A Study on Evacuation Behaviors in the 2011 Great Japan Earthquake

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SUMMARY:
The authors studied relationships between place and time of evacuation, preparedness before disasters, and evacuation behavior and survival rate for both death/missing people and survivors in the 2011 Great East Japan Earthquake. In order to elucidate the human impacts, thousands of witnesses from Tohoku to Kanto area were analyzed. With a sample data number 1,153, this study's results show that earlier evacuation was positively associated with higher survival rate. This study also revealed that behaviors during the disaster differed for survivors and non-survivors. In addition, a comparative study was carried out the difference between the casualty in Banda Aceh in Indonesia during the 2004 Indian Ocean Tsunami and several typical affected areas in Japan. Based on these results, integrated strategies are proposed and discussed for the reduction of casualties in a future large-scaled natural disaster.

Keywords: 2011 Great East Japan earthquake, disaster mitigation, evacuation, 2004 Indian Ocean Earthquake

1. INTRODUCTION

On March 11, 2011, a gigantic earthquake of magnitude 9.0 struck off the Pacific coast of Tohoku, Japan and generated a huge tsunami that left 15,868 fatalities and 2,848 missing (The National Police Agency, August 22, 2012). Of the fatalities, over 90% of the dead drowned due to the earthquake-induced tsunami: Of the 13,135 fatalities recovered by April 11, 2011, 12,143 (92.5%) died by drowning, 578 (4.4%) were caused by crushing, 148 (1.1%) by fire, and 266 (2%) were unknown.

The Japan Meteorological Agency (JMA) monitors and forecasts tsunami height and arrival time in order to maximize time for evacuation and to reduce casualties, and warns all areas expecting severe events. The JMA released quick warnings on March 11, 2011: the first warning was within three minutes after the earthquake had occurred, and 28 minutes later as the second warning with the expected height of the tsunami being more than 10 meters. However, not everyone always evacuates. In addition, many persons went back to their homes before the tsunami completely ended.

Full preparation needs to be made against earthquake and tsunami since earthquake can occur anywhere in Japan. For the huge disasters, it is clear that a different approach is necessary. Instead of protecting against loss of life, the most important goal becomes trying to save as many lives as possible (Spence et al, 2011). The past studies provide few qualitative assessments, however, of how individuals behave during disasters.

The 2011 Great East Japan earthquake caused unprecedented damage to the people and the society of Japan. It will take a long time for the reconstruction of the damaged areas and recovery of normal lives. Nevertheless, we have to find future directions to create a society safer from and more secure against earthquakes and tsunamis based on the lessons from this disaster.

The purpose of this study is, therefore, to examine the four research questions, after a comparative study with the 2004 Indian Ocean Earthquake, that influenced the survival rate from the 2011 Great East Japan Earthquake: (1) safety of an evacuation site; (2) preparedness before disaster; (3) evacuation time; and (4) evacuation behavior differences between survivors and non-survivors.

1.1. Damages: comparative study on the 2004 Indian Ocean earthquake

Many researches and media mentioned the impacts and scenes of the above two disasters are similar to one another. Therefore, cross national and comparative studies provide a lens into the mechanisms used to understand, manipulate, or evaluate them in disaster consequences and its recovery.
As the 2011 Great East Japan Earthquake tragically demonstrated a rare and extreme tsunami event that might have caused thousands of fatalities. Most wooden houses on the flat affected area were entirely flooded. Reinforced concrete (RC) buildings were damaged, but it did not collapse. Also, a number of destroyed vehicles, ships, and houses were observed to be floating out on the road. Some of buildings and concrete bridges which located in the tsunami inundated area survived from the tsunami attack as shown in Figure 1.1. The concrete building shown in Figure 1.1 has a five-story, and the fifth floor was flooded. In other words, the water flew through the whole building. However, any structural damage to the super structure and concrete piles foundation was not found.

Figure 1.1. Survived a Five-story Concrete Building at Rikuzentakada, Iwate Prefecture in Japan(2011)

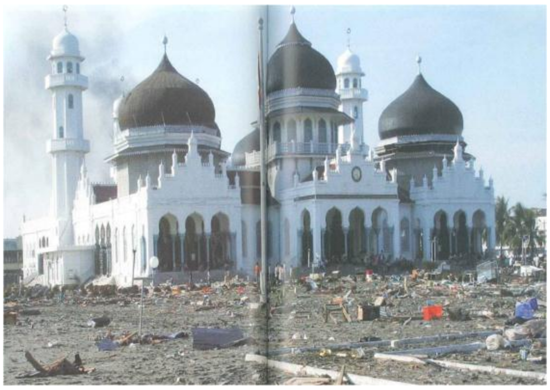

Figure 1.2. Survived the Baiturrahman Mosque, Banda Aceh in Indonesia (2004)

Same thing was observed in Banda Ache of Indonesia during the 2004 Indian Ocean Tsunami that devastated shores of the Indian Ocean (Mw 9.3 on December 26, 2004) and the number of victims was estimated 230,000. Figure 1.2 shows a survived mosque from the tsunami, which located along the shoreline. The examples of survived buildings shown in Figure 1.1 and Figure 1.2 suggest us a possibility of the construction of concrete buildings which can withstand tsunami attack. Then, when those kinds of characters apply to larger and taller building along the shoreline, the building can be a safe haven for evacuees from tsunami. Moreover, lots of bridges survived the tsunami as shown Figure 1.3. This bridge was constructed by steel girders with concrete slab for a road. The tsunami exceeded the bridge's height, but no structural damage was observed. Same thing was reported from the Indonesia in 2004. A concrete bridge in Band Ache shown in Figure 1.4 is also entirely survived from the tsunami. This bridge has concrete shear keys to prevent lateral movements of the girder, which might resist tsunami force. The examples shown in Figure 1.3 and Figure 1.4 also give us some insights into the possibility of the construction of bridges against tsunami.

Figure 1.3. Survived the Bridge in Japan (2011)

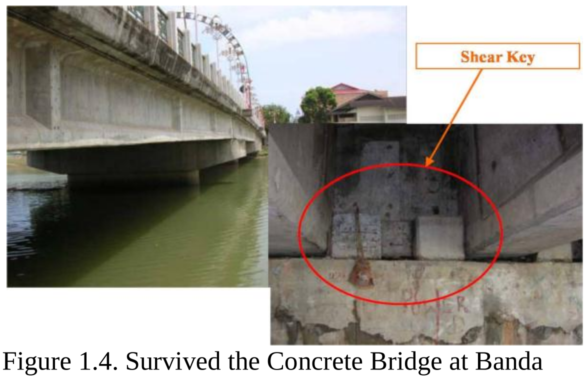

Figure 1.4. Survived the Concrete Bridge at Banda Aceh in Indonesia (2004)

Although the engineering effects of the earthquakes within the individual buildings have been extensively studied in recent years, little work has been done in documenting precisely how people behave during earthquake and tsunami. This study extends and complements previous research in disaster mitigation field by investigating behavioral perspective of evacuees during disasters.

2. THEORETICAL BACKGROUND AND RESEARCH QUESTIONS

Natural disasters such as earthquakes or tsunamis can cause extensive human and economic losses. It is argued that natural hazards are not catastrophic of themselves but only become so when they adversely affect human lives and assets. In order to reduce disaster loss and to break the cycle of disaster damage, mitigation plans form the foundation for a community's long-term strategy, reconstruction, and repeated damage (Hamada and Yun, 2011). The mitigation of deaths and injuries is a primary concern of all disaster prevention efforts (Spence et al, 2011).

Human behavior plays a significant role in natural disaster preparedness as well as in structural and non-structural preparedness efforts. These efforts could be linked to concepts of structural, locational, and operational risk mitigation (Scawthorn, 2002).

In particular, as illustrated in Figure 2.1, we examine (1) evacuation place safety -- to what extent do deaths have structural causes?; (2) preparedness before disasters -- what is the relationship between levels of disaster prevention education and survival rate?; and (3) evacuation time -- how do survivors and the dead and missing differ in the behavior of individuals in response to a warning or a ground shaking? In addition, we investigated (4) differences in behavior between groups of non-survivors and single survivor.

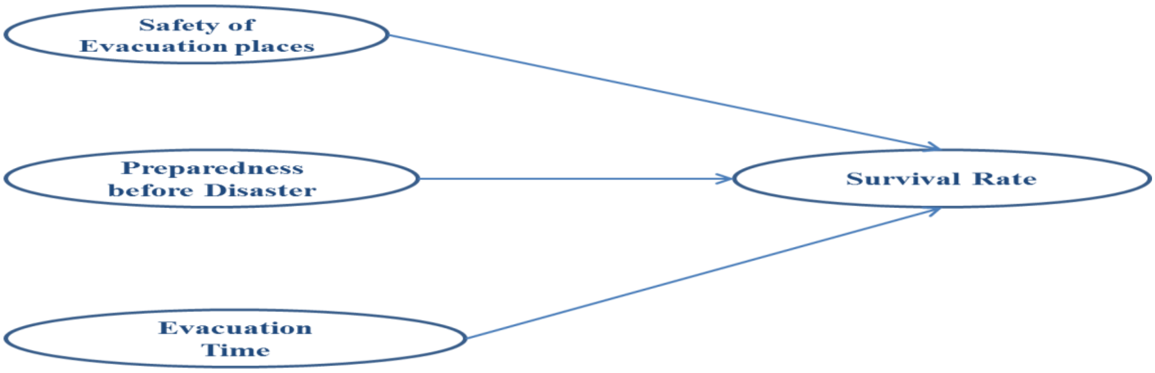

Figure 2.1. Research Model

2.1. Previous research evacuation

Evacuation rates, defined as the number of evacuees from the total population, vary from place to place for the same tsunami and from tsunami to tsunami for the same place. An overview of the tsunami in Japan since 1980, for example, illustrates results of surveys on the affected residents. Alarms were issued 28 times and four of these alarms were for warnings for tsunamis more than three meters in height. Evacuation rates did not, however, depend on the size of the disaster. It ranged from 1.1% in 1982 to 89.2% in 1993 (The Central Disaster Prevention Council, September 21, 2011). This shows that more comprehensive studies should be performed to understand evacuation behavior.

2.1.1. Studies of residents' behaviors in the 2011 Great East Japan Earthquake

There is no common agreement on evacuation rate because the 2011 Great East Japan Earthquake is still being investigated and analyzed. Interviews were conducted with 870 refugees from Iwate, Miyagi, and Fukushima Prefecture through joint investigation by the JMA, the Fire and Disaster Management Agency, and the Cabinet Office of Japan. Results of analysis revealed that there were 496 immediate evacuees and 267 delayed evacuees. 16 % evacuated because of the tsunami warning. Of evacuees, 31 % after some hesitation and 11 % of respondents who did not evacuate were not able to withdraw immediately. Out of total sample, 34 % went back to their home to look for or pick up family members, and 11 % believed that it was not possible for a big tsunami to come to their area,

given their past experiences or other reasons, such as the strong breakwaters in their areas. Some hesitant evacuees went to an undesignated location or to the upper floors of the same building.
This indicates that it is important to examine the place and time of evacuation, preparedness before disaster, and evacuation behavior, which is analyzed in this study.

2.2. Safety of evacuation places

An initial step in protecting human lives from a tsunami is evacuating to a higher place swiftly and autonomously, without hesitation, as soon as strong or an extended shaking is felt. It is also critical for evacuees to go to a safe place.
We therefore rank evacuation place safety and investigate the relationship evacuation place safety and the survival rate because there is no previous study of this relationship. Based on a guideline for tsunami evacuation buildings, higher and specified shelter is ranked with the highest score of 4 (see Table 2.2.).

Table 2.2. Safety of evacuation places level

Description	Degree
Higher and specified (Designated shelters on a hill /Headed for a specified high-rise building)	4
Higher and non-specified (non-specified high-rise building)	3
Not higher and specified (Designated shelters not on a hill)	2
Not higher and non-specified (Non-designated shelters not on a hill, possibly away from the ocean)	1

Hypothesis 1: There was a greater number of survivors that escaped to a safer or higher ground.

2.3. Preparedness before disasters

Ministry of Education, Culture, Sports, Science and Technology (MEXT) has been developing disaster education to foster the viability of disasters with three major efforts: effort in the nation, effort in the community, and effort in school. As a result, while the casualty is nearly 1,000 in Kamaishi and Kesennuma, 5 out of 3,244 children and 12 out of 6,054 students, respectively, are victims of the disaster.
More details are needed, however, because there are not enough resources for knowing what persons really do in preparing before a disaster to reduce death in future events. Since there was no existing scale to relate to the disaster preparedness, we made a five-scale table (see Table 2.3.).

Table 2.3. Preparedness before disaster level

Description	Degree
Participate disaster prevention training	4
Walk evacuation route	3
Know evacuation route	2
Know evacuation place	1
Unprepared	0

We assumed that if f persons prepared more than two activities listed in the Table 2.3, then the higher degree activity is chosen for the analysis.
Hypothesis 2: There was a greater number of survivors among persons who had prepared for disasters.

2.4. Evacuation time

Evacuation actions taken by residents are fundamental to human damage mitigation measures against disasters. Residents' disaster preparedness capabilities need to be enhanced and combined with other structural and non-structural aspects.
Evacuations have been studied under various categories and definitions and clearly some overlap of the concepts is present. In line with this, despite some of the differences among these concepts, many

scholars agree that early evacuation is vital for ensuring safety from tsunamis. The present study therefore does not deal with the arguments about definitions and scope in depth but rather with research concerning evacuation time and its resulting negative effect on the survival rate. In this study, evacuation time means the evacuation start time.
Hypothesis 3: There was a greater number of survivors among persons who evacuated quickly.

2.5. Evacuation behavior

Two distinguished behaviors -- frequency and types -- of the non-survivors and the survivors can be involved as potential factors explaining why some more than others become victims by disaster. That is, two groups may show significant differences in their behavior during disasters. Therefore, this study considers the role of behaviors explanation and tests those.
Hypothesis 4: There are significant differences in behavior types and behavior frequency between survivors and the dead and missing.

2.6. Survivor Vs. the dead and missing

In this study, survivor vs. the dead and missing as a dummy variable are used to measure how many survivors there were and defined the following:

$$\text{Survivor Vs. the dead and missing} = \frac{\textit{Number of survivor in inundated place}}{\textit{Sum of survivor and the dead and missing in inundated palce}}$$

For inundated place information, data respond to prefecture classification (e.g., Miyagi prefecture). In order to analyze the purpose of this study, comment about survivor is marked as ‘1’, and one about the dead and missing is marked as ‘0’.

3. USE WEATHERNEWS DATA

To test the four research questions in depth with a bigger sample size, we received and analyzed two datasets from Weathernews. The main reason we used existing Weathernews data was to avoid redundant surveys and to analyze massive data from Japan nationwide.
Weathernews, a company that specializes in dealing with disaster data, conducted several surveys and collected vast amounts of data using the Internet and mobile web sites.

3.1. Data for hypothesis 1, 2, and 3

We received data and utilized them for our purpose of study. In addition, this study analyzed gathered witnesses’ full text comments about the dead and missing in the five prefectures affected – Miyagi, Iwate, Fukushima, Ibaraki and Chiba. The focus of the present study is on the death toll because of the huge number of deaths in a widely inundated areas -- 56㎢, 62 cities, 6 prefectures -- is still in ongoing classification (Geospatial Information Authority of Japan).

3.1.1. Survey period and target areas and questionnaire
5,296 data including 1,998 witness’ statements for the dead and missing were collected from May 18, 2011 to June 12, 2011. The survey we used asks and provides not only survivors but also the stories of the dead and missing, including their behavior during the disaster.

3.1.3. Participants
Reflecting a response rate of 53% for the current study, 2,500 fully unanswered questions were excluded, and 2,798 items of data were used. Since the purpose of this study is to analyze differences between survivors and the dead and missing, we mainly analyzed 1,153 data in an inundated area – 522 survivors and 631 dead and missing (Table 3.1) regardless of inside buildings or outside when the earthquake hit with major shaking.

Table 3.1. Target data in an inundated area

Category		Survivor	Death	Survivor Ratio (Number of people)
Inundated Area	In building	299	415	41.9% (714)
	Outside	223	216	50.9% (439)
Inundated Total		522	631	45.3% (1,153)

3.2. Data for evacuation behavior analysis

3.2.1. Survey period, target areas, and questionnaire

From March 14, 2011 to May 10, 2011, information was gathered from 88,604 witnesses from Tohoku to Kanto. At first, 9,136 items of data from the Tohoku area were reviewed, but 6,549 were excluded because there was no information about any behavior. The survey questionnaire includes 20 items: 17 questions with 2 open-ended questions to measure participants' perceptions during the disaster; and Prefecture, gender and age information are included.

3.2.2. Participants

Approximately 10% (9,136) of total 88,604 data was gathered near the coast of Aomori, Iwate, Miyagi, Akita, Yamagata, and Fukushima prefectures. Participants were male (39.1%) and female (60.9%). Regarding the age, 6.9% people were less than 19 years old, 37.8% were 30-39 years old, 25.7% people were between 40-49, 21.0% were 20-29 years old, 7.3% were 50-59 years old, and 1.4% people were older than 60 years old. Due to usage mobile and the Internet site for data, aged persons, especially over 60s, rarely use it. The number of aged persons in this study is therefore few.

4. RESULTS OF ANALYSIS

In this paper, evacuation-disturbance behaviors referred to as action that led a respondent's death because of obstacles preventing their fleeing to safe places. Some of the evacuation-disturbance behavior that was shown during the disaster was not evacuating and/or no action, evacuating too late, and/or being held back during evacuation. These were actions that led them to a path that brought major injuries or death. Success-induced behavior during evacuation, in contrast, had the opposite effect. A typical example for success-induced behavior is evacuating without hesitation.

4.1. Dealing data: text analysis

Open-ended responses in particular inform us about what occupants were doing and their reactions when the earthquake struck. To analyze numerous full-text comments, we ran a text mining tool in Japanese with selected key words. Based on the frequency of specific words that appeared in comments, we classified comments into five groups. In order to figure out and classify meaningful sentences, key words and key sentences are gathered. This study analyzed 107 selected comments regarding the dead and missing in the five prefectures. An expert in this field extracted 183 meaningful words and/or sentences from the comments. Comments were classified into groups of evacuation-disturbance behavior, success-induced behavior, reporting self or environment, concern and condolences, and thanks to people or God. Table 4.1 presents results concerning the types of comments, and 7.2% did contain any meaningful actions.

Table 4.1. Analysis of comments

Comments (4,450 from Tohoku area)	Frequency
Reporting about oneself or the environment	90.9%
Gratitude for the help received & for God saving them and their family	1.2%
Concerns and condolences	0.7%
Success-induced behaviors	3.7%
Evacuation-disturbance behaviors	3.5%

Figure. 3. Illustrates the three steps of analyzing documents: (1) an expert in this field read and selected key behavior for non-survivors and survivors; (2) grouping of the key words and sentences into two groups; and (3) sorting ranks into each of the behaviors within the two groups based on frequency. Based on this study, furthermore, it extends to future research: ranking of key behaviors regarding to regions, other conditions such as tsunami height, experiences of past tsunami, and clarification of important behaviors for survival.

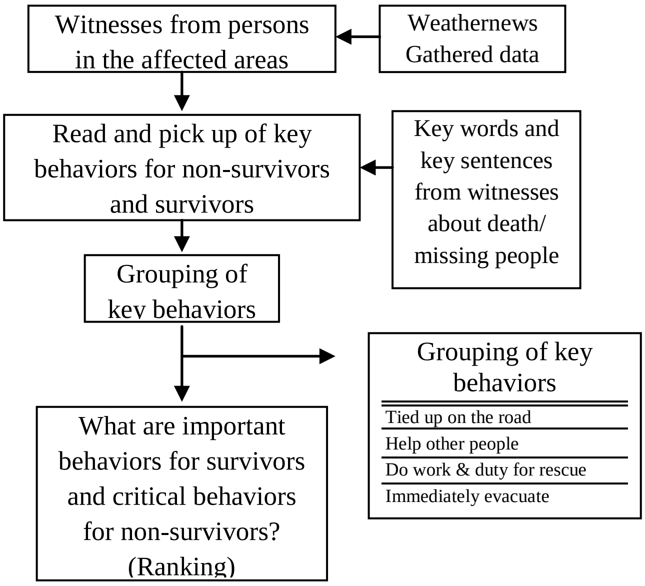

Figure. 3. Analysis flow of data

4.2. Results of analysis

4.2.1. Descriptive Analysis

Regardless of who was inside or outside a building when the earthquake hit with major shaking, we mainly analyzed 522 survivors and 631 the dead and missing in an inundated area.

Table 4.2 presents the results of age analysis between survivors and the dead and missing. We can see that vulnerable age groups of those more than 50 years old more easily became victims.

Table 4.2. Age analysis

	Sample in this study		Actual Death/ Missing in 3 Prefectures
	Survivors (N_S=464, excluding 58)	The Dead and Missing (N_D=479, excluding 152)	
-19yrs	8% (38)	4% (20)	6% (885)
20-29yrs	18% (81)	10% (47)	3% (515)
30-39yrs	37% (172)	15% (72)	6% (847)
40-49yrs	24% (113)	3% (12)	7% (1,116)
50-59yrs	10% (45)	22% (107)	12% (1,883)
60-69yrs	2% (9)	21% (100)	19% (2,945)
70yrs-	1% (6)	25% (121)	47% (7,140)
Total	100% (464)	100% (479)	100% (15,331)

There are differences between this study's results and those of other studies. Notably, the dead and missing aged 65 or older accounted for 46% -- this showed about 20% of differences from other reports because data in this study was gathered via mobile phone or the Internet. Other studies, in contrast, had different methods of gathering data, such as door-to-door questionnaires. It is therefore apt to be tilted toward younger respondents.

4.2.2. Safety of evacuation places

Table 4.3 shows the evacuation place safety graded based on Table 2.2, and there is not clear different among them.

Table 4.3. Safety of evacuation places result

Safety of Evacuation Places	Survivors (Ns=428, excluding 94)	Death/Missing (ND=172, excluding 459)
Higher and specified	29%(122)	38%(66)
Higher & non-specified	32%(138)	23%(40)
Not higher & specified	15%(66)	20%(35)
Not higher & non-specified	24%(102)	18%(31)
Total	100%(428)	100%(172)

4.2.3. Evacuation time

Table 4.4 presents the two groups' evacuation starting time, but there is no clear difference among them except for no evacuation. This reveals that the most important thing is initiating evacuation without hesitation. Out of total sample, 48% of the dead and missing did not or could not evacuate. This means that one in two persons who died in inundated areas did not evacuate.

Table 4.4. Evacuation time result

Evacuation Time	Survivors (Ns=505, excluding 17)	Death/Missing (ND=351, excluding 280)
Immediately	14% (71)	10% (36)
1-5 minutes	17% (84)	7% (23)
6-10 minutes	19% (94)	11% (38)
11-20minutes	17% (87)	8% (28)
21-30minutes	11% (56)	9% (32)
31-60minutes	8% (42)	6% (20)
61-120minutes	2% (9)	1% (2)
More than 120 minutes	1% (4)	1% (2)
No evacuation	11% (58)	48% (170)
Total	100% (505)	100% (351)

4.2.4. Preparedness before disasters

Based on Table 2.3, we graded and calculated data regarding descriptions of preparedness. Results are presented below in Table 4.5.

Table 4.5. Preparedness before disaster result

Preparedness (Ns=465, excluding 57; ND=307, excluding 324)	Survivors	The Dead and missing
Participate disaster prevention training	13% (66)	8% (49)
Walk evacuation route	4% (23)	2% (10)
Know evacuation route	9% (48)	6% (40)
Know evacuation place	10% (52)	15% (92)
Unprepared	53% (276)	18% (116)
Unknown/Blank	11% (57)	51% (324)
Total	100% (522)	100% (631)

We initially assumed two things: (1) participation in disaster prevention training is the most effective way of saving lives because it includes other activities (Table 2.2) and (2) if preparation had been greater, there would have been a higher rate of survival. As a result, walking evacuation routes was the most effective based on data.

4.2.5. Ranking of behaviors

According to the definition of evacuation-disturbance or success-induced behavior, frequencies of each of the behaviors groups were analyzed. Table 4.6 summarize ranks of the evacuation-disturbance or success-induced behaviors based on the frequency of such behaviors.

Table 4.6. Ranking of the negative behaviors and ranking of the positive behaviors

Rank	Ranking of the Negative Behaviors	Frequency	Rank	Ranking of the Positive Behaviors	Frequency
1	Tied up on the road (traffic jam)	26.3%	1	Immediately evacuated	52.5%
2	Help other people	22.4%	2	Follow other people's direction	39.4%
3	Do work and duty for rescue	13.9%	3	Remember former disasters	8.1%
4	Do not evacuate due to no/wrong information	13.7%			
5	Find family/relatives	9.7%			
6	Ignore warnings based on past experiences	8.9%			
7	Leave the assigned place	5.1%			

Based on Table 4.6, it is clear that initiating early evacuation is vital for safety in a tsunami. Moreover, some people who were not expecting a tsunami managed to evacuate as a result of having been verbally warned by those around them. Therefore, it is crucial for residents who could be affected by tsunamis to understand an importance of initiating early evacuation. Regarding evacuation-disturbance behavior in Table 4.6, despite tsunami warnings, many persons who were in plains did not have time to evacuate to higher places. Furthermore, it is important to stay in safe and assigned locations. After tsunami alarms were issued, persons relocated to refuges but then went back to their houses before the tsunami completely ended. Such evacuation-disturbance behavior led, however, to irreversible risk.

To summarize, Figure. 4 drew results of statistical analysis using SPSS 12 (Bryman and Cramer, 2005). It is necessary to interpret the results whether these are significant, considering above $p < .05$.

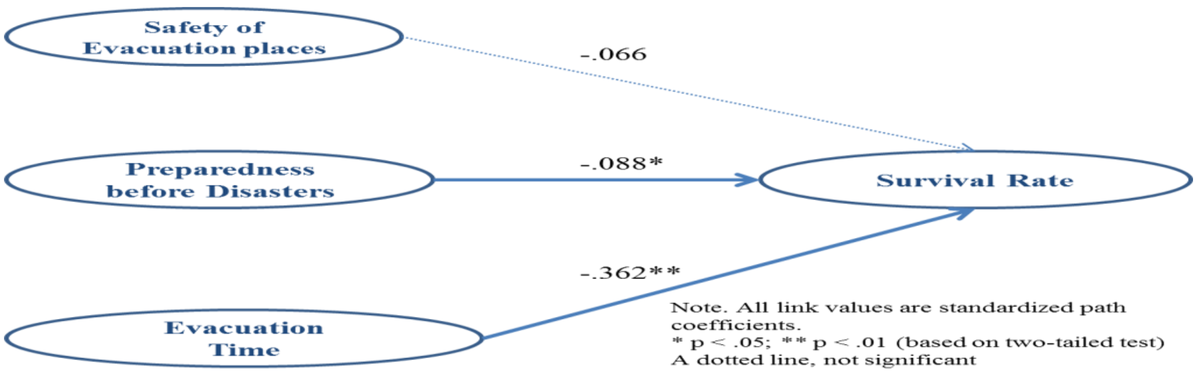

Figure 4. Results of Hypotheses

Hypothesis 1 was not supported. Safety of evacuation places was neither significantly no positively related to survival in this study (N=600, F=2.632, df=599, p=0.105). In spite of safe locations for evacuation, the time at which persons initiate evacuation is more meaningful under the disaster.

Hypothesis 2 was not supported. We tested models that showed opposite effects on survival (N=772, F=6.036, df=771, p<0.05). As was mentioned, it is most important to put knowledge – thoughts -- into action. As Goto (2011)[6] stated, "…almost all (of) the drills had focused to earthquake and fire." (p.1622) This could be one possible reason for the results in this study. It is necessary, moreover, to review disaster preparedness drill contents in a more detailed manner.

Hypothesis 3 was supported (N=856, F=129.110, df=855, p<0.05). For this study, it is necessary that evacuation time be reversed for analysis because earlier time has lower value than later time. The fact that the start time of evacuation was significantly and positively related to survival indicates that earlier evacuation has a positive impact on survival, especially during a tsunami.

In addition, Table 4.7 showed that the difference in behavior between those dead and missing and survivors is significantly distinguished. Hypothesis 4 was supported.

5. Discussion

Among points of convergence from prior mitigation efforts, the first was to examine the effect of place

safety, disaster preparedness, and evacuation time on the survival rate. Persons who started evacuation within 30 minutes reported greater survival rates. Safer evacuation place and better preparedness before the disaster, however, had no positive effect on survival in this study.
Fig. 5 shows the integration of disaster mitigation efforts. This is the first time that this was considered separately as disaster mitigation that has been scientifically described. It can be utilized as a first step and provide an integrated viewpoint for monitoring disaster mitigation planning for future disasters. The second was to investigate the difference of behavior between groups of the dead and missing and one of the survivors. After the analysis, success-induced behavior from survivors and evacuation-disturbance behavior from the dead and missing were extracted. Based on the frequency of these behaviors, ranks of behavior were provided. In addition, the difference in behavior between the two groups of the dead and missing and of survivors was significantly distinguished. It indicates that there were some behavior distinguished between survivors and non-survivors.
Although a tsunami warning was announced, there were cases of persons losing their lives due to traffic jams (Imamura and Anawat, 2012 [7]). Hence, it is necessary, moreover, to consider the smoothness of an evacuation plan using cars.
Instead of relying only on hardware approaches such as improving and strengthening buildings, disaster prevention emphasizes software approaches such as improvements in warning systems and a more thorough evacuation education. It is difficult to change human behavior, but the rewards are worth the effort.

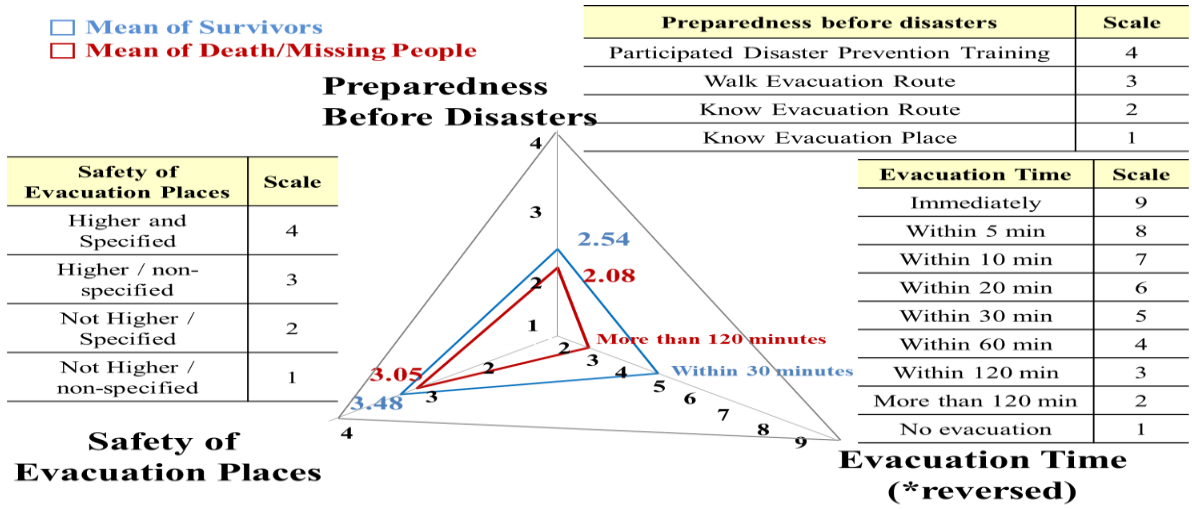

Figure 5. Result as integrated mitigation efforts

AKCNOWLEDGEMENT

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