Developing an Integrated Tsunami and Agent Based Evacuation Simulator

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1. Introduction

Quantification of the ability of residents to reach a safe area after a tsunami warning sign is a key component in tsunami risk and vulnerability analysis (Post et al., 2009). Despite the great improvements on tsunami early warning system technology, still some people remained in the risk area when the tsunami arrived (Imamura, 2009). As a result, lots of casualties were observed in recent tsunamis (Samoa, 2009; Chile, 2010; Japan, 2011). Besides psychological considerations that affect individual decision of evacuation (Mas et al., 2011), spatial and local issues influence the final outcome of casualties. In this study, we developed an integrated tsunami and agent based evacuation simulator. The model integrates the results of numerical simulation of tsunami scenarios into a micro-scale simulation of pedestrians and cars evacuating. Through this integration, casualty estimations respond to hydrodynamic features of tsunami and spatial and local conditions of the evacuation. Outcomes such as estimation of evacuation times and other variables can be obtained through simulations. Evacuation simulator becomes a practical tool for tsunami mitigation planning and education of tsunami awareness.

2. Objective

The objective of the study is to assess the necessity of management tools for evacuation feasibility analysis by developing an Integrated Model of Tsunami Evacuation Simulation in a multi-agent system.

3. Methodology

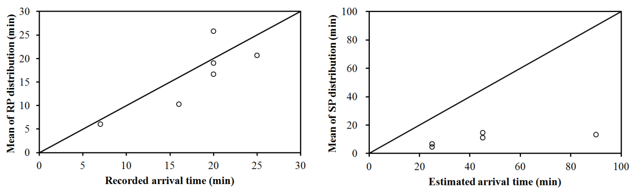
The model for tsunami evacuation was developed in Netlogo, a multi-agent programming language and modeling environment for simulating complex phenomena (Wilensky, 2001). Hundreds or thousands of agents can operate concurrently in order to explore the connection between the micro-level behavior of individuals and the macro-level patterns that emerge from their interactions. The model uses GIS data as spatial input. Tsunami characteristics are obtained from the outputs of TUNAMI numerical model.

3.1. Questionnaire survey data

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. According to Naser and Birst (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. 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.

3.2. Start time of evacuation

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. 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 and Prater, 2007; Southworth, 1991). 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.



(a) ETA vs RP means (b) ETA vs SP means

Figure 1: RP & SP surveys correlations with the estimated tsunami arrival time (ETA)

Fig1(a) and Fig1(b), show that there is a 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 behavior was observed in previous events and confirmed by the several videos available on the web. Based on these figures we argued that 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, 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.

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3.3. Agent architecture

Agents are provided with abilities to process information and execute their evacuation, through a simple layered behavior:

- Layer 0: The evacuation decision, assigned randomly based on the departure times distributions explained above.
- Layer 1: The Shelter decision, as an option for scenario exploration, two alternatives are possible for agents; the nearest shelter or any of the shelters.
- Layer 2: 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).
- Layer 3: 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 for cars (Meister, 2007; Suzuki and Imamura, 2005).

Agents of pedestrian and car types move along streets and the collision avoidance should be taken into account. In the model, agents move in a continuous grid space according to their actual speed. In order to move according to the spatial accuracy or grid size, a certain number of agents are allowed in an area. Due to the dynamic movement of agents the 100% used of the grid is not a real condition. Then, through a corridor test (Helbing, 1991) and the use of the predictive collision avoidance proposed by Karamouzas et al. (2009) we counted the maximum number of agents passing through a $5mx5m$ area at each time step, the results show that the maximum used space in the grid is a 70% of its total area. 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.

3.4. 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 (Eq.1). 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 $0.85m$, after this value, at any velocity, an agent trapped into tsunami will be considered as casualty. In the case of cars casualty estimation, following Yasuda and Hiraishi (2004)'s research, a value of $0.50m$ 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 $0.50m$, a car trapped in the tsunami is considered as a casualty with all its passengers.

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

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

4. Conclusions

A model of Integrated Tsunami and Evacuation Simulator was introduced. 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.

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