Agent-Based Simulation Disaster Evacuation Awareness on Night Situation in Aceh

Sinung Widiyanto[1*], Dimas Adi[2], Rahul Vijay Soans[3]

***Abstract*— In 2004 at least 230,000 people were victims of the Aceh tsunami disaster. To prevent the recurrence of many victims, the Aceh government held an evacuation exercise in 2008. To improve effectiveness dan reduce the cost reduction during evacuations drills, simulation is the best option. Agent-Based Modeling is a simulation program that was employed for tsunami evacuation in Aceh. This study on tsunami evacuation using agent-based modelling presented and evaluated the different control parameters that affect the evacuation rate. Evacuation scenario during day or night has different environmental, agent base, road modelling, and population approach. The Road Network Model has explained that to analyze the effect of agents in the evacuation process, resident agents are presumed to know the direction and shortest path to the nearest evacuation points. This simulation designed in Netlogo is also able to assess the congestion possibility on the road network. The road network emphasized the different scenarios to discover the possibility of congestion points. Nighttime is proven to be the best scenario for performing the evacuation in the simulation. The key reason to select the night scenario is to maximize the effects of an evaluation of the road network. In addition, simulation using night scenarios is also expected to raise people's awareness.**

***Keywords*— Evacuation simulation model, Tsunami, Decision choice**

I. Introduction

There were more than 230,000 people dead due to the Indian Ocean earthquake and tsunami in 2004; and more than 16,000 fatalities due to Tohoku earthquake and tsunami in 2011 [1]. These catastrophes were caused by failed evacuation done on the areas affected by the tsunami. Fumihiko Imamura et al. presented three procedures that guide people for a safety evacuation plan [2]. The procedures are releasing official warning, deciding evacuation plans based on the previous experience, and lastly selecting an appropriate path that leads to a shelter. In November 2008, the city government of Banda Aceh conducted a tsunami evacuation drill but the result was too expensive to be conducted and difficult to gather people to participate [3]. However, evacuation is still one of the most possible and effective methods to minimize the catastrophes since it is almost impossible to build structures which resist tsunami forces.

Hereby, tsunami evacuation modeling is a tool developed to determine whether the decision made regarding the evacuation is effective and able to rescue the people and areas affected by the disaster or not according to the established policy. Such a model has actually existed but barely developed since it does not consider the behavioral aspects involved in the model including the time and mode needed for the evacuation. In addition to loss of life, disaster also causes damage on infrastructure system. The damage leads to another issue needs to be considered in evacuation since evacuation carried out due to disaster is a complex system involving transport operation and planning to minimize catastrophes, including the potential damages to critical infrastructure and communication systems due to the disaster. Thus, further study needs to be conducted on both evacuation and required infrastructure so that an effective emergency evacuation can be carried out.

One of the most essential infrastructures is transportation network. However, it is susceptible to natural disaster such as earthquakes although its performance is essential in encountering emergency situation due to large-scale disaster such as earthquake. The level of damage suffered by transportation network depends on the magnitude and duration of an earthquake. It usually experiences certain levels of mobility losses (due to link failures) either caused by landslide, rockfalls, or bridge failure which is essential for the network operation. However it becomes progressively worse over time and specifically susceptible to seismic hazards [4]. After a catastrophic earthquake, it is important that bridges maintain their capacity in accommodating people so that they can quickly be rescued to safer areas. Refitting existing bridges is a generally agreed and fairly inexpensive way of enhancing the protection of bridges against earthquakes and reducing their functional losses [4].

However, retrofitting all existing bridges due to budget constraints is neither feasible nor economical. The retrofitting level is, however, considerable importance to be considered. There- fore, prioritizing the retrofitting of the bridges with an effective strategy is important. Besides bridges, it might also be necessary to preserve some of the transport links. During an evacuation situation, the criticality of any single link or bridge is compounded by a lack of alternate connections. The effectiveness of a near-field tsunami evacuation can be determined based on the aspect of life safety in which by examining the impact of network disruption via evacuation mortality will offer an insightful and clear viewpoint to prioritize a retrofitting strategy to reduce mortality levels given the limited resources.

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Based on the background above, author summed up that Indonesia's number of victims of the disaster is considered high for many reasons. For example: weak network infrastructure and strategic planning, lack of early warning system, low mitigation budget and local government 's low awareness/preparedness for implementing the evacuation plan. As an assistance for this issue, The World Bank Board of Executive Directors has approved a US 160 million loan for the Indonesia Disaster Resilience Initiatives Project (IDRIP) on November 27, 2019 To endorse Indonesia's efforts in establishing a holistic approach to resilience against disasters [5] Similar to Indonesia Disaster Resilience Initiatives Project (IDRIP), author aims to make contribution to the issue by proposing research on Evacuation Simulation using Agent Based Modeling approach. This method is expected to improve Indonesia's preparedness against dis- aster and improve the local-level emergency management systems.

Through this research, author aims to determine the time and decision-making behavior needed by every evacuee/agent regarding the evacuation as well as the factors affecting the mortality rate of the scenario such as congestion in the road network. Based on their evaluation, it is expected that this simulation will give overview for city planning in responses for disaster management and mitigation.

II. METHOD

In this Chapter, steps on how developing the Agent-Based Modeling for tsunami evacuation in Aceh are introduced. Those of the steps are Global environment modeling, identifying agent types, defining agent attributes, Agent internal behavior modeling, Defining interaction rules among agents, and Defining interaction rules between Environment and agents. Also, other important components in the tsunami evacuation model are explained in detail.

2.1. Research Method of Agent Based Modeling

The development of this tsunami evacuation modeling refers to [6], which contains of six activity groups.

- Global environment modeling.
- Identifying agent types.
- Defining agent attributes.
- Agent internal behavior modeling.
- Defining interaction rules among agents.
- Defining interaction rules between Environment and agents.

The keys in developing accurate model are identifying the agents, accurately specifying their behaviors, and appropriately representing agent interactions. The method of creating an agent-based model was initially achieved by defining the agent types (classes) along with their attributes. Agents have role as the decision-makers, whether they are individual, organization or automated. If the agents are identified, the behavior of the agent is determined. An agent-based model also consists of agent relationships. Such relationship adjoins methods to monitor which, when and how the agents interact with other agents or the environment.

In addition, NetLogo will also be used to test the tsunami evacuation as long as with its effects on the road network. Netlogo is a high level integrated framework for modeling via agent-based programming language [7]. The most complex part of evacuation modeling is primarily due to the interactions between the agents that presents the behavior in encountering emergency situation in the whole system. Furthermore, with these benefits, NetLogo's GIS compatibility further confirms the use of this platform to model and simulate the evacuation dynamics at a community level, from engineering to sociology study [7]. In addition, Netlogo was design for agent-base modelling using integrated developing Environmental (IDE). However Environmental and agent-base model, built in Netlogo for this experimental are using real time data base on Aceh government statistic data. Each Agent defines by two cluster individual person and Car representative of one family consist of 4 persons.

It must be noted that the simulation developed in this research focuses only on the pattern of people evacuation from tsunami and identifies the congestion or bottleneck. The main question is: how long does it take for people to leave the area swept by tsunami optimally? What about the congestion, is it possible? This research will not mention the effects of the tsunami threat, and the direct effects of the earthquake on the population or the physical environment. However, the ABM platform will allow future work to extend to a multi-hazard model. The behavior of the agent is believed to be autonomous and heterogeneous, since their decisions are affected directly by their surrounding environment and interactions. To make it simpler, during evacuation, agents are believed to not change their mode, thus an agent who begins to save their life by car will not change their mode to on foot and vice versa. In the purposes of evaluating the network instability, it is believed that all agents want to be rescued, while past observations have shown that a small proportion of people have chosen to stay[8][9][10].

2.1.1. Population Distribution Model

During day and night, the concentration of people in similar places may be different. For example, there is a chance that people may be more active in the office area and on the road during the day, while other people prefer to stay at home at night. Many different people conditions may lead to different reactions to any disaster. Identifying that evacuation planning is being considered for a particular time period is also of great significance.

Nighttime is claimed to be the best scenario for performing the evacuation in the simulation. The key reason to select the night scenario is to maximize the effects of an evaluation of the road network. In addition, simulation using night scenarios will raise people's awareness. Therefore, earthquakes and tsunamis occurred at night that is known to be people's most vulnerable moment. Although this scenario is not entirely plausible due to the fact that catastrophe will also occur during the day, this is considered true for the purpose of road network evaluation.

This simulation employed census-based population data [11] of each sub-district. Based on [12] on Figure 2. the population was distributed throughout the urban area and the boundaries of the sub-districts. Table 1. presents the census data of population on each sub-district, the population is distributed within the sub-district area on Figure 1.

TABLE 1.
LANDMASS, NUMBER OF
HOUSEHOLDS AND POPULATION IN MEURAXA DISTRICT 2017 [11]

Sub-districts	Landmass (ha)	Households	Population
Surien	41.2	363	1244
Aso Nanggroe	16.8	201	629
Gampong Blang	71.5	140	456
Lamjabat	27.8	224	868
Gampong Baro	58.2	348	1149
Punge Jurong	42.2	1016	4006
Lampaseh Aceh	59	607	2087
Cot Lamkuweuh	34.8	259	911
Gampong Pie	32.1	169	516
Ulee Lheue	67.5	212	791
Deah Glumpang	53.3	268	936
Lambung	31	251	606
Blang Oi	85	609	2020
Alue Deah Teungoh	39.8	404	1153
Deah Baro	44.8	205	580

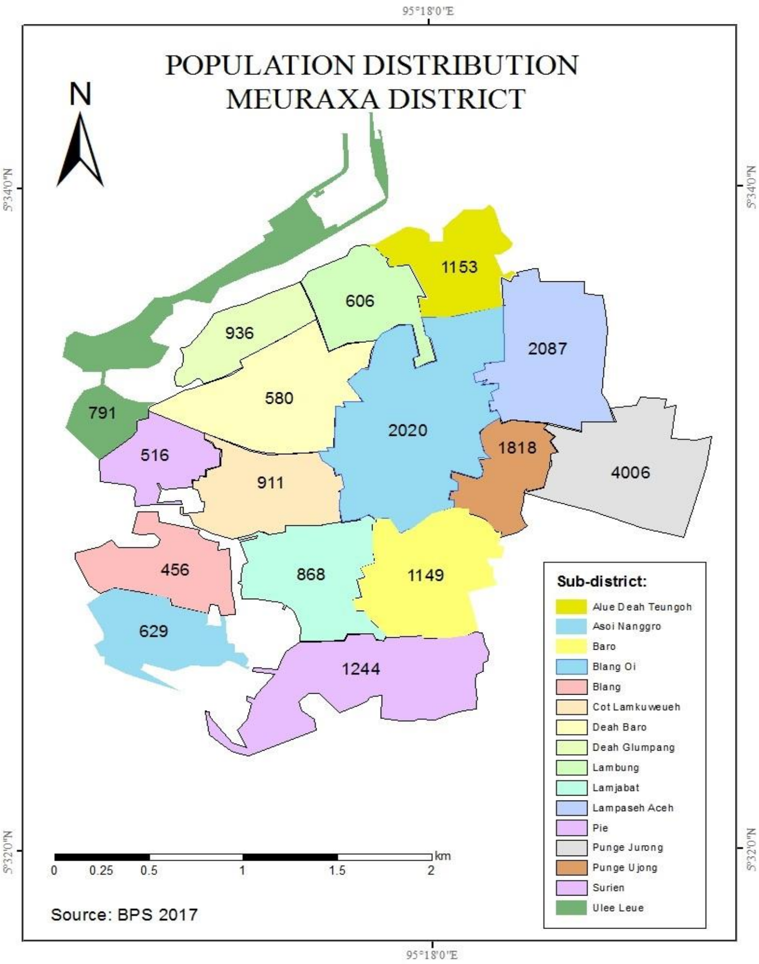


Figure 1. Population Distribution from census data [11]

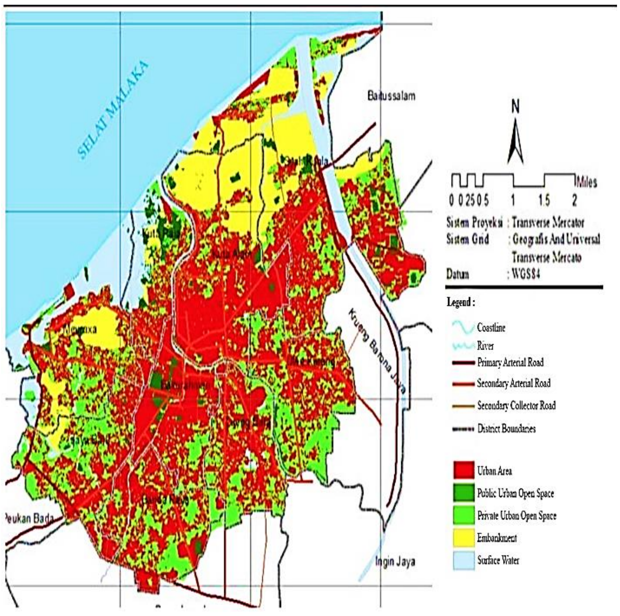


Figure 2. Demography Map of Banda Aceh based on [12]

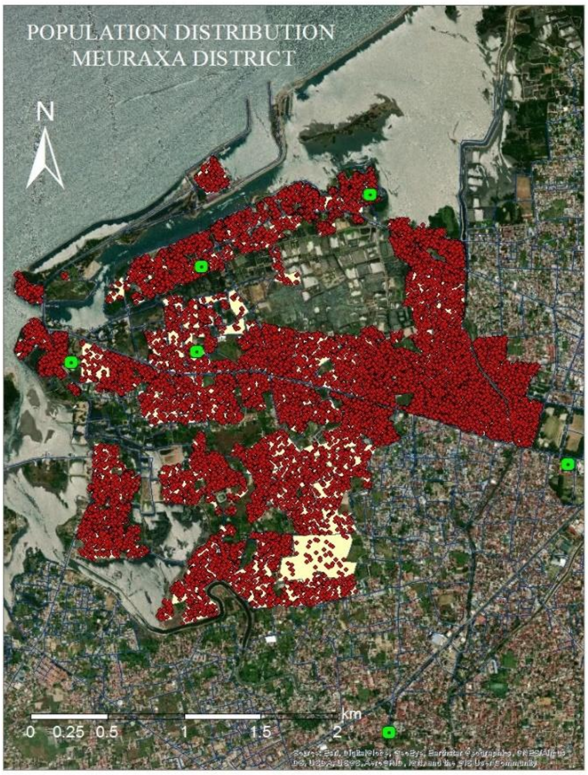


Figure 3. Population Distribution in Night Scenario

2.1.2. Road Network Model

In this simulation, the road network model is obtained in the form of shapefiles from ArcGIS data which are later used to simulate the route. For this simulation the Shape file was used as an input to build a road network as shown in Figure 4. In reaching the nearest shelter location, all agents are expected to follow this road network. In this model simulation, the use of alternative paths or shortcuts is forbidden. It is also generally assumed that all roads have two-way direction, since there is tendency that people will ignore traffic regulation during the disaster. When the earthquake stops, or is equal to zero in our model time, all agents should go to the nearest road, then they will choose three options for evacuation in the simulation model.

The frame of each area determines using actual map site that related to statistic data base on population distribution. Muster point in the Map already divine by Gov base on assessment after tsunami disaster. As the data taken from 2008 during disaster simulation, the agent-base simulation was determined. The agent-base model was already clustered by closeness to muster point in each area.

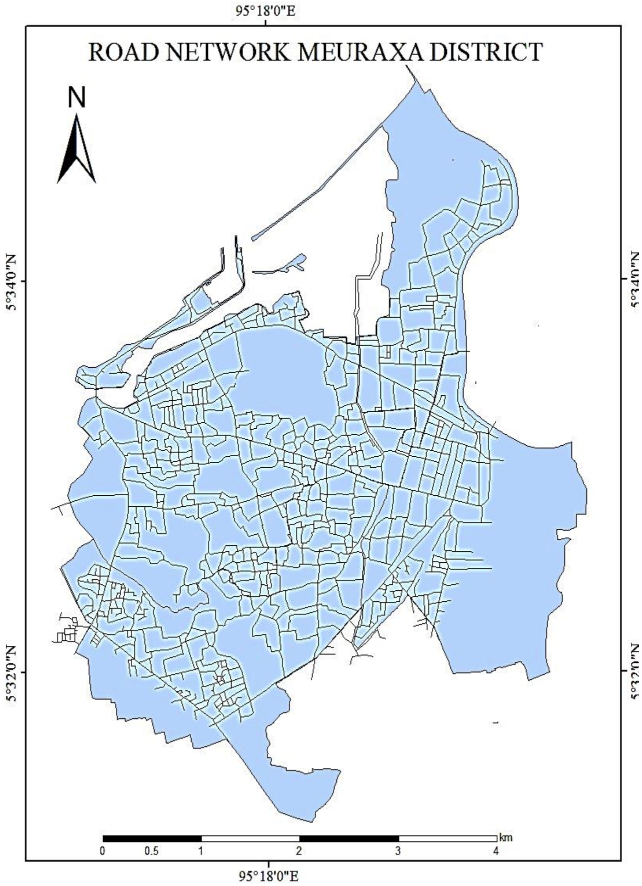


Figure 4. Road Network of Meuraxa District

2.1.3. Shelter Location

Following the destructive tsunami that occurred in 2004 [13], the government of Banda Aceh has particularly planned and constructed four Tsunami Vertical Evacuation (TVE) buildings or escape buildings in the coastal communities region that experienced near-total destruction and would be the hardest to evacuate in the event of a potential tsunami [14]. Based on the result of survey conducted by [15] about community living near tsunami vertical evacuation (TVE) buildings, it shows that they specifically prefer horizontal evacuation, in which only 26 percent were rescued to a TVE site, while the remaining 74 percent were rescued horizontally. It means that when a tsunami happens people often going to evacuation points which are flat or inland hills as an option. Such result is confirmed by the result of other survey on the choice of alternative evacuation buildings by [15].

Therefore, there are four evacuation buildings including the Grand Mosque, the Tsunami Museum, and three inland hills chosen as designated locations for shelter.

2.1.4. Agent Decisions

The Road Network Model has explained that to analyze the effect of agents in the evacuation process, local resident agents are presumed to know the direction and shortest path to the nearest evacuation points from the point at which they are situated at the start of the simulation. The nearest evacuation places for each agent and the shortest routes are determined using the A* algorithm [16]. This statement was also implemented in the context of research on tsunami evacuation in Padang, Indonesia [17].

In addition, each agent gets out of their building and then goes to the nearest lane. When the agent has hit the nearest road, he has three decisions to choose. These three decisions are based on the premise that each agent is not in their vehicle or car during the simulation in which it is whether they are inside or outside the building. When the agent is inside the building, he will rescue himself to the designated shelter location.

The two decisions agents have been: Decision 1 is Horizontal Evacuation by on foot. When the agent chooses this decision, it means that the agent knows the best path to arrive at the shelter. Meanwhile, Decision 2 is horizontal evacuation by car. Similar to Decision 1, when the agent will take a car once they reach the nearest road and head straight to the shelter spot. However, in the actual evacuation situation, some local authorities advised people not to use cars while evacuating themselves [18], since the road capacity will be limited due to high population density. Complete traffic queues are likely to occur if people attempt to evacuate themselves by car, and in the end, there is a risk that people will abandon their cars and escape on foot. Within this simulation, the option of evacuation by car is still considered, as it is important to test which areas would be affected by traffic congestion. However, in this research, car speed (very small possible) and car-pedestrian contact are ignored.

The number of agents who select either Decision 1 or 2 is presented in percentage. For example, in this simulation, 70 percent of the agent will select Decision 1, while the remaining 30 percent will select Decision 2. The social interaction of the agents in our simulation is also restricted, so that agents do not form any social interaction such as traveling in a group or using 1 car with 3 or 4 people inside. However, social interaction is considered for future development.

III. RESULTS AND DISCUSSION

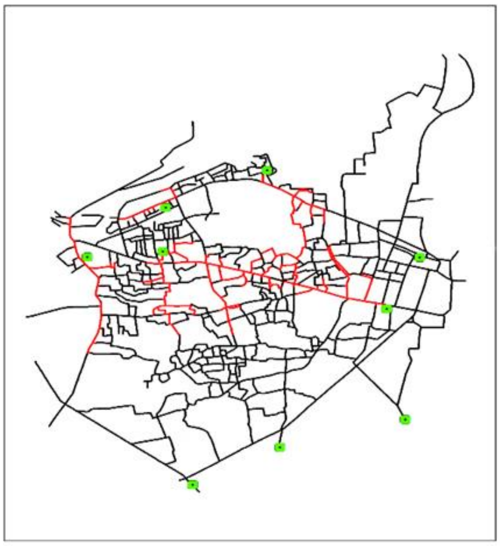
3.1. Network Congestion

Knowing the possibility of disturbances in the road network, especially knowing where the congestion will occur is very important in preparing an evacuation plan. Loss of total capacity on connecting roads to shelter may result in increased travel time and changes in travel behaviour. Consequently, increasing the travel time to reach the shelter location will decrease the evacuation rate.

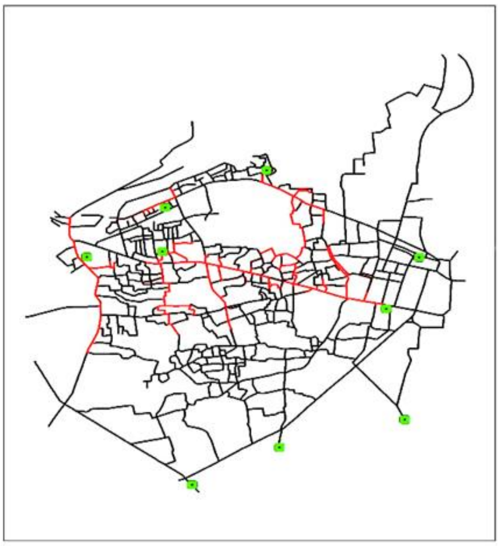
Figure 5 shows the location of possible congestion on the road network under all the different scenarios. Figure 5 (a) shows the state of the road network in a stressed condition where 100% of the cars are on the road network. In this scenario, it can be seen in the upper area, almost all roads connected to or leading to the shelter location are in a traffic jam (red colored roads). This is because population density is concentrated around the main road or orange colored road in Figure 5 (e). In 100% car condition, almost all roads and intersections connected to the main road will be in a traffic jam. However, if the number of vehicles in the road network is reduced as shown in Figures 5 (b) to (d), congestion will only be on the main road connected to the location of the shelter.

3.2. Integrated Analysis

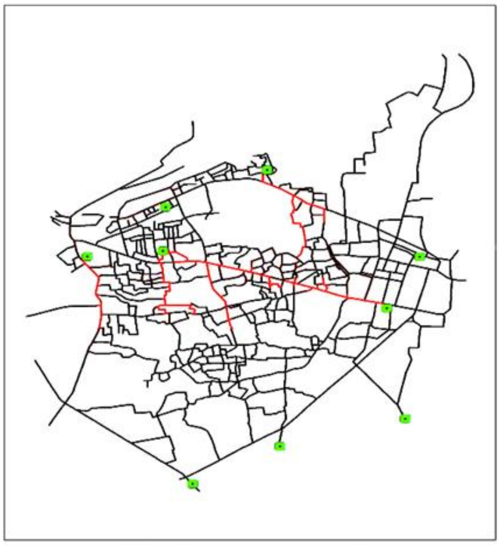
In Figure 6, the map is divided into three areas. Area (a) within the yellow square represents the area where most of the population live with only two evacuations building on the left and right side which are connected by the main road. Area (b) within the blue line is representing the recommendation area for new evacuation buildings in the central part. Area (c) within the aquamarine line, is the second recommendation area in the lower part of the map. Due to the fact that only two evacuation buildings exist in this dense area (a), congestion most likely occurs as presented in the Congestion Network Analysis. In order to prevent con- gestion in the area (a), a solution is needed so that the population density can be split by more than 2 and agent movement is not only focused on the evacuation buildings on the left and right of the area. Therefore, it is recommended in area (b) to build a new evacuation building for the reasons mentioned. For residents who are under area (a) or around area (c), they only have the option of going to Inland Hills as an option for evacuation in the real conditions. This choice is not quite the right choice because the location of the Inland Hills is quite far, and it is feared that agents could be trapped or still on the road when the tsunami occurred. To overcome this problem, it is recommended to build a new evacuation building in area (c) so that agents can cut the evacuation time when heading to a safe location.



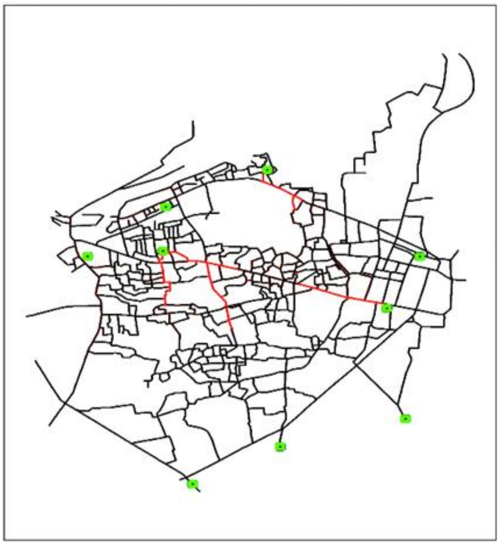
(a) 100% Cars - 0% Pedestrians



(b) 75% Cars - 25% Pedestrians



(c) 50% Cars - 50% Pedestrians



(d) 25% Cars - 75% Pedestrians

(c) Main Road Map

Figure 5. Congestion in Road Network represented in red colored road

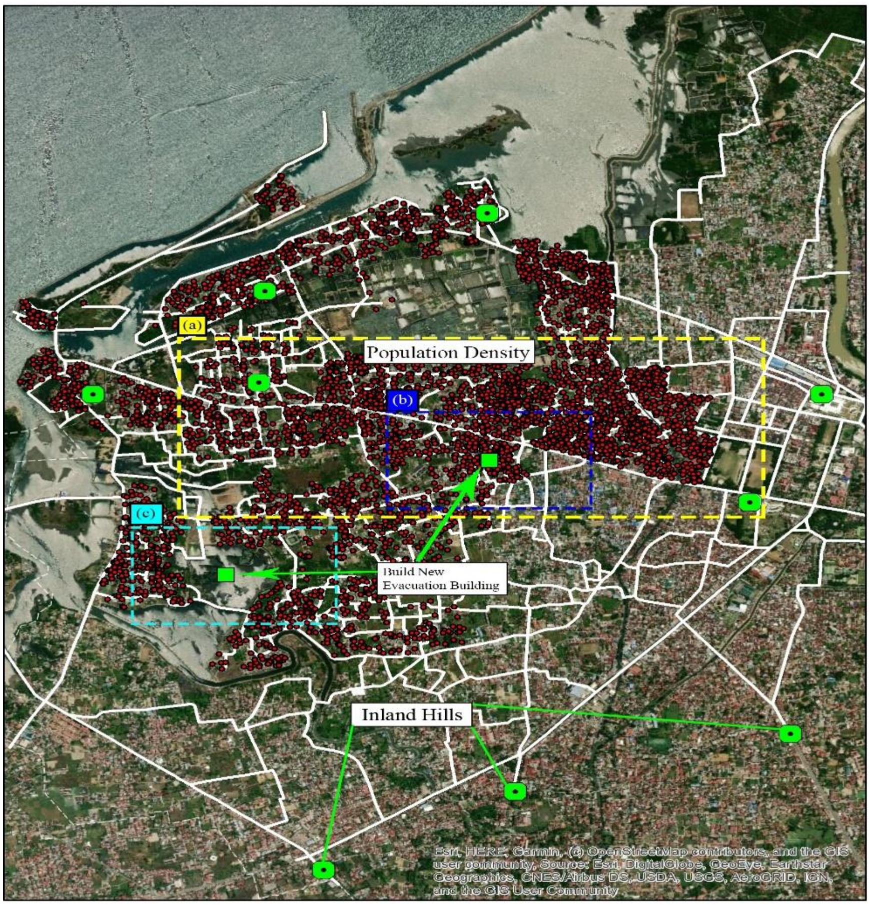


Figure 6. Map of Location Recommendation for New Evacuation Buildings

IV. CONCLUSION

This study on tsunami evacuation using agent-based modeling presented and evaluated the different control parameters that will affect the evacuation rate. This simulation designed in Netlogo is also able to assess the congestion possibility on the road network. The road network has been stressed in the different scenarios in order to discover the possibility of congestion points. Due to this ability to discover the congestion point, city planning on the best location to build another evacuation site as shown in the Integrated Analysis chapter. Although there have been many studies regarding the Tsunami Evacuation Planning in Indonesia, the implementation of these studies is considered very low. Indonesia government should make serious moves in this area because the occurrence of many kinds of disasters is high. Therefore, expertise in the simulation modelling is needed to prevent serious damage when the disaster comes.

In order to capture the stochasticity of the evacuation planning, the presence of the factors aside that have been introduced in this simulation should be taken into consideration. Therefore, in the future this simulation should consider parameters like “preparation time” and “delay time” to replicate the real human behavior in disaster situations. In addition, the social aspects of the evacuation scenario (i.e., group moving and information exchange) should be investigated more. Moreover, to capture more accurate representation of the evacuation planning, the real interaction for pedestrians and cars should be also taken into consideration. Ability to interact with the agent in the middle of the evacuation is also important to assess the evacuation. For example, removing some roads to replicate the network damage situation and adding a new evacuation building. As an isotropic model, this simulation assigns different attributes for each agent. Also, the repetition of the simulation needs to be conducted in order to increase the reliability of the result. As a consequence, running the simulation has a very expensive computation cost. As the last one, newest data related to the population (i.e.), population number and population distribution) also could be beneficial for the correctness of evacuation planning using agent based and modeling.

REFERENCES

[1] E. Krausmann and A. M. Cruz, “Impact of the 11 March 2011, Great East Japan earthquake and tsunami on the chemical industry,” *Nat. hazards*, vol. 67, no. 2, pp. 811–828, 2013.

[2] F. Imamura, T. Suzuki, and M. Taniguchi, “Development of a simulation method for the evacuation from the tsunami and its application to Aonae, Okushiri Is., Hokkaido,” *J. Japan Soc. Nat. Disaster Sci.*, vol. 20, no. 2, pp. 183–195, 2001.

[3] M. Affan, Y. Goto, and A. Sabti, “Tsunami evacuation simulation for disaster awareness education and mitigation planning of Banda Aceh,” 2012.

[4] L. Chang, F. Peng, Y. Ouyang, A. S. Elnashai, and B. F. Spencer Jr, “Bridge seismic retrofit program planning to maximize postearthquake transportation network capacity,” *J. Infrastruct. Syst.*, vol. 18, no. 2, pp. 75–88, 2012.

[5] Marilene B. Montemayor, “Indonesia - Disaster Resilience Initiatives Project (IDRIP),” 2019. https://www.worldbank.org/en/news/loans-credits/2019/11/27/indonesia-disaster-resilience-initiatives-project-idrip.

[6] C. M. Macal and M. J. North, “Tutorial on agent-based modeling and simulation,” in *Proceedings of the Winter Simulation Conference, 2005.*, 2005, pp. 14-pp.

[7] S. Tisue and U. Wilensky, “Center for Connected Learning and Computer-Based Modeling Northwestern University, Evanston, Illinois,” in *NetLogo: A Simple Environment for Modeling Complexity*, Citeseer, 1999.

[8] E. Mas, F. Imamura, and S. Koshimura, “Modeling the decision of evacuation from tsunami, based on human risk perception,” 2011.

[9] E. Mas, A. Suppasri, F. Imamura, and S. Koshimura, “Agent-based simulation of the 2011 great east japan earthquake/tsunami evacuation: An integrated model of tsunami inundation and evacuation,” *J. Nat. Disaster Sci.*, vol. 34, no. 1, pp. 41–57, 2012.

[10] E. Mas, F. Imamura, and S. Koshimura, “An agent based model for the tsunami evacuation simulation. A case study of the 2011 great east Japan tsunami in Arahama town,” 2012.

[11] Badan Pusat Statistik Kota Banda Aceh, “Kecamatan Meuraxa Dalam Angka 2018,” Banda Aceh, 2018. Accessed: Mar. 21, 2022. [Online]. Available: https://bandaacehkota.bps.go.id/publication/2018/09/26/8fa8afdc3aef05bc19609177/kecamatan-meuraxa-dalam-angka-2018.html.

[12] C. H. Fadhila, K. Murtilaksono, and K. Munibah, “Arahan pemenuhan ruang terbuka hijau kota banda aceh,” *TATALOKA*, vol. 21, no. 1, pp. 180–191, 2019.

[13] H. Kanamori, “Lessons from the 2004 Sumatra–Andaman earthquake,” *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.*, vol. 364, no. 1845, pp. 1927–1945, 2006.

[14] M. Munirwansyah, H. Munirwan, M. Irsyam, and R. P. Munirwan, “Escape hill development as a strategy to improve urban safety after earthquake and tsunami Aceh 2004 based on regional planning and geotechnical aspect,” in *Journal of Physics: Conference Series*, 2020, vol. 1572, no. 1, p. 12030.

[15] J. W. McCaughey, I. Mundir, P. Daly, S. Mahdi, and A. Patt, “Trust and distrust of tsunami vertical evacuation buildings: Extending protection motivation theory to examine choices under social influence,” *Int. J. disaster risk Reduct.*, vol. 24, pp. 462–473, 2017.

[16] H. Reddy, “PATH FINDING-Dijkstra’s and A* Algorithm’s,” *Int. J. IT Eng.*, pp. 1–15, 2013.

[17] M. Di Mauro, K. Megawati, V. Cedillos, and B. Tucker, “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*, vol. 68, no. 2, pp. 373–404, 2013.

[18] “Kamakura City Office, Tsunami Evacuation Plan for Kamakura City, 2015.” https://www.city.kamakura.kanagawa.jp/sougoubousai/documents/01-1tunamikeikaku.pdf (accessed Mar. 21, 2022).