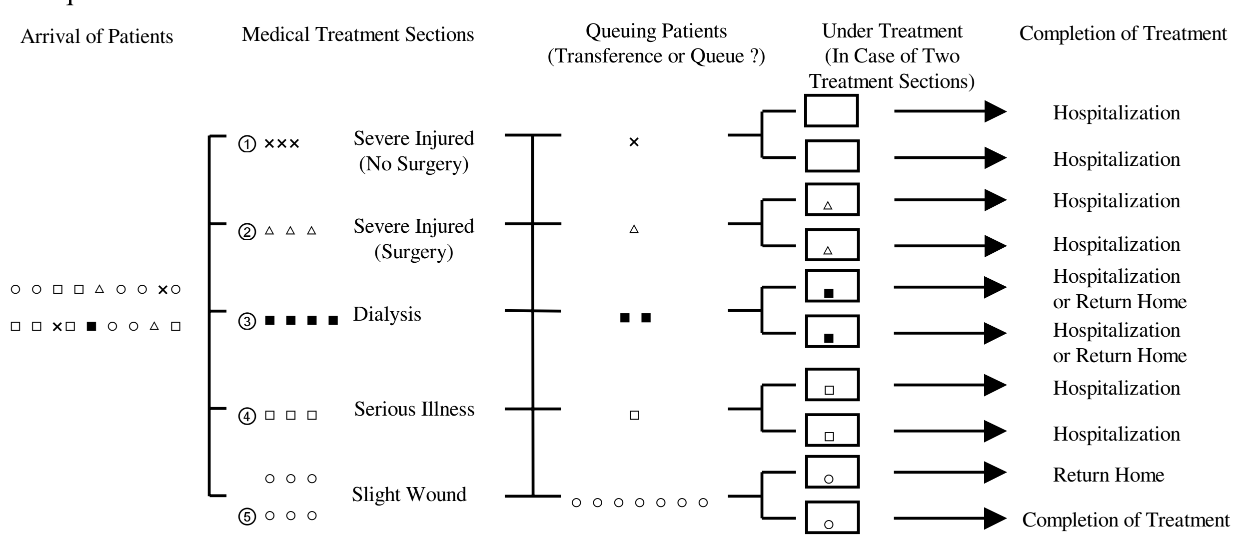


Figure 4. The Model of Triage-Treatment-Transportation of Patients (3T Model)

These patients are sorted into categories (1) to (5) and allocated to the corresponding treatment section. The arrival of patients at treatment sections is different for each hospital and section, and the model also incorporates differences in the arrival process with the passage of time (first/second/third day of disaster), reflecting the situation after the 1995 Hanshin Awaji Earthquake.

The example in Figure 4 shows two treatment sections for each hospital, but the model enables any number to be set, with independent treatment sections for each type of patient. Patients must wait if they arrive while the treatment section they require is busy. The model is designed to transfer waiting patients among hospitals in the network. Each waiting patient is transferred to another hospital if the transfer will result in faster treatment for that patient. So, the model is designed to check the number of patients waiting at other hospitals periodically.

Arbitrary values have been used for the amount of time needed to transport patients between each set of hospitals, but if a specific area is input into the model, transport times can be set based on the area's set emergency routes.

Since the amount of treatment time required by each patient is likely to be random according to each case, the model uses random distributions of treatment times (normal logarithmic distribution, exponential distribution and constant distribution, etc.). These treatment times of each patient types have been investigated statistically by Kobe University (Prof. N. Ishii). Patients with minor injuries are never transferred.

When a patient has finished receiving treatment, the model determines whether they should be admitted to that hospital or sent home (based on patient type), and uses the cumulative admitted patient total to calculate the number of beds required. The number of patients waiting is calculated over time and used to determine whether the status is acceptable. Critically injured patients, patients needing dialysis or seriously ill patients face a life-threatening situation if kept waiting for a long time. To save lives, long waiting times are not permissible. If waiting times become too long, the number of treatment sections or network hospitals must be increased.

The results of our simulation can be used to help set hospital treatment section capacities, numbers of hospitals in networks, and boundaries of hospital network regions, based on a given acceptable risk level or set risk level.

SIMULATION RESULTS

Table 1 shows the average (hypothetical) value of the distribution of arrival times and treatment for each type of patient at network hospitals. Arrival times of patients at treatment sections have an exponential distribution with the average value given in Table 1.

Figure 5 shows the comparison of statistical data of patients arrived at hospital attached to Kobe University and numerical results obtained by using exponential distribution for arrived patients during 1995 Great Hanshin Awaji Earthquake. Both of them are seemed to be in good agreement.

Treatment times have a normal logarithmic distribution here. In an example, hospital No. 2 stopped providing medical functions on the day of the disaster and the next day due to a utility line shutdown, and resumed providing treatment on the third day. The average number of patients arriving at hospital Nos. 1 and 3 is the same, but since arriving patients were represented by random numbers generated independently for each, the results are different for each hospital. The number of patients arriving at hospital No. 4 was set slightly lower. Hospital Nos. 1 and 3 represent hospitals located in an area of severe earthquake damage, while hospital No. 4 represents a hospital in an area of less damage.

Table 1. The Parameters of Simulation for the Model of Arrival - Treatment -Transportation of Patients

1. Severe Iniured(No Surgery)				
	Hospital(H)	That Day	Second Day	Third Day
Mean Interval of Arrival Time in Min. (Exponential Distribution)	No.1	30 min./person	45 min./person	60 min./person
	No.2	out of service	out of service	120 min./person
	No.3	30 min./person	45 tnin./person	60 min./person
	No.4	60 min./person	90 min./person	120 min/person
Mean Treatment Time for a patient (Log-normal Distribution)	No.1	30 min./person	30 min./person	30 min./person
	No.2	out of service	out of service	30 min./person
	No.3	30 min./oerson	30 min./person	30 min./oerson
	No.4	30 min./person	30 min./person	30 min./person
Number of Treatment Sections		2,(3,4,5, 10)		
2. Sever Injured (Surgery)				
Mean Interval of Arrival Time in Min. (Exponential Distribution)	No.1	30 min./person	45 min./person	60 min./person
	No.2	out of service	out of service	120 min./person
	No.3	30 min./person	45 min./person	60 min./person
	No.4	60 min./person	90 min./person	120 min./person
Mean Treatment Time for a patient (Log-normal Distribution)	No.1	60 min./person	60 min./person	60 min./person
	No.2	out of service	out of service	60 min./person
	No.3	60 min./person	60 min./person	60 min./person
	No.4	60 min./person	60 min./person	60 min./person
Number of Treatment Sections		2,(3,4,5, 10)		
3. Dialysis				
Mean Interval of Arrival Time in Min. (Exponential Distribution)	No.1	30 min./person	45 min./person	120 min./person
	No.2	out of service	out of service	120 min./person
	No.3	30 min/person	45 min./person	120 min./person
	No.4	60 min./person	90 min./person	120 min./person
Mean Treatment Time for a patient (Log-normal Distribution)	No.1	180 min. /person(const)	180 min./person(const)	180 min./person(const)
	No.2	out of service	out of service	180 min./person(const)
	No.3	180 mm./person(const	180 min./person(const	180 min./person(const)
	No.4	180 min./person(const	180 min./person(const	180 min./person(const)
Number of Treatment Sections		2,(3,4,5, 10)		
4. Serious Illness				
Mean Interval of Arrival Time in Min. (Exponential Distribution)	No.1	30 min./person	45 min./person	120 min./person
	No.2	out of service	out of service	120 min./person
	No.3	30 min./person	45 min./person	120 min./person
	No.4	60 min./person	90 min./person	120 min./person
Mean Treatment Time for a patient (Log-normal Distribution)	No.1	20 min./person	20 min./person	20 min./person
	No.2	out of service	out of service	20 min. /person
	No.3	20 min./person	20 min./person	20 min./person
	No.4	20 min./person	20 min./person	20 min./person
Number of Treatment Sections		2,(3,4,5, 10)		
5. Slight Wound				
Mean Interval of Arrival Time in Min. (Exponential D istribution)	No.1	10 min./person	20 min./person	60 min./person
	No.2	out of service	out of service	60 min./person
	No.3	10 min./person	20 min./person	60 min./person
	No.4	20 min./person	40 min./person	60 min./person
Mean Treatment Time for a patient (Log-normal Distribution)	No.1	15 min./person	15 min./person	15 min./person
	No.2	out of service	out of service	15 min./person
	No.3	15 min./person	15 min./person	15 min./person
	No.4	15 min./person	1 5 min./person	15 min./person
Number of Treatment Sections		2,(3, 4, 5,10)		

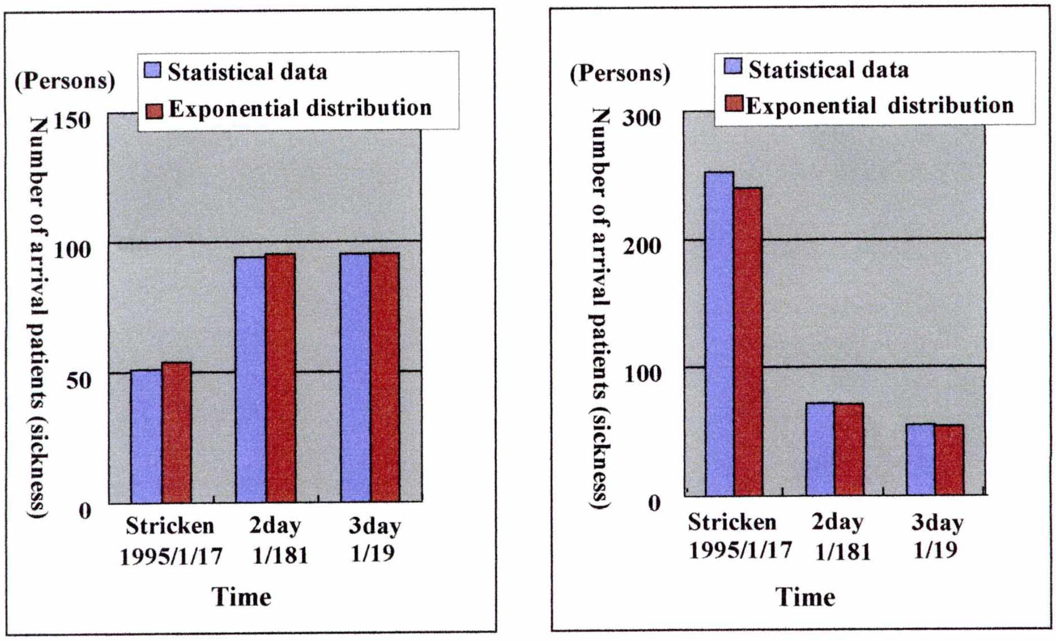
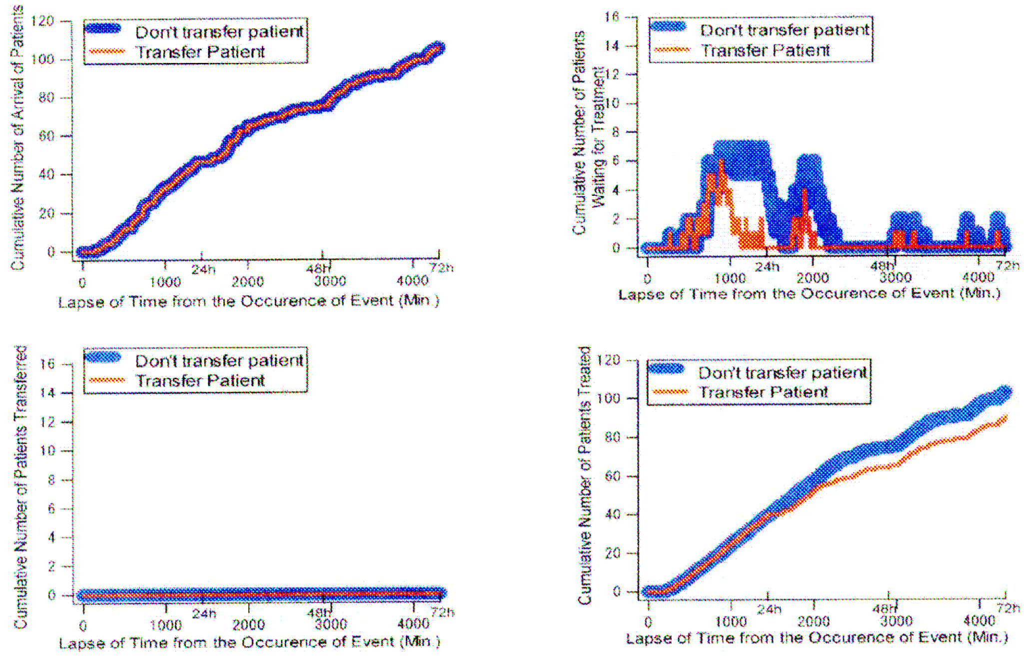


Figure 5. Patients of Sickness and Injury, During 1995 Hansin-Awaji Great-earthquake (Hospital attached to Kobe University)

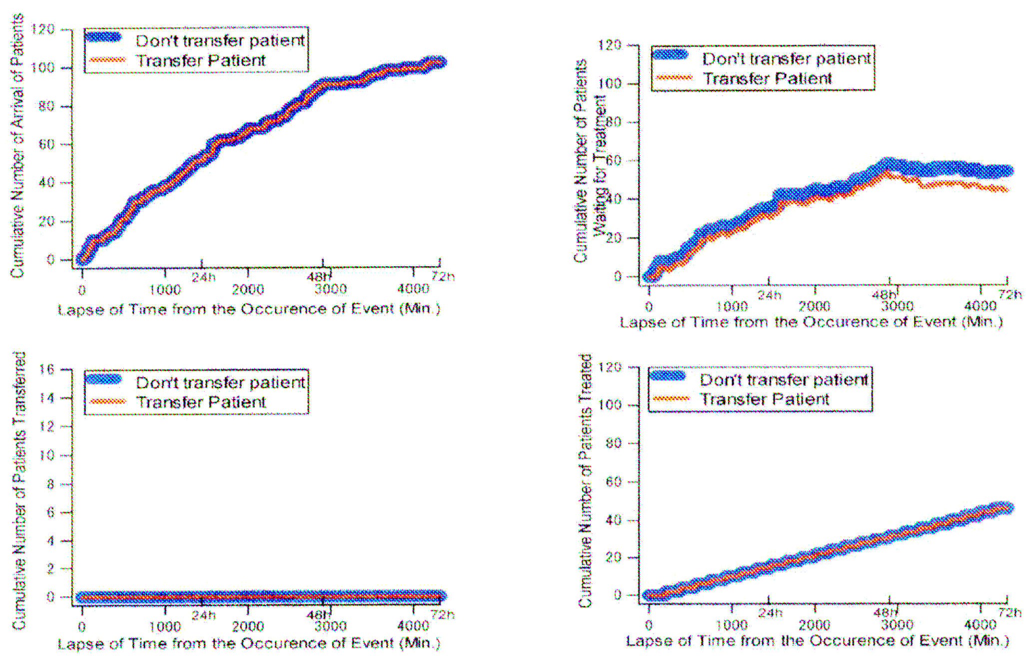
Figures 6(a) to 6(e)) show the examples of the results of the simulation. Figure (6-a) shows the case of hospital No. 1 (H1), two treatment sections, G2 , and patient type L-2 (critically injured patients (needing surgery)). The simulation covers a three-day period starting with the day of the disaster. We used three days as the critical number of days for emergency medical treatment, but the number of days can be set to any value. The upper and left-hand side shows the cumulative number of arrived patients at the L2 treatment section for three days. The upper right-hand side shows the cumulative number of waiting patients at treatment section over time. The results with and without patient transfer enabled are shown in overlay. For patients needing surgery (L2), the waiting list for critically injured patients needing surgery (L2) rises to only one patient several times after around 4.000minutes (2.7 days) after earthquake occurrence for arriving patients. The lower and left-hand side shows the cumulative number of patients transferred from other networked hospitals to hospital No. 1. Unfortunately, No. 1 hospital (H1) could not accept any number of patients from other hospitals, because this hospital has many patients injured around hospital No. 1. The lower and right-hand side shows the cumulative number of patients of L2 patient type treated by No. 1 hospital over time. From this result the required number of beds are forecasted.

Figures 6(b), 6(c), 6(d), and 6(e), also show (1) the cases of hospital No 1 (H1), two treatment sections G2, and patients type L3 (needing dialysis), (2) the case of hospital No l , five treatment sections G5, and patient type L3, (3) the case of hospital No. l , ten treatment sections G10, and patient type L3, and (4) the case of hospital No. 2, two treatment sections G2, and patient type L3, respectively. No. 2 (H2) hospital resumed medical operations on the third day after the earthquake occurrence. For patients needing dialysis, the treatment time is long (three hours), and the waiting list become long. It is clear from Figure 6(e) that the hospital which lost two-day's medical operation (hospital No. 2 case) had no effective activity for medical treatment activities among network hospitals.



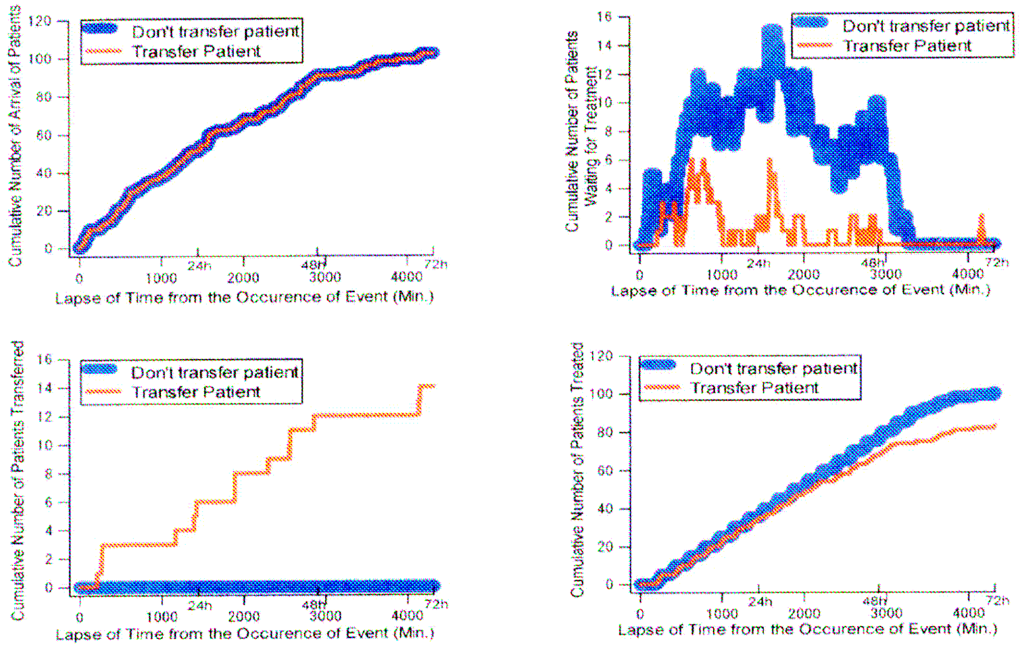
(a) H1G2L2

Figure 6.(a~b) The Example of Simulations. In each Figures, the upper Left-hand Side is the cumulative Number of Patients arrived at each Treatment Sections. The upper Right-hand Side is the Cumulative Number of Waiting Patients. The lower Left-hand Side is the cumulative Number of Patients transferred the Hospital.
The lower Right-hand Side is the cumulative Number of Patients treated.
(H1, H2 indicate the Hospital No. 1 and No. 2 ,G2,G5,G10 indicate the Number of Treatment Sections. L2, L3 indicate the Patient Types)



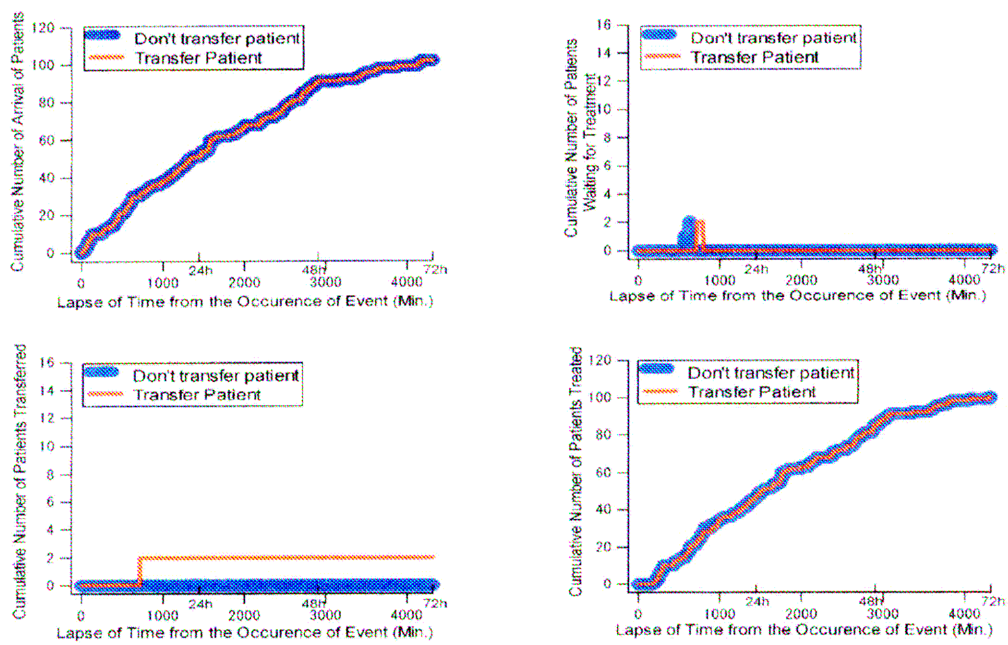
(b) H1G2L3

Figure 6(b). continued



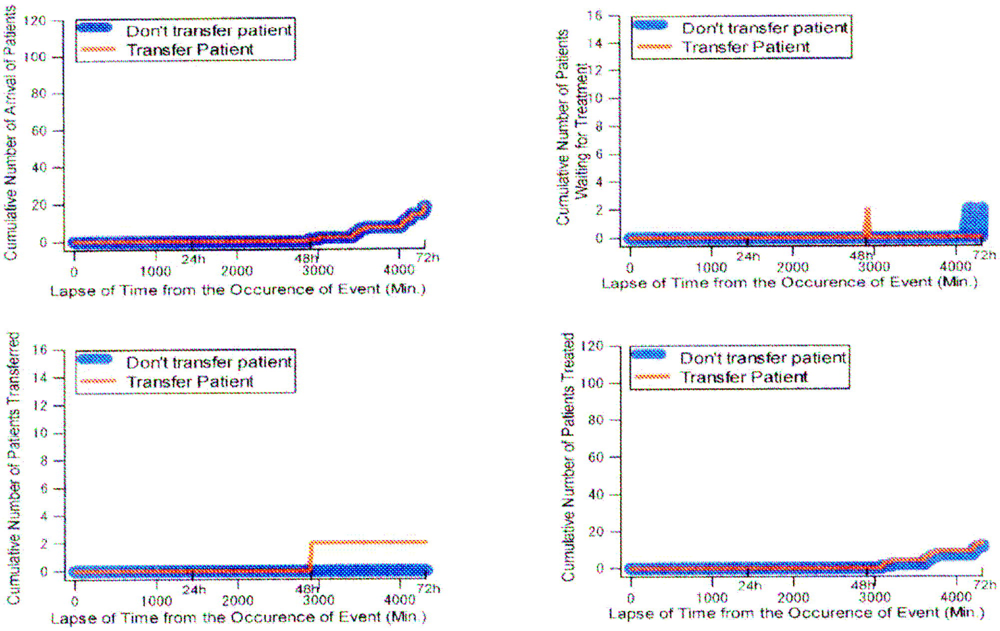
(c) H1G5L3

Figure 6(c). continued



(d) H1G10L3

Figure 6(d). continued



(e) H2G2L3

Figure 6(e). continued

THE DESIGN OF NETWORK OF HOSPITALS

Figure 7 shows the hierarchical network system of hospitals. The fundamental medical networks unit will be built in each municipalities in Japan. So, the base hospitals for disaster medical treatments in the municipalities will be networked with a management control center. The number of patients arrived at each hospitals are counted and send its data from each network hospitals to the center by using some wireless communications or some other ways. The activities of each network hospitals will be simulated by the medical treatment support system proposed in this paper by using such data on arrival patients. The control center will make decision how to control the activities of each hospital. If the disaster spread widely over the area of municipalities, the prefectures must control centers of each municipalities as upper level network system. In this case, control center of each municipalities are linked and center of prefecture will be control the linked network activities. According to this, the national government will be linked to the centers of each prefecture to control the medical treatment activities nation widely.

CONCLUSION

To examine crisis management for urban disaster prevention driven by the notion of acceptable risk levels, our research focuses on the concept of city functions. Among the several functions of a city, this paper has examined medical functions, looking at a model of an emergency medical network during a disaster, and providing example analysis results. Our medical function impairment evaluation model enables setting of arbitrary values for parameters such as the distribution of patient arrival times at hospitals, distribution of length of treatment times, number of treatment sections, number of network hospitals, and amount of time needed to transfer patients.

This flexibility enables simulations under almost any foreseeable condition. Since the model evaluates damage to functions, it enables specific planning of measures (such as adjustment of number of treatment sections, number of network hospitals, or hospital patient capacities) for a given function level requirement. The model also helps plan for disasters not anticipated by current emergency medical organizations, such as planning where to transport victims of earthquakes striking main transport arteries running through many different prefectures, such as the Tokaido Shinkansen line.

During a major earthquake disaster, medical cooperation among hospitals in and around the affected area is vital. The aim of this paper has been to show that medical treatment should be considered one of the functions of the city, and that by evaluating possible earthquake damage to this function, specific contingency plans can be created.

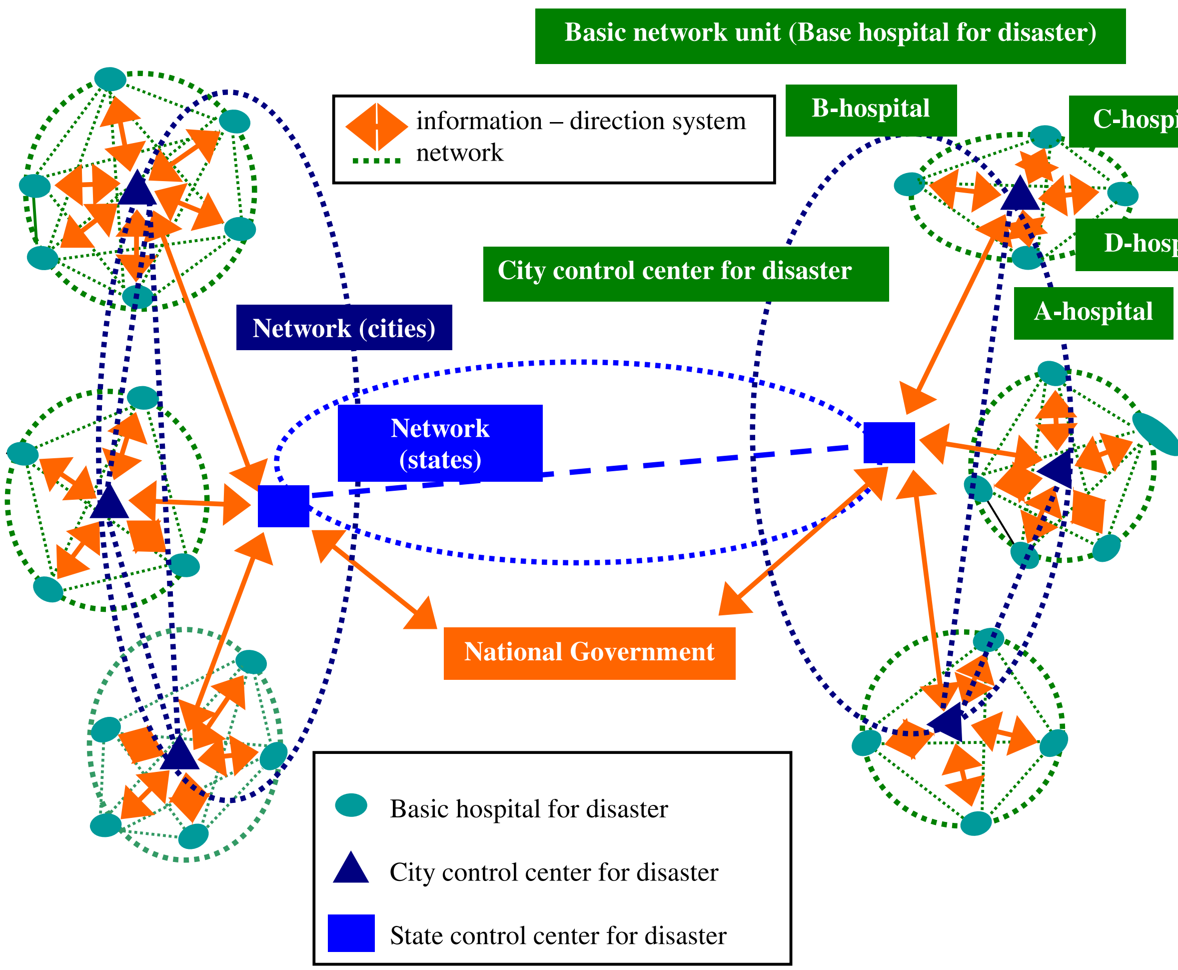


Figure 7. Hierarchical Network of Hospitals for Disaster Medical Treatment.

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