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Assessment of Medical Response Capacity in the time of Disaster: the Estimated Formula of Hospital Treatment Capacity (HTC), the Maximum Receivable Number of Patients in Hospital

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INTRODUCTION For the assessment on medical response capacity for disaster in local area (such as rescue capacity, transport capacity and treatment capacity), it is necessary to assess it in peace time, and understand how many sufferers from disaster the hospital can respond to. Here the estimated formula of Hospital Treatment Capacity (hereinafter shortened to HTC), the maximum receivable number of patients in hospital (hereinafter shortened to MRN) was showed, which derived from the assessment on emergency medical response in Kobe University Hospital as an example.

MATERIALS AND METHODS We treated a total of 12,032 patients transferred and admitted to Kobe University Hospital from April 2003 to January 2005. We calculated the required number of medical personnel, equipment and length of treatment time in order to respond to 410 severe traumas, 35 burn injuries, and 28 patients with blood purification, which were considered to be main clinical conditions in disaster. Beside, the occupation of emergency room and the operation room per hour were also investigated in our hospital.

RESULTS HTC (MRN) for each clinical condition within H hours is expressed by following formula:

(1) HTC (MRN) for burn injuries

= The maximum integer of
 $(\leq \text{Doctors}/2 \cap \leq \text{Respirators}/1 \cap \leq \text{outpatient beds}/1 \cap \leq \text{inpatient beds}/1 \cap \leq \text{monitors}/1)$
x the minimum integer of $(\geq H/1.85)$

(2) HTC (MRN) for patients with blood purification

= The maximum integer of
 $(\leq \text{doctors}/2 \cap \leq \text{blood purification systems}/1 \cap \leq \text{outpatient beds}/1 \cap$
 $\leq \text{inpatient beds}/1 \cap \leq \text{monitors}/1)$
x the minimum integer of $(\geq H/2.00)$

(3) HTC (MRN) for severe traumas

= The maximum integer of
 $(\leq \text{doctors-a}/2 \cap \leq \text{surgeons}/1 \cap \leq \text{anesthetists}/1 \cap \leq \text{radiologists}/1 \cap \leq \text{respirators}/1 \cap$
 $\leq \text{outpatient beds}/1 \cap \leq \text{inpatient beds}/1 \cap \leq \text{monitors}/1 \cap \leq \text{operation rooms}/1 \cap$
 $\leq \text{angiography rooms}/1)$

x the minimum integer of ($\geq H/2.82+b$)

CONCLUSION The treatment capacity within local area is able to be assessed by adopting the estimated formula of HTC (MRN).

The concept of a disaster medical plan and its management has been improved since the Great Hanshin-Awaji Earthquake on 17 January 1995 in Japan. Based on the lesson learned in coping with the earthquake, proactive efforts to improve the emergency management system have been made, such as introducing an information system for emergency medicine, designating more key disaster hospitals and implementing disaster medicine education and trainings. However, even after the earthquake, delays in early response were identified in mass-casualty incidents like the Tokyo Sarin gas attack, the O-157 mass food poisoning, the Wakayama curry poisoning, the flood Nagoya, and the mass-gathering disaster at Akashi fireworks festival. These delays occurred because, under current system, in the initial stage of a disaster, the assessment of medical response is made first in the local area, and only after it turned out that the amounts and types of damage are beyond the capacity of local emergency management, they request support to neighbor cities.

Therefore, in order to shorten response times, it is necessary to assess the capacity for emergency medical response in local areas during normal times, and share the results in order to determine the capacity for deal with disasters and major accidents in the local area. For the assessment on medical response capacity for disaster in local area, (such as rescue capacity, transport capacity and treatment capacity), it is necessary to assess it in peace time, and understand how many sufferers from disaster the hospital can respond to. In Japan, most of the severe injuries are transported to the tertial emergency hospital such as critical care center. Here we show the estimated formulas of Hospital Treatment Capacity (hereinafter shortened to HTC), the maximum receivable number of patients in hospital (hereinafter shortened to MRN), which derived from the assessment on emergency medical response in the tertial emergency hospital, Kobe University hospital as an example.

MATERIALS AND METHODS

We treated a total of 12,032 patients transferred and admitted to Kobe University Hospital from April 2003 to January 2005. Then we calculated the required number of medical personnel, equipment and length of treatment time to respond to clinical conditions from the daily emergency medical care. The subjects of clinical conditions were severe traumas, burn injuries, and patients with blood purification, which were considered to be main clinical conditions in disaster. Based on the result, we developed estimated formulas, which could suggest MRN during a certain time. As a premise, we focused on the period for treatment (treatment time) from the emergency room to the admission. The time is measured by computer system in Kobe University Hospital, and the past average time during patient's stay in ER was adopted as treatment time.

For the response of emergency visit in Kobe University Hospital, basically 2 emergency doctors are required to respond to 1 patient with severe trauma. If one needs to have an operation, 2 emergency doctors, 1 surgeon, and 1 anesthetist are required. If one needs to take angiography, 2 emergency doctors and 1 radiologist will respond. If one needs neither operation nor angiography, 2 emergency doctors will respond (Figure 1). Besides, 2 emergency doctors are required to 1 patient with burn injury or needed blood purification (Figure 2).

There are the facilities in Kobe University hospital, there are 6 beds in ER, 34 in Intensive Care Unit, 13 operation rooms, 4 angiography rooms, 60 respirators, 14 anesthetic

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machines, 30 portable monitors, 37 fixed bedside monitors, central monitors for 144 patients, 26 blood purification systems, 11 beds in dialysis and 5 PCPS (Table 1).

The occupation of emergency room and the operation room per hour were also investigated in our hospital.

Required Medical Personnel (in Kobe University Hospital)

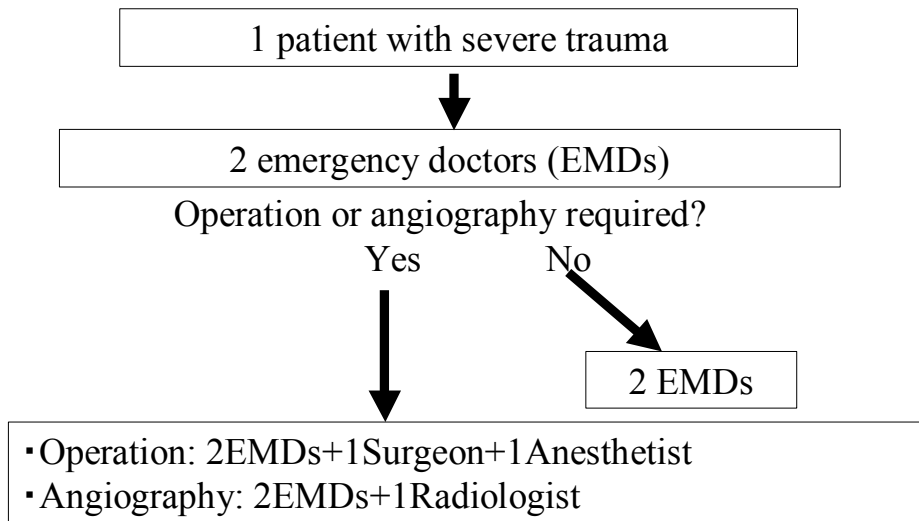


Figure 1. 2 emergency doctors are required to respond to 1 patient with severe trauma. If one needs to have an operation, 2 emergency doctors, 1 surgeon, and 1 anesthetist are required. If one needs to take angiography, 2 emergency doctors and 1 radiologist will respond. If one needs neither operation nor angiography, 2 emergency doctors will respond.

Required Medical Personnel (in Kobe University Hospital)

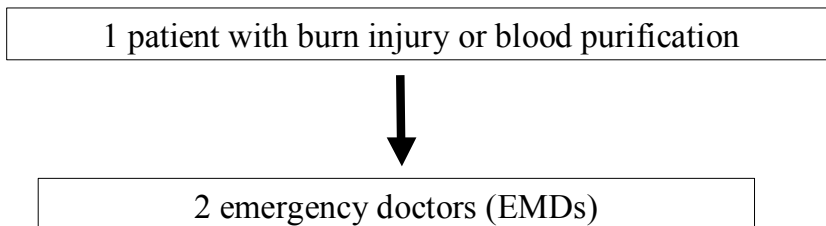


Figure 2. 2 emergency doctors are required to 1 patient with burn injury or needed blood purification in Kobe University Hospital.

Table 1. Facilities in Kobe University Hospital

Emergency room	6 beds
ICU	34 beds
Operation Room	13 rooms
Angiography room	4 rooms
Respirator	60
Anesthetic Machine	14
Monitor	30 portable 37 fixed bedside monitors Central monitors for 144 patients
Blood purification system	13 CHDF 11 beds in dialysis room
PCPS	5

RESULTS

The number of patients and the average length of treatment time for the three types of conditions in ER were showed at Table 2. The patients with these three types of conditions need to be admitted. There were 35 burn injuries, and the average time of their treatment was 1.85 hours per patient. There were 28 patients required blood purification, and the average time of their treatment was 2 hours per patient. There were 410 severe traumas, and the average time of their treatment was 2.82 hours per patient.

The average number of patients in the emergency room per hour was showed in Figure 3. The number increased during the beginning of day and twilight shift.

The average number of occupied operation rooms was showed in Figure 4. They were mostly used during day-time and not much during night-time hours.

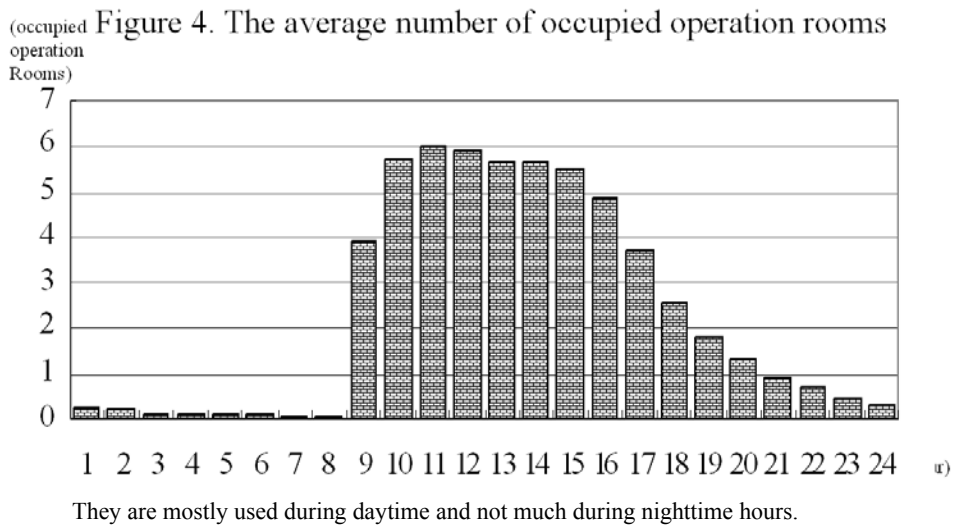
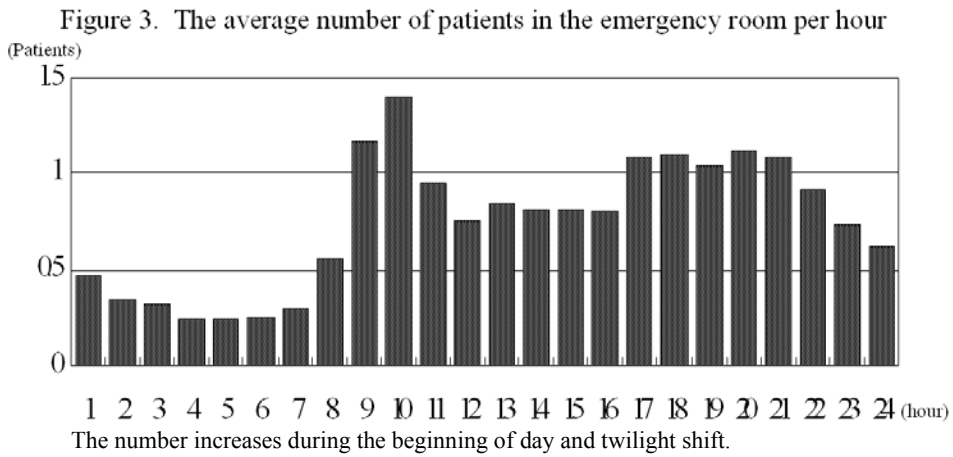
Table 2. The average length of treatment time for the three types of conditions in ER

Clinical Condition	The number of Patients	The average length of treatment time per patient in ER (= treatment time)
Burn injury	35	1.85
Blood Purification	28	2.00
Severe trauma	410	2.82

The time is measured by computer system in Kobe University Hospital, and the past average time during patient's stay in the ER was adopted as treatment time

There were 35 burn injuries, and the average time of their treatment was 1.85 hours per patient. There were 28 patients required blood purification, and the average time of their treatment was 2 hours per patient. There were 410 severe traumas, and the average time of their treatment was 2.82 hours per patient.

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The maximum receivable number of patients in hospital at once can be expressed by the following formula. Setting the required number of medical personnel per patient as $A_1 \dots A_n$, the actual number of personnel to participate as $B_1 \dots B_n$, the required number of facilities to accept 1 patient as $C_1 \dots C_n$, and the actual number of facilities to use as $D_1 \dots D_n$ (Table 3), then

MRN (HTC) in view of only element A_1 = The maximum integer of $(\leq B_1/A_1)$.

MRN (HTC) in view of only element A_2 = The maximum integer of $(\leq B_2/A_2)$.

MRN (HTC) in view of only element A_n = The maximum integer of $(\leq B_n/A_n)$.

MRN (HTC) in view of only element C_1 = The maximum integer of $(\leq D_1/C_1)$.

MRN (HTC) in view of only element C_2 = The maximum integer of $(\leq D_2/C_2)$.

MRN (HTC) in view of only element C_n = The maximum integer of $(\leq D_n/C_n)$.

Table 3. The estimated Formula for Hospital Treatment Capacity (HTC)

The required personnel per patient	$A_1, A_2, \dots, A_n$
The actual number of personnel to participate	$B_1, B_2, \dots, B_n$
The required number of facilities to accept one patient	$C_1, C_2, \dots, C_n$
The actual number of facilities to use	$D_1, D_2, \dots, D_n$

The maximum receivable number of patients in hospital (MRN)
 = HTC = The maximum integer of
 $(\leq B_1/A_1 \cap \leq B_2/A_2 \cap \dots \cap \leq B_n/A_n \cap \leq D_1/C_1 \cap \leq D_2/C_2 \cap \dots \cap \leq D_n/C_n)$

The mathematical symbols mean as follows: $\leq$: and under $\geq$: and over $\cap$. And in view of all element $A_1 \dots A_n, C_1 \dots C_n$, MRN (HTC) can be expressed by the next formula:
 MRN (HTC) in view of all element $A_1 \dots A_n, C_1 \dots C_n$

= The maximum integer of $(\leq B_1/A_1 \cap \leq B_2/A_2 \cap \dots \cap \leq B_n/A_n \cap \leq D_1/C_1 \cap \leq D_2/C_2 \cap \dots \cap \leq D_n/C_n)$

If the treatment time is set as E hours, because E hours later, medical personnel and facilities become free, the maximum receivable number of the patients in hospital within H hours will be expressed by the following formula:

MRN within H hours

= The maximum integer of $(\leq B_1/A_1 \cap \leq B_2/A_2 \cap \dots \cap \leq B_n/A_n \cap \leq D_1/C_1 \cap \leq D_2/C_2 \cap \dots \cap \leq D_n/C_n)$

x The minimum integer of $(\geq H/E)$

If we look at the aspect of facilities (ex, inpatient beds), which are irrelevant to the time and occupied by patients, MRN will be described by the following formula:

MRN defined by the facilities without time constraints

= The maximum integer of $(\leq D'_1/C'_1 \cap \leq D'_2/C'_2 \cap \dots \cap \leq D'_n/C'_n)$

D'_n/C'_n : without time constraints (Figure 5)

MRN within H hours
 = The maximum integer of
 $(\leq B_1/A_1 \cap \leq B_2/A_2 \cap \dots \cap \leq B_n/A_n \cap$
 $\leq D_1/C_1 \cap \leq D_2/C_2 \cap \dots \cap \leq D_n/C_n)$
 x The minimum integer of $(\geq H/E)$
 E= treatment time

Figure 5. The estimated Formula for HTC (MRN) within H hours

Next, we would like to explain these formulas adopting for each clinical condition.

(1) In the case of burn injuries:

HTC (MRN) for burn injuries

= The maximum integer of

$(\leq \text{Doctors}/2 \cap \leq \text{Respirators}/1 \cap \leq \text{outpatient beds}/1 \cap \leq \text{inpatient beds}/1 \cap \leq \text{monitors}/1)$

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x The minimum integer of ($\geq H/1.85$)

MRN without time constraints

= The maximum integer of ($\leq \text{respirators}/1 \cap \leq \text{inpatient beds}/1 \cap \leq \text{monitors}/1$)

(2) In the case of patients with blood purification:

HTC (MRN) for Patients with blood purification

= The maximum integer of

($\leq \text{doctors}/2 \cap \leq \text{blood purification systems}/1 \cap \leq \text{outpatient beds}/1 \cap$

$\leq \text{inpatient beds}/1 \cap \leq \text{monitors}/1$)

x The minimum integer of ($\geq H/2.00$)

MRN without time constraints

= The maximum integer of ($\leq \text{blood purification systems}/1 \cap \leq \text{inpatient beds}/1 \cap \leq \text{monitors}/1$)

(3) In the case of severe traumas:

HTC (MRN) for severe traumas

= The maximum integer of

($\leq \text{doctors}-a/2 \cap \leq \text{surgeons}/1 \cap \leq \text{anesthetists}/1 \cap \leq \text{radiologists}/1 \cap \leq \text{respirators}/1 \cap$

$\leq \text{outpatient beds}/1 \cap \leq \text{inpatient beds}/1 \cap \leq \text{monitors}/1 \cap \leq \text{operation rooms}/1 \cap$

$\leq \text{angiography rooms}/1$)

x The minimum integer of ($\geq H/2.82 + b$)

with operation: add the number of surgeons, anesthetists and operation room

a=the number of surgeons + anesthetists.

b=3(operation time: which was based on past data in our hospital)

with angiography: add the number of radiologists and angiography rooms

a=the number of radiologists.

b=0

without operation and angiography

: Delete the parts indicated with underline.

a=b=0

MRN without time constraints

= The maximum integer of ($\leq \text{respirators}/1 \cap \leq \text{inpatient beds}/1 \cap \leq \text{monitors}/1$)

Next we present the actual case as an example. The train derailment occurred at 9:18 a.m. on April 25, 2005 on JR Hukuchiyama railway line in Amagasaki city, causing many people injured. The available number of personnel and facilities in Kobe University Hospital is as follows: Set B1 equal to 31 doctors, who are able to participate. Among of them, set B2 as 5 surgeons, B3 as 3 anesthetists, and B4 as 2 radiologists. Regarding facilities, 5 vacant beds in emergency room shows as D1, 1 available angiography room as D2, and 4 available operation rooms as D3. For the facilities, without time constraints are: Set D4 equal to 8 available inpatient beds, D5 to 35 available respirators, D6 to 13 available monitors, D7 to 12 available blood purification systems. Then MRN in each condition within 5 hours is next numbers:

MRN for severe traumas (need operation)

=The maximum integer of ($\leq 31-5-3/2 \cap \leq 5/1 \cap \leq 3/1 \cap \leq 35/1 \cap \leq 5/1 \cap \leq 8/1 \cap \leq 13/1 \cap \leq 4/1$)

x The minimum integer of $(\geq 5/5.04) = 3 \times 1 (\leq 8) = 3$

MRN for severe traumas (need angiography)

= The maximum integer of $(\leq 31-2/2 \cap \leq 2/1 \cap \leq 35/1 \cap \leq 5/1 \cap \leq 8/1 \cap \leq 13/1 \cap \leq 1/1)$

x The minimum integer of $(\geq 5/2.04) = 1 \times 3 (\leq 8) = 3$

MRN for burn injuries

= The maximum integer of $(\leq 31/2 \cap \leq 35/1 \cap \leq 5/1 \cap \leq 8/1 \cap \leq 13/1)$

x The minimum integer of $(\geq 5/1.11) = 5 \times 5 (\leq 8) = 8$

MRN for patients with blood purification

= The maximum integer of $(\leq 31/2 \cap \leq 12/1 \cap \leq 5/1 \cap \leq 8/1 \cap \leq 13/1)$

x The minimum integer of $(\geq 5/1.58) = 5 \times 4 (\leq 8) = 8$

The actual number of patients transferred to Kobe University Hospital was 4 all together:

1 patient with aortic injury, fracture of rib and spine;

1 patient with hemopneumothorax and fracture of the clavicle and scapula;

1 patient with head contusion and peroneal nerve palsy;

1 patient with fracture of rib and whiplash.

DISCUSSION

Early emergency medical response capacity at the time of major disasters and mass-gathering disasters consists of these three capacities: rescue capacity, transport capacity and medical treatment capacity. Rescue capacity and transport capacity are depended on fire department capacity, which has comparatively enough support system.

This time, medical treatment capacity was assessed mathematically. Hospital preparedness assessment and planning or surge capacity at the time of major disasters and mass-gathering disasters have been reported previously. With regard to hospital preparedness assessment and planning, Higgins and colleagues published an article on a hospital assessment tool that was piloted in 116 hospitals (4). In order to assess the receivable number of patients in hospital, the questionnaire survey is useful, but there are so many hospitals that it is difficult to carry out the survey (317 hospitals in Hyogo prefecture only, in which 182 are designated emergency hospitals). Besides, because the questionnaire survey tends to be subjective, and has difficulty to decide the suitable man who answers the questionnaire, it is not considered to be suitable for this research. Chaffee and colleague presented a program designed to assess and strengthen hospital preparedness in US hospitals (2). But they did not present receivable number of patients in hospital. Hutchinson, Christopher and colleagues published an article on mass casualty prediction methodology (5). De Boer examined 416 disasters over a 40-year period using the disaster severity scale (3). With regard to surge capacity, the ability of an organization to rapidly increase its operating capability during a disaster, Hick and colleagues published a state of the science review on surge capacity that included strategies for increasing capacity (6). Community preparedness, including emergency preparedness funding, was examined by McHugh and colleagues (9). Developing community surge capacity also was explored by Bekemeier and Dahl (1). McKenzie and colleagues documented the number and configuration of trauma centers in the United States gaps in coverage (10). Posner and colleagues presented a strategy to expand burn unit capacity based on work in Israel (11). The often-overlooked capacity of long-term care facilities was described by Saliba and colleagues (12). Milsten A compiled and reviewed

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lessons learned from past disaster-related operational failures and reviewed importance and types of disaster planning by the available literature from 1977 through March 1999 (8). There was no literature which presented MRN in his report, because most of these literatures presented adequate response to disaster mainly, based on disaster experience. Ishida and Ohtori presented a model of emergency medical networks at the time of disaster and the examples of its analysis, which can set up the distribution of visiting patients, that of treatment time, the number of departments and network hospitals, and the time of patients transport (7). They presented patients shift with the passage of time. But they did not present MRN, because they might think it is difficult to decide MRN. Although there are such reports above, there has been no report that suggests the concrete receivable number of patients in hospital in the time of disaster. Besides, we can come across some formulas to suggest conceptual thought for disaster management occasionally, but such formulas are unpractical, and cannot be used in real disasters. In real disasters, it is important to make objective judgment in order to determine how many patients are able to be received to the hospital. Such formulas enable each hospital, each municipal, and each prefecture to show the receivable number of patients, and to determine the range of backup hospitals from their receivable number of patients and that of casualties in the disaster.

This time we take Kobe University Hospital as an example and suggest the receivable number of patients. Basic formula might gain consensus, but we need further discussion on parameters of personnel and equipment. If the parameters, however, can obtain one's consent, they can use in a wide range. Because the estimated formula of HTC was considered to be very complex by adding data of the occupation rate of emergency room and operation room per hour, the data were not added to the formula. HTC may be decided by the maximum receivable number of patients in hospital without time constraints (ex. Inpatient bed) in the end. Moreover, regarding the concept of time, though there are gap between treatment times because of different levels of ability, we can show MRN per hour. If the facilities without time constraints are not occupied, MRN can be received over and over within a certain time because the needed personnel and facilities become free every treatment time. Although we did not discuss this time, if there are surveys on the means of transportation between hospitals, and the time of transportation, we can suggest the receivable number of patients per hour on a regional basis accurately. If this formula of HTC can be introduced to information system, MRN may be able to be presented just by inputting some necessary parameters at the time of disaster. We established a precedent of the train derailment in results, but the actual number of patients transferred to Kobe University Hospital was less than MRN. Thus, it may be useful to decide support area by calculating MRN every hospital or every local area (for example: Kobe city, Hyogo prefecture). This formula of HTC is also considered to be useful for the preparedness assessment of disaster. The weak point at each local area may be able to be clear by HTC assessment there at a certain time. The weak point may be useful for judging the suitable place that new hospital is established.

CONCLUSION

The estimated formula to assess Hospital Treatment Capacity (HTC), the maximum receivable number of patients in hospital (MRN), was presented according to the examples in Kobe University Hospital. HTC (MRN) within H hours can be calculated as follows.

Set A1 . . . An equal to the required number of personnel per patient, B1 . . . Bn to the actual number of personnel to participate, C1 . . . Cn to the required number of facilities, and D1 . . . Dn to the actual number of facilities to use, and treatment time are E hours,

HTC (MRN) within H hours

= The maximum integer of

$$(\leq B1/A1 \cap \leq B2/A2 \cap \dots \cap \leq Bn/An \cap \leq D1/C1 \cap \leq D2/C2 \cap \dots \cap \leq Dn/Cn)$$

x The minimum integer of ($\geq H/E$)

While further examination is necessary for the parameter of personnel and facilities, the treatment capacity within local area is able to be assessed by adopting the estimated formula of HTC (MRN).

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