DLR-IRIDES-UN-SPIDER Joint Workshop on Remote Sensing and Multi-Risk Modeling for Disaster Management

GEOSPATIAL SIMULATION OF TSUNAMI EVACUATION USING GIS DATA AND AGENT BASED MODELING

Erick Mas, PhD

Assistant Professor

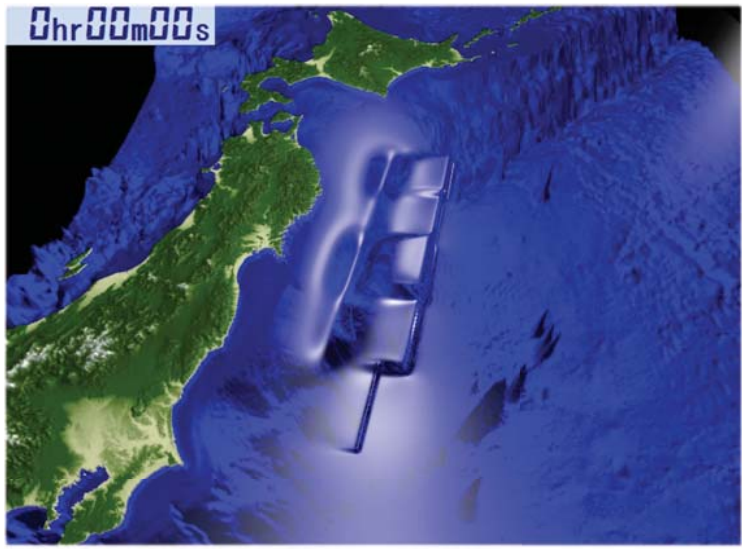
Laboratory of Remote Sensing and Geoinformatics for Disaster Management,
International Research Institute of Disaster Science, Tohoku University, Sendai, Japan

Bonn, Germany, September 19, 2014

Problem

- Population exposed to tsunami
- Need of tools to conduct and evaluate tsunami evacuation plans
- Evacuation drill? - Good for training, but not for experimentation. (i.e. threat of injury, lack of realism)

TUNAMI-N2 (Shallow water equations)



Background and Objective

- **Hazard** - Tsunami Simulation
- **Vulnerability** - Exposure, Preparation, Behavior, etc

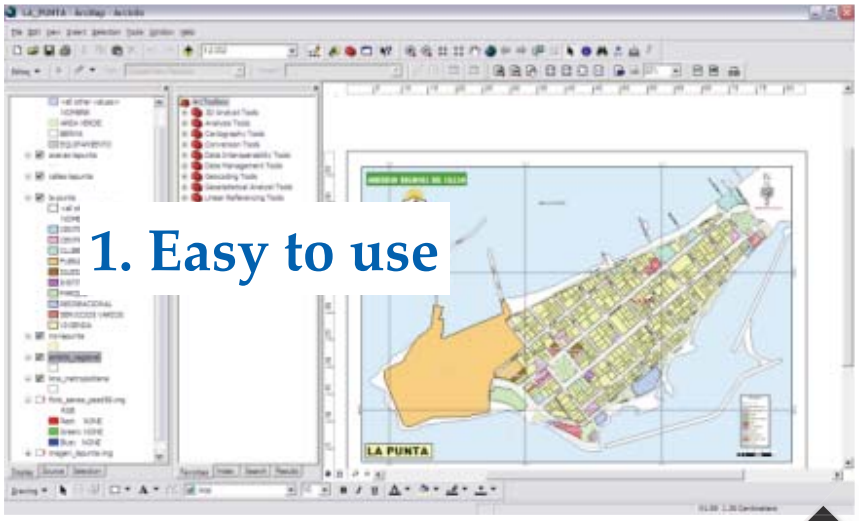
- **Risk** - Human losses
- **Risk Reduction measures**

Japan tsunami 2011

Arahama-Sendai, Miyagi, Japan

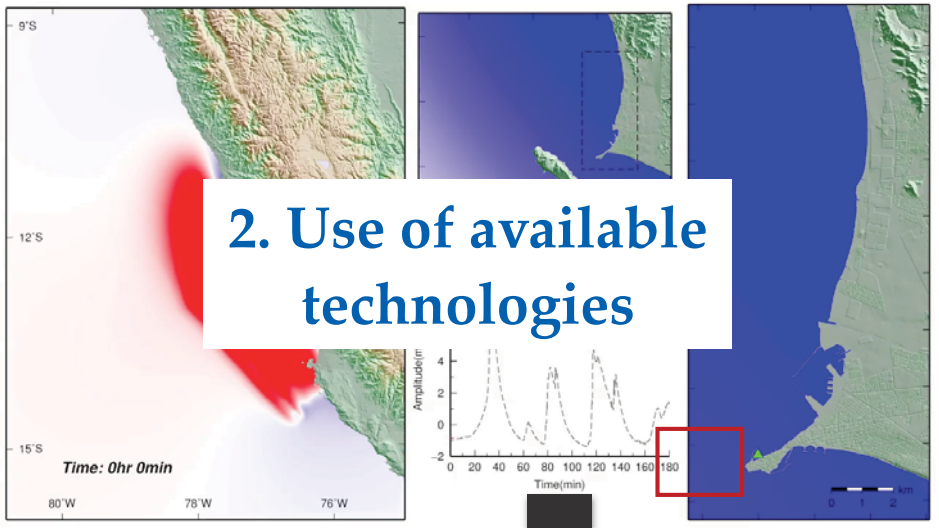
APPROACH

Tsunami numerical simulation results

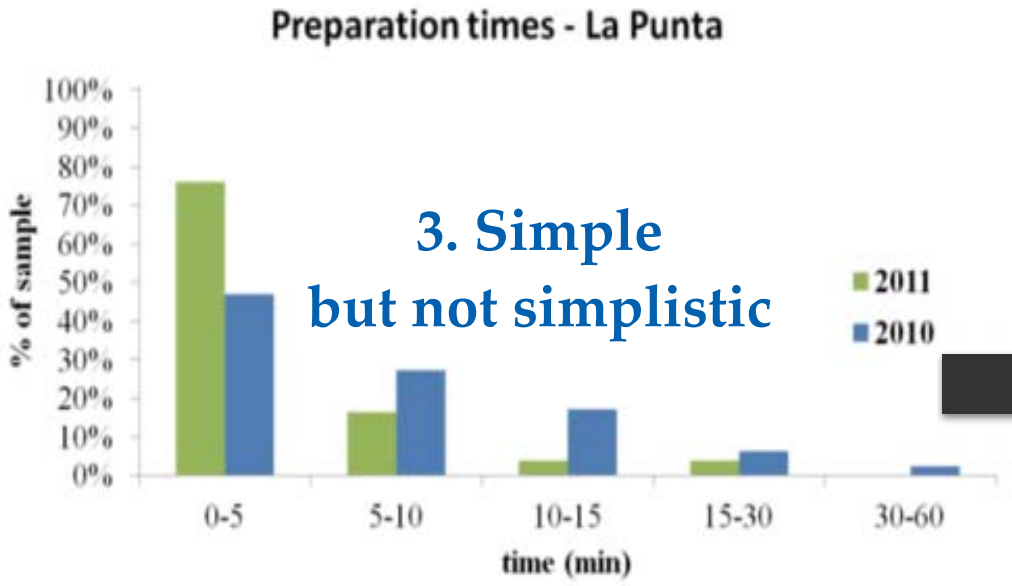


1. Easy to use

GIS data



2. Use of available technologies



3. Simple but not simplistic

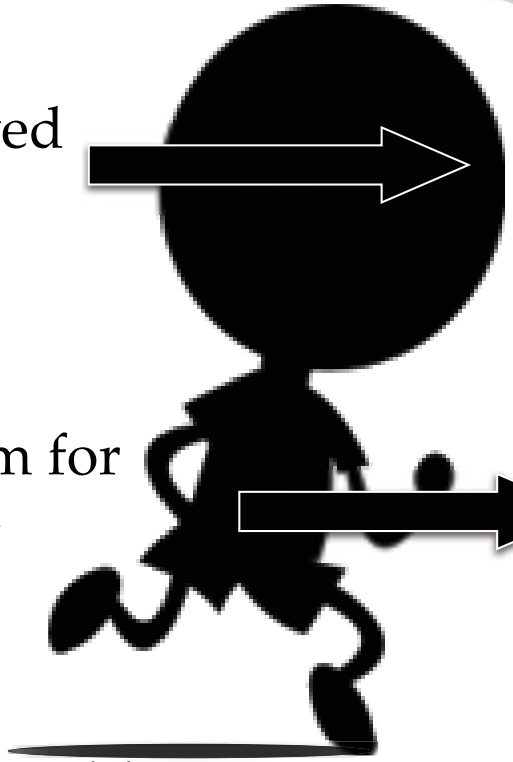
Questionnaire survey data

4. Easy to understand outputs

AGENT RULES

Tsunami Departure Curves → Evacuation decision (time)

Based on surveyed preferences → Shelter decision



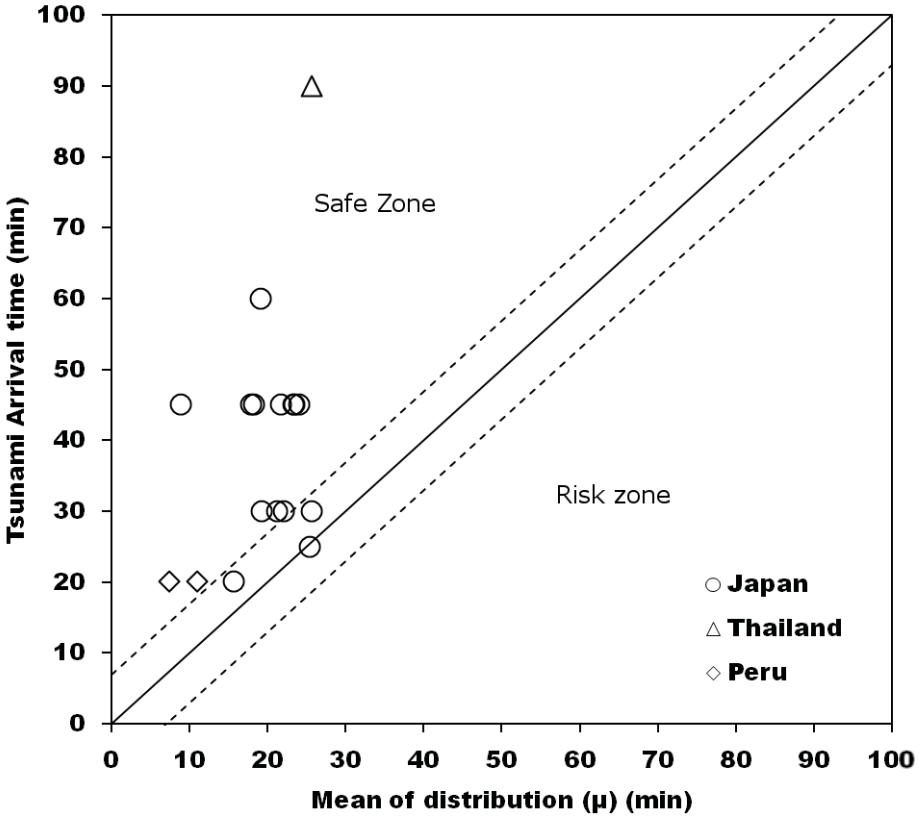
A* algorithm for pathfinding → Path finding behavior

Density recognition within FOV → Traffic and congestion recognition

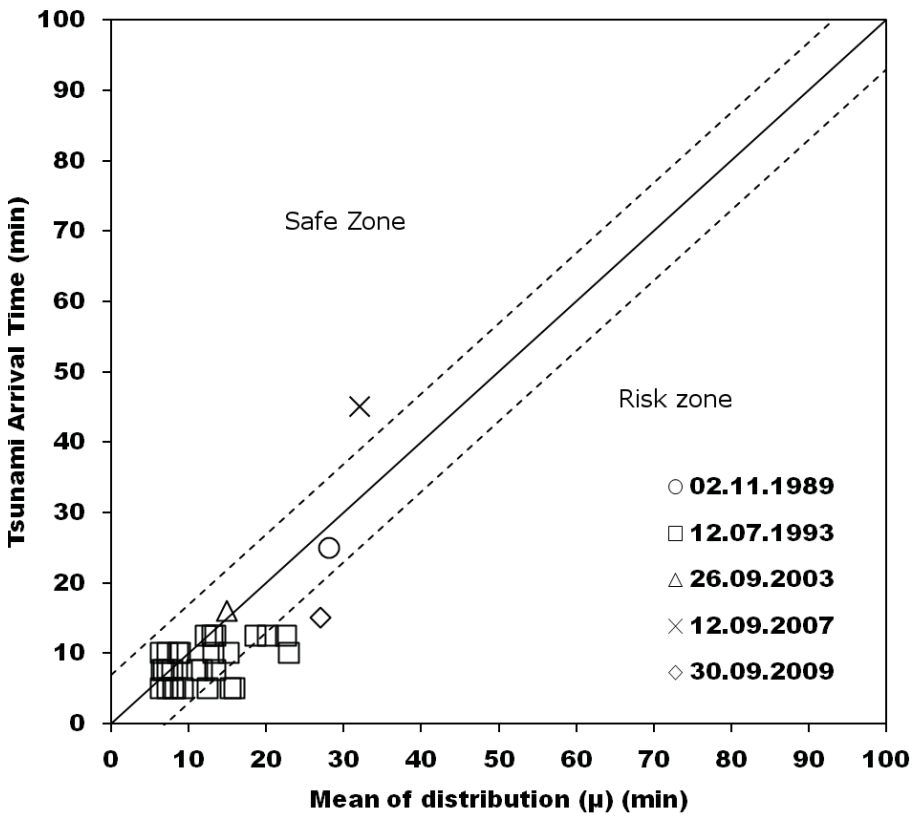
Density in FOV → Speed variation

From pre and post tsunami evacuation behavior surveys

Stated Preference surveys



Revealed Preference surveys



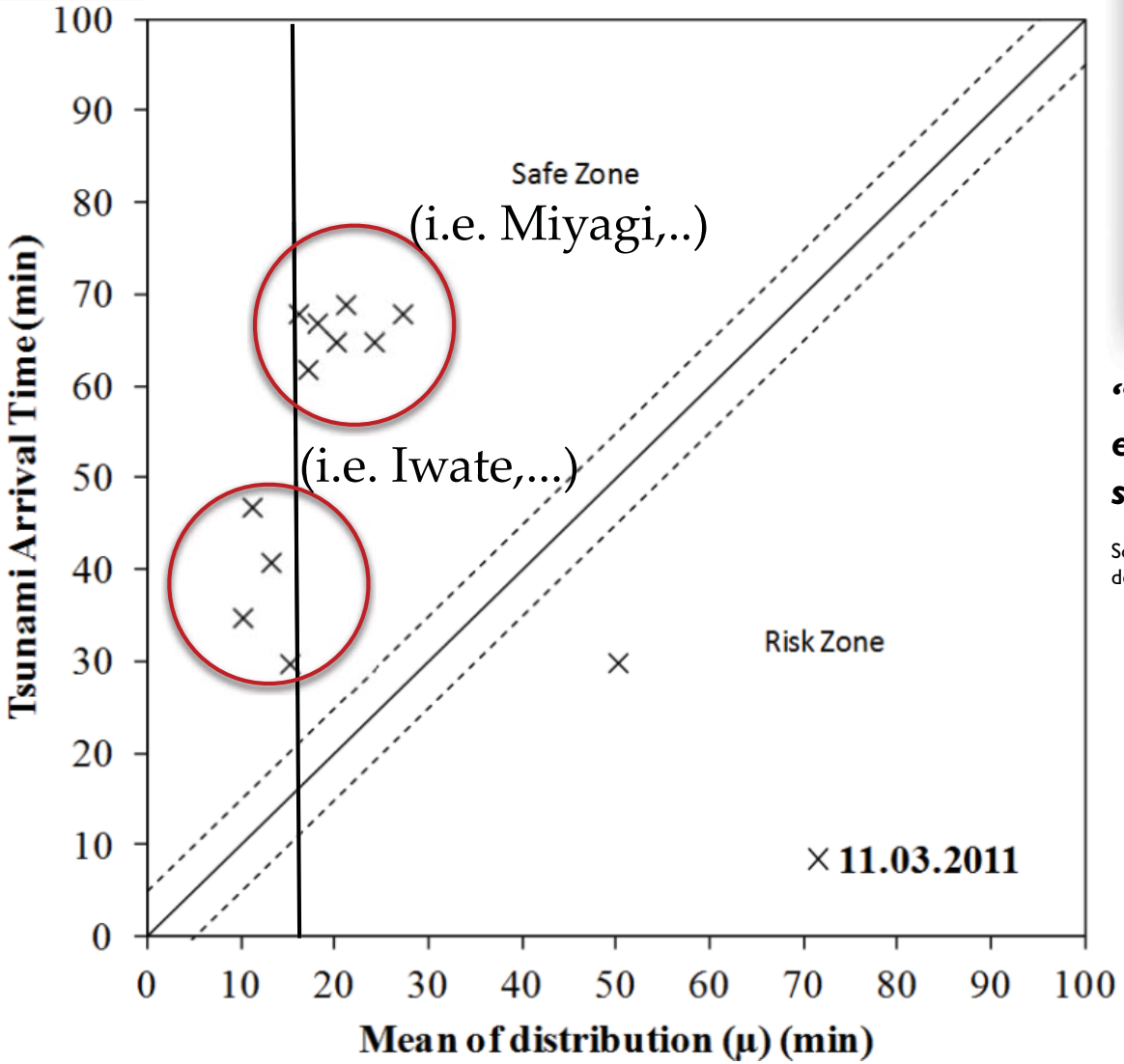
$$D(t) = 1 - e^{\frac{-\pi . t^2}{4\mu^2}}$$

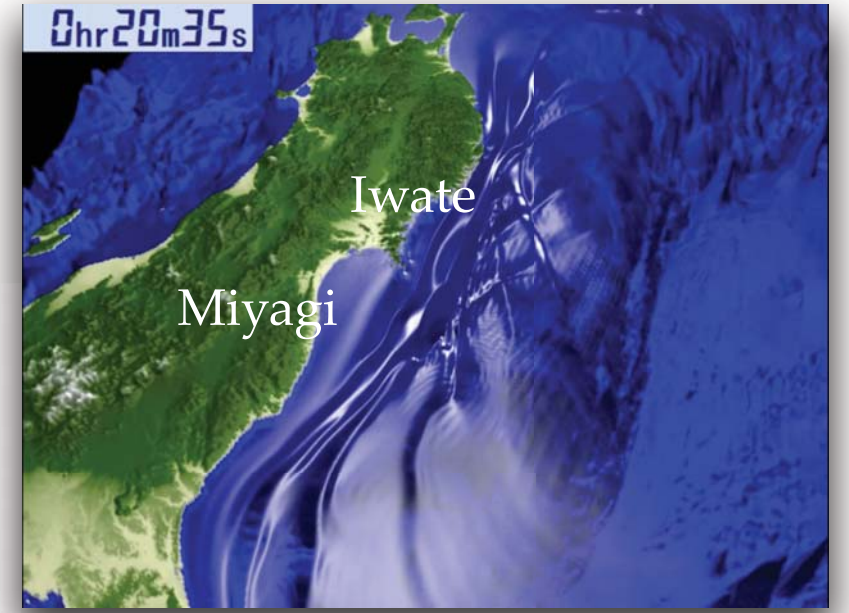
Based on a Rayleigh distribution

"People appear to adjust the rapidity of their evacuation behavior in accordance with the severity and timing of the impending threat."

Sorensen, J. H. (1991). When Shall We Leave? Factors Affecting the Timing of Evacuation departures. *International Journal of Mass Emergencies and Disasters*, 9(2), 153-165.

The Japan 2011 tsunami evacuation behavior confirms it

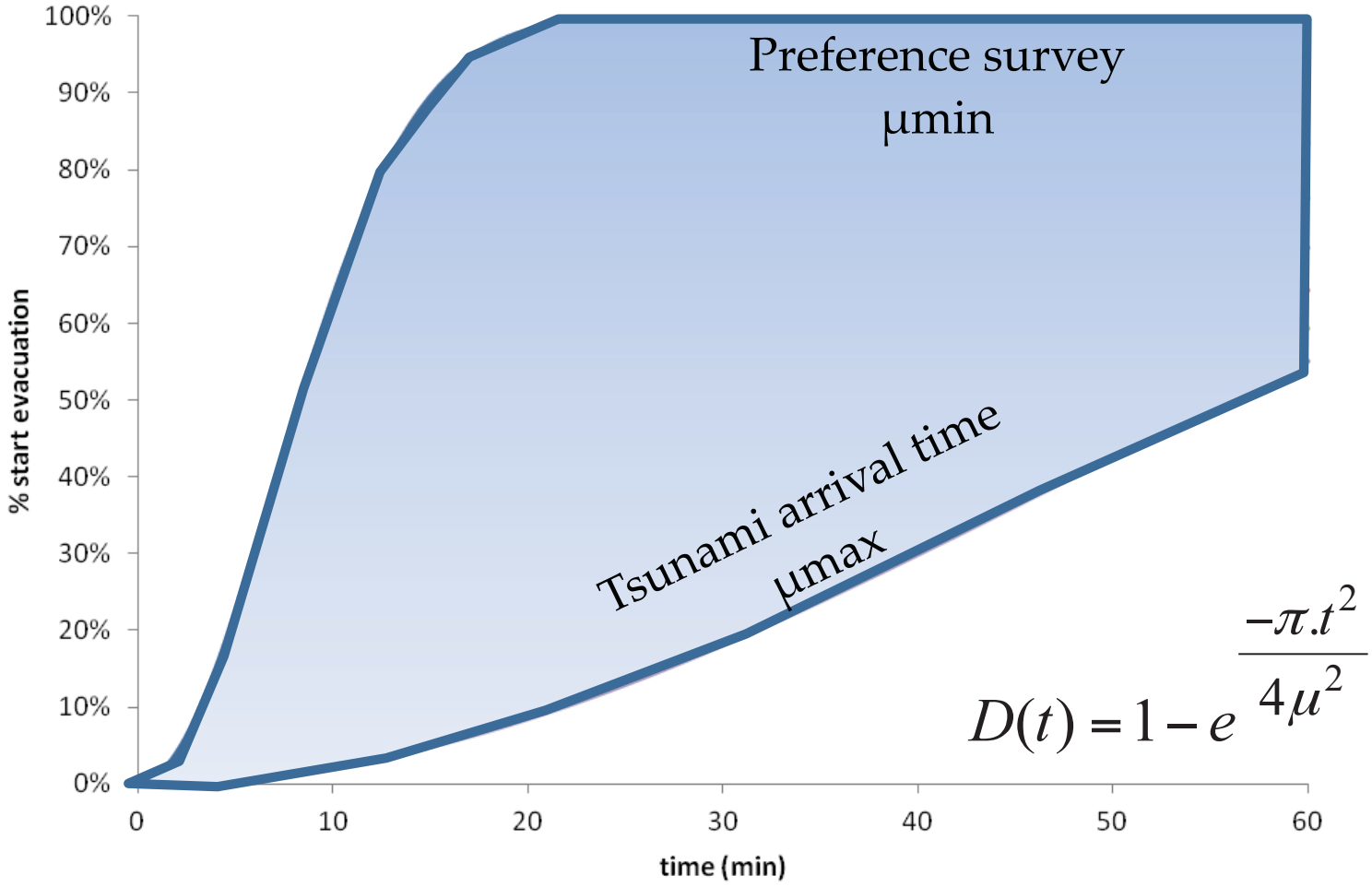




"People appear to adjust the rapidity of their evacuation behavior in accordance with the severity and timing of the impending threat."

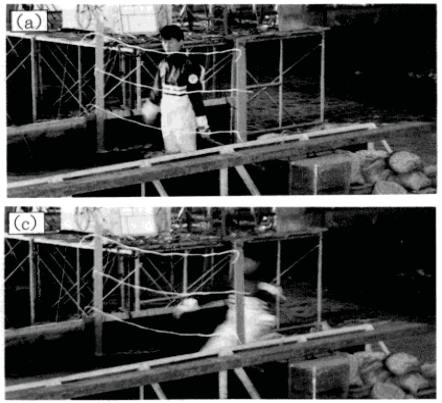
Sorensen, J. H. (1991). When Shall We Leave? Factors Affecting the Timing of Evacuation departures. *International Journal of Mass Emergencies and Disasters*, 9(2), 153-165.

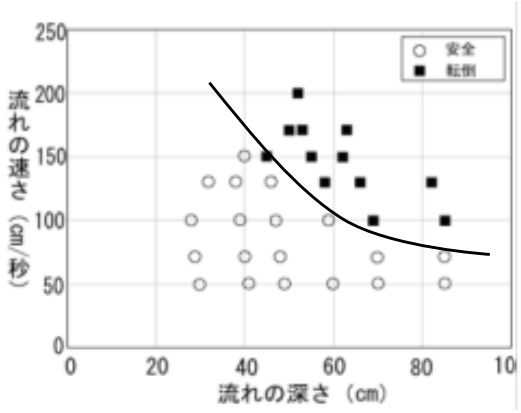
Tsunami Departure Curves for evacuation start time



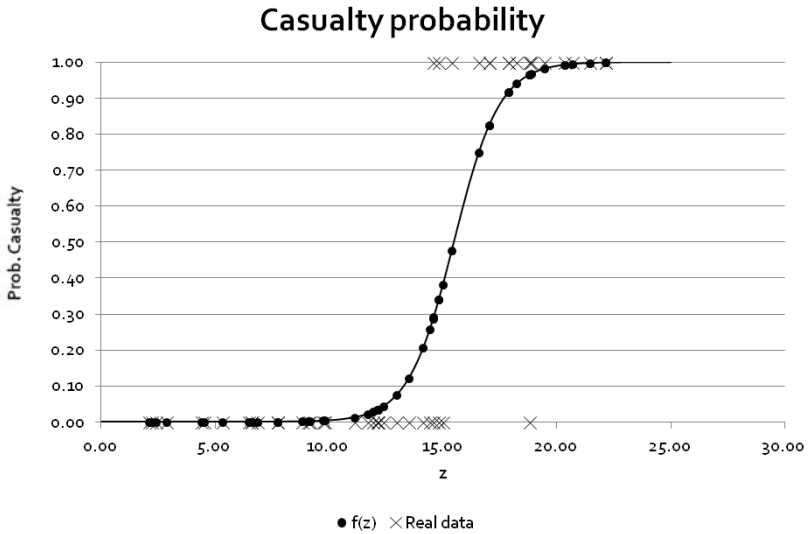
Stochastic simulation of several possible behaviors of departure curves bounded by Stated Preference surveys (μmin) and the arrival time of the tsunami in the study area estimated by numerical simulation (μmax).

Casualty estimation using tsunami features





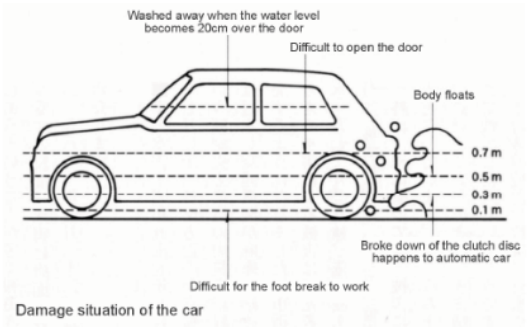
Takahashi et al, 1992



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

$$z = \beta_0 + \beta_1 * h + \beta_2 * u$$
$$\beta_0 = -12.37$$
$$\beta_1 = 22.036$$
$$\beta_2 = 11.517$$

Note: Equation is applicable for h [0.28,0.85] (m) & u [0.50,2.00] (m/s) (Nagelkerke $R^2 = 0.83$)



Yasuda et al, 2004

Pedestrian

$(h \leq 0.85)$ f(z)

$(h > 0.85)$ -> casualty

Car

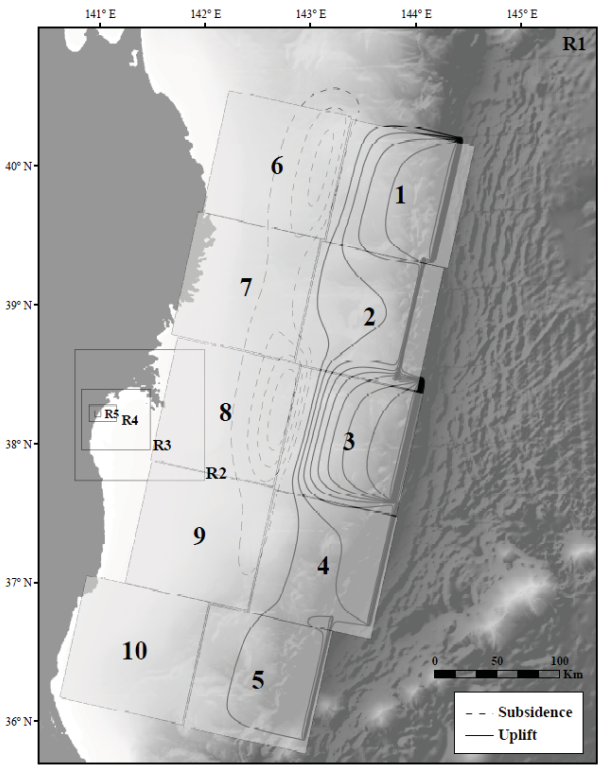
$(h > 0.50)$ -> casualty

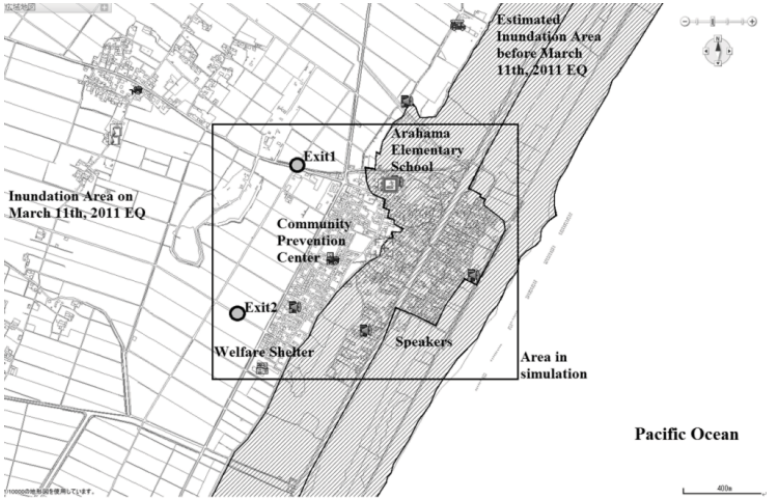
TSUNAMI EVACUATION SIMULATOR

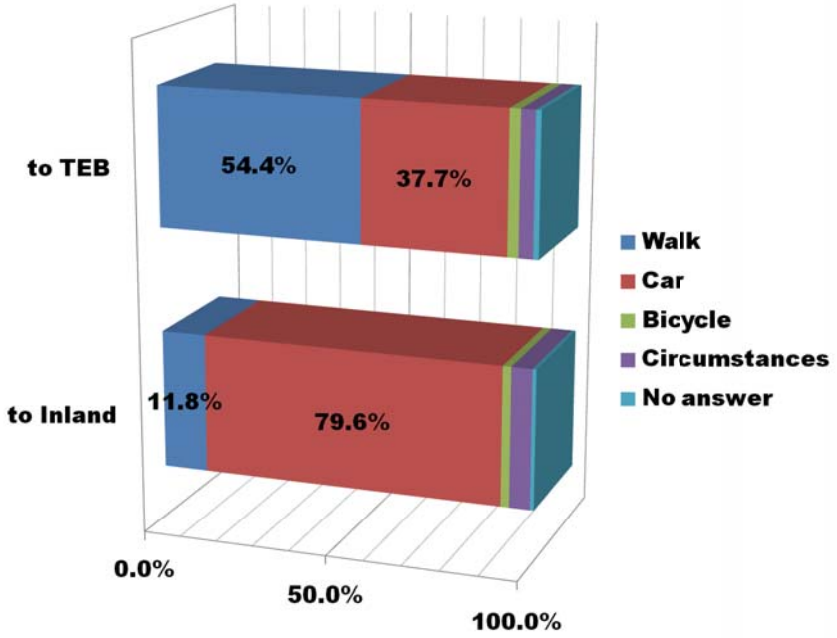
Interactive Environment for modeling

Case studies

1. Arahama, Japan



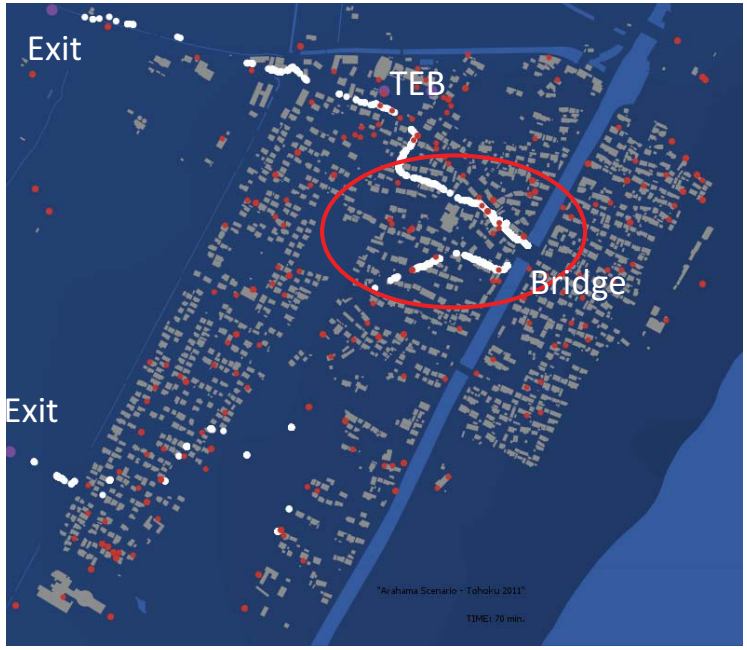




- **2011 Japan tsunami**
- **2,271 residents (peds. & cars)**
- **Objective: Verify bottleneck and casualties**

Mas, E., Suppasri, A., Imamura, F., & Koshimura, S. (2012). Agent-based Simulation of the 2011 Great East Japan Earthquake / Tsunami Evacuation : An Integrated Model of Tsunami Inundation and Evacuation. Journal of Natural Disaster Science, 34(1), 41–57.

1. Arahama, Japan



- Casualties
- Casualties on "traffic"
- Crowd density condition fulfilled at any moment of the computation

Results

Case	Casualties	TEB	Inland
Model	406	498	1367
Real	283	520	1468

TEB: Tsunami Evacuation Building

- **2011 Japan tsunami**
- **2,271 residents (peds. & cars)**
- **Objective: Verify bottleneck and casualties**

Mas, E., Suppasri, A., Imamura, F., & Koshimura, S. (2012). Agent-based Simulation of the 2011 Great East Japan Earthquake / Tsunami Evacuation : An Integrated Model of Tsunami Inundation and Evacuation. Journal of Natural Disaster Science, 34(1), 41–57.

2. Yuriage, Natori, Japan

Population: 5,612

Casualties: 762

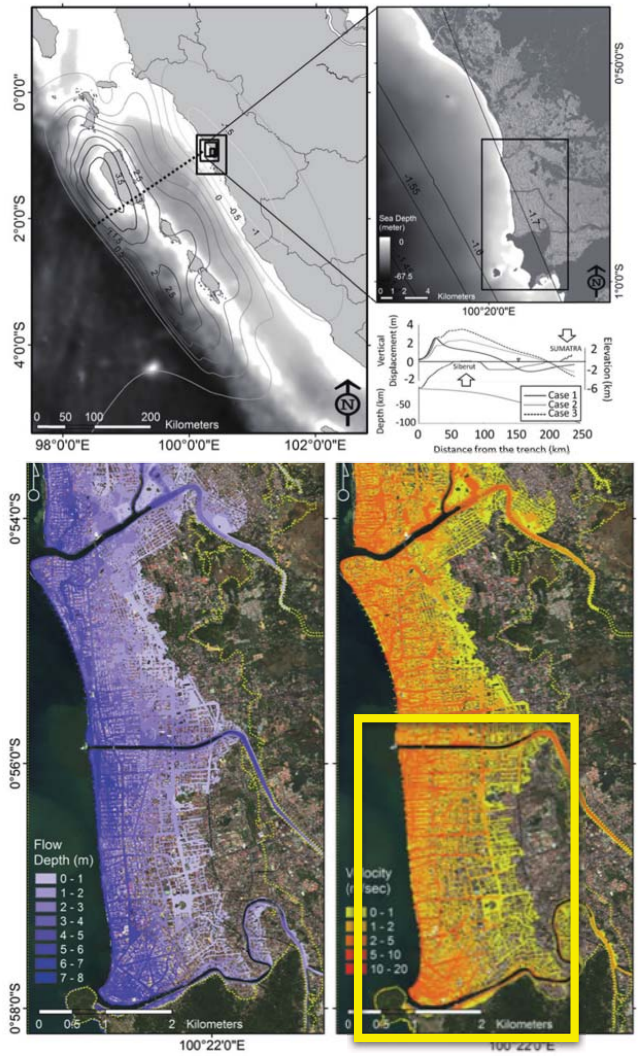
Case	Casualties	TEB1	TEB2	TEB3	Inland
Model	774	43	1050	699	1367
Real	762	~30	~1000	~870	1468

TEB: Tsunami Evacuation Building

- **2011 Japan tsunami**
- **3,944 residents (peds. & cars)**
- **Objective: Verify bottleneck, casualties and double evacuation**

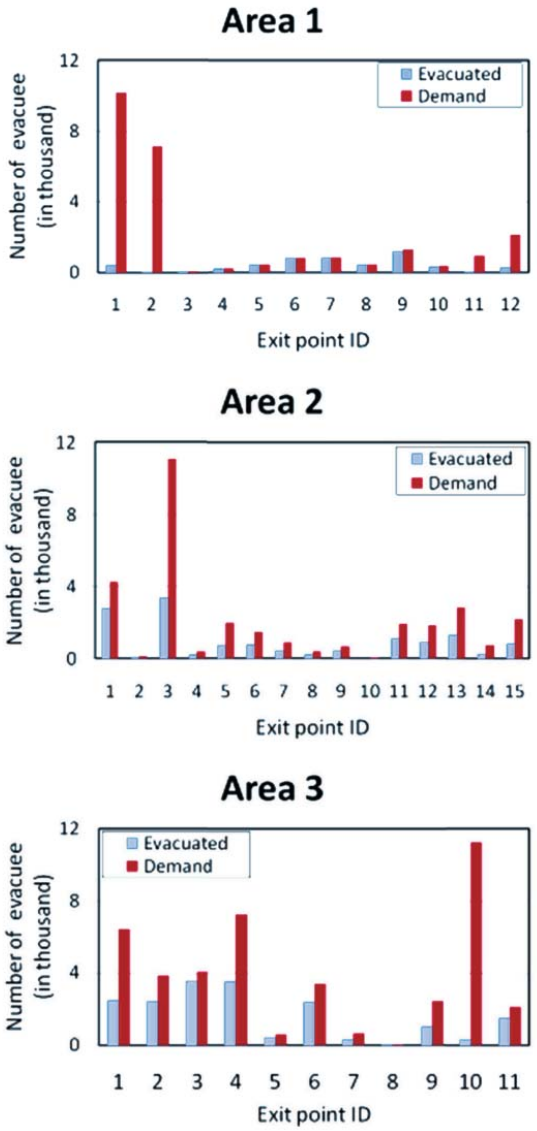
Takagi, H., Mas, E., & Koshimura, S. (2014). Analysis of the evacuation behavior in Natori, Yuriage during the Great East Japan Earthquake Tsunami. In Annual Meeting of the Tohoku Branch Technology Research Conference, Japan Society of Civil Engineers (Vol. 3, pp. 2011–2012).

3. Padang, Indonesia



Model layout

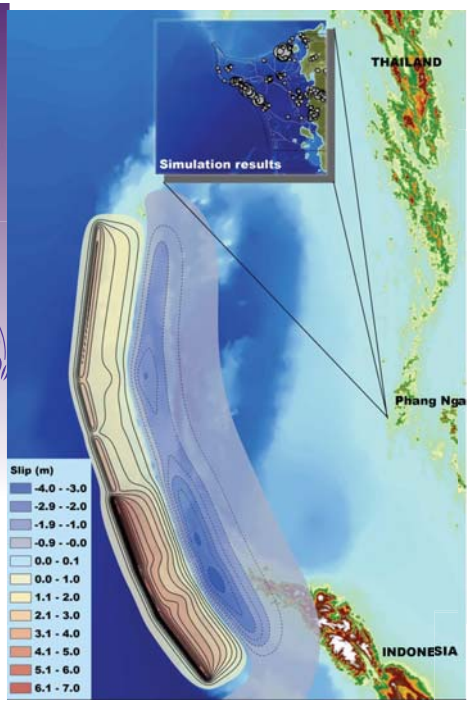
Results

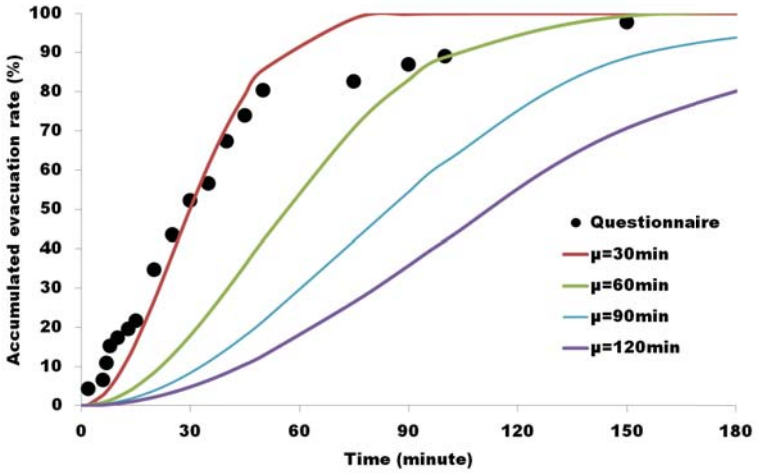


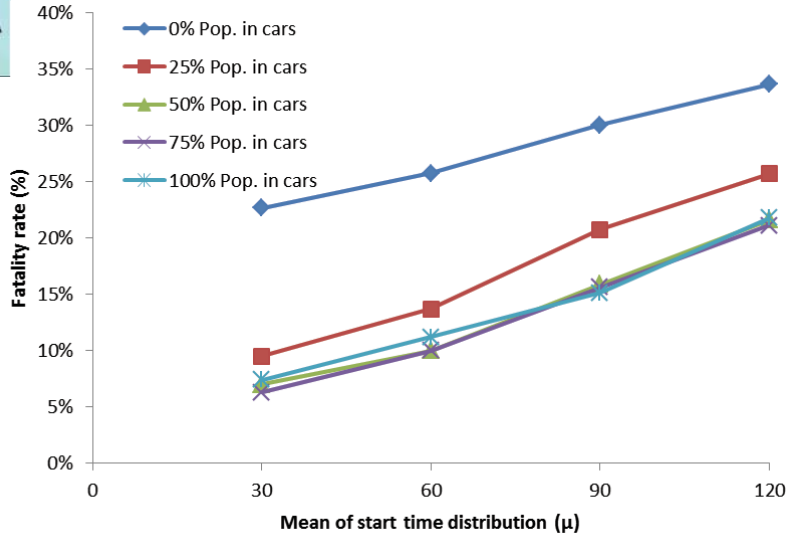
- **Mega earthquake in Padang**
- **104,352 pedestrian agents**
- **Objective: Identify bottleneck areas, evaluate casualty estimation (62% pop.)**

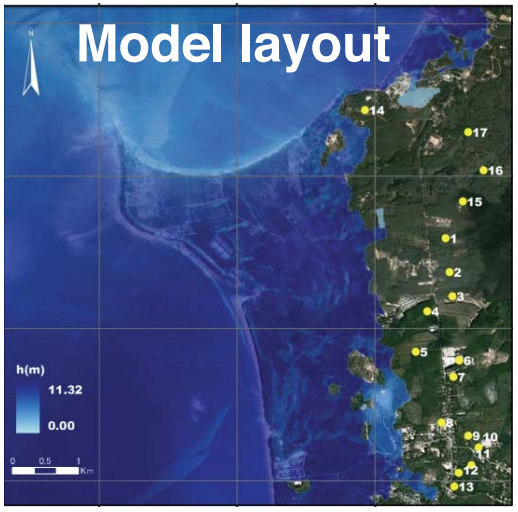
Imamura, F., Muhari, A., Mas, E., Pradono, M. H., Sugimoto, M., & Post, J. (2012). Tsunami Disaster Mitigation by Integrating Comprehensive Countermeasures in Padang City, Indonesia. Journal of Disaster Research, 7(1)

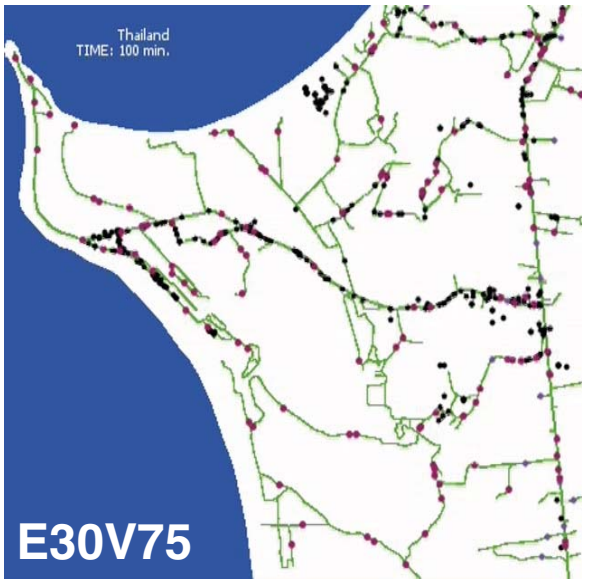
4. Phang Nga, Thailand

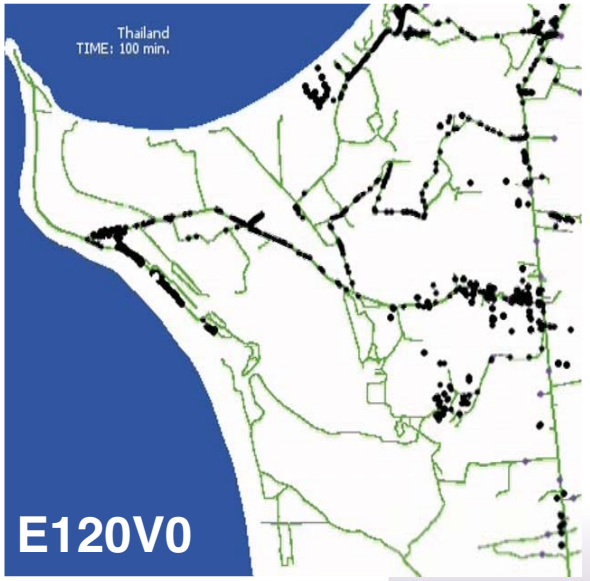












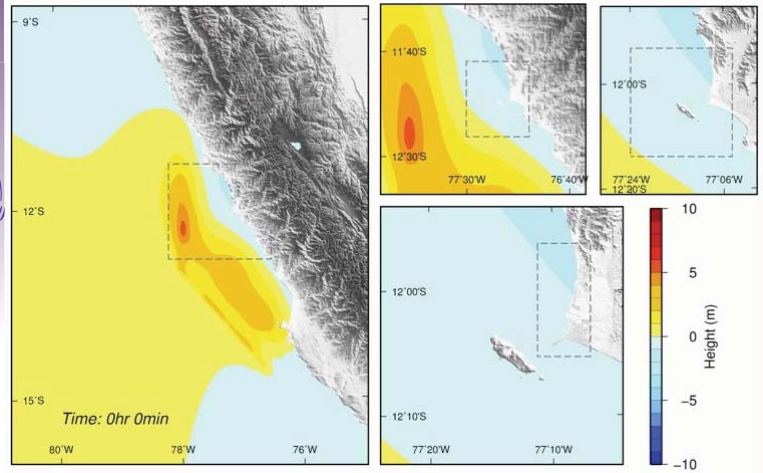
- **2004 Indian Ocean tsunami**
- **2,649 residents (peds. & cars)**
- **Objective: Vehicle evacuation**

Population in Vehicle	Start Time of Evacuation (min)			
	30	60	90	120
0%	E30V0	E60V0	E90V0	E120V0
25%	E30V25	E60V25	E90V25	E120V25
50%	E30V50	E60V50	E90V50	E120V50
75%	E30V75	E60V75	E90V75	E120V75
100%	E30V100	E60V100	E90V100	E120V100

- **Vehicles**
- **Pedestrians**

Mas, E., Suppasri, A., Srivihok, P., & Koshimura, S. (2013). Feasibility of Evacuation at the Pakarang Cape in Thailand based on Tsunami Inundation Model and Human Evacuation Simulation. In 10th International Conference on Urban Earthquake Engineering (pp. 1–6). Tokyo, Japan.

5. La Punta, Peru



Total Shelter capacity: ~7,000

- **Future mega earthquake scenario**
- **4,370 residents (peds. & cars)**
- **Objective: Estimate shelter demand**

Population: 4,370 / Casualties: 271

Mas, E., Adriano, B., Koshimura, S., Imamura, F., Kuroiwa Horiuchi, J., Yamazaki, F., Zavala, C., Estrada, M. (2014). Identifying Evacuees Demand of Tsunami Shelters Using Agent Based Simulation. In Y. A. Kontar, V. Santiago-Fandino, & T. Takahashi (Eds.), Tsunami Events and Lessons Learned (pp. 347–358). Springer Netherlands. doi:10.1007/978-94-007-7269-4_19

5. La Punta, Peru

Vertical Evacuation

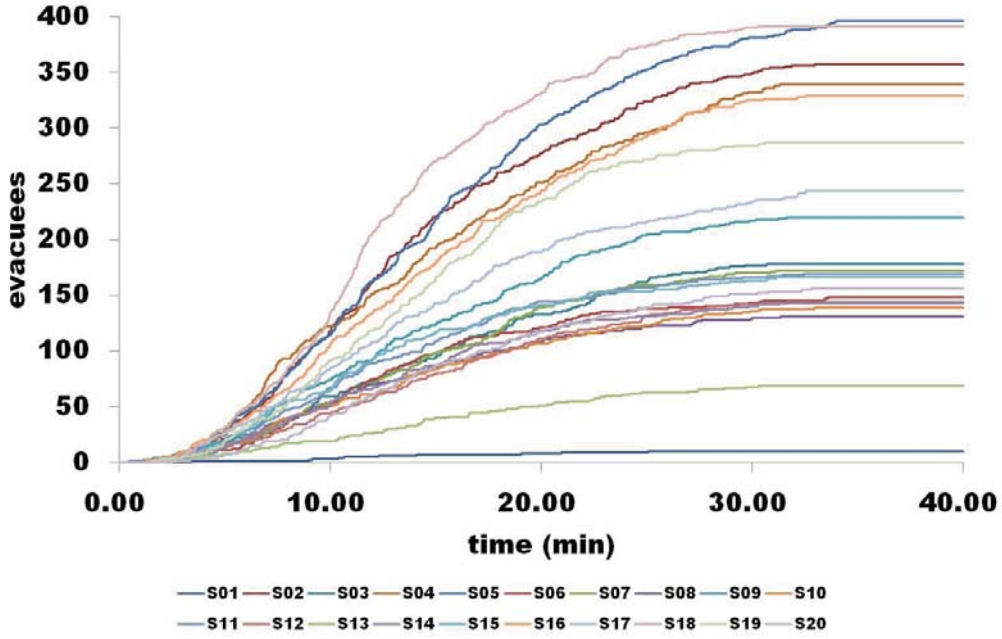
Casualties = 16

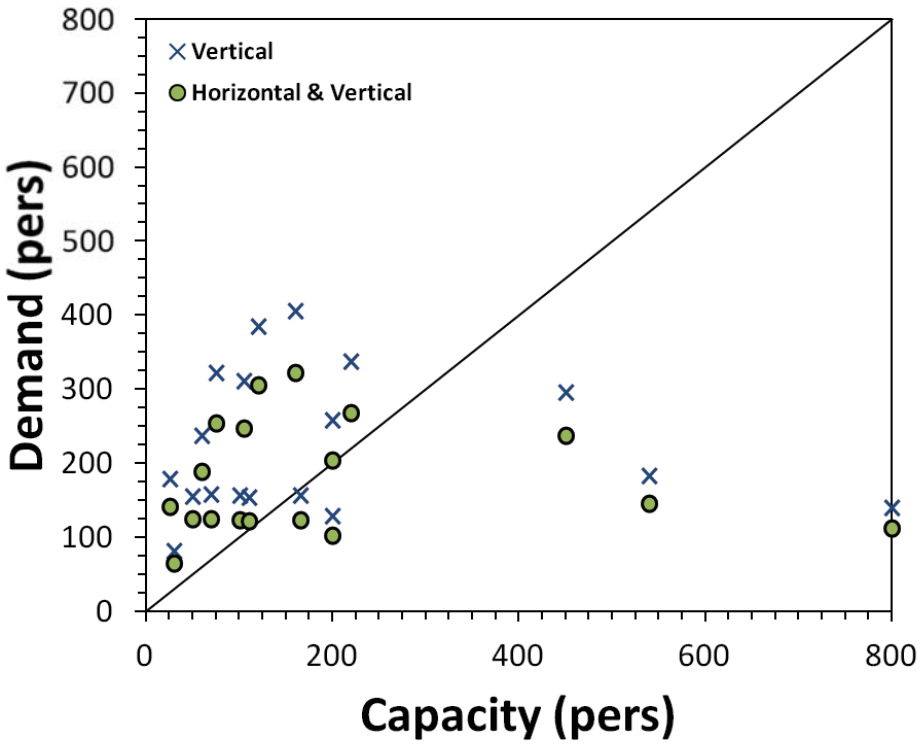
Horizontal and Vertical Evacuation

Casualties = 153

- **Vertical evacuation yields better results because no vehicles are involved for traffic congestion.**
- **<u>Notice that here the use of vehicles is not convenient, different to the case shown in Thailand</u>**

5. La Punta, Peru



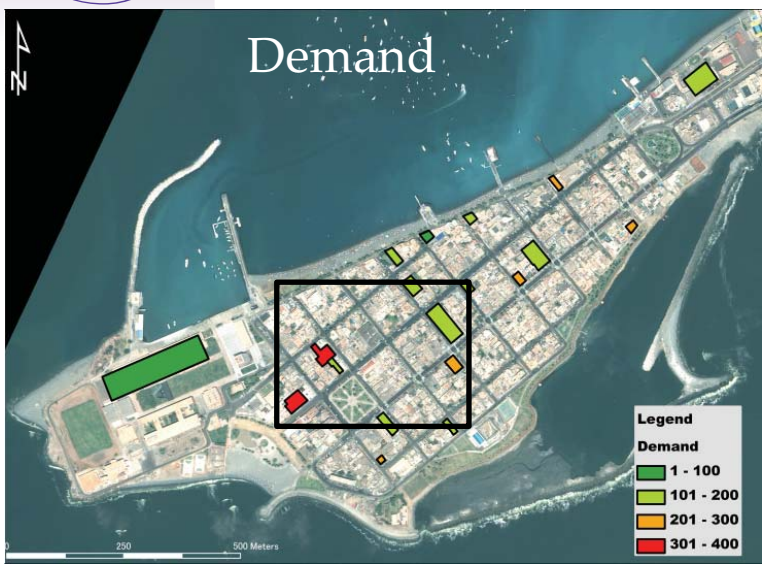


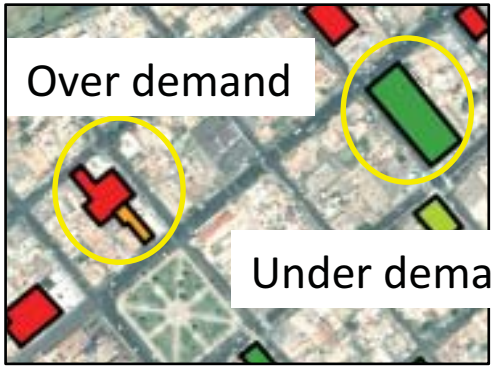
- **At least 13 out of 20 shelters can experience over demand in case of emergency evacuation**

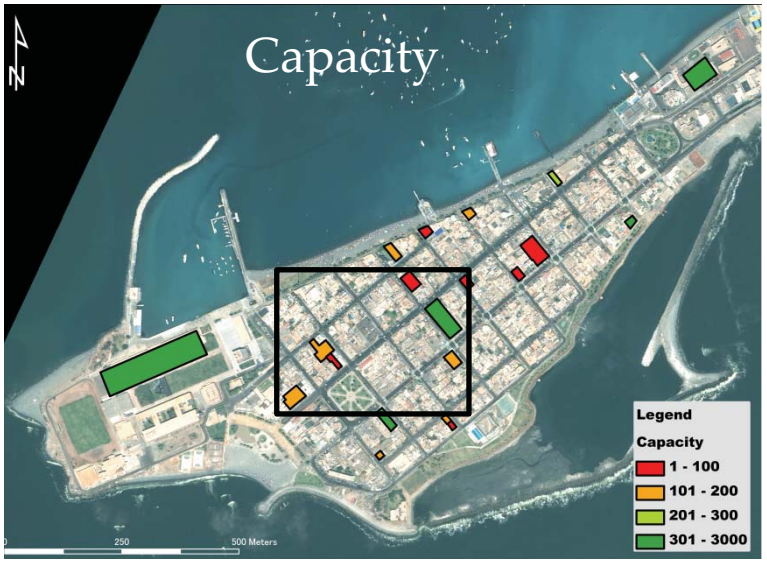
5. La Punta, Peru

Another way is to spatially look at the results

RED: OVER DEMAND
GREEN: UNDER DEMAND

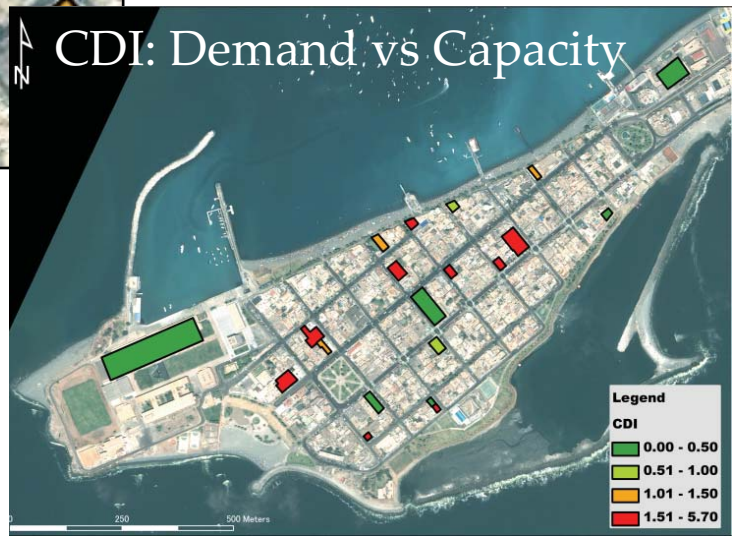






Capacity-Demand Index (CDI)

$$CDI = \frac{Demand}{Capacity}$$



Conclusions

- Complex environments can be simulated using simple and basic rules. (Agent based paradigm)
- Physical simulation, Social behavior and Geospatial information are put together in an easy to understand manner as a tool for tsunami evacuation planning.
- The model was built in NetLogo, an easy language to understand the core, limitations and even modify the model.
- Multiple applications can be tested by modifying the model to answer specific research questions.

Thank you for your attention

mas@irides.tohoku.ac.jp