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An agent-based model of a multimodal near-field tsunami evacuation: Decision-making and life safety

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ABSTRACT

This paper presents a multimodal evacuation simulation for a near-field tsunami through an agent-based modeling framework in Netlogo. The goals of this paper are to investigate (1) how the varying decisn time impacts the mortality rate, (2) how the choice of different modes of transportation (i.e., walking and automobile), and (3) how existence of vertical evacuation gates impacts the estimation of casualties. Using the city of Seaside, Oregon as a case study site, different individual decision-making time scales are included in the model to assess the mortality rate due to immediate evacuation right after initial earthquake or after a specified milling time. The results show that (1) the decision-making time (τ) and the variations in decision time (σ) are strongly correlated with the mortality rate; (2) the provision of vertical evacuation structures is effective to reduce the mortality rate; (3) the mortality rate is sensitive to the variations in walking speed of the evacuee population; and (4) the higher percentage of automobile use in tsunami evacuation, the higher the mortality rate. Following the results, this paper concludes with a description of the challenges ahead in agent-based tsunami evacuation modeling and simulation, and the modeling of complex interactions between agents (i.e., pedestrian and car interactions) that would arise for a multi-hazard scenario for the Cascadia Subduction Zone.

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1. Introduction

1.1. Near-field tsunami hazard

The Cascadia Subduction Zone (CSZ) is a major source for near-field tsunami through mega-thrust earthquake raptures threatening the costal community life safety in the Pacific Northwest region (Goldfinger et al., 2012). A near-field tsunami is likely to come onshore within 20–40 min after the initial earthquake, while a far-field tsunami (eq. distant-source) is typically 1000 km away from the area of interest which can take hours to reach seashores. Near-field tsunamis pose a greater risk for coastal communities because the first waves can move on shore in minutes (40 min or less).

Essentially, tsunami warning times are much shorter than other natural disasters such as hurricanes and floods, and even a well established system such as the Pacific Tsunami Warning Centre (PTWC) may not provide sufficiently long lead time for evacuation before a disaster happens, especially for locally-generated tsunamis (Katada et al., 2006). The near-field tsunami

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event is particularly devastating because the tsunami arrives in a very short time after the earthquake. Under such circumstances, evacuation is the most important and effective method to save human lives because it is impractical to construct all building to resist tsunami forces. The large-scale evacuation represents a complex system for transport operation and planning to minimize casualties, including the potential for critical infrastructure and communication systems to be damaged from the earthquake (Lammel, 2011).

1.2. Evacuation modeling from natural hazards

Fig. 1 shows the length and time scales from the perspective of an evacuee for several types of natural hazards. Evacuation plans for earthquakes and building fires generally occur over short time scales, seconds to a few minutes, and evacuees are on foot to shelter in place or nearby. For example in the case of an earthquake, an evacuee might take refuge under a desk within a few seconds of feeling the strong shaking of the building. On the other hand, evacuations from hurricanes often have several hours to days of advanced warning, and evacuees rely on vehicles to seek shelter several miles away beyond the hazard zone. Nearfield tsunamis present a complex case of multi-modal evacuation because the tsunami arrives within several minutes of the earthquake and can travel several kilometers inland. Moreover, evacuees may be faced with choices of sheltering near place (vis-a-vis vertical evacuation) on foot or to travel outside of the inundation zone typically by car.

There is extensive emergency evacuation modeling research due to its significance to human life safety, and advances in technology as is shown in Fig. 2. We are not planning to review each paper listed in Fig. 2 in this work, however interested readers are directed to the original papers/reports for more information. Fig. 2 presents five distinct hazard groups whose warning time increase from seconds level (i.e., earthquake) to hours range (i.e., hurricane) as is revealed in the hazard length and time scales in Fig. 1. For earthquake and building fire with very short warning times, the mode of evacuation is primarily on foot. However, for wildfire and hurricane with relatively longer warning time, people generally drive to evacuate the affected areas to safer places. Near-field tsunami represents the middle range of the five hazard groups in terms of warning time scales which is typically in the range from 20 min to 40 min. Therefore, transportation evacuation modes, may be multimodal rather than a single mode.

1.3. Tsunami evacuation modeling

Recent research efforts have begun using agent-based modeling frameworks for hurricanes and coastal community tsunami evacuation (Mas et al., 2011); however the existing tsunami evacuation research models typically assumes 100% pedestrian walking with little consideration of other modes of transportation such as auto-mobiles or bicycles. This is despite recent work where it was observed that a large number of evacuees left from low-topography areas by car (Mas et al., 2011).

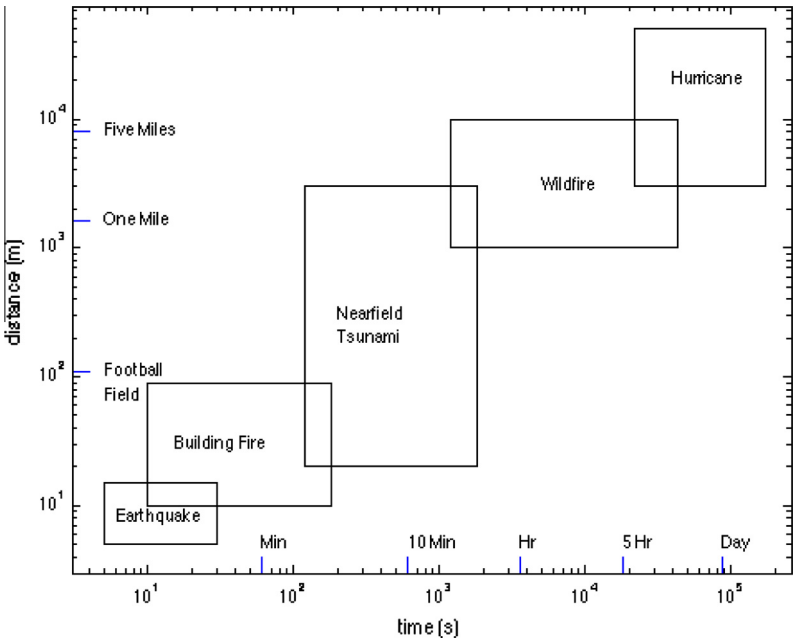

Fig. 1. Time and length scales from evacuees perspective for different hazards.