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AN EVALUATION MODEL OF MEDICAL TRANSPORT WITH TSUNAMI EARLY WARNING SYSTEM

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ABSTRACT: The Japanese Central Disaster Management Council announced a new damage estimate in the event of an earthquake with its epicenter in the Nankai Trough. The estimate shows the huge human damage. However, they mentioned the possibility of minimizing the casualty count by constant preparation for prompt evacuation to higher places in the event of a tsunami. This study aims to develop a reliability analysis model for medical transport activity considering a tsunami risk. The model includes a risk evaluation model developed to evaluate medical transport activity when a tsunami early warning system can be used. By applying it to Chita Peninsula in Japan, it is demonstrated that the proposed model effectively implements the evacuation and medical transport planning. Some proposals are given for the road network in the area.

Keywords: Risk management, Tsunami, Medical transport, Evacuation

1. INTRODUCTION

The Japanese Central Disaster Management Council recently announced a new damage estimate in the event of an earthquake with its epicenter in the Nankai Trough. The new estimate shows the huge human damage. However, they mentioned the possibility of minimizing the casualty count by constant preparation for prompt evacuation to higher places in the event of a tsunami. In response to this situation, many local tsunami evacuation plans have been reconsidered. Especially, the Tokai area is pointed out as a high tsunami risk area by the Nankai trough earthquake.

After a large-scale disaster, medical transport is very important for life-saving. D.Goldschmitt conducted some phases of a medical disaster response. First is the extrication. The purpose in this phase is to get victims out of the hot zone and to safety. Second is the filed triage. The victims are evaluated to determine their needs for medical attention. The third is evacuation and transport. The phase is to transport them to the definitive care location or the emergency departments of local hospitals [1]. N.Koike et al. made an evaluation model for the transport of victims in an airplane accident in the third phase [2]. The model has been made for serious incidents like airplane accidents. The origin of the injured is one place just like an airport. In a large-scale disaster, however, many places may be defined as the origin, and the injured will be transported to some hospitals under the risk of a tsunami.

There are many previous studies about the evacuation. B.Wolshon published to a comprehensive review of evacuation plans of the area affected by hurricanes. In this review, he discussed the needs of emergency plan for special needs and low mobility groups [3]. The medical transport planning for victims and patients from view point of transport management may be needed.

This study aims to develop a reliability analysis model for medical transport considering the tsunami risk. The model includes a risk evaluation model developed to evaluate medical transport when a tsunami early warning system can be used. The tsunami early warning system determines the possibility of a tsunami by the seismic intensity and magnitude of the earthquake at almost the same time after an earthquake. The system serves to draw people's attention to the risk of a tsunami.

Through applying them to the Chita Peninsula in Japan, it is demonstrated that the proposed model effectively implements the evacuation and medical transport planning.

2. METHODOLOGY

2.1 Outline of proposed method

In the previous model, three risk factors were proposed for reducing the risk of death. One is the left behind risk, which is an index to explain how long the injured must wait for pickup at the injury site. The second is the medical confusion risk, which is indicated by the arrival interval. Major injured persons are often brought to the hospital closest to the incident site, and smooth medical service is difficult. If they can be transported to a wider array of hospitals, the hospitals may accept a few injured within their ability. The third is the transport risk itself. It is the risk with a long transport time. As convalescence of the injured may be determined by many personal factors, it cannot be evaluated by only an index such as lifesaving time limit. The proposed indices are significant to compare some alternative plans.

For the evaluation of the medical transport with a tsunami risk, the left behind risk is out of the consideration. The problem is who and when will be rescued from high-risk places. For their rescue, a warning system to assure their fast evacuation is important. Our proposed model has included reducing the risk by improvement of the warning system.

The outline of our proposed model is shown in Fig.1. First, the area is divided for some zones, and set the transport origin point and emergency hospitals. Second, finding the shortest path between all of origin and hospitals, the distance matrix is obtained. The influence of tsunami attack for road network can be considered. Third, the number of victims by the earthquake and the tsunami is estimated for each zone. In this step, we take into account the effect of the tsunami early warning system with EEWS. Forth, the injured select a hospital. Fifth, we calculate the transport risk and medical over-capacity risk. At last, we discuss the strategy of reducing risks.

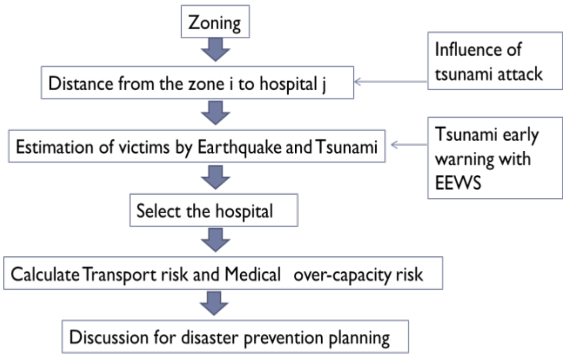

Fig.1 Calculation Flow

2.2 Reducing risk by the warning system

The best and unique countermeasure against a tsunami attack is to evacuate from the coast. However, it does not mean that all earthquakes cause a huge tsunami. When a tsunami is expected to cause coastal damage, the Japan Meteorological Agency (after this, JMA) issues a tsunami warning or advisory within 2-3 minutes after an earthquake. The tsunami information is transmitted immediately to disaster management organizations and media outlets. However, the best countermeasure is for people to flee coastal areas immediately after an earthquake. But the time to check the information from the government reduces the chance of evacuation. In Japan, the early earthquake early warning system (after this,

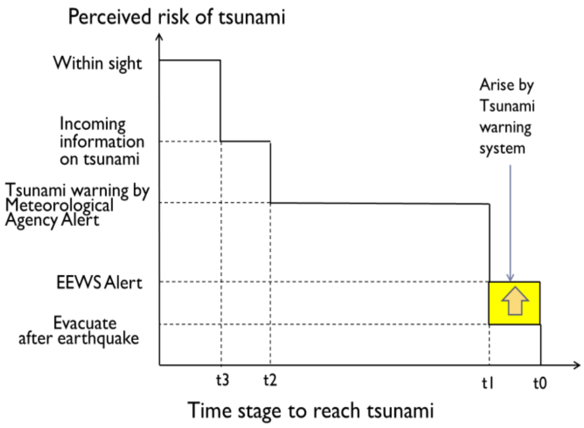

Fig.2 Relation between time distribution and probabilities of tsunami

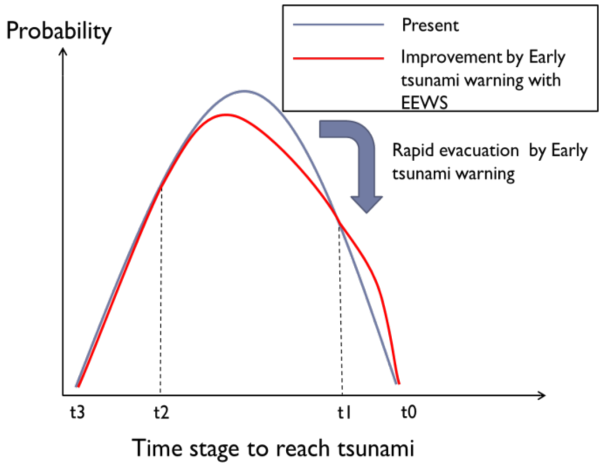

Fig.3 Relation between time distribution and probabilities of tsunami

EEWS) is the earliest warning for the earthquake disaster. Kurahashi et al. have been developing early tsunami warning system used by the EEWS magnitude. [4]. The system algorithm includes the equation proposed by K.Iida. K.Iida pointed out the earthquake magnitude is related tsunami occurrence [4]. If the system can be put to practical use, the tsunami risk may well be reduced.

Fig. 2 shows an image between the time the risk of a tsunami is perceived and the time to reach a tsunami after an earthquake. “t0” is the time immediately after an earthquake. Time “t1” means the timing of the tsunami alert by the JMA. The perceived risk of tsunami will arise by the EEWS at this period. The time “t2” involves a person who has received information of a tsunami reaching in or near the coast. This is certain information of the tsunami danger. And at the time “t3”, the tsunami is within sight, so people must escape to a safe place. The perceived risk can be exchanged for the probability of evacuation. Fig. 3 shows the relation between the time distribution and probabilities for evacuation. If the improvement by the EEWS can prompt evacuation immediately, the distribution of the probability of evacuating may shift to an early time. It will contribute to reduction of the number of tsunami victims.

Table 1 shows the evacuation ratio of people from the tsunami risk area after an earthquake. This is estimated by the empirical data in Japan from the Japanese Central Disaster Management Council. The estimation is considered to reflect people's awareness about the risk of tsunami. In Case A, which is high awareness and effective warning, 70% of people can evacuate immediately, whereas only 20% of people can evacuate in Case C. It means the awareness and warning have a great influence on evacuation behavior.

Table 1 Evacuation ratio at the report by Japanese Central Disaster Management Council

(%)

Items	Evacuate immediately after earthquake	Evacuate less quicking	Evacuation as imminent tsunami danger
Case A	70	30	0
Case B	70	20	10
Case C	20	50	30

Case A: High rapid evacuation ratio and effective warning
Case B: High rapid evacuation ratio.
Case C: Low rapid evacuation ratio.

2.3 The risk factors

Fig. 4 illustrates the medical conditions transport after a tsunami. At first, people fail to escape and undergo injury. Of course, some people are injured by a seismic motion.

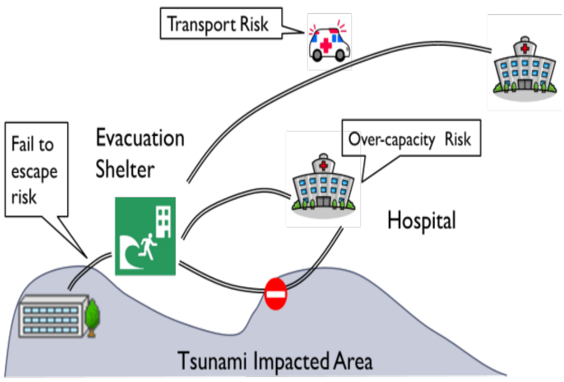

Fig. 4 Risk of injured persons

Second is the medical over-capacity risk. Because some nearby hospitals must accept many injured, those hospitals may be in disturbed due to over-capacity. To avoid over-capacity, they hope to transport to a nearby hospital, and are forced to transport long distances. In addition, some nearby routes cannot be used. This is the transport risk.

2.4 The Problem formulation

The model area is divided into some zones which are set as the origin of medical transport.

Second, the distance *Dij* is defined from origin zones *i* to hospital *j* . *Dmax* is the farthest distance from all zones to the farthest hospital. As people try to go to the nearest hospital, possibility to select the hospital can be defined as Fig.5.

We define the hospital select coefficient from zone *i* to hospital *j* as follows;

$$Yij = (Dmax - Dij)/\sum_i \frac{(Dmax-Dij)}{Dmax} \quad (1)$$

The hospital select coefficient means the gravitation of the hospital *j* from zone *i*. When the information about the damage of the road network can be gotten, people will be changed the hospital. In this paper, we calculate the indexes in the uninformed case and the informed case.

The Transport risk is written as follows;

$$TRij = Yij \times Dij \quad (2)$$

When many hospitals are located near the damage area, the transport risk may be low, but when hospitals are far from the damage area, the risk may be high.

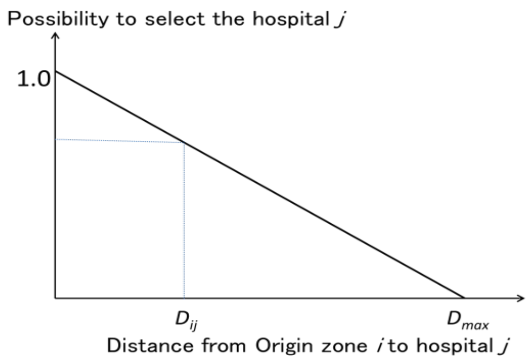

Fig. 5 Relation between distance and possibility to select the hospital *j*

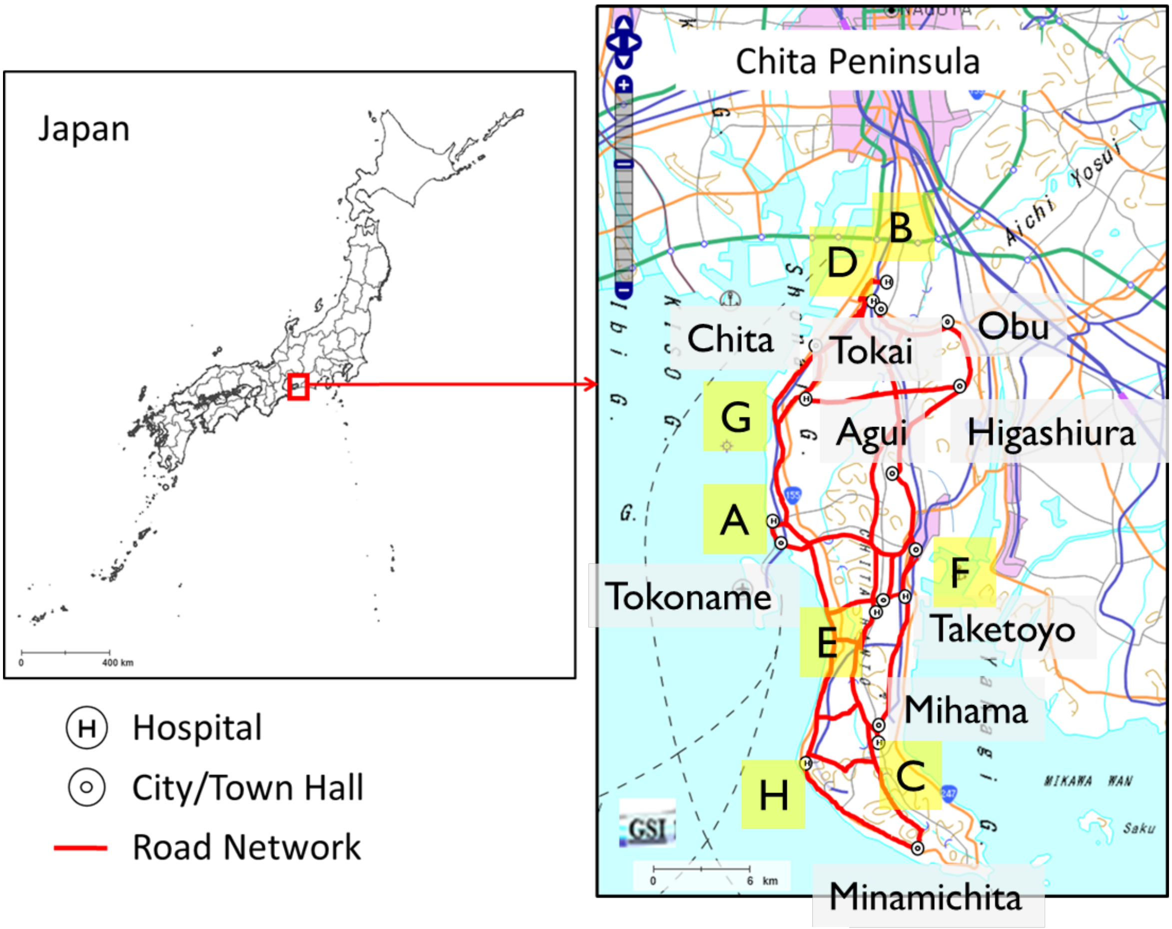

Fig. 6 Chita Peninsula road network and hospitals

This model calculates how many injured people go to the hospital. However, the estimated number of injured persons is uncertain. In this paper, the relative damage estimation at the zone *i* is defined as follows;

$$Ei = Vi/\sum_i Vi \qquad (3)$$

Where *Vi* indicates human damage in the area *i*. We can discuss the priority of countermeasures for many injured by *Ei*.

Using the relative risk of human damage, the medical demand can be described with the hospital select coefficient and the relative risk of human damage.

$$RHj = \sum_i Yij \times Ei \qquad (4)$$

RHj: the medical over-capacity risk at hospital *j*
Ei: the relative risk of human damage at the zone *i*

If the ability of all hospitals is almost equal, the ideal would be for the medical over-capacity risk *RHj* to be dispersed around the hospitals.

3. CASE STUDY

3.1 Case study area

We have applied our model to the Chita Peninsula in Central Japan with its population of about six hundred thousand. The administrative district is 10 blocks. There are 8 emergency hospitals. There is a high-risk area by tsunami attack in an earthquake with its epicenter in the Nankai Trough. Fig. 6 shows the road network from the city or town office to the emergency hospitals in Chita Peninsula.

3.2 Results

There are the results of the proposed model. Because of rounding off, some total value of the results are not added up.

Table 2 shows the results of the hospital select coefficient *Yij* when the road network condition has not informed. For example, 25% of the people in the Minamichita area will go to hospital C. On the other hand, hospital B and D are far from the Minamichita area. Most people will not go to hospital B and D.

Table 3 shows the hospital select coefficient *Yij*

Table 2 Hospital select coefficient(uninformed case)

Zone / Hospital	Minami chita	Mihama	Taketoyo	Tokoname	Handa	Agui	Higashiura	Obu	Tokai	Chita
A	0.11	0.09	0.14	0.18	0.13	0.13	0.11	0.10	0.12	0.14
B	0.01	0.05	0.07	0.09	0.11	0.14	0.18	0.22	0.22	0.18
C	0.25	0.21	0.14	0.11	0.12	0.08	0.07	0.06	0.06	0.05
D	0.01	0.06	0.07	0.10	0.11	0.14	0.18	0.21	0.22	0.19
E	0.18	0.17	0.19	0.14	0.16	0.14	0.11	0.10	0.08	0.08
F	0.17	0.16	0.18	0.14	0.16	0.14	0.12	0.10	0.10	0.11
G	0.04	0.07	0.09	0.13	0.12	0.15	0.18	0.18	0.19	0.20
H	0.22	0.18	0.13	0.11	0.10	0.08	0.04	0.03	0.03	0.06
total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 3 Hospital select coefficient (informed case)

Zone / Hospital	Minami chita	Mihama	Taketoyo	Tokoname	Handa	Agui	Higashiura	Obu	Tokai	Chita
A	0.08	0.10	0.14	0.20	0.13	0.14	0.11	0.10	0.10	0.14
B	0.01	0.05	0.07	0.09	0.12	0.14	0.18	0.23	0.23	0.18
C	0.26	0.21	0.14	0.12	0.11	0.09	0.07	0.06	0.06	0.05
D	0.01	0.06	0.07	0.09	0.12	0.14	0.18	0.22	0.23	0.19
E	0.19	0.16	0.19	0.15	0.16	0.15	0.12	0.10	0.09	0.08
F	0.17	0.17	0.19	0.15	0.17	0.14	0.13	0.11	0.10	0.11
G	0.04	0.07	0.09	0.14	0.13	0.15	0.18	0.18	0.19	0.20
H	0.23	0.18	0.10	0.05	0.08	0.04	0.02	0.00	0.01	0.06
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 4 Transport risk (uninformed case)

Zone / Hospital	Minami chita	Mihama	Taketoyo	Tokoname	Handa	Agui	Higashiura	Obu	Tokai	Chita	*Toatal*
A	3.05	2.17	1.58	0.22	1.62	1.57	2.47	2.54	2.29	2.03	19.55
B	0.44	1.66	1.79	1.94	1.82	1.52	1.96	1.46	0.30	1.32	14.22
C	2.36	0.09	1.49	1.89	1.78	1.90	2.07	1.91	1.70	1.56	16.74
D	0.44	1.68	1.80	1.92	1.81	1.51	1.95	1.63	0.24	0.88	13.88
E	3.32	1.56	0.13	1.56	1.03	1.43	2.48	2.49	2.15	2.04	18.18
F	3.35	1.60	0.33	1.53	0.90	1.49	2.50	2.57	2.26	2.21	18.73
G	1.54	1.95	1.93	1.67	1.71	1.33	1.95	2.36	1.27	0.53	16.23
H	2.97	1.21	1.71	1.90	1.90	1.89	1.50	0.95	0.91	1.73	16.67
Total	17.47	11.92	10.76	12.63	12.56	12.63	16.89	15.91	11.12	12.29	

Table 5 Transport risk (informed case)

Zone / Hospital	Minami chita	Mihama	Taketoyo	Tokoname	Handa	Agui	Higashiura	Obu	Tokai	Chita	*Toatal*
A	2.57	2.18	1.63	0.24	1.69	1.64	2.53	2.61	2.33	2.03	19.45
B	0.46	1.67	1.85	2.10	1.89	1.58	2.01	1.50	0.32	1.32	14.70
C	2.45	0.09	1.58	2.12	1.95	1.98	2.12	1.96	1.78	1.56	17.59
D	0.46	1.69	1.85	2.10	1.89	1.57	2.00	1.67	0.25	0.88	14.37
E	3.44	1.68	0.14	1.73	1.07	1.49	2.54	2.55	2.25	2.04	18.92
F	3.48	1.60	0.34	1.70	0.93	1.55	2.56	2.64	2.36	2.21	19.37
G	1.60	1.96	2.00	1.85	1.77	1.38	2.00	2.42	1.33	0.53	16.83
H	3.11	1.21	2.00	1.58	1.88	1.41	0.82	0.00	0.21	1.73	13.95
Total	17.58	12.09	11.38	13.42	13.07	12.60	16.58	15.35	10.81	12.29	

when the road network condition has informed to people. Some Yij has changed. Form the Minamichita zone, Yij of hospital A decrease. The other hand, one of hospital C,E,H increase. People will select the nearby hospitals because they recognize the road network condition.

Table 4 shows the result of the transport risk in the uninformed case. Minamichita has the highest transport risk. Because Minamichita is located in the southeast of the Chita Peninsula, many hospitals are far from the area. Hospital A has the highest transport risk. Because hospital A is located at the center of the Chita Peninsula, many people may come from all over the area.

Table 5 shows the transport risk in the informed case. Because people will be forced to detour, the transport risks of 5 zones are raised. However, the transport risks of some zones are down. Some people avoid to select far hospitals.

Table 6 denotes the medical over-capacity risk in the uninformed case. Because much human damage by tsunami attack is estimated, Minamichita is a high-risk area for human damage. Many people will go to hospital C from the Minamichita area.

Table 7 shows the medical over-capacity risk with the EEWS improvement in uninformed case. The relative risk of human damage is changed with the decreasing number of tsunami victims. For example, the relative risk of Minamichita goes down from 0.37 to 0.30. On the other hand, the relative risk of the Handa area increases from 0.16 to 0.18. It does not mean that the victims in the Handa area increase, but the victim ratio goes up. The total injured number of people will decrease. Comparing both cases, the medical over-capacity risk of some hospitals is changed. Because of decreasing the relative risk of human damage of the Minamichita area, the medical over-capacity risk of hospital C decreases.

Table 8 denotes the medical over-capacity risk in the informed case. As people get the road network information, the risk of hospital A and H are decreased. Hospital A and H are located near the sea. People have to avoid the damage roads by tsunami attack.

Table 9 shows the medical over-capacity risk with the EEWS improvement in uninformed case. Some variation can be shown. Especially, the risk of hospital H is a lowest of those all cases. This is because the decease of the tsunami victims by EEWS and the avoidance of going to the hospital near the sea.

Table 10 shows the result of the medical over-capacity risk and the ratio of bed number. We refer to the bed number as the scale index of hospitals. Comparing with the results and ratio of bed number, the medical over-capacity risk of hospital C, E, F and H are higher than the ratio of bed number, whereas the hospital A, B, D and G are lower. Although those hospitals have many beds, they are located far from the high-risk area.

Table 6 Medical over-capacity risk (uninformed case)

Zone / Hospital	Minami chita	Mihama	Taketoyo	Tokoname	Handa	Agui	Higashiura	Oubu	Tokai	Chita	*Total*
A	0.04	0.01	0.01	0.02	0.02	0.00	0.00	0.00	0.01	0.01	0.13
B	0.00	0.01	0.00	0.01	0.02	0.00	0.01	0.00	0.01	0.01	0.08
C	0.09	0.02	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.17
D	0.00	0.01	0.00	0.01	0.02	0.00	0.01	0.00	0.01	0.01	0.08
E	0.07	0.02	0.01	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.16
F	0.06	0.02	0.01	0.02	0.03	0.00	0.00	0.00	0.00	0.01	0.15
G	0.02	0.01	0.01	0.02	0.02	0.00	0.01	0.00	0.01	0.01	0.10
H	0.08	0.02	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.14
Relative Risk of human damage	0.37	0.10	0.06	0.13	0.16	0.03	0.03	0.02	0.05	0.05	

Table 7 Medical over-capacity risk of proposed system (uninformed case)

Zone / Hospital	Minami chita	Mihama	Taketoyo	Tokoname	Handa	Agui	Higashiura	Oubu	Tokai	Chita	*Total*
A	0.03	0.01	0.01	0.03	0.02	0.00	0.00	0.00	0.01	0.01	0.13
B	0.00	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.01	0.01	0.08
C	0.08	0.02	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.16
D	0.00	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.01	0.01	0.09
E	0.05	0.02	0.01	0.02	0.03	0.01	0.00	0.00	0.00	0.00	0.15
F	0.05	0.02	0.01	0.02	0.03	0.01	0.00	0.00	0.01	0.01	0.15
G	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.00	0.01	0.01	0.10
H	0.07	0.02	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.14
Relateive Risk of human damage (improvemnt)	0.30	0.11	0.07	0.14	0.18	0.04	0.04	0.02	0.05	0.05	

Table 8 Medical over-capacity risk (informed case)

Zone / Hospital	Minami chita	Mihama	Taketoyo	Tokoname	Handa	Agui	Higashiura	Oubu	Tokai	Chita	*Total*
A	0.03	0.01	0.01	0.03	0.02	0.00	0.00	0.00	0.00	0.01	0.12
B	0.00	0.01	0.00	0.01	0.02	0.00	0.01	0.00	0.01	0.01	0.08
C	0.10	0.02	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.17
D	0.00	0.01	0.00	0.01	0.02	0.00	0.01	0.00	0.01	0.01	0.08
E	0.07	0.02	0.01	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.16
F	0.06	0.02	0.01	0.02	0.03	0.00	0.00	0.00	0.00	0.01	0.16
G	0.02	0.01	0.01	0.02	0.02	0.00	0.01	0.00	0.01	0.01	0.10
H	0.08	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.13
Relative Risk of human damage	0.37	0.10	0.06	0.13	0.16	0.03	0.03	0.02	0.05	0.05	

Table 9 Medical over-capacity risk of proposed system (informed case)

Zone / Hospital	Minami chita	Mihama	Taketoyo	Tokoname	Handa	Agui	Higashiura	Oubu	Tokai	Chita	*Total*
A	0.03	0.01	0.01	0.03	0.02	0.01	0.00	0.00	0.01	0.01	0.12
B	0.00	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.01	0.01	0.09
C	0.08	0.02	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.16
D	0.00	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.01	0.01	0.09
E	0.06	0.02	0.01	0.02	0.03	0.01	0.00	0.00	0.00	0.00	0.16
F	0.05	0.02	0.01	0.02	0.03	0.01	0.00	0.00	0.01	0.01	0.16
G	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.00	0.01	0.01	0.11
H	0.07	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.12
Relateive Risk of human damage (improvemnt)	0.30	0.11	0.07	0.14	0.18	0.04	0.04	0.02	0.05	0.05	

4. DISCUSSION

We can observe the difference in the medical over-capacity risk for the normal and the EEWS warning situation. Especially, the medical over-capacity risk of some hospitals located near the water decreases. The improvement of initial behavior will avoid the over-capacity in the particular hospital.

The transport risk is shown for each zone and hospital. In addition, the medical over-capacity risk is not in proportion to the scale of the hospitals. It needs countermeasures for the high-risk zones and hospitals. For example, if the medical ability of the hospitals near the water is reinforced, the injured can avoid transport for a long time. The hospital select coefficient *Yij* is only decided by the distance *Dij*. In future, one should consider how to select the hospital by a questionnaire survey.

Table 10 Medical over-capacity risk and ratio of bed number

Case / Hospital	uninformed		informed		Ratio of bed number
	Normal	Improve	Normal	Improve	
A	0.13	0.13	0.12	0.12	0.16
B	0.08	0.08	0.08	0.09	0.15
C	0.17	0.16	0.17	0.16	0.15
D	0.08	0.09	0.08	0.09	0.18
E	0.16	0.15	0.16	0.16	0.08
F	0.15	0.15	0.16	0.16	0.04
G	0.10	0.10	0.10	0.11	0.18
H	0.14	0.14	0.13	0.12	0.07
total	1.00	1.00	1.00	1.00	1.00

5. CONCLUSION

This study proposed a reliability analysis model for the medical transport activity considering the tsunami risk. The model includes a risk evaluation model to evaluate medical transport activity when the tsunami early warning system can be used. Our model can evaluate the influence of the road network condition.

Through applying it to the Chita Peninsula in Japan, the proposal model serves to implement the evacuation and medical transport planning.

Because we set the relative risk of human damage in our model, we cannot compare the absolute number of injured persons between the normal and the improvement case. If detailed data of estimate number about of the human damage are available, we can evaluate the relation between the acceptable number of hospitals and the number of injured people.

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