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[Research Paper]

Household evacuation behavior during a Natech accident

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This study analyzed data on household evacuation behavior in terms of departure time, transportation use, and evacuation shelter selection during a Natech accident (natural disaster triggered technological accident) occurred at an industrial park in Sendai during the Great East Japan Earthquake and Tsunami, on March 11, 2011. The questionnaire survey was conducted to the households within 2.5 km of the Natech accident as a case study. The results indicate that some households carried out multiple evacuations for different reasons. We presented and analyzed the distribution of departure time according to respondents' evacuation reasons. Furthermore, we found that proximity to the disaster influenced households' use of transportations, but not the choice of evacuation shelters. Moreover, it is found that the departure time and the transportation use were different among the groups with different age. The findings of this study advanced knowledge concerning when, how and where households evacuated when the Natech accident occurred and can assist emergency managers to develop strategies for protecting people under such conjoint risks.

1. Introduction

Natural disasters can trigger chemical accidents resulting in fire, explosion or releases of hazardous material. Such conjoint accidents are known as Natechs (Natural-Technological accidents)[1)]. Natural triggers such as earthquake[2)]; hurricane[3)]; flood[4)]; and the tsunami of Great East Japan in 2011[5)] were documented in previous studies. In their works, they reported the severe consequences of the Natechs and investigated the specific features of scenarios. Moreover, Natechs threaten the lives and property of residents living close to the Natech hazards. For example, due to the Liquefied Petroleum Gas (LPG) leak during the Great Hanshin-Awaji Earthquake, 1995, 72,000 inhabits were recommended to evacuate[6)]. During the Kocaeli Earthquake, 1999, two Natech events in a refinery and a acrylic fiber production plant forced local authorities to evacuate the residents in a range of 5km of and 6km, respectively[7)]. Krausmann, et al [8)] reported that during the Wenchuan earthquake, 2008, 6000 residents near an ammonia factory needed to evacuate due to the releases of ammonia and sulphuric acid, etc. Even evidence has already shown that the Natechs may require evacuating large number of residents in a large scale, the study with detailed analysis of evacuees' behavior during a Natech is still limited.

Natech events may harm population either directly or indirectly. Salzano et al[9)]indciated that the direct effects may include fire, spread of toxic clouds or toxic fumes, environmental pollution and other events difficult to control after the strike of a natural disaster. Indirect damage may be caused by the overloading of emergeny system, the loss of critical supply lines that may hider and delay the rescue and recover operations. Futhermore, during a Natech accident, people may need to evacuate more than once due to the simultaneous natural events and technological accident.

To protect residents under such complex and uncertain situation, a detailed analysis of their evacuation behavior is required. With such information, emergency managers can develop efficient emergency plans to protect people under the risk of Natech accidents. In this study, we analyzed household evacuation behavior in terms of departure time, transportation use and the option of shelters. Data were collected from the randomly selected households within 2.5 km of the Natech accident occurred at a refinery in Sendai industrial park during the Great East Japan Earthquake and Tsunami (GEJET).

2. Study design

At 14:46 (Japan local time) on March 11, 2011, the most powerful earthquake in Japanese history and its triggered tsunami struck off the northeast Japan. This disaster is named as '2011 off the Pacific Coast of Tohoku Earthquake' or 'Great East Japan Earthquake and Tsunami (GEJET)'[10)]. The earthquake and tsunami struck the industrial park within the port of Sendai and triggered a series of severe Natech accidents. The only refinery in the northeast of Japan locating in the industrial park was severely damaged. The earthquake and/or tsunami triggered big fires in the west part of the refinery (see Fig.1), which involved asphalt tanks, a gasoline tank, molten sulfur tanks and the shipping yard[11)]. The fire started at 9:25 pm, March 11 and the fire was so big that personal from the refinery requested the authorities in Shichigahama town to evacuate residents immediately. After that, a series of evacuation orders was issued by Shichigahama town (9:25 a.m. March 12), by Tagajo city (10:26 a.m. March 12) and Sendai city (7:30 a.m. March 13). The fire lasted five days and the evacuation order canceled at 3:00 pm March 15.

To better understand how residents responded to the Natech accident, two field person-to-person surveys and one mail survey were conducted. The interviewees of the first two field surveys included 13 randomly selected residents within 3 km of the Natech accident, personal at the refinery[1], and the disaster

[1] ResTO-TerRiN Project: French ministry of ecology, sustainable development and energy (MEDDE) funded project, entitled Contribution to the Systemic Modeling of Technical and Organizational Resilience of a Territory to Natech Risk: from microscopic to macroscopic (2013-2016).

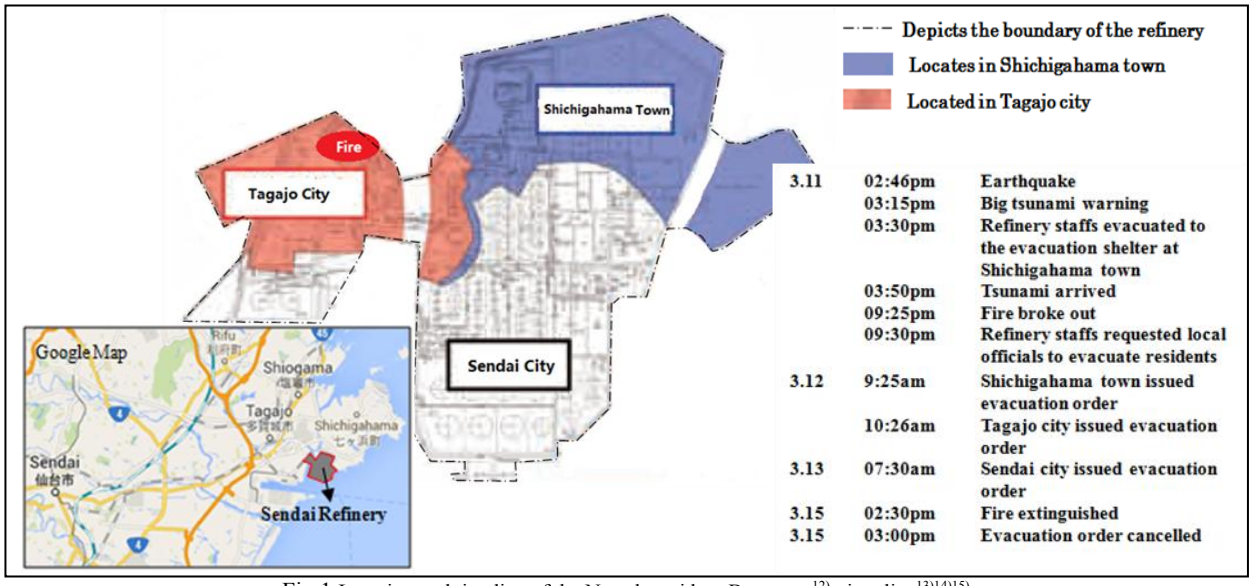

Fig.1 Location and timeline of the Natech accident Base map[12]; time line[13)14)15)]

management officer who experienced or were in charge of investigating the Natech accidents during GEJET. Based on the information collected from the interviews, a household survey questionnaire was designed and conducted from March 31 to May 25, 2014. Respondents were asked a series of questions on their risk perception, evacuation and reentry experiences. This study focuses on examining household evacuation behavior on departure time, and the use of transportation and evacuation shelters.

The sampling process consisted of a disproportionate stratified sample based on direction and distance from the Natech accident (Fig.2, a). The area was divided into 0.5 km concentric zones around the Natech accident and four quadrants (west, northwest, northeast, and east). We used the Zenrin Co., Ltd detailed address database as a sampling frame. The refinery physically located across three different jurisdictions: Tagajo city, Shichigahama town and the Sendai city. However, only the residents in the first two cities were sampled because there were no residents of Sendai city in our survey range. The initial sample size of 1,732 was reduced to 1,632 due to the 100 undeliverable questionnaires. The questionnaires were sent to 20 communities (see Fig.3). A total of 484 questionnaires were returned with a response rate of 29.4%.

To ease analysis, the number of returned questionnaires is presented in eight areas (see Fig.2, b, A1-A8). As indicated in Fig.2, 197 returned questionnaires from the areas locate within 1.5 km of the Natech accident (A1-A4); whereas 287 returned questionnaires from the areas between 1.5km and 2.5km (A5-A8). A1 and A4 returned the least number of questionnaires, whereas A3 and A7 returned the most. As indicated in Fig.3, only 4 communities were partly divided by the 1.5km line.

The questionnaire respondents were predominantly male (58%), the elderly (arithmetic mean, M=61 years), couples (37%), two generations (38%), and had a more than 20 years residency length (61%). Most respondents were house owners (90%) without the Natech training (88%) and Natech evacuation experience (99%).

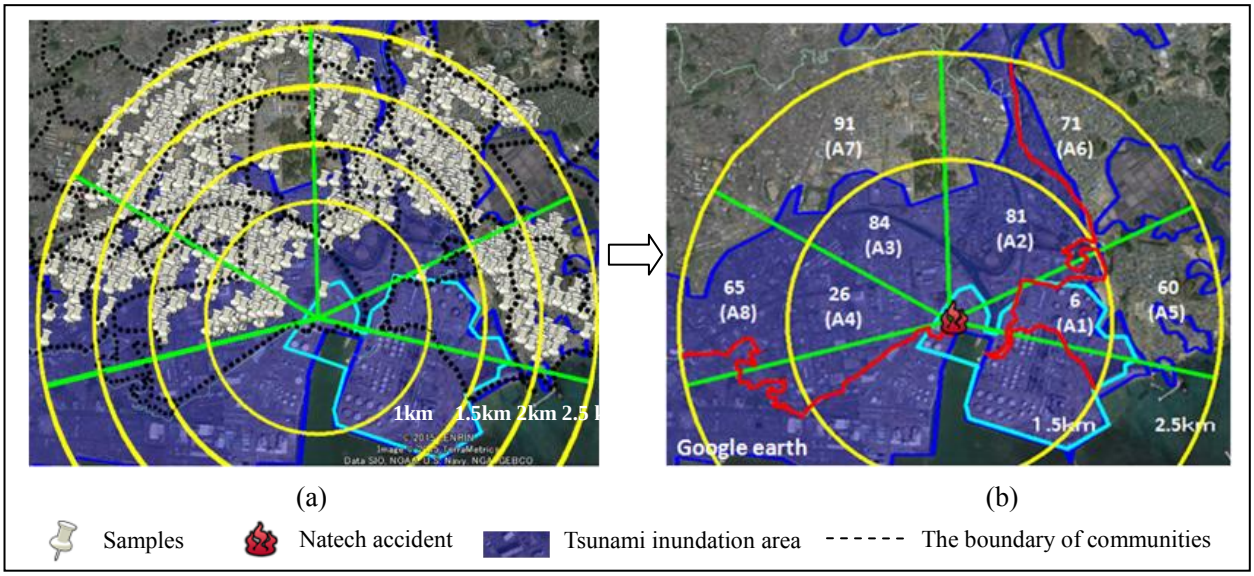

Fig.2 Distribution of sending (a) and responding samples (b)

Fig.3 the communities of sending samples

3. Results

3.1 Reasons for the multiple evacuations/relocations

In the questionnaire, respondents were asked to indicate the reasons for four times evacuations by providing a list of multiple options. As presented in Fig. 4, 311 respondents provided the reasons for their first evacuation, 149 provided for the second time of evacuation or relocation, 99 for the third time of evacuation or relocation and 41 for the fourth time of evacuation or relocation. Over half of them started their evacuation because of the earthquake (EQ) and/or tsunami (54%). More respondents indicated that they had to relocate more than once was because of the shelter problems such as the shelter was too crowed or the shelter lacked necessaries for the family members with special needs. Some of them also indicated that they were rescued by the Self Defense Force or being picked up by family members. During the four times evacuations or relocation, household behavior was influenced by the Natech accident in three ways: a. evacuating for receiving its evacuation order; b. evacuating for perceiving its environmental threat; and c. evacuating for the compound function of the EQ and/or tsunami and the Natech accident.

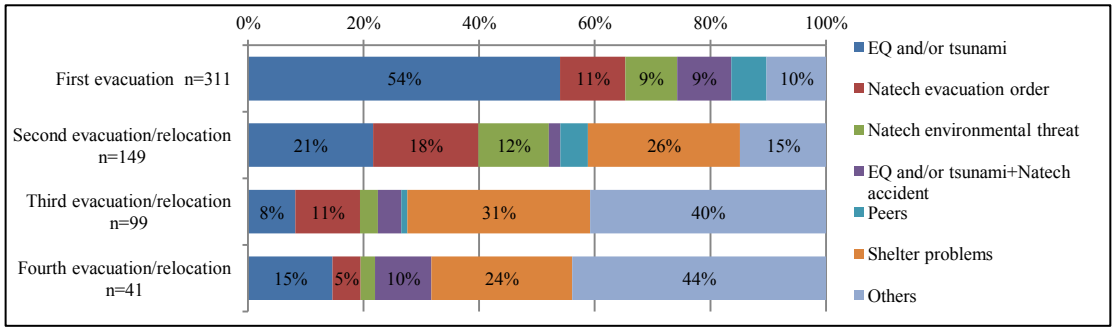

Fig.4 Reasons of multiple Natech evacuations/relocation

3.2 The location of evacuees

Table 1 summarizes the number and percent of respondent according to their evacuation behavior and Natech evacuation order receipt in eight areas as presented in Fig. 2 (A1-A8). Table 1 shows that respondents' evacuation behavior varied among the eight areas. Households in A1, A3, A4, and A8 evacuated mainly because of the EQ and/or tsunami. Households in A2 tended to evacuate owing to the compound function of the EQ and/or tsunami (18%) and the Natech evacuation order (18%). In A5, 27% of respondents evacuated owning to perceiving the Natech threat and 30% of them followed the Natech evacuation order. In A6, 32% of respondents complied with the Natech evacuation order,

whereas, 34% of them stayed. Most respondents in A7 (60%) indicated they did not evacuate for any type of disasters. Table 1 also shows that there were 166 respondents evacuated more than once and most of them from A2 (63%) and A3 (72%), respectively. Moreover, as indicated in Table 1, a highly proportion of respondents in A2, A5, and A6 received the Natech evacuation order. In contrast, other areas rarely received the Natech evacuation order.

In summary, evacuation disparities for the Natech accident exist based upon locations. More households in A2, A5 and A6 evacuated due to the Natech accident than the rest areas. The first reason may be the disparities of the tsunami impact. For example, households in A1, A3, and A4 may had had evacuated to the safe place when the Natech accident occurred, whereas households in A5 and A6 maybe at home when the Natech accident occurred. Another reason may be the disparities of the Natech evacuation order penetration, except A2, A5, and A6, households in other areas barely received the Natech evacuation order. According to our interview to the disaster officials in Tagajo city, the earthquake and/or tsunami damaged many outdoor warning facilities within few hours. Moreover, it was difficult for local authorities to notice residents door-to-door, because many roads were blocked or inundated by the tsunami. This may be the reason that many residents in the areas under the jurisdiction of Tagajo city did not receive the Natech evacuation order. This is very danger for the areas that were not affected by the tsunami but within the Natech influencing scope, such as A7. Households in A7 were under the risk of being affected by the explosion but many of them did not prepare for it.

Table 1 Number (%) of respondents by evacuation reasons, evacuation times and Natech evacuation order receipt by locations

	A1	A2	A3	A4	A5	A6	A7	A8	Total
Evacuation reasons									
EQ and/or tsunami	5(63%)	42(43)	55(60)	17(71)	15(21)	15(18)	29(34)	36(51)	214
Natech evacuation order	0(0)	18(18)	7(8)	1(4)	20(27)	26(32)	2(2)	1(1)	75
Natech environmental threat (own judgments)	2(25)	11(11)	7(8)	1(4)	22(30)	6(7)	1(1)	0(0)	50
EQ and/or tsunami& Natech	0(0)	18(18)	8(9)	0(0)	5(7)	7(9)	2(2)	0(0)	40
Did not evacuate	1(13)	9(9)	14(15)	5(21)	11(15)	28(34)	51(60)	34(48)	153
Total	8(100)	98(100)	91(100)	24(100)	73(100)	82(100)	85(100)	71(100)	532
Evacuation times									
Once	1(20)	25(37)	19(28)	11(58)	33(69)	22(51)	22(67)	16(52)	149
More than once	4(80)	43(63)	49(72)	8(42)	15(31)	21(49)	11(33)	15(48)	166
Total	5(100)	68(100)	68(100)	19(100)	48(100)	43(100)	33(100)	31(100)	315
Received the order	2(1)	36(25)	12(8)	4(3)	42(29)	40(27)	8(6)	2(1)	146

3.3 Departure time

Respondents were asked to indicate the time they started their evacuations. Fig.5 presents the departure time distribution of respondents who evacuated for EQ and/or tsunami, for receiving the Natech evacuation order and for perceiving the Natech environmental threats (own judgment). Fig.4 shows that 60% of respondents who evacuated for the EQ and/or tsunami left within one hour of the tsunami landing (2-4p.m.). For those decided to evacuate for the Natech accident based on their own judgment, almost 40% of them left between 7 p.m. and 8 p.m., March 11. During the night of March 11, 21% of Natech evacuation order compliers departed between 9p.m. and 10 p.m. when the Shichigahama town started to evacuate residents based on the request from the refinery staff. On March 12, 26% and 17% of respondents started to evacuate for the Natech accident after receiving its evacuation orders from Shichigahama town and Tagajo city at 9:25a.m. and 10:26 a.m., respectively. The evacuation rate also increased between 3 and 4 p.m.; however, after 4p.m. the number of departures become very low.

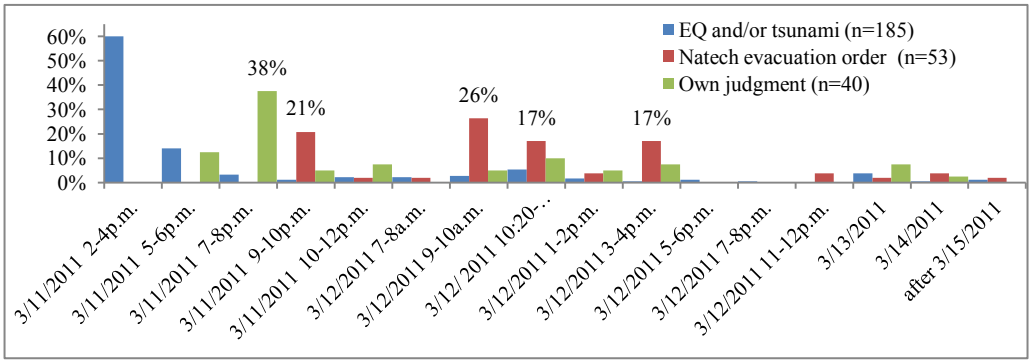

Fig.5 Departure time according to evacuation reasons

3.4 Transportation mode

In order to understand what transportation evacuees used to move to the evacuation shelter, respondents were provided the options such as personal cars, walking, rode with others (car pooling with friends/relatives or being picked up by officials), and others (bicycle and motorbike, etc). Results were listed in Table 2 according to the evacuation reasons and respondent's distance to the industrial park. Table 2 shows that 48% of respondents who evacuated because of the EQ and/or tsunami evacuated by walk, whereas 37% of them left driving personal cars. In comparison, most respondents drove their personal cars when they evacuated for the Natech accident either because of receiving its evacuation order (49%) or of perceiving its threat through its environmental cues (52%). Furthermore, we found that respondents living further from the coast (>1.5km) tended to walk to evacuate for the EQ and/or tsunami (57%); whereas those living closer to the coast (1.5-2.5km) tended to use personal cars. However, this tendency was not found for the groups that evacuated for the Natech accident.

Table 2 Transportation use according to evacuation reasons and the distance to the industrial park [N (%)]

	EQ and/or tsunami			Natech evacuation order			Own judgment		
	≤1.5km	1.5-2.5km	Total	≤1.5km	1.5-2.5km	Total	≤1.5km	1.5-2.5km	Total
Personal car	47 (43%)	24(29)	71(37)	7(32)	26(57)	33(49)	6(32)	17(68)	23(52)
Walk	46(42)	47(57)	93(48)	6(27)	11(24)	17(25)	4(21)	6(24)	10(23)
Rode with others	10(9)	8(10)	18(9)	5(23)	5(11)	10(15)	2(11)	1(4)	3(7)
Others	7(6)	4(5)	11(6)	4(18)	4(9)	8(12)	7(11)	1(4)	8(18)
Total	110(100)	83(100)	193(100)	22(100)	46(100)	68(100)	19(100)	25(100)	44(100)

3.5 Shelters Types

Respondents were asked to indicate their evacuation shelters. We summarized their answers and listed in Table 3, which are official shelters, friends/relatives' home, high ground, tsunami building, public places (shopping center and commercial buildings, etc), Japan Ground Self-Defense Force (JGSDF) Camp Tagajo, and others (convenience shop, and working place, etc). It was reported that during the GEJET, (JGSDF) Camp Tagajo was opened as the evacuation shelter due to the emergency situation, and accommodated more than 700 evacuees during the night of March 11[16]. Table 3 shows the shelter choice according to the evacuation reasons and respondent's distance to the industrial park. It indicates that no matter what reasons motivated respondents to evacuate and how far they were from the coast or the industrial park, official shelters were their first choice of sheltering in. The second large group was the respondents who went to their friends/relatives' home. Very few respondents sheltered in other places.

Table 3 the options of evacuation shelters according to evacuation reasons and the distance to the industrial park [N (%)]

	EQ and/or tsunami			Natech evacuation order			Own judgment		
	≤1.5km	1.5-2.5km	Total	≤1.5km	1.5-2.5km	Total	≤1.5km	1.5-2.5km	Total
Official shelters	63(56%)	62(67)	125(61)	13(52)	33(72)	46(65)	6(29)	22(76)	28(56)
Friends/relatives' home	25(22)	15(16)	40(20)	4(16)	3(7)	7(10)	6(29)	5(17)	11(22)
High ground	4(4)	5(5)	9(4)	0(0)	8(17)	8(11)	2(10)	2(7)	4(8)
Tsunami building	7(6)	1(1)	8(4)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
Public places	7(6)	2(2)	9(4)	0(0)	1(2)	1(1)	1(5)	0(0)	1(2)
(JGSDF) Camp Tagajo	3(3)	0(0)	3(1)	6(24)	0(0)	6(8)	4(19)	0(0)	4(8)
Others	3(3)	7(8)	10(5)	2(8)	1(2)	3(4)	2(10)	0(0)	2(4)
Total	112(100)	92(100)	204(100)	25(100)	46(100)	71(100)	21(100)	29(100)	50(100)

3.6 Age

Age might be a factor that influences respondents' departure time and transportation use. For example, many older people are vulnerable, thus, they may start their evacuation late or cannot drive a car to evacuate by themselves. However, older people may have more experience of evacuation or are more familiar with the hazards than younger people. Therefore, for the older people who have ability to undertake evacuation may depart early and drive personal cars. Fig.6 shows respondents' age according to their departure time and evacuation reasons. Results in Fig.6 indicate that older people departed earlier than younger people did for the EQ and/or tsunami at the beginning of the disaster (2p.m.-4p.m. 3/11). Forty-three percent of the respondents aged 71 and over evacuated at the early stage of the disaster, while only 17% of those aged less than 50 left during this time. Fig.6 presents respondents' age according to their use of transportation and evacuation reasons. Fig.7 indicates that the proportion of those using personal car to evacuate for the EQ and/or tsunami decreased with age. 30% of respondents with the age less than 50 years old evacuated by personal car, whereas 22% of those with age over 71 years old

did so. Furthermore, as indicated in Fig.7, the proportion of those evacuated by walk after receiving the Natech evacuation order increased by age, from 13% with the age less than 50 years old to 38% with age over 71 years old. However, this finding is based on a small sample (n=16), thus, further study should be conducted to testify it.

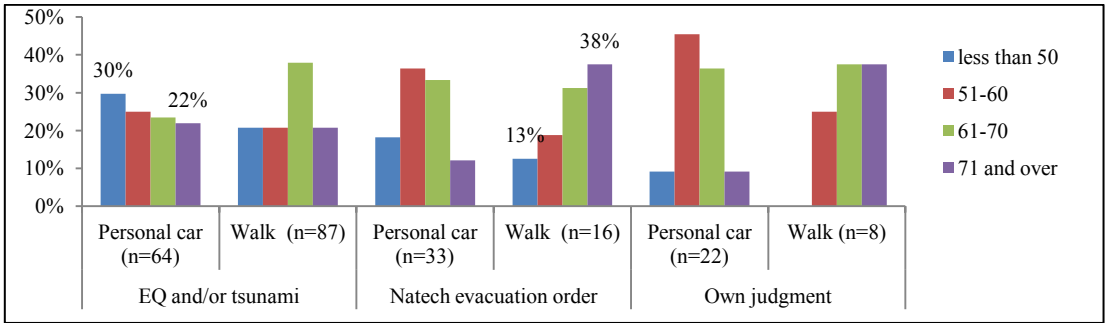

Fig.6 Respondents' age by departure time and evacuation reasons

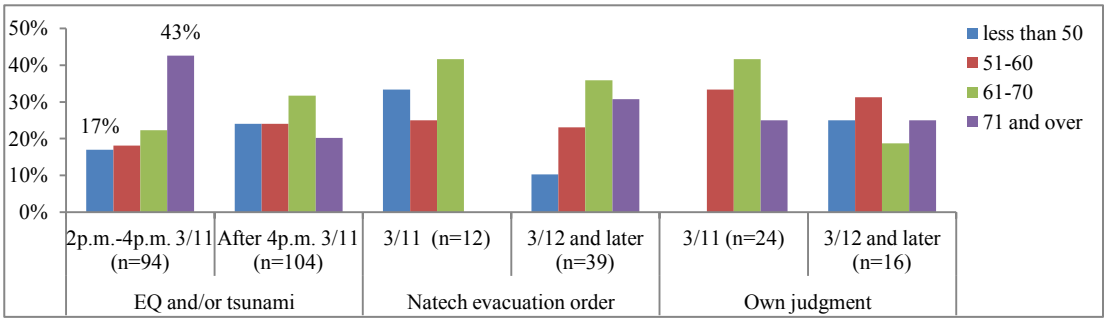

Fig.7 Transportation use by departure time and evacuation reasons

4. Conclusion

This study summarized and analyzed the findings of household evacuation behavior on departure time, transportation use and the choice of evacuation shelters in response to the Natech accident based on randomly selected samples following the Natech accident at a refinery during the GEJET. The evacuation behavior was discussed according to the evacuation reasons, the proximity to the disaster, and respondents' age. The findings about the behavioral information can assist emergency and transportation officials to develop evacuation plans for the Natech accident.

According to our study, the evacuation for the EQ and/or tsunami peaked within about one hour of the earthquake. 38% of respondents evacuated for perceiving the Natech accident departed between 7 and 8 p.m. on March 11. According to the report from Shichigahama town[14], black smoke from the refinery was observed at 5:10 p.m. March 11. Even though this was not dangerous enough to force local officials to issue the evacuation order, some respondents had had started to evacuate for it. For the group that evacuated because of receiving the Natech evacuation order, most of them departed within one hour after the evacuation order issued. To efficiently use the limited emergency resources, emergency mangers can make plans to coordinate and mobilize emergency team and resources according to the distribution of evacuation peak times.

Proximity to the coast was found to be related to the transportation use for the EQ and/or tsunami. Those who lived further to the coast were more likely to evacuate by walk. There is evidence that those lived close to the coast tended to take their own vehicles when they evacuated for the EQ and/or tsunami, but the difference was not much between distances. Further study should be conducted to examine this finding. Proximity to the Natech accident was not found to a factor that influence evacuees' options of transportation and evacuation shelters. Households were more likely to drive personal cars and shelter in the official shelters regardless of their distance to the Natech disaster. The high use rate of personal cars for the Natech evacuation may create pressures on the traffic system especially during the evacuation peak times. To avoid traffic jams during the evacuation, local authorities need strategies to discourage a large amount of residents evacuating at the same time.

Age influenced household departure time and transportation use. According to our results, older people tended to depart earlier then the younger people did. This is good news for the emergency managers who worry about the elderly are reluctant to leave home. Moreover, older people were found to be less likely to take personal car when they evacuated for the EQ and/or tsunami. Furthermore, older people tended to evacuate by walk after receiving the Natech evacuation order. However, the last finding needs further test due the small samples.

This study provides information about when, how and where households evacuated when the conjoint Natech disaster occurred. One limitation of this study is that most respondents in this study are house owners, thus, the behavior of renters are unknown. Lindell et al (2011) contended that most transients lack property to protect and they can remove their important belongings easily because they packed them to bring them into the risk area[17]. Future study should examine the evacuation behavior of this group. Another future study should examine the demand for official evacuation shelter space. According to the results of this study, the majority of evacuees went to the official evacuation shelters regardless evacuation reasons and distance to the disaster. However, the finding that many households had to evacuate more than once because of the

inconvenience in the public shelter suggests the need of creating additional capacity and services of official evacuation shelters.

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