

Macroscopic Comparison of Infrastructure for Evacuation from Tsunami in Case of the Great East Japan Earthquake in 2011

Jun LEE¹, Kiichiro HATOYAMA² and Hitoshi IEDA³

¹Ph. D. Candidate, Dept. of Civil Eng., University of Tokyo
(7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan)
E-mail:lee@trip.t.u-tokyo.ac.jp

²Member of JSCE, Dept. of Civil Eng., University of Tokyo
(7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan)
E-mail:kii@civil.t.u-tokyo.ac.jp

³Fellow of JSCE, Professor, Dept. of Civil Eng., University of Tokyo
(7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan)
E-mail:ieda@civil.t.u-tokyo.ac.jp

In this study, we would like to suggest individual car as one of the possible escaping mode. For the research, we will focus on the car mode, and we will compare the level of infrastructure among the Tohoku regions. Key concept for the comparison is supply, Total Needed Distance (TND), should be bigger than demand, Total Available Distance (TAD) on the EASY (Evacuation Assessment Support sYstem) Chart. The Natori, Kesennuma, Yamamoto and Higashimatsushima are needed more shelters otherwise evacuee could not reach to refuge by walk and if they use car, it could be make congestions easily than other cities. The Kamashi, Rikuzentakata, Ofunato and Otsuchi, they also could not reach to refuge easily by walking, but they could use the car because of the lower population density. In this research, we would like to make general guidance for evacuation which based on the given conditions of refuge and population density as well as the traffic mode and trip distance. It could make a general recommendation for refuge plan and mode choice for escaping. Along the EASY Chart, we can compare what evacuation characteristics have among the various cities. It could be one of useful method to understand conditions of infrastructures and travel behaviors in the macroscopic level. However, this EASY Chart has some limitation for applying to real field because we use average values to derive the different characteristics. Depending on the average values, the sessions will be changed and the result could be different when we apply this Chart to more specific case.

Key Words: Car Evacuation, EASY (Evacuation Assessment Support sYstem) Chart, Total Needed Distance (TND), Total Available Distance (TAD), Tsunami Evacuation

1. INTRODUCTION

This disaster, March 11th 2011 in East Japan, make 92.4% victims by drown caused by Tsunami, it was a totally different aspect with Kobe earthquake which caused mainly shaking and collapses. This disaster had been broadcasted and we could see and feel how much Tsunami can have tremendous destructive power and wide effective area. As a lesson of this disaster, a great deal of attention has been directed to the topic of Tsunami disaster, and several researchers have been studied for evacuation from earthquake as well as Tsunami.

In this study, we would like to suggest individual car as one of the possible escaping mode. When we

find the emergency action plans (EAP), mainly the main mode for the evacuation has written the walk because of the serious congestion and uncertainty of road condition, or quick movement for emergency vehicles (Ministry of Land, Infrastructure, Transport and Tourism in Japan, 2011, Federal Emergency Management Agency U.S. Department of Homeland Security (FEMA) 2011, National Emergency Management Agency in Korea, 2012). Additionally there were so many reasons more why evacuee could not use a car instead of walk, and it looks like rational plans or unique strategies for the survival. However, reality was different from the Table 1, showed that the mode ratio for the evacuation after this earthquake among the cities in Tohoku area. In the case of

Table. 1 Mode Ratio for Evacuation in Tohoku Area (Data: 復興支援調査アーカイブ , N=9,559) ,

Name	Car	Others	Name	Car	Others
Yamamoto	0.94	0.06	Rikuzentakata	0.63	0.37
Rifu	0.90	0.10	Tanohata	0.61	0.39
Iwaizumi	0.90	0.10	Hirono	0.59	0.41
Hirono	0.89	0.11	Minamisanriku	0.58	0.42
Shinchi	0.86	0.14	Kesennuma	0.58	0.42
Iwanuma	0.86	0.14	Yamada	0.57	0.43
Watari	0.81	0.19	Otuchi	0.57	0.43
Kuji	0.79	0.21	Higashimatsushima	0.56	0.44
Minamisoma	0.78	0.22	Tagajo	0.54	0.46
Soma	0.78	0.22	Onagawa	0.52	0.48
Iwaki	0.75	0.25	Ishinomaki	0.52	0.48
Sendai	0.74	0.26	Shiogama	0.52	0.48
Natori	0.70	0.30	Miyako	0.49	0.51
Ofunato	0.69	0.31	Matsushima	0.41	0.59
Noda	0.64	0.36	Kamaishi	0.39	0.61
Shichigahama	0.64	0.36	Average	0.67	0.33

Yamamoto, evacuee of 94% used the car mode for evacuation and average value, 67%, is higher than 50%. If we pay more attention to the Rikuzentakata (63%), Otuchi (57%), Onagawa (52%), and Ishinomaki (52%) which are most serious damaged area, their mode ratio for the car is lower than average value. Of course, these results could not explain main causes of a mount of victims, but previous EAP did not cover these phenomena enough.

For the research, we will focus on the congestion of car mode, and we will compare the level of infrastructures among the Tohoku regions. We are interesting the macroscopic comparison and assumed that the mode ratio for car is bigger than 50% and also some specific regions could be a car as a main evacuation mode. Key concept for the comparison is supply, Total Needed Distance (TND), should be bigger than demand, Total Available Distance (TAD) on the EASY (Evacuation Assessment Support

sYstem) Chart.

2. EMERGENCY ACTION PLANS IN OTHER COUNTRY AND CHARACTREISTICS OF EVACUATION IN TOHOKU EARTHQUAKE

(1) Evacuation Action Plans

Usually only walking is accepted for evacuee as the escaping mode. In the case of MLIT (Ministry of Land, Infrastructure, Transport and Tourism in Japan), FEMA (Federal Emergency Management Agency U.S. Department of Homeland Security), and NEMA (National Emergency Management Agency in Korea) already published the EAP (Emergency Action Plan) and the main guidance are in Table. 2. To keep the roads open and clear for emergency vehicles, they recommend ‘do not drive’.

Table. 2 Emergency Action Plan for Individual Evacuee (Summary, MLIT, FEMA, NEMA)

<u>Prepared Manual for Earthquake</u>	<u>Prepared Manual for Tsunami</u>
During an Earthquake - Take COVER by getting under a sturdy table or furniture. - HOLD ON cover until the shaking stops. - STAY INSIDE until the shaking stops - If it is safe, GO OUTSIDE. - FIRE ALARMS may TURN ON. [Conditioned Reflex] - DO NOT use the elevators	After the Earthquake, Before the Tsunami - IMMEDIATELY MOVE to your local tsunami shelter area - If there are no routes, move to HIGHER ground A MILE inland - If your are already in a safe location, STAY there - Move on FOOT when possible. - DO NOT DERIVE - Keep roads open and clear for emergency vehicles

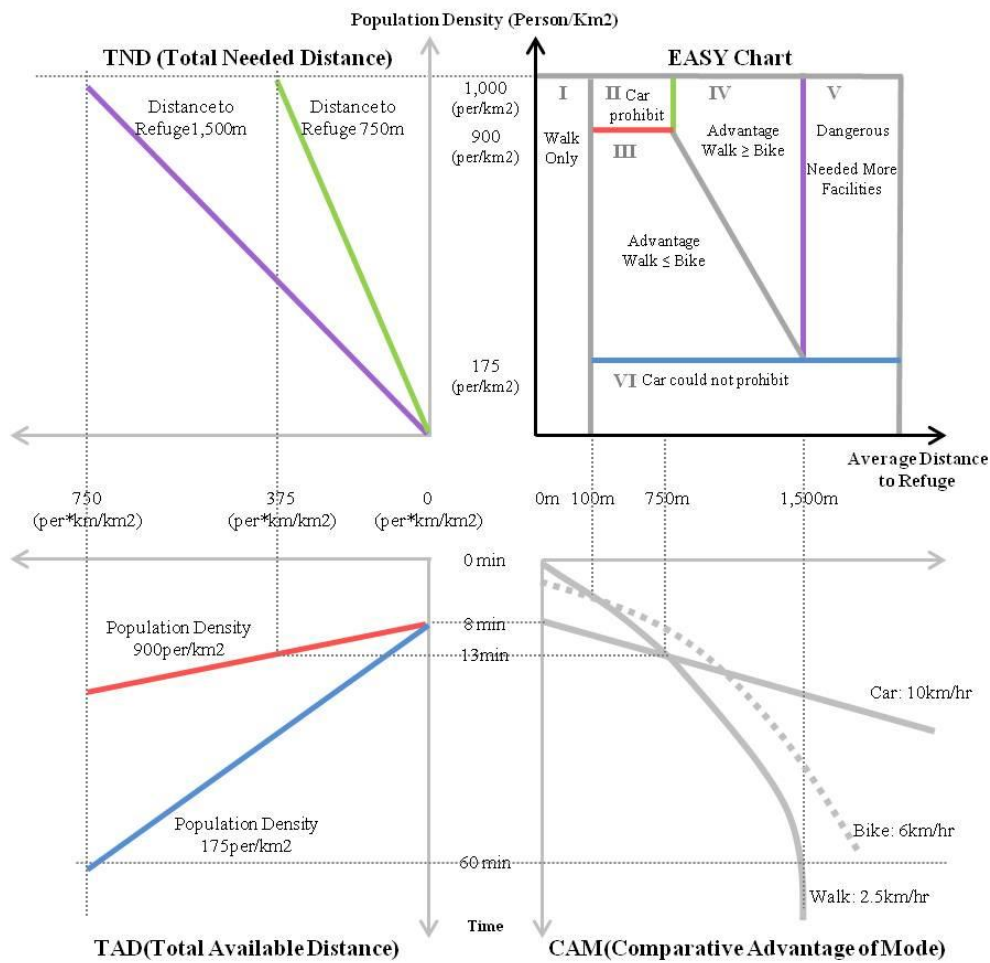


Fig.1 Concepts for EASY(Evacuation Assessment Support sSystem) Chart
Combined TND, TAD and CAM

(2) Characteristics of Evacuation

We would like to introduce the survey results conducted by MLIT (復興支援調査アーカイブ, 2012). In this report, the mode share for car was 55% and 60% of 30s used the vehicle for evacuation. 51% of car user did not have any problems for escaping when they drive. The main reasons of delaying among the car users (29%) were broken signal (12.5%) and traffic Jam (11.7%). When they escape, they wanted to escape with family (57.6% Rias, 56.8% Plain area) and they thought that the distance to refuge or safe area are too far away (50.4% Rias, 54.8%), so they choice car for evacuation. More than 50% of car user escaped more than 1,750m to find the safe area.

Given geographical conditions and distance to safe area could affect to mode choice, many evacuees use car because they could not reach to the safe area on foot and they could not escape alone.

3. EASY (Evacuation Assessment Support sSystem) CHART

(1)Effective parameters

When we drive the main parameters, we are focusing on the effects of traffic congestions and simplifying for easy application.

The first parameter is population density (per/km²) combined population and area of each region. The population includes various humanities and economic situation, and we can guess briefly the society, for example, humanities in high population density shows the huge community group and complex and variety work places, but economy in low population contains smaller size of financial support from government, low infrastructures and lack of road and so on. These are not always correct, however, there are no doubt that population density could be a useful parameter to explain various characteris-

tics of any society.

The second parameter is distance to refuge (average distance to official refuge). When we focus the movement of evacuation, intuitively escaping speed, time, and distance could be considered, however, speed and time could not be the permanent parameter and also it is very difficult to measure them. So we applied the average distance to refuge which is better to calculate from number of refuge and area.

The third parameter is mode ratio of car (cMR). When we assumed same capacity of road, the congestion could be different depending on cMR, however, in this chapter we assumed it 0.5 first and this value will be discuss again in chapter 4.

The sessions from I to VI came from the CAM (Comparative Advantage of Mode) between car and walk mode basically, which are shown in Figure 1 (EASY Chart). The deriving process will be shown in (2) ~ (3).

(2) Demand and Supply of Evacuation

The reasons of traffic congestions during the evacuation are not easy to explain using one or two aspects. So we tried to derive the basic capacity problems of infrastructures. That is comparison of demand and supply for evacuation road.

To conceptualize the demand we used TND (Total Needed Distance), which meant that how much distance evacuee need for escaping under given ADR (Average Distance to Refuge) in Equation (1a). Green line in Figure 1 is the TND line in case of ADR, 750m, $[375 (\text{per} \cdot \text{km}/\text{km}^2) = 750 (\text{m}) \times 1,000 (\text{per}/\text{km}^2) \times 0.5 (\text{mode ratio})]$.

TAD (Total Available Distance) meant that how much distance evacuee can use under given SC (Speed of Car) in Equation (1b). Blue line is one of TAD line in case of PD, 175 (per/km²), $[758 (\text{per} \cdot \text{km}/\text{km}^2) = 175 (\text{per}/\text{km}^2) \times 52 (\text{min}) \times 10 (\text{km}/\text{hr}) \times 0.5 (\text{mode ratio})]$

$$\text{TND} = \text{ADR} \times \text{PD} \times \text{cMR} \quad (1a)$$

$$\text{TAD} = \text{PD} \times \text{GT} \times \text{SC} \times \text{cMR} \quad (1b)$$

TND: Total Needed Distance (Person•km/km²)

TAD: Total Available Distance (Person•km/km²)

ADR: Average Distance to Refuge (m)

PD: Population Density (Person/km²)

cMR: car Mode Ratio

GT: Given Time for evacuation (min)

SC: Speed of Car (km/hr)

(3) Deriving EASY Chart

To clarify the characteristic of each session, divisions are derived from human availability and equal point between the supply and demand mainly.

There are two solid lines in CAM, Figure 1. Vertical Divisions in EASY Chart follow the cross points among the different modes and maximum walkable distance of human. If the refuge is within 100m, walk could be the best mode to access than the other modes. In the case of walk line, evacuee can start escaping without any preparation time, but the speed is not so high and 98% of them could not walk more than 1,500km within 1 hour because the walk depends on the human energy directly(復興支援調査アーカイブ, 2012). However, the evacuees who are using car needs more preparation time to star, but their speed is around 10km/hr. In ideal condition, before the 13min, walk has CAM, but, on 13min later and at 750m distance, car could have the CAM.

Horizontal Divisions are connected with TND and TAD. The first line could be derived by 13min and 375(per•km/km²), TAD in case of PD 900(per/km²) could cover TND in case of ADR 750(m). It meant that demand (TND) and supply (TAD) are equal in 13min for PD 900(per/km²) in case of ADR 750 (m). If ADR increases, TNS will change to left side and needed more high density of TAD to find equal point.

However, the TAD line will be changed by the CAM, which means that we are assumed the SC, 10km/hr, but if there are more cars, the congestion will be increased and the SC also will be decreased simultaneously. In chapter 6A, we will discuss this problem again.

4. INFRASTRUCTURES ON EASY CHART

(1) Escaping Distance with Portion of Modes

Before we discuss the characteristics of each session, we would like to review survey result conducted by MLIT (復興支援調査アーカイブ, 2012).

Table 3 Evacuation Distance

Portion	Walk	Car
90%	750m	5,000m
80%	635m	3,250m
50%	250m	1,500m
20%	125m	500m
5%	-	250m

Walk of 50% moves for evacuation within 250m, and those 90% are within 750m, while car used only 5% of trip for 250m, which are filled in Table 3.

(2) Definition of Sessions and Characteristics

(a) Session I (Walk Only):

The walk has great CAM than other modes until

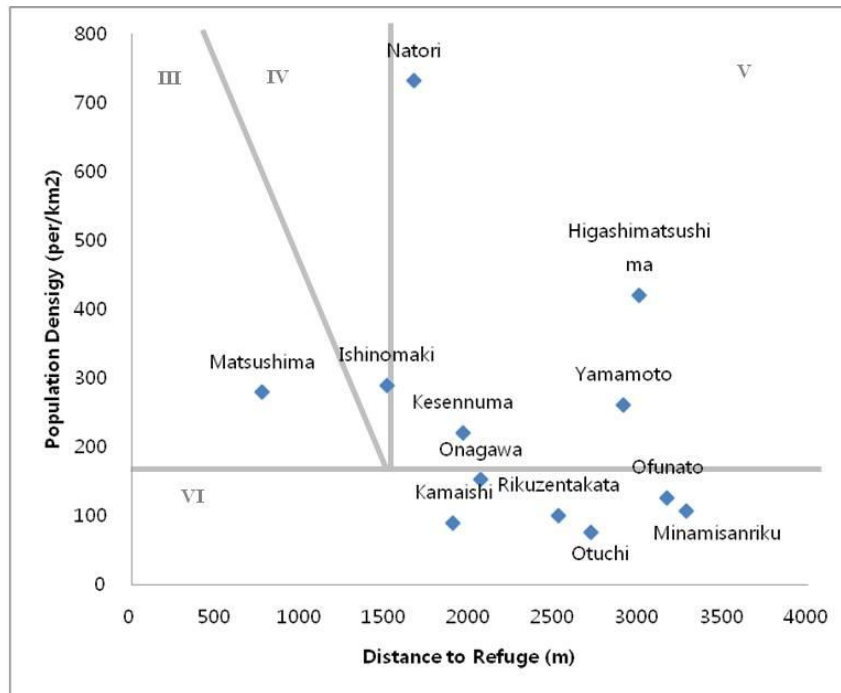


Fig.2 Result of City Level on EASY Chart

100m in Figure 1. If the evacuation distance is less than 250m, few people will use the car for escaping because only 5% evacuee used the car less than 250m in table 3. In session I, walk could be a main mode for evacuee naturally regardless of population density.

(b)Session II (Car should be prohibited):

It has high PD, and the walk has more CAM than car. If evacuees use cars as an evacuation mode, it could make serious congestion easily because of the high PD. However, the distance to refuge is less than 750m and it could be an available distance for walk. In this case, we lead people use the walk to reduce congestion so that roads should be used for emergency vehicles or special needs.

(c)Session III (Bicycle has CAM):

Bicycle could be a great alternative as an escaping mode, this mode is faster than the walk and reaching longer distance as well as we could throw away the bicycle when there are any problems to ride bicycle easily. However less than 1% of evacuee used bicycles for escaping and it might be people want to use car than bicycle when they could choice alternative mode. People can use more bicycles when we let people know the advantage of bicycles as the escaping mode.

(d)Session IV (Walk has CAM):

This session has very similar condition with session III, but main difference of this session contains the very high PD area. One of the essential reasons of

congestion in the high PD is highly mixed traffic modes along the report (復興支援調査アーカイブ, 2012). In the case of high PD, we could consider how to reduce the serious congestion even though the main mode is not a car.

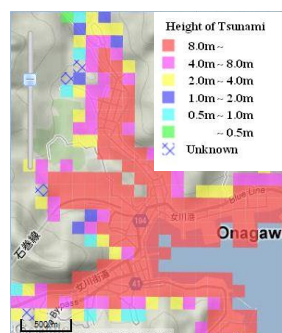
(e)Session V (Dangerous, needed more facilities):

This session has great problems basically, people might have difficulties to reach the refuge by walk, that is, evacuees have to use the car for evacuation and it might be a very vulnerable mode because there are no guarantees for the normal conditions of road after the strong earthquake. In fact, this session does not have any other alternative except cars, we do not know the road conditions as well as high PD will make serious congestion when every evacuee uses car mode. So we need more facilities like temporal refuges and constructing more roads for car users.

(f)Session VI (Car could not be prohibited):

Lower parts of session III and V made the session VI, which contains low PD and any distance to refuges. As a lower part of session III, the number of cars is not so high, and their speeds could not be affected by PD. As a lower part of session V, this session has same problems which have session V, but low PD could help their free evacuation mode because of less congestion. In this session, we do not need prohibit the car use for evacuation. However, in this session, we should consider safe evacuation route from Tsunami to survive during escaping under serious congestion.

Table 4 Details of Each City in Tohoku Region



Onagawa

(Death+Missing)/Pop: 8.53%

Num of Refuge/Area: 0.24

Mode Ratio Car: 52%

Live alone (>65 age): 12%

Pop. Density(Per./km²): 152



Otsuchi

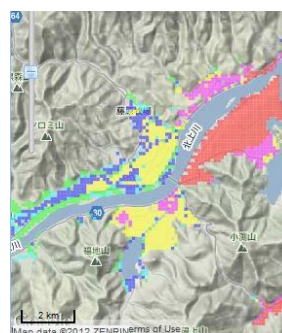
(Death+Missing)/Pop: 8.22%

Num of Refuge/Area: 0.18

Mode Ratio Car: 57%

Live alone (>65 age): 13%

Pop. Density(Per./km²): 76



Ishinomaki-

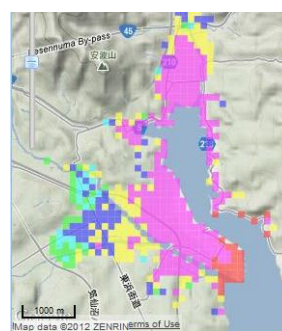
(Death+Missing)/Pop: 2.26%

Num of Refuge/Area: 0.33

Mode Ratio Car: 52%

Live alone (>65 age): 9%

Pop. Density(Per./km²): 289



Kesennuma

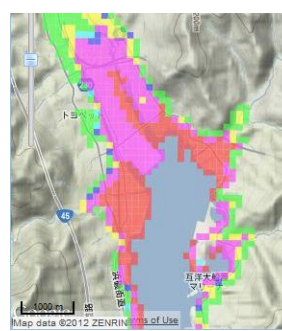
(Death+Missing)/Pop: 1.71%

Num of Refuge/Area: 0.26

Mode Ratio Car: 58%

Live alone (>65 age): 9%

Pop. Density(Per./km²): 221



Ofunato

(Death+Missing)/Pop: 1.05%

Num of Refuge/Area: 0.16

Mode Ratio Car: 69%

Live alone (>65 age): 9%

Pop. Density(Per./km²): 126

Data: Digital Japan Portal Web Site
Metropolitan Police Department
Ministry of Internal Affairs and Communications
Geospatial Information Authority of Japan
復興支援調査アーカイブ

5. COMPARISON

City level's results are shown in Figure 2 and 80% of cities in Tohoku region are located in session V and VI. The details of each regions are shown in Table 4. In this chapter we will discuss about the each city based on the detail information.

The Natori, Kesennuma, Yamamoto and Higashimasutshima (session V) are needed more shelters otherwise evacuee could not reach to refuge by walk and if they use car, it could be make congestions easily than other cities. The Kamashi, Rikuzentakata, Ofunato and Otuchi (session VI), they also could not reach to refuge easily by walking, but they could use the car because of the lower population density. However when we compare the death ratio, we should find various reasons of victims by detail information in Table 4.

(1) Onagawa and Otsuchi

In the case of Onagawa (session VI), and Otsuchi (session VI), the people who lived alone and aged (live alone > 65age) has difficulty to evacuation because of the long distance to refuge area (more than 2km). However the mode ratio of car is lower than the others in Table 1. So basically we could not reduce the victims who are aged and lived far away from shelters.

(2) Kesennuma and Ishinomaki

The PD of Kesennuma and Ishonomaki are similar but main difference is geographical condition. In the case of Kesennunma, the distance of official refuge is longer than Ishonomaki, but the damaged area in first one is very wide along the river while there are many mountains around the second one with in 500m. So they could escape to safe area in a short time.

6. DISCUSSIN AND CONCLUSION

In this research, we would like to make general guidance for evacuation which based on the given conditions of refuge and population density as well as the traffic mode and trip distance. It could make a general recommendation for refuge plan and mode choice for escaping. Along the EASY Chart, we can compare what evacuation characteristics have among the various cities. It could be one of the useful methods to understand given conditions of infrastructures and travel behaviors in the macroscopic level.

However, this EASY Chart has some limitation for applying to real field because we use average values

to derive the sessions from I to VI. Depending on their values, the sessions will be changed and the result could be different when we apply this Chart to more specific case. To apply this Chart to regional area, we should reconsider the each average values again.

Until now, EASY Chart could reflect only special case and it has considered only CAM, TND, and TAD as ideal conditions. However, we had to extend more reasonable situations and values to apply the small regions. EASY Chart could be changed flexibly and it could contain real problems more. In the future work, we should derive general cases for TAT (Tsunami Approaching Time), variations of speed and different mode ratio. When we derived the EASY Chart in this research, we assumed the same speed of car (10km/hr) and mode ratio (0.5) in chapter 3.

(a)Expected Reaching Time of Tsunami

Actually, we do not know exact inundation time from Tsunami, but we could predict the TAT, and it could be help we lead reasonable EASY Chart which contains time limitation. If one region has 5min of TAT, people do not have any options or alternatives for evacuation. They should walk or run to refuge or safe area and those distances might be within 100m, otherwise, many people could fail the evacuation. So EASY Chart will be divided into two groups: session I (walk only) and V (dangerous, needed more facilities). In the second case, if TAT is 30min, people can move until 1,500m on foot, but they could not reach 1,500m within 30min, so the division line between session IV and V will be move to left side.

Each area has different expected TAT, so vertical line will be changed along with predicted time.

(b)Variation of Speed

When we drive the EASY Chart in Figure 1, we

use 10km/hr, that is average speed of car and it is fixed for every PD. However, the speed of car could be changed by the PD which has great relationship with congestions. The relationship between density and speed of car might have negative non-linear correlation.

(c)Mode Ratio

When we drew the horizontal line in Figure 1, we supposed same mode ratio (0.5) in TND and TAD. Actually, if we use the same ratio at the same time, these lines could not be changed, but the value of mode ratio could be different along given condition of the topography or individual situations. Mode ratio of TND are derived by our assumption, evacuees will use car around 50%, but that of TAD will be affected by various condition, for example, the age of evacuee, road condition, ground level, and ownership of car. However, we did not contain these detail information for the macroscopic comparison and we could use any values in this time.

REFERENCES

- 1) Federal Emergency Management Agency (FEMA), www.fema.gov
- 2) Ministry of Land Infrastructure, Transport and Tourism (MLIT), www.mlit.go.jp
- 3) National Emergency Management Agency (NEMA), www.nema.go.kr
- 4) 復興支援調査アーカイブ, <http://fukkou.csis.u-tokyo.ac.jp/>
- 5) Digital Japan Portal Web Site <http://portal.cyberjapan.jp>
- 6) Metropolitan Police Department <http://www.keishicho.metro.tokyo.jp>
- 7) Statistics Bureau, Director-General for Policy Planning & Statistically Research and Training Institute, www.stat.go.jp
- 8) Geospatial Information Authority of Japan, www.gsi.go.jp

(Received July 31, 2012)