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# BEHAVIOR PATTERNS IN MAJOR DISASTERS

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## ABSTRACT

Many factors have an influence on people's behavior in a disaster: age and gender, marital status, children, education, social networks, native to area or not, disaster experience, awareness of hazard and preparedness. All these affect the level of risk, the probability of casualty and the capacity to recover. During disasters, every second can be decisive but most people are unable to think clearly, and their decision-making is often illogical and irrational, or at best sub-optimal.

In Japan after the Great East Japan Earthquake (GEJE) and tsunami in 2011 the majority of deaths were caused by the tsunami that was much larger than had been anticipated and prepared for. Survival was largely determined by timely evacuation. Evacuation procedures are highly developed in Japan and people are drilled in evacuation from childhood. There is evidence that the vast majority of nationals evacuated successfully but that many evacuation centers were overwhelmed by the unprecedented size of the waves. The casualty rates amongst foreigners were as high as predicted by other similar events, but exceptionally, more men died than women. (Koyama et al, 2012)

This paper reports three pieces of research that explore evacuation after the 2011 event. The first is evidence of people's actual behavior in Yuriage-, Natori, one of the places badly affected by the tsunami, during the first hour after the warning. The second simulates evacuation behavior in the same place to better understand why so many people died. Finally a survey in Natori and Sendai cities and of students in Kyoto University questioned people's evacuation behavior and level of preparedness. One of the aspects studied is the difference between what people say they will do in a disaster and what they actually do in a real event. For example, in Japan many respondents said that they would run to a safe place, but in fact many people went home, often into danger, to seek and care for family members. People's assessment of risk and their actual reactions will be tested against a set of factors including, level of understanding and preparedness, gender, country of origin, dependent children or elderly relatives etc.

How people respond to the crisis and how they decide these issues will have important implications for government policy at a national and local level, since they determine, in part at least, how much government aid is needed and for how long. Different cultures and different places respond differently to disasters. One of the key aims of the study is to learn from the 2011 event to produce better evacuation guidelines for Japan and other countries facing tsunami risk.

## INTRODUCTION

Natural disasters have been around mankind since the beginning of the history. Volcanos, tornados, floods, earthquakes etc. are the symbols of the great power of earth. Japan is a good example of a country that has a high number of natural disasters. The recent major disaster in Japan occurred in March 11 and as Japanese National Police Agency reported, there were 15,878 deaths, 6,126 injured, and 2,713 people missing across twenty prefectures along the Tohoku east coast of country.

As an ongoing effort of human beings to improve the quality of life and resilience to the changing environment of the world, researchers, by studying the dynamics of the disasters and human

reactions, have focused on process of saving lives, as well as all the other aspects of disaster prediction and mitigation.

The aim of this research is to understand and model crowd behavior and analyse the differences between what people think they will do in an emergency and how they really act in an evacuation setting. By analyzing human behavior and time required for evacuation, it is argued in this paper, that one can predict the impact of future disasters for different urban societies and different geographic locations. Through understanding the main causes of high fatalities, researchers would be able to advise about devising plans to mitigate exposure and reduce the level of risk.

A survey of survivors in one settlement, Yuruage, one of the places affected by Great East Japan Earthquake, compares theory and practice – thinking and behavior – of nationals and foreigners, of men and women and a range of other socio-economic factors. A model was devised to simulate people's behavior in the minutes before the area was hit by the tsunami to explore the gap between real fatalities and what might have happened if people had made better evacuation decisions.

Finally, to better understand why people behave in apparently irrational ways in a crisis situation the authors report the findinsg of a survey conducted among the Kyoto university students.


## PEOPLE ACTUAL EVACUATION BEHAVIOR DURING TSUNAMI 2011

This section focuses on people's reaction In Yuriage, one of the places badly hit by the tsunami of 2011, after they heard the radio warning about the height and timing of the tsunami. The analysis is based on information from a NHK documentary and information collected through the interviews with survivors and communities on several field studies by the authors of this paper.

The Great East Japan Earthquake was not only the most powerful earthquake, known in the history of Japan, but also one of the most powerful earthquakes in the world, producing 5% of the global cumulative seismic energy released since 1900 (Witze, 2011). The epicenter was located in the east of Tōhoku with a depth of 32 km and the earthquake has affected almost 650 km of the Miyagi, Sanriku, Joban and Kanto coastline along the Pacific Ocean shores of Northern Honshu Island (Witze, 2011). A number of large foreshocks and hundreds of aftershocks are reported for the main earthquake. The main earthquake was followed by a major tsunami with an estimated wave height of 38.9 meters  waves reaching run up heights of up to 40.5 meters, and travelled up to 10 km inland in the Sendai area.

Our case study, Natori city of Miyagi prefecture, is located to the south of Sendai city. The followed the earthquake's main shock with a magnitude of 9.1 that arrived at the coast line in Yurage area of Natori city approximately one hour and nine minutes after the main earthquake occurred at 15:55 (JST) (Mahdavian  et al., 2012). Shaking lasted 4 minutes, electricity was lost in the first minute of shaking and immediately after the main shock the city faced a deep silence (NHK, 2011).

Yuriage area with total population of 5100 people was divided into seven districts of which districts number 4 and 5 were located right next to the shoreline, districts number 3 and 6 in the middle and districts number 1,2 and 7 to the west furthest way from the coast, shown in Fig.1. Tsunami inundation height was 8.81m as reported by Murakami et al. (2012) and residential areas completely washed away. In the Yuriage area the tsunami inundation zone extended approximately 4km inland from the coast, which made evacuation progress difficult for people who left it until the last few minutes.

Considering the gap between the main earthquake and arrival of tsunami waves, and the fact that it happened during daytime, it was expected that people in the affected areas should have been at relatively high disaster preparedness levels.  But in the first 10 minutes nobody tried to evacuate, then a few people, who were living in areas No 4 and 5 (nearest areas to coast line) left their homes to escape from danger, while most residents, especially those in areas far from the sea, started to run to a safe zone about half an hour after the main shock. (Murakami et. al. 2012)

Most interestingly we expected to see more fatality in the areas next to the sea. But Table 1 (Murakami et. al. 2012) shows that these two areas, 4 and 5, have the least human loss. The highest fatality ratio was for area No 2 which was almost the furthest from the coast line.

This finding is extremely important and raises questions and concerns about the evacuation and disaster preparedness planning in these areas. According to survivors' statements the 2010 Chile

tsunami, inundation did not go beyond the Teizanbori canal located between areas No 2 and 3 and shown as a blue line in Figure 1.

Table 1. Official number of fatalities and collapsed houses in Natori city and Miyagi prefecture

| Yuriage areas | Area1 | Area2 | Area3 | Area4 | Area5 | Area6 | Area7 |
|---|---|---|---|---|---|---|---|
| Number of human loss | 49 | 200 | 43 | 84 | 64 | 138 | 89 |
| Population | 667 | 895 | 356 | 755 | 533 | 1062 | 832 |
| Fatality ratio (%) | 7.3 | **22.3** | 12.1 | 11.1 | 12.0 | 13.0 | 10.7 |
| Ratio of elders - age over 75(%) | 11.8 | 14.6 | 17.3 | 16.5 | 7.4 | 9.7 | 4.9 |
| Ratio of houses washed away(%) | 21 | 81 | 100 | 100 | 96 | 90 | 91 |



Figure 1. Seven areas in Yuriage-Natori City, Teizanbori canal (blue line) and Yuriage area location  (Size of Yuriage is about 1.2 $Km^2$ to 1.4 $Km^{2)}$

Inhabitants of area No 2 were unaffected by 2010 tsunami. Consequently, many people in these areas, having the image of the 2010 Chile tsunami in their mind, did not take the warning of 2011 tsunami seriously, assuming that again this time, the tsunami would have a low inundation height. Accordingly, in 2011, many people delayed the evacuation and did not attempt to escape in time. However, the 2011 tsunami was much more severe than any previous tsunami in living memory and one and produced a much higher inundation compared to 2010 Chilean tsunami. It seems that people's background image from recent events clouds their judgment and affects their reaction when encountering a new event. It seems that being closer to the danger zone is a crucial factor in people's preparedness.

In addition there are other factors that play a vital role in critical moments. Multiple announcements on the radio about tsunami height – first 6 meters and then over 10 meters Murakami and Umezu (2011), spread doubt made people discredit the warning and cause critical loss of time. The second announcement, which indicated a higher inundation height, provoked people to relocate to second indicated safe zone. Some of them were hit by the tsunami and washed away because they lost time by obeying traffic rules and sticking in slow moving or congested traffic. The NHK documentary movie shows nearly all drivers were obeying the traffic rules in the main street, and not overtaking stationery vehicles in front of the evacuation center building, even in last few minutes before the arrival of the tsunami (NHK 2011).

The authors made several visits to the Natori city damaged area with a group of researchers from Kyoto University, Yamaguchi University and the EEFIT team. During these surveys, conducted in November 2012, June 2013 and September 2013, some of survivors of the tsunami were interviewed, and the results of the interviews were analysed to understand the causes behind the high fatalities. We interviewed thirteen survivors who were living in temporary housing. Four women and nine men, ten were over 45 and three were less than 45 years old.

As Table 2 shows only one out of the thirteen people ran away in time. He was a 13 year old boy. All other twelve just attempted to help others or tried to return home for any reason other than escape. Five of the survivors were actually hit by tsunami and could only survive with great difficulty. One of them was in water for 24 hours. Of the five who went to help others, they all mentioned trying to convince elder people to leave their houses and helping them which made their evacuation speed much slower.

Table 2. Reaction after the tsunami warning

| Total | Use car to evacuate | Help people | Return Back home | Run to safe place | Trapped by tsunami |
|-------|---------------------|-------------|------------------|-------------------|--------------------|
| 13    | 6                   | 5           | 7                | 1                 | 5                  |

Factor influencing fatality rates
1. Making right decision in time to run to safe and avoid wasting time in the critical situation rather than going back home
2. People's preparedness and awareness, being familiar with this kind of intensity of disaster in the area they lived.
3. Having accurate and realistic assessment of the risk rather than an over optimistic impression created by a smaller recent disaster such as the Chilean Tsunami.
4. Cultural inhibitors on people's behavior, for example obeying traffic regulations and road signs in a crisis situation when the normal rules of behavior might usefully be suspended.
5. Multiple announcement on the radio about tsunami height caused doubt, disbelief and loss of time
6. Helping people and seeking family members.
7. Distance to risk center. Fatalities were higher amongst those furthest from an evacuation centre.
8. Time lost convince elder people to evacuate and helping them move.

The reaction of government to the evidence about unexpectedly slow evacuation in some places has been self-critical. Instead of defending the system they have been frank about what failed and it is in the character of Japan to always review and look back and learn lessons. For example, ideas about evacuation are changing. Japan national broadcasting has changed the way it announces the early warning. Rather than giving precise information that is open to error and misinterpretation it will from now on give much simpler direct warning to evacuate immediately. (EEFIT, 2013)

As part of the research, authors made a simulation for evacuation pattern by using the Distinct Element Method (DEM) to show what could be the fatality rate and what really occurred.


SIMULATION OF PEOPLE"S EVACUATION BEHAVIOR

The simulation program used for this research was developed by Kiyono et al. (2000). In this study to make a more realistic model of for analyzing the human behavior, two circles are deployed for each person. These two circles share the same center, while having different radiuses. The smaller circle represents human body, known as a physical circle while the larger represents human behavior, known as the psychological circle. The radius of the physical size of human body, is set at 0.295 meter (Tatebe et al.1989). People naturally tend to keep distance and avoid contacting each other when they are walking or even running. This constant distance is called virtual radius of the human body. When one person, or element in the model, approaches another, a repulsive force acts to keep the distance between the two. The Distinct Element Method (DEM) represents each element by spring and dashpot forces in normal and tangential directions. In the case of the virtual radius, when one element approaches another, the virtual spring and dashpot forces act between the two. Consequently, the virtual radiuses of each person prevent the physical contact between the two people. The Algorithm

we proposed in this simulation has the potential to let the two elements to overtake each other without any collision by changing their velocity and direction. This model also considers two types of collisions, one is between elements and the other is between the element and obstacles.

Two individual elements collide if the following condition is not met. Eq.(1)

$$r_i + r_j \le d_{ij} \le r_i' + r_j \qquad (1)$$

Where in equation 1 is the distance between the centers of the two elements i and j, and are the physical radius, and represents the virtual radius of the psychological circles.

Since the DEM is a numerical analysis method, movement of the elements can be determined by solving the equation of motion. Basically by solving this equation and updating it for each time step, we can calculate a new position of each element for that particular time step. In the model used for this research, it is assumed that people can pass each other without bumping into each other just like the normal human behavior. Moreover, they can overtake those who are slower than them without any physical contact. Eq.(2 and 3)

$$m_i \ddot{x}_i(t) = f_i^x(t) \qquad (2)$$
$$m_i \ddot{y}_i(t) = f_i^y(t) \qquad (3)$$

Forces for directions of X and Y are calculated for each element by using the equation of motion. Number of element is in range of i=1, …, N , where N is the total number of elements. In this equation is the mass of ith person, and are displacement in two direction for ith element. And resultant force equals the combination of all the different forces, which act on human body..Eq.(4)

$$f_i^j(t) = f_k + f_c + f_k' + f_c' + f_{wk} + f_{wc} + f_f + f_a \qquad j = x, y \qquad (4)$$

In this equation, and are the spring and the dashpot forces of each of the elements. These forces are made as a result of a contact of one element with another. On the other hand, and are virtual springs and dashpots.

This model was applied to Yuriage area, Figure 2 the simulation was made for the main walking evacuation routes studied by Professor Murakami at Yamaguchi University (Javanbarg et al. 2012). Even though the pre-evacuation time was reported as 69 min for this area, most of people wasted half of this time because of doubt about the importance of the warnings, looking for other family members, and other factors that were discussed earlier in this report. Therefore, this study simulates only the last 25 minutes before the arrival of tsunami in the area. It should be noted that we considered all possible routes in the simulation, and each element in the simulation represents a group of individuals rather than a single person.

Careful surveys and psychological experiments are required to obtain a more accurate estimate of the evacuation time, but the time-span of 25 minutes seems to match closely the data obtained from sampling reality. In Figure (2.A), the layout map shows the modeled evacuation routes and location of Yuriage Junior High School, the safe zone, and the position in which congestion was reported. The direction of evacuation is indicated. In the following simulation snapshots, each point represents a group of evacuees.

Based on the simulated model, 18.2% of the evacuees got caught in congestion and were unable to survive by entering the school (i.e. the safe zone). This result gives an accurate estimation of evacuation behavior since the actual percentage of people failing to reach the school because of congested routes was 16%. The main finding is that The Distinct Element Method (DEM) can accurately predict evacuation behavior and fatality rates, but is extremely sensitive to time. In the actual case people had over 1 hours warning but wasted half this time procrastinating. The following additional observations can be made from analysing the simulation:

(A)        (B)

(C)        (D)

Figure 2. Walking Evacuation Routes ( Max Length:   850 m and Max Width:   1141 m)

1. People in this area had 69 minutes to evacuate, had they heeded the warning immediately then the fatality rate would have been much less than 16%.  (The model would have modelled this accurately if the evacuation time period had been adjusted from 25 to 60 minutes)

2. According to Murakami et al. (2012), 65% of the 256 survivors had evacuated in their own or another person's car. This simulation, however, did not model evacuation by car. Everyone able to walk would have been able to reach safety if they had made the right decision and evacuated immediately after the warning.

3. There were three evacuation centers in Yuriage area. The one nearest to the coast was unsafe to evacuate to because the first floor was inundated. The other two were safe for evacuation. The distance from the coastline to nearest safe zone was about 1 kilometer. If everyone had left their place and walked to safe zone, most of them would have survived since they could have easily walked this distance in half an hour.

4. The inundation zone extended about 4 Km in land from the coast, which means that everyone could have walked or driven from whenever they were out of the inundation zone in 60 minutes which, with the 69 minute warning, would have been sufficient time to evacuate safely.

5. In this simulation, as mentioned earlier, only the movement of pedestrians is modeled. In fact the results show that even if everyone had evacuated on foot they still would have had a big chance of surviving. To demonstrate this the authors are developing the model in following ways:

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1. Including cars
2. Considering contraflows
3. Assuming different delay times for people to start evacuating.


## SURVEYING HOW PEOPLE SAY THEY WILL REACT IN AN EVACUATION

The previous sections examined how people behaved after the main shock of 2011 Tohoku earthquake early warnings and the critical issues that influenced people's decision making. We also gained several useful insights from the simulation exercise by comparing the modelled results with real data.

This section examines the people's attitudes to risk and how they imagine they will behave in the abstract while no danger threatens them and they have to imagine themselves in the crisis. It is based on a questionnaire amongst students at Kyoto University and other universities in Japan all of whom were aware of and sensitive to the 2011 disaster. The aim of this survey was to investigate in greater depth why people seem to have problems making the right decision to evacuate immediately to a safe area and what factors might influence people's behavior. Greater understanding of the thinking processes of people when they imagne themselves in a similar crisis will help devise policies to reduce fatalities in future disasters. It would be possible by comparing the result of questionnaire with what we could find through our interviews and site surveys.

The questionnaire was distributed amonst graduate and undergraduate students including different nationality and gender on paper after various university lectures and disseminated on the Internet. There a total of 215 responses, 121 from the paper based version and 94 on the Internet. Of these 186 respondents answered the relevant questions about response, nationality etc.

The respondents came from 41 different countries. For the purpose of the analysis presented here they are divided into Japanese (19%) who are familiar with their country and had been drilled in tsunami awareness and evacuation procedures since childhood, and foreigners (81%) who in the main were not trained in tsunami evacuation but in some cases may have experienced the 2011 tsunami either directly or indirectly.

The respondents' level of tsunami awareness was tested with a number of questions about awareness, preparedness, experience, and knowledge of his or her living area and understanding of the types of natural disaster that might threaten them. The main question was: "If earthquake occurs then what would be your reaction?" The pre-coded possible answers were: "Run to the safe area, return home, help other people or looking family member? This pre-coded range of possible behavior was derived from findings from previous research described earlier about people's actual reactions in the 2011 tsunami.

Table 3 presents the breakdown of respondents by gender, nationality and marital status. 56% were men and 44% women; 24% were married and 76% single; 19% were Japanese nationals and 81% were foreigners.


Table 3. Reaction after the tsunami warning

| Nationality | Men | Women | Married | Single | Total |
|---|---|---|---|---|---|
| Japanese | 22 | 13 | 1 | 34 | 35 |
| Foreigner | 82 | 68 | 43 | 106 | 151 |
| Total | 104 | 81 | 44 | 140 | 186 |


The analysis the data had thrown up some interesting and unexpected results presented in the three following summary tables. (The statistical significance of the findings is measured using Chi-Square, where the ratio reported is the probability of the samples being the same ie 1 is 100% probability that there is no difference.)

Just over one third of respondents (37%) said that they would run to safety. Nearly two-thirds (63%) said they would do something else. (38% would look for family members, 20% would help others and 4% would return home.)

Table 4. Gender, Marital status, Nationality

| | Women | Men | Married women | Married men | Single women | Single men | Foreigner | Japanese |
|---|---|---|---|---|---|---|---|---|
| Run | 40% | 31% | 76% | 75% | 55% | 67% | 36% | 44% |
| Other | 60% | 69% | 24% | 25% | 45% | 33% | 64% | 56% |

| | | | | |
|---|---|---|---|---|
| Number responses | 198 | 45 | 150 | 198 |
| Chi-Square | 0.19 | 0.93 | 0.12 | 0.37 |

There is a difference in the anticipated behavior of men and women – more women than men said that they would run to safety (Chi-Square 0.19). This difference is even more significant for single people, since an equally high proportion of both married men and women (75%) report that they will run to safety. The difference between Japanese nationals and foreigners was less significant than one might have expected. This is most surprising since Japanese students who are native to the area have been drilled in evacuation since childhood and might have been expected to have a different reaction to foreigners who have only been living in the area a few years (Table 4).

Table 5. Experience, Possible disaster, Drill

| | Have experience | No experience | Familiar with possible disaster | Unfamiliar with possible disaster | Having drill experience | No drill |
|---|---|---|---|---|---|---|
| Run | 37% | 41% | 38% | 38% | 38% | 38% |
| Other | 63% | 59% | 62% | 62% | 62% | 62% |

| | | | |
|---|---|---|---|
| Number responses | 174 | 193 | 195 |
| Chi-Square | 0.5 | 1.0 | 0.8 |

To test the impact of experience respondents were asked about their experience of previous disasters, their familiarity or awareness of possible disasters and their previous experience of evacuation drilling (Table. 5). None of these factors had a significant effect on anticipated evacuation behavior. This is an astonishing finding given the huge effort that is put into awareness raising and evacuation drilling in Japan.

Table 6. Distance to office, Knowing evacuation center, Transportation mode

| | >20 minutes distance | ≤20 minutes distance | Know evacuation center | Don't know | Walking or bicycle | Public or private vehicle |
|---|---|---|---|---|---|---|
| Run | 30% | 43% | 33% | 40% | 39% | 40% |
| Other | 70% | 57% | 67% | 60% | 61% | 60% |

| | | | |
|---|---|---|---|
| Number responses | 179 | 196 | 180 |
| Chi-Square | 0.1 | 0.3 | 0.94 |

The final set of factors that were analysed were those related to the physical constraints on evacuation: dusance to the evacuation centre, knowing the location of the nearest evacuation centre and the imagined preferred mode of tansport. The travel time distance between home or work and the nearest evacuation centre does seem to have a significant effect. Respondents living within 20 minutes of the nearest centre were significantly more likely to run to safety than those further away. This means the closer evacuation centres are placed the more likely people are to use them, which seems logical. Knowledge of the location of the nearest centre also have an impact, though less significantly.

Finally, and perhaps most surprisingly, mode of transport seems to have little impact on anticapated behavior (Table. 6). One might have expected people with cars to be more likely to go to look for family members or help others, since they had a vehicle. But this was not the case.

## CONCLUSION

The main findings of these various research studies and analyses are:

There was unprecedentedly high level of inundation: 8.81m reported in some areas. People were doubted the early warning and were then shocked by the magnitude of tsunami severity and danger. These uncertainties were compounded by unreliable warnings and multiple announcements on the radio about the tsunami height that caused people disbelief and loss of time. Narrow evacuation routes caused congestion, traffic jams and difficulty in handling the return flow of people seeking family members, helping others or checking their propery.

Yuriage has a particularly constricted geographic shape and is a flat area with no immediate visibility of the approaching danger. Elderly people were reluctant to evacuate and some were infirm and unable to move.

Car use could have significantly reduced fatalities if people had driven to a safe area immediately they received the first early warning, 69 minutes before the tsunami struckWhile people with car might have got stuck in traffic jams trying to get to the evacuation centers, they would have had time to drive out of town. But many used their cars to drive in opposite direction to find family or help others and in the last minutes this caused intense traffic congestion. The interviews revealed that many people returned to their home or went in search of family members. This was one of the most significant factors in making the fatality ratio higher than it might have been. Many people were washed away when they got stuck in a traffic jam and stayed with their vehicle rather than trying to run away on foot.

The survey of university students in Japan found that distance from home to the nearest evacuation centre and knowing where it was located are significant factors in peoples imagined reation to an evacuation situation. Marital status and gender also have an influence, and more women than men and more married people than single people run to saftety. But surprisingly given how much effort is put into awareness raising and crisis training in Japan, neither experience of previous disasters nor previous training in evacuation driills seem to have an effect. Also most surprisingly native japanese seem no more likely to imagine running to safety than do foreigners.

These findings, of people's actual behavior, simulated behavior and what people imagine they will do in crisis, are cause for concern and call into question some of the received wisdom about evacuation policy in Japan and elsewhere. However, these were relatively small samples in one location and it is impossible to generalise more widely either within Japan or elsewhere. Nevertheless they suggest that further and more exhaustive research would be wise.

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(Yomiuri Shimbun evening edition 2-11-04-15 page 15, nearby Aneyoshi fishery port (姉吉漁港 )(Google map E39 31 57.8, N 142 3 7.6) 2011-04-15, 大震災の津波、宮古で 38.9 m…明治三陸上回る by okayasu Akio (岡安 章夫)Archived 18 April 2011 at WebCite)