# Vertical Evacuation for Pedestrians of Near-Field Tsunami Using Agent Based Modeling (ABM)

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**Abstract.** One of the critical actions in catastrophe conditions is how to evacuate effectively. However, instead of horizontal evacuation, vertical evacuation is the better protective action. This research aims to evaluate the vertical evacuation for pedestrians near field tsunami using agent-based modelling (ABM). The data was obtained from the Tsunami disaster in Banten in 2018, such as milling time, walking speed, shelter location and tsunami wave. We evaluated the effectiveness of evacuation regarding the number of people evacuated safely and the mortality rate. Some scenarios was evaluated with various parameters. This research reveals that milling time and walking speed are critical points to create good vertical evacuation.

## 1. Introduction

Indonesia is one of archipelago country with many active volcanoes. Also, it is located in the ring of fire which is surrounded by three world tectonic plates, namely the Indo-Australian Plate, the Eurasian Plate and the Pacific Plate. The volcanic activity causes catastrophic eruptions, while the activity of tectonic plate may cause earthquakes and tsunamis[1]. The impact of the disaster is in the high risk category. The data show that the total number of people exposed to the risk of tsunami disaster in Indonesia is 4,102,406 people in all provinces in Indonesia with a potential loss of IDR 879 Trillion[2]. One of the areas that has a risk of earthquake and tsunami threat is Banten Province with the potential for earthquake and tsunami losses calculated to reach 148,390 people[1].

These risks can't be avoided, but their impact should be minimized. The way to minimize the catastrophe's risk is evacuation. Afew of studies attempt to analyze how to carry out an effective evacuation[3–5]. However, these researchesare still limited to hurricane disasters.

Furthermore, as an effort in terms of planning an effective evacuation strategyis necessary to know the behaviour disaster evacuation. The agent based model (ABM) approach is the appropriate model to determine evacuation behaviour during disasters such as explosions[6], excavations[7], fires[8,9], volcanoes [10], earthquakes[11,12], as well as earthquakes and tsunamis[13].

Unlike other disasters, tsunamis take approximately 20-40 minutes after the initial earthquake and generally have limited time to provide early warnings before the disaster strikes [14]. Thus the evacuation will be different. Research that discusses tsunami evacuation is carried out by [15] where evacuation is carried out using vertical evacuation with the help of a tsunami evacuation building

(TEB). this study only simulates the effectiveness of buildings in saving people. On the other hand, the effectiveness of evacuation is strongly influenced by human behaviour[16–18] during early warning, during a disaster and after a disaster with factors that influence, including age, gender [19,20], early evacuation and location safe [20] .

Thus, research is needed to examine the effectiveness of evacuation that focuses on human behaviour in responding to disaster information. While one of the approaches used is the agent based model (ABM). Research using ABM has been carried out, where this study focuses on the behaviour of individual agents[21,22]compared to the community, because it is closer to reality. While other studies add the agent's behaviour on foot [23] or the interaction between car and walking transportation modes[14,22,24,25]. However, the car mode of transportation creates a new problem, namely overcrowding which can cause a slowdown in evacuation, so[26]suggests evacuating by foot.

In this study, observations were made for the evacuation of walking with the consideration of avoiding overcrowding during evacuation. As a consideration in the evacuation, evaluate evacuation routes, shelter locations. Thus, this study will develop a model that can help to identify the vertical behaviour of earthquake and tsunami evacuation for walkers using an agent-based model (ABM) approach.

## 2. Methods

The object of this research is the behaviour of earthquake and tsunami evacuation based on age, gender, occupation, shelter location, shelter capacity. To develop this simulation model, it involved the participation of communities disaster-affected by the earthquake and tsunami in Carita Beach, Banten. The model evaluates the interactions that occur between evacuating groups and walker evacuation behaviour. For research stages are: (1) identify the behaviour of the earthquake and tsunami mode, (2) conduct *focus group discussion* (FGD) on disaster evacuation behabiour for pedestrians in Carita Beach, Banten, (3) determine of agents, (4) using computational agent-based model simulation (ABMS), and (5) determine the best alternative solution.

In this study, the agents involved were evacuees and tsunamis with the explanations as shown in Table 1. While the description of the model showed in Table 2.

**Table 1.** Agents of Model

| Agents | Functionalities |
|---|---|
| Evacuees | Represents the people in the vulnerable area. In the simulation, the number of evacuee agents is taken between 300 and 500. The speed of evacuees is taken by various parameters. |
| Tsunami | Represents the tsunami. For initial tsunami is random at speed defined based on the various parameters. |

**Table 2.** Description of Model

| Agents | State | Action | behaviour |
|---|---|---|---|
| Evacuees | Alive, in motion, dead | Walk towards the shelters, die | When the agents see the tsunami indication, they walk toward the shelters |
| Tsunami | Propagate, stop propagate, affect evacuees | Disperse, affect the evacuees | The tsunami starts at the beginning of simulation and disperse with the time. |

Based on the literature review stage, this study uses several parameters and simulation scenarios. The scenarios are divided into three which differ on the parameters used. For details as in Table 3.

**Table 3**. Paremeter dan Scenarios

| Parameter | Scenario A | Scenario B | Scenario C |
|---|---|---|---|
| Walking speed | 1 $ms^{-1}$ | 1.5 $ms^{-1}$ | 2,5 $ms^{-1}$ |
| Tsunami speed | 5 $ms^{-1}$ | 5 $ms^{-1}$ | 5 $ms^{-1}$ |
| Milling time | 10 minutes | 10 minutes | 10 minutes |
| Location Shelter | 5 in random | 5 in random | 5 in random |
| Capacity/Shelter | Undefined | Undefined | Undefined |

## 3. Results and Discussion

For three scenarios, the results are shown in figure 1. Number of survived evacuees is depend on walking speed that she/he took. In scenario C with walking speed that is fastest than the others, It gets the best result with 441 alive evacuees (59 missing persons). In other hand, the worst result is scenario A with 399 alived evacuees. From these scenarios reveals that with lower walking speed-represents the physical ability- impacts on high mortality rate.

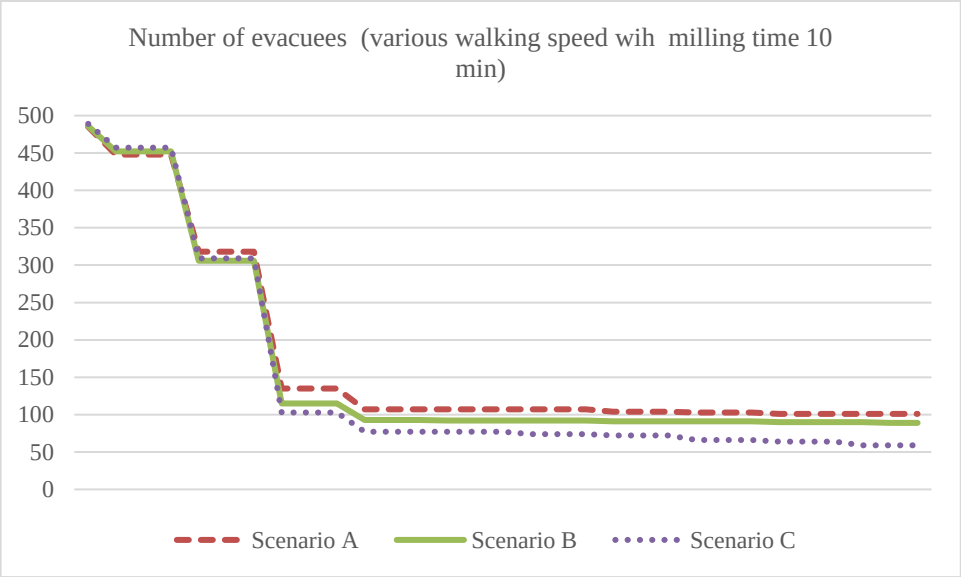


**Figure 1**. Number of evacuees based on three scenarios

Furthermore, Figure 2 shows the number of evacuees with scenario C in longer milling time (20 minutes). For this scenario, the number of alived evacuees is higher than scenario C in shorter milling time (10 minutes) with 452 and 441 refugees respectively. These means the impact maximum of milling time on mortality rate is lower.

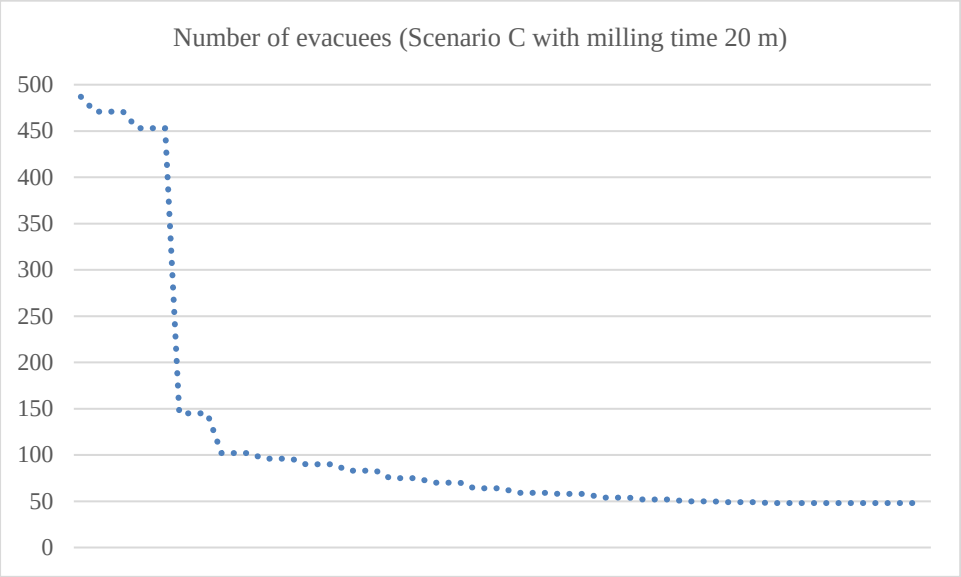


**Figure 2**. Number of evacuees based on scenario C with mlling time 20 minutes

## 4. Conclusions

In this paper, we conducted a framework the vertical evacuation behavioural for near-field tsunami using agent based model. Focusing on both milling time and walking speed, this research reveals that both of them are critical points that impact on mortality rate. It means that maximum milling time and walking speed impact on good vertical evacuation.


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## References


[1] Amri M ., Yulianti G, Yunus R, Wiguna S, Adi A ., Ichwana A ., Randongkir R . and Septian R . 2016 *Risiko Bencana Indonesia* (Jakarta)

[2] BNPB 2014 *Rencana Nasional Penanggulangan Bencana 2015-2019* (Jakarta)

[3] Yin W, Murray-tuite P, Ukkusuri S V and Gladwin H 2014 An Agent-Based Modeling System for Travel Demand Simulation for Hurricane Evacuation *Transporatation Res. Part C* **42** 44–59

[4] Lindell M K, Kang J E and Prater C S 2011 The Logistics of Household Hurricane Evacuation *Nat. Hazards* **58** 1093–109

[5] Huang S-K, Lindell M K, Prater C S, Wu H-C and Siebeneck L K 2012 Household Evacuation Decision Making in Response to Hurricane Ike *Nat. Hazards Rev.* **13** 283–96

[6] Cimellaro G P, Mahin S and Domaneschi M 2019 Integrating a human behavior model within an agent-based approach for blasting evacuation **34** 3–20

[7] Yang W, Hu Y, Hu C and Yang M 2018 An agent-based simulation of deep foundation pit emergency evacuation modeling in the presence of collapse disaster *Symmetry (Basel).* **10** 1–22

[8] Mehmood S, Ahmed S and Kristensen A S 2019 Application of integrated model of evacuation psychology in an agent-based simulation *ACM International Conference Proceeding Series* pp 70–4

[9] Adam C and Gaudou B 2017 Modelling human behaviours in disasters from interviews: Application to Melbourne bushfires *J. Artifiicial Soc. Soc. Simul.* **20** 1–17

[10] Jumadi, Carver S and Quincey D 2016 A conceptual framework of volcanic evacuation simulation of Merapi using agent-based model and GIS *Procedia - Social and Behavioral Sciences* vol 227 (The Author(s)) pp 402–9

[11] Lu X, Yang Z, Cimellaro G P and Xu Z 2019 Pedestrian evacuation simulation under the scenario with earthquake- induced falling debris *Saf. Sci.* **114** 61–71

[12] Cimellaro G ., Ozello F, Vallero A, Mahin S and Shao B 2017 Simulating earthquake evacuation using human behavioral models *Earthq. Eng. Struct. Dyn.*

[13] Takabatake T, Fujisawa K, Esteban M and Shibayama T 2020 Simulated effectiveness of a car evacuation from a Tsunami *Int. J. Disaster Risk Reduct.*

[14] Wang H, Mostafizi A, Cramer L A, Cox D and Park H 2016 An Agent-Based Model of A Multimodal Near-Field Tsunami Evacuation: Decision-Making and Life Safety *Transp. Res. Part C Emerg. Technol.* **64** 86–100

[15] Karon J and Yeh H 2011 *Comprehensive Tsunami Simulator For Cannon Beach, Oregon* (City of Cannon Beach)

[16] Prati G, Saccinto E, Pietrantoni L and Pérez-Testor C 2013 The 2012 Northern Italy Earthquakes: Modelling human behaviour *Nat. Hazards* **69** 99–113

[17] Durage S W, Kattan L, Wirasinghe S C and Ruwanpura J Y 2014 Evacuation Behaviour of Households and Drivers During A Tornado: Analysis Based on A Stated Preference Survey in Calgary, Canada *Nat. Hazards* **71** 1495–517

[18] Yang H, Morgul E F, Ozbay K and Xie K 2016 Modeling Evacuation Behavior Under Hurricane Conditions *Transp. Res. Rec. J. Transp. Res. Board* **2599** 63–9

[19] Yeh H and Asce M 2010 Gender and Age Factors in Tsunami Casualties *Nat. Hazards Rev.* 29–34

[20] Yun N Y and Hamada M 2015 Evacuation Behavior and Fatality Rate During the 2011 Tohoku-Oki Earthquake and Tsunami *Earthq. Spectra* **31** 1237–65

[21] Helton W S, Kemp S and Walton D 2013 Individual Differences in Movements in Response to Natural Disasters *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* vol 57 pp 858–62

[22] Di-Mauro M, Megawati K, Cedillos V and Tucker B 2013 Tsunami Risk Reduction for Densely Populated Southeast Asian cities: Analysis of Vehicular and Pedestrian Evacuation for The City of Padang, Indonesia, and Assessment of Interventions *Nat. Hazards* **68** 373–404

[23] Wood N J and Schmidtlein M C 2012 Anisotropic Path Modeling to Assess Pedestrian-Evacuation Potential from Cascadia-Related Tsunamis in The US Pacific Northwest *Nat. Hazards* **62** 275–300

[24] Mas E, Suppsri A, Imamura F and Koshimura S 2012 Agent-based Simulation of the 2011 Great East Japan Earthquake / Tsunami Evacuation : An Integrated Model of Tsunami Inundation and Evacuation *J. Nat. Disaster Sci.* **34** 41–57

[25] Aguilar L, Wijerathne L, Ichimura T, Hori M and Tanaka S 2016 Mixed Mode Large Urban

Area Ttsunami Eevacuation Considering Car-Pedestrian Interactions *J. Japan Soc. Civ. Eng. Ser. A2 (Applied Mech.* **71** I_633-I_641

[26] Usman F, Murakami K, Dwi Wicaksono A and Setiawan E 2017 Application of Agent-Based Model Simulation for Tsunami Evacuation in Pacitan, Indonesia *MATEC Web of Conferences* vol 97 pp 2–16