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AN AGENT BASED MODEL FOR THE TSUNAMI EVACUATION SIMULATION. A CASE STUDY OF THE 2011 GREAT EAST JAPAN TSUNAMI IN ARAHAMA TOWN

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Abstract: After the 2011 Great East Japan Earthquake of magnitude 9.0(Mw) where most of the structural countermeasures were destroyed by the tsunami, "evacuation procedures" remains as the most important and effective method to save human lives. In this paper, an agent based model of tsunami evacuation integrated with the tsunami simulation is presented. In the model, GIS capability for inputs allows its application in different areas; GUI interaction makes it suitable even for non-experts usage as part of educational programs, and the microscale simulation permits to track individuals' evacuation. The model was applied to Arahama's evacuation as a case study. Arahama is a town located near the coastline of Sendai city, around 300 people were killed here by the tsunami, and some others had saved due to a fast evacuation decision to the inland or high reinforce concrete buildings in the area.

1. INTRODUCTION

Evacuation is the most important and effective method to save human lives (Shuto, 2005). In order to simulate realistically a major population evacuation, for example in a tsunami scenario, one of the important information required is an accurate representation of the timing of people's response to the emergency (Southworth, 1991). The timing of evacuee response can have a significant effect on the traffic congestion and bottlenecks during the evacuation procedure (Naser, et al., 2010). It is desirable that people leave the risk area immediately after a natural or official warning is received. However, it is an apparently non-rational behavior that people sometimes do not evacuate, even when authorities suggest that they should (Riad, et al., 1999). According to Imamura (2009), three steps can lead to a safe evacuation after an earthquake and tsunami: first, collect information and issue an official warning; second, make the decision to evacuate based on the risk perception and previous experiences of the residents of the area; and third, select a proper route and safe destination for the evacuees. Focusing on the second step, risk perception and evacuees' experiences are part of individual behaviors, therefore it is expected that these differ from person to person. In this study, a tsunami evacuation simulator was developed to explore the individual behavior of start time of evacuation, also the casualty estimation and issues related to the process of evacuation in the case of tsunami. Tsunami modeling results are integrated into the model to estimate casualty conditions based on hydrodynamic characteristics of tsunami. The agent based approach allows for tracking the individual evacuation decision, route and shelter.

2. THE 2011 GREAT JAPAN EARTHQUAKE AND TSUNAMI

2.1 Overall damages

Japan is well known for the world's best tsunami counter measures and evacuation recognition because they have long historical tsunami experience, especially along the Sanriku coast that was heavily damaged. Before the 2011 event, the expected occurrence of the Miyagi-oki earthquake was one of the most concern seismic gaps in Japan. The calculated probability of an earthquake with M7.5-8.0 in Miyagi was estimated on 99% within 30 years. That was the highest probability of earthquake in Japan. On 14:46 of 2011 March 11th, the massive earthquake recorded in Japan occurred at N38.1, E142.9 with the magnitude of 9.0 at 24 km depth (JMA, 2011) followed by many aftershocks and devastating tsunami. The earthquake was ranked as the fourth in the world, followed by the 1960 Chile (M9.5), 2004 Sumatra (M9.3) and 1964 Alaska (M9.2). The earthquake had a long period (about three minutes) and the largest slip of approximately 30 m (USGS, 2011). The maximum recorded earthquake intensity was 7 (JMA, 2011). Earthquake early warning system was issued 8 seconds after a detection of the first P-wave (JMA, 2011). Tsunami warning was issued 3 minutes after the earthquake. The tsunami caused 19,212 dead and missing and more than 50,000 damaged houses and buildings (NPA, 2012; Suppasri, et al., 2011)

2.2 Tsunami Evacuation

According to (Yalciner, et al., 2011), in Kamaishi, Iwate Prefecture from a survey to 113 individuals and 105 in Natori, Miyagi Prefecture; 65% of them reported that the main reason for the evacuation was that they thought a tsunami will come, while 13% reported that people around them recommended the evacuation. Apparently in Kamaishi, the majority of interviewed people evacuated in less than 10min (60%), while in Natori the 30% of respondents escaped within 20 to 30 min. Tsunami arrived to Kamaishi around 20min after the earthquake and 68 min in Natori. It was observed that a large number of population in the coast evacuated by car, especially in plain areas like Sendai.

3. TSUNAMI MODELING

3.1 Tsunami Source model

An instantaneous displacement of the sea surface identical to the vertical sea floor displacement is assumed in the model of tsunami source. Ten sub fault segments based on the Tohoku University Source model version 1.1 (Imamura et al., 2011) were used as initial surface deformation (Fig. 1). The parameters are shown in Table 1.

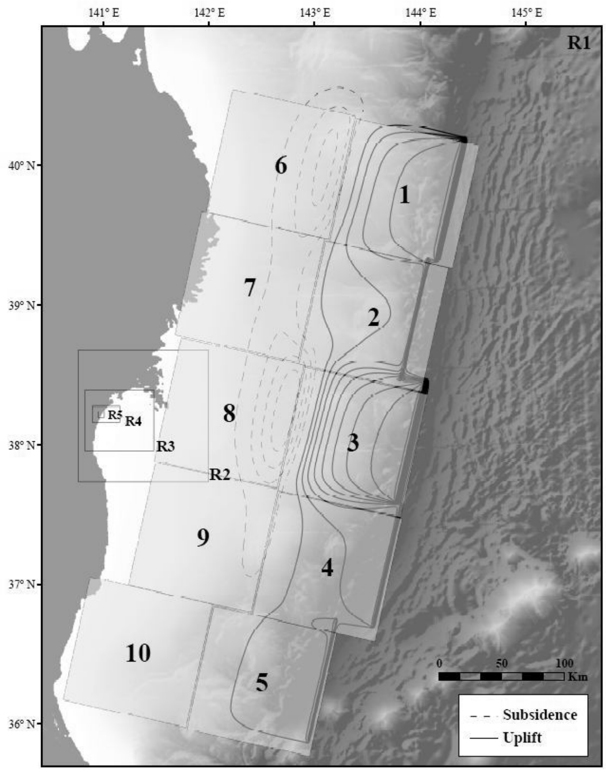

Figure 1 Tsunami source model and Nested Grid setting

3.2 Numerical model setup

The source model presented above was use for the numerical simulation of tsunami into Arahama town. The Tohoku University's Numerical Analysis Model for Investigation of Near-field tsunamis (TUNAMI model) was used as the tool for tsunami modeling (Imamura, 1995). A set of non-linear shallow water equations (1) to (3) are discretized by the Staggered Leap-frog finite difference scheme, with bottom friction in the form of Manning's formula constant in the whole domain.

$$\frac{\partial \eta}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0 \quad (1)$$

$$\frac{\partial M}{\partial t}+\frac{\partial}{\partial x}\left(\frac{M^2}{D}\right)+\frac{\partial}{\partial y}\left(\frac{MN}{D}\right)=-gD\frac{\partial \eta}{\partial x}-\frac{gn^2}{D^{7/3}}M\sqrt{M^2+N^2} \quad (2)$$

$$\frac{\partial N}{\partial t}+\frac{\partial}{\partial x}\left(\frac{MN}{D}\right)+\frac{\partial}{\partial y}\left(\frac{N^2}{D}\right)=-gD\frac{\partial \eta}{\partial y}-\frac{gn^2}{D^{7/3}}N\sqrt{M^2+N^2} \quad (3)$$

Where,

$$M=\int_{-h}^{\eta} u dz \quad (4)$$

$$N=\int_{-h}^{\eta} v dz \quad (5)$$

$$D=\eta+h \quad (6)$$

M and N are the discharge flux of x and y direction respectively, η is the water level and h is the water depth above the mean sea level.
Bathymetry and topographic data from the Central Public Disaster Prevention Council of Japan were used. Grid sizes vary from 405 m、135 m, 45 m, 15 m and 5 m in five regions of nested grid system shown in Fig. 1.

4. EVACUATION MODELING

Tsunami hydrodynamic models, have contributed widely to tsunami investigation from a scientific and engineering point of view. However, not only a scientific approach, but the social and risk management is necessary. Considering that evacuation is probably the most important and effective method to save human lives (Shuto, 2005) more emphasis has been put on social science in tsunami mitigation. Thus, tsunami modeling technique is also related to tsunami evacuation modeling practices. However, human behavior is the most complex and difficult aspect of the evacuation process to simulate (Gwynne, et al., 1999). Human behavior, with a high complexity in problem solving (Gagne, et al., 2004) and characteristics of individuality, is difficult to capture on computers with mathematical equations (Pan, et al., 2007). In this study, we developed a tsunami evacuation model considering outputs of the previous section. The model of evacuation follows the agent based approach. Thousands of agents with parameters of individual characteristics follow simple rules towards different goals.

Figure 2 Interface of the Tsunami Evacuation Simulator

4.1 Overview of the model

The model for tsunami evacuation was developed in Netlogo, a multi-agent programming language and modeling environment for simulating complex phenomena (Wilensky, 2001). Hundreds or thousands of "agents" can operate concurrently in order to explore the connection between the micro-level behavior of individuals and the macro-level patterns that emerge from their interactions. The model uses GIS data as spatial input and if available population spatial distribution. Tsunami characteristics are introduced as raster files at each tsunami numerical step time of simulation. Input parameters of scenario, model view and outputs are observed during the simulation on real time. Outputs are exported into file reports. A snapshot of the model interface is shown in Figure 2.

4.2 Start time of evacuation

In order to simulate realistically a major population evacuation, for example in a tsunami scenario, one of the important information required is an accurate representation of the timing of people's response to the emergency (Southworth, 1991) (Suzuki, et al., 2005). The timing of evacuee response can have a significant effect on the traffic congestion and bottlenecks during the evacuation procedure (Naser, et al., 2010). Moreover, it is expected that human damage will decrease depending on the early evacuation (Sugimoto, et al., 2003). Efforts of simulating the evacuation of humans from tsunami have considered this factor in so many approaches that all these models may result on different casualty estimation and congestion points. Three main approaches can be described from the efforts on developing the start time of tsunami evacuation modeling. First, an "all together" evacuation based on scenarios of 0min, 5min, etc. starting time for the whole population under study (Suzuki, et al., 2005) (Sugimoto, et al., 2003) (Fujioka, et al., 2002) (Ohhata, et al., 2005) (Post, et al., 2009) (Meguro, et al., 2005), however such instantaneous group behavior has never been recorded in past events. In general, individuals from a large population at risk never start their evacuation at the same time, due to individuality behavior of decision. A second approach is similar to the previous one, however the fixed values are assigned to groups or areas and directly based on questionnaires (Imamura, et al., 2001) (Saito, et al., 2005). Basically, this is a special case of the first approach, where a whole population is divided in small groups and the average of starting time is obtained through questionnaire surveys conducted in the area. Although, this may lead to better approximations in the evacuation process of a large population, the use of one questionnaire result may not explain the complexity and uncertainty of human behavior or spatial initial condition of population. The third approach is a more sophisticated approach with introduction of psychological parameters obtained through questionnaires and treated in the individual scale considering aspects of rationality (Sato, et al., 2008) (Mas, et al., 2011), however for this cases, the definition of parameters and values for the simulation are of difficult assessment in large populations.

In this paper, we will introduce to the tsunami evacuation modeling community a fourth approach modified from the emergency, urban and traffic planning fields, where departing times are sketched under derivations of sigmoid curves (Lindell, et al., 2007).

4.3 Questionnaire surveys

Tsunami evacuation models often utilize data provided by questionnaire surveys in order to establish an average start time of evacuation or an estimated distribution of evacuation decision. The need of these data is common to researchers and stakeholders, however, conducting surveys and updating survey data is usually faced by budget and time constraints, delaying decisions for new mitigation actions. According to (Naser, et al., 2010) surveys that are designed to collect data describing actual travel or evacuee behavior are classified as Revealed Preference (RP) surveys, while hypothetical behavior in the future is obtained through Stated Preference (SP) surveys. Hence, RP surveys are related to past tsunami experiences while SP surveys collect data on how the evacuee would respond to a hypothetical situation in the future. Both tools pretend to obtain an idea of the human behavior during the emergency; however the use of one questionnaire result may not explain the complexity and uncertainty of human behavior or the spatial initial condition of population. Moreover, there is a frequent variation of the level of awareness and risk perception of individuals, due to recent experiences, public information or education. As a result, previous estimations of evacuation times on past surveys may decrease or in the opposite case, where events have been forgotten, there might be an increase of estimations (Tatano, 1999).

4.4 Tsunami evacuation departure times

In order to deal with the complex and variability on time of human behavior and preference of evacuation time, a set of distributions of departing time might be use to convolve all the possible behaviors in the population. However, how to decide the most suitable distribution parameters?. Following the state of the art of departure times in large scale events such as hurricane or nuclear accidents evacuation, previous researchers found that sigmoid curves agreed on the population load rate into the evacuation network (Lindell, et al., 2007) (Southworth, 1991) (Tweedie, et al., 1986). Here, we used several RP and SP surveys of tsunami evacuation and compared them with the theoretical Rayleigh distribution which is similar to the shape proposed by (Tweedie, et al., 1986) for traffic simulation.

$$F(t) = 1 - e^{-\frac{t^2}{2\sigma^2}} \quad (7)$$

$$\mu = \sigma\sqrt{\frac{\pi}{2}} \quad (8)$$

Table 2 shows the results of correlations and values of mean of distribution (Eq. 8) compared to the reported or estimated tsunami arrival times in RP or SP surveys respectively.

Moreover as observed in Fig 3a and Figure 3b, there is higher correlation between the recorded arrival times of tsunami and preparation times in RP surveys than the estimated arrival times through numerical simulation and preparation times related to the tsunami in SP surveys.

This means that an SP survey might be obtaining from respondents what it is considered a “correct” answer, a fast evacuation. However on RP surveys it is possible that at least half of the population at risk waited to the last minute to start the evacuation, close to a time of confirmation of tsunami arrival. This apparently irrational behavior of some people not evacuating until the last minute was observed in previous events and confirmed by the several videos available on the web.

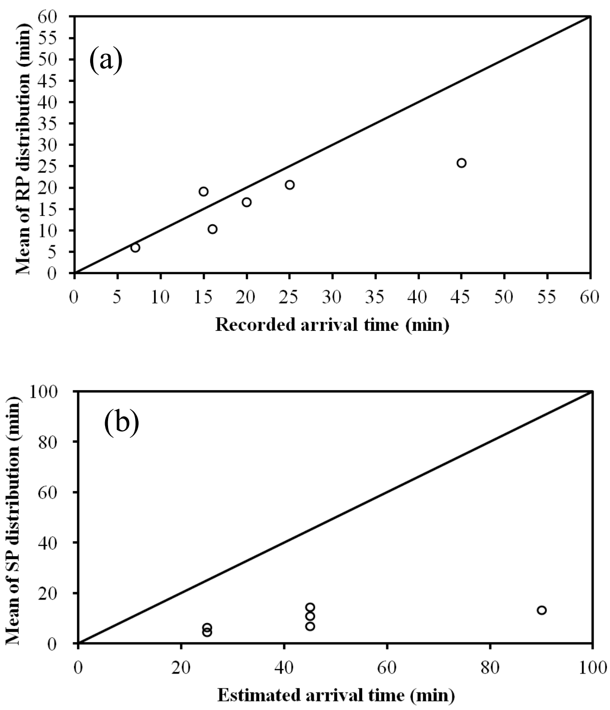

Figure 3 (a) Stated Preference surveys. (b) Revealed Preference surveys

Based on Figure 3, one might be tempted to rely on the distributions of previous revealed preference surveys as an input in the evacuation model. However, due to individualities on behavior we cannot neglect the state preference surveys since some individuals might follow according to their expectations. Therefore, a better approach will be a bounded behavior between these two results.

It is the case of many areas on desire of evaluating their tsunami risk, that recent events have not occurred, and then RP surveys might be not available. In this case, based on the results explained before, stakeholders may apply SP surveys and estimate the arrival time of tsunami through numerical simulations. The final boundary distributions of behavior are obtained from these two methods.

4.5 Agent architecture

We provide agents the minimum necessary abilities to process information and execute their evacuation, through a simple behavior divided on layers. Explained as follows:

a) Layer 0: The evacuation decision, assigned randomly based on the departure times distributions explained above
b) Layer 1: The Shelter decision, as an option for scenario exploration, two alternatives are possible for agents; first, to choose the nearest shelter; second, to choose any of the shelters. Traditionally nearest shelter condition has been applied, however in many cases preferences are not for the nearest sheltering place.
c) Layer 2: Pathfinding. As a method for finding a route (not necessary the best or closest), we used the A* (A star) algorithm on grid spaces. This is the most popular graph search algorithm also used in the video game industry (Anguelov, 2011).
d) Layer 3: Speed adjusting: Speed conditions are assumed as a half tail Normal Distribution of density in the agent field of view, with a maximum value of 1.33m/s for pedestrians and 30km/h (8.33m/s) for cars (Meister, 2007) (Suzuki, et al., 2005).

4.6 Agent movement

A large number of agents move around streets in the model, either pedestrians or cars, therefore collision avoidance should be taken into account. In the model, agents move in a continuous grid space according to their actual speed. Notice that an agent not necessary “jumps” from grid to grid strictly at the center of grid (integer coordinates), but he may step on borders or in between (real coordinates). In order to move and according to the spatial accuracy or grid size, a certain number of agents are allowed in an area. Assuming a $1m^2$ personal area for each pedestrian, it is expected that for example 25 pedestrians can fit in a 5m x 5m grid. However, due to the dynamic movement of agents the 100% used of the grid is not a real condition. For that reason, we used the predictive collision avoidance proposed by (Karamouzas, et al., 2009) and test the movement of pedestrians through a corridor (Helbing, 1991). In a 1m x 1m grid size corridor, and counting the number of agents passing through a 5 x 5m area at each time step, the results show that the maximum used space in the grid is a 70% of its total area. In summary, in a $25m^2$ grid only 18 agents can be allowed in a movement condition. Finally, we established a congestion condition no more than the round number of a 70% used of the grid space for pedestrians and in a similar approach a 7% for cars.

4.7 Casualty estimation

As for the casualty model, we used the experimental results of (Takahashi, et al., 1992) which consist on flow depth (cm), flow velocity (cm/s) and casualty condition of binomial explanation – safe or fall. A binomial logistic regression was performed to obtain the casualty probability as a function of flow characteristics. Results are shown in Fig. 4 and Eq. 9.

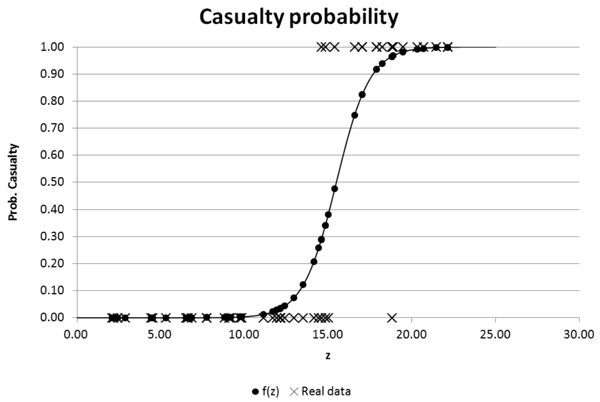

Figure 4 Binomial Logistic Regression Model from experimental data in Takahashi, et al. (1992)

$$f(z) = \frac{1}{1 + e^{(15.48 - z)}} \quad (9)$$

Where:

$z = \beta_0 + \beta_1 * h + \beta_2 * u$

$\beta_0 = -12.37$; $\beta_1 = 22.036$; $\beta_2 = 11.517$

h = tsunami inundation depth

u = tsunami velocity

The applicability of this probability model is bounded by the experimental conditions, therefore in our evacuation model we used this condition of casualty probability up to inundation depths of 0.85 m, after this value, at any velocity, an agent trapped into tsunami will be considered as casualty. In the case of cars estimation, although some cases evacuees were found saved inside the car after the tsunami, in the majority of cases passengers caught by tsunami did not survive due to car drowning or debris impacts. Following (Yasuda, et al., 2004) a value of 0.50 m of inundation depth is enough to lose control of the vehicle and in many cases the car begins to float. Thus, when inundation depth is over 0.50 m, a car trapped in the tsunami is considered as a casualty with all its passengers.

4.8 Outputs in model

Outputs in the model are presented on three ways: a) Model view; b) Reporters; c) Files. The Model view shows agents movement and tsunami propagation. Reporters show during simulation the number of saved or casualty agents, plots of shelter demands or evacuation rate. Files, report the total simulation step by step on text, image or video formats.
Analysis of outputs and possible applications will be shown as a case study in the next section

5. CASE STUDY: ARAHAMA TOWN

5.1 Study Area

Arahama is a populated village of the Wakabayashi ward of Sendai city in the Miyagi Prefecture, Japan. It is located between the Natori and the Nanakita rivers, six kilometers south of Sendai Port. A total of 2,704 residents lived in this area; after the 2011 tsunami, Sendai city bureau reported a total of 2,421 residents (Census, 2011). The discounted 283 might be the maximum possible number of casualties. After the earthquake local media reported between 200 to 300 victims found in the area. Tsunami arrived after one hour of the earthquake with maximum wave height of 10m. Tsunami inundated 5 km inland, around ten times of the expected Offshore Miyagi tsunami. Arahama is provided with not so many high reinforced concrete buildings; however the only official tsunami evacuation building in the area is the Arahama Elementary School of four stories and accessible roof. It remained after the earthquake and tsunami sheltering around 520 evacuees (NGA, 2011)

5.2 Spatial and Tsunami data

Local spatial data for the simulation was provided by the GSI of Japan on a shape format and converted for the model into a 5m x 5m grid raster. Tsunami data is taken from the output of calculations in the smallest domain shown previously (Fig. 1 & Fig. 2).

5.3 Population data

It is very difficult to determine the exact number of evacuees at the moment of the earthquake. However, an estimation of possible number of agents in the area is considered. It is not of the scope in this paper to fully reproduce the evacuation of March 11^{th}, but to introduce the model capabilities with the available data of a real event. Therefore, out of 2,704 residents reported in the census, 84% of the residential area was modeled and also the same percentage of population was considered. Thus, from the 2,271 residents in the model area, a 72% was taken as on-car evacuees according to (Suzuki, et al., 2005) questionnaire results (Fig 5). Finally, assuming 4 passengers per car, 410 cars were modeled plus 631 pedestrians.

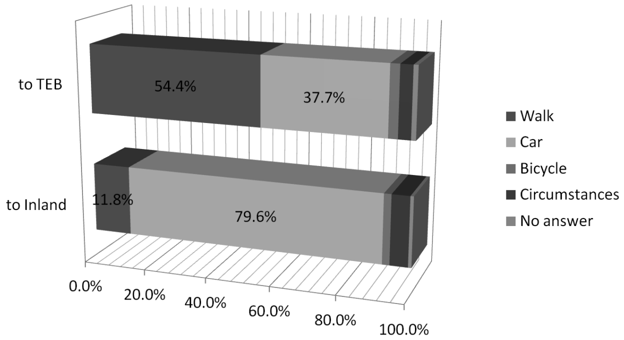

Figure 5 Questionnaire results of evacuation mode preferences, from Suzuki, et al. (2005)
(TEB: Tsunami Evacuation Building)

5.4 Stochastic simulation

The use of multi agent paradigm or agent based models typically contain stochastic elements (Ormerod, et al., 2009). Consequently a set of runs should be conducted to obtain the mean of outputs as an estimation of the value of interest. We conducted 1000 runs with a random initial spatial distribution of pedestrians and cars. Start time of evacuation decision is based on a random selected value in a distribution bounded between results from Suzuki et al, (2005) with mean of distribution 7min, and the recorded arrival time of tsunami on March 11th, equaled to 67min (Fig. 6).

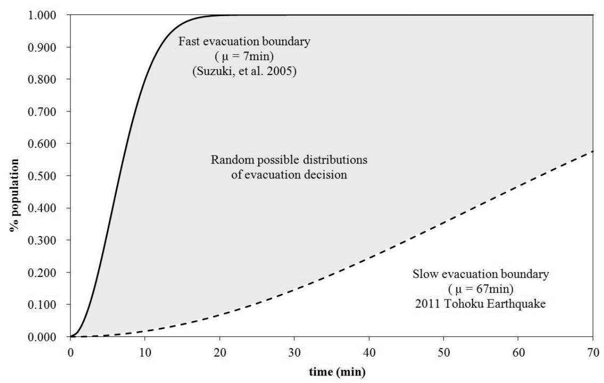

Figure 6 Boundary distributions for start time decision of evacuation from tsunami.

5.5 Results and discussion

Each simulation provides information such as number of evacuees sheltered plus number of evacuees who have passed one of exits (Safe); number of evacuees trapped into tsunami and with more than 50% probability of falling (Casualty); number of evacuees in Tsunami Evacuation Buildings (TEB#); number of evacuees who got to one of the exits before falling by tsunami (EXIT#). The average, standard deviation and other statistical values of the 100 repetitions are shown in Table 3. The model shows that 82± 3.0% of the population evacuated before the tsunami arrived or had a characteristic enough to make them fall. Apparently preferences on evacuation shelter are balanced between the three options given. An average of 22±0.5% decided to sheltered in the Tsunami Evacuation Building (TEB), while nearly 30±3.0% and 30±3.0% preferred to exit the area through EXIT#1 and EXIT#2, respectively.

Table 3 Statistical values of 1000 repetitions of simulation scenario

	Safe	Casualty	TEB	EXIT1	EXIT2
Averages	1,864.66	406.34	497.55	685.10	682.00
Median	1,875.00	396.00	498.00	684.00	688.00
S.D.	68.75	68.75	10.18	66.30	64.41
Variance	4,726.88	4,726.88	103.58	4,395.05	4,148.56
Skewness	-5.58	5.58	-0.04	-2.76	-2.93
Kurtosis	43.60	43.60	0.03	22.16	24.52
Coeff. Of Variability	0.04	0.17	0.02	0.10	0.09
Minimum	1,154.00	293.00	465.00	12.00	12.00
Maximum	1,978.00	1,117.00	527.00	824.00	824.00
Range Width	824.00	824.00	62.00	812.00	812.00
Mean Std. Error	2.17	2.17	0.32	2.10	2.04
Population			2,271.00		
%Pop	82.11%	17.89%	21.91%	30.17%	30.03%
%error	3.03%	3.03%	0.45%	2.92%	2.84%

According to local media and census of the city office before and after the earthquake, around 90% of the population saved from tsunami, and 520 evacuees at the shelter building. Although we never expected to obtain the exact values of predictions, the average estimations of 82±3.0% survivors and 498 evacuees at TEB show a good capability of the model to reproduce a suitable emergent behavior of decision and casualty estimation in the area.

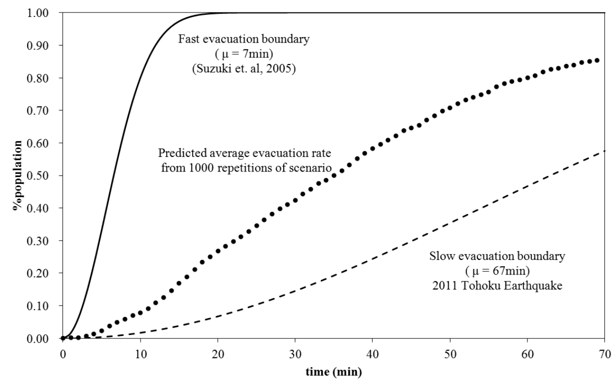

Figure 7 Average distribution of evacuation decision

Fig. 7 shows one of the 1000 simulations of random selected values for evacuation decision of all agents according to boundaries shown. The average distribution follows also the sigmoid shape. At the point of arrival time of tsunami (t=67min), a total of 85% of population had already decided to evacuate. An important characteristic of micro simulations is the capability to explore, at the individual level, the behavior of the model variables. For example, focusing on the departure times shown in Fig. 7 for all the population involved in the scenario, and taking into consideration the casualty outputs in the model, a graph of one simulation showing sheltered evacuees departure times – Survive – next to the start time of evacuation for agents caught on tsunami – Casualties – is shown in Fig. 8. It is clear the influence of late departure times on the casualty estimation. The majority of resulting casualty agents decided to start the evacuation around 53 min and even over the 70min simulated here. On the other hand, the big amount of survivors decided to evacuate at much less time. Notice that even after 53 min some agents got on time to their shelter, this is due to spatial conditions of distance to the shelter, and modes of evacuation with higher speeds.

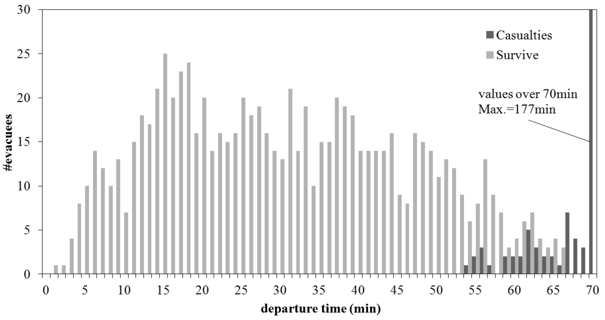

Figure 8 Departure times of agents and their final condition as survivor or casualty. The influence of faster evacuation is clear in the graph.

From the sheltered evacuees, we divided the modes of evacuation as pedestrians and cars and show in Table 4 the average distance to shelter, start time of evacuation, time of evacuation considering only the dynamic stage, the total evacuation time and the average speed. Due to the size of the model area, the distance to shelter in average is around 500m. Because we have used same random seed number and same algorithm to decide departure times for pedestrians and cars, the STE values are similar, however in the case of moving to the shelter (ToE), as expected cars are faster than pedestrians in accordance to the speed rules given. The total evacuation time is almost the same due to the great influence of the departure time. The average speed of 1.10 m/s agrees with the maximum value of 1.33 m/s explained before, same observation is applicable to car speed of 5.03 m/s (18.11 km/h). In general resulted average speed values are lower than the ruled given values, due to the dynamic condition of increasing and decreasing speed according to bottlenecks and crowd conditions.

Table 4 Average values of sheltered evacuees in one example of simulation.

Sheltered evacuees

Agent	D_sh (m)	STE (min)	ToE (min)	TET (min)	Spd (m/s)
Pedestrian	489	29.2	7.4	36.6	1.10
Car	671	32.5	2.2	34.7	5.03

D_sh: Distance to shelter
STE: Start Time of Evacuation
ToE: Time of Evacuation (only move)
TET: Total Evacuation Time (STE+ToE)
Spd: Average speed (D_sh / ToE)

6. CONCLUSIONS

A model of Integrated Tsunami and Evacuation Simulator was introduced. TUNAMI model and the Tohoku University source model for the 2011 Great Tohoku Earthquake and Tsunami were used as the tsunami modeling tool and scenario for evacuation. The model of evacuation was developed in Netlogo considering the human behavior and individual characteristic of start of evacuation time. The analysis of several questionnaire surveys with a statistical distribution showed that state preferences surveys follow an expected fast evacuation by respondents, while revealed preference surveys showed a late distribution of start time of evacuation. In this study we have proposed to use human behavior data from questionnaires of stated preferences and features of tsunami obtained by numerical simulation, such as the arrival time, to construct boundary distributions for a stochastic simulation of evacuation decision. Also, tsunami features of hydrodynamic conditions were used for the casualty estimation. A case study was conducted through simulation of Arahama town evacuation in the last 2011 Great Tohoku Earthquake and Tsunami. The study case shows the capability of the model to explore individual parameters and outcomes. Evacuation models like the one introduced here allows for studying the emergent behavior of individuals in a complex process of tsunami evacuation.

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