Advantages of Cooperative Behavior During Tsunami Evacuation

Adam Slucki and Radosław Nielek(✉)

Polish-Japanese Institute of Information Technology (PJIIT), Warsaw, Poland
{adam.slucki,nielek}@pjwstk.edu.pl

Abstract. Considering the case in which not every individual is able to efficiently evacuate, due to the lack of knowledge about safe spots and available routes to them, close cooperation between community members plays a critical role. Using agent-based simulation, we tested two hypothetical scenarios of human behavior during tsunami evacuation and their efficiency, considering time and number of rescued people. In the first scenario, individuals did not cooperate with each other. In the second one, community members were trying to organize in groups, even if they could evacuate by their own. The results showed that in the second scenario not only substantially higher percentage of citizens evacuated in a shorter time, but it was nearly as efficient as the evacuation of a community in which almost every individual know at least one safe spot.

1 Introduction

On the 11th March 2011 in Japan occurred an earthquake of magnitude 9 that was followed by a tsunami, of which the maximum noted height reached 40.5 m. Number of people reported as dead or missing exceeded 20 000 [1].

In the opinion of *Shiminkatsudou Information Center* number of victims would be even greater if not the close cooperation between members of the communities [2]. On the other hand, there are cases showing that a collective decision caused death of the whole or majority of a group. One of the examples can be the case of Okawa's primary school in Ishinomaki town. Despite the suggestion of one of the teachers, majority of citizens that had chosen Okawa's school as a shelter insisted on staying there, instead of evacuate to a spot situated on a higher altitude. Eventually, water level exceeded estimations and reached Okawa's school, causing death of 83 people. 25 citizens survived only because they decided to separate from the group and evacuate to another spot [3]. This example reveals potential risk of cooperation which is not only the possibility that a group will make a wrong decision. The process of organizing and sharing opinions may be time consuming and slow down evacuation of a whole group.

Using agent-based system we try to answer the following research questions: 1) *Is the cooperative behavior during evacuation more advantageous than selfish behavior?* 2) *How does the average knowledge about available evacuation points affect evacuation efficiency?* 3) *Does the information dissemination in cooperative commu-*

N. Agarwal et al. (Eds.): SBP 2015, LNCS 9021, pp. 203–212, 2015.
DOI: 10.1007/978-3-319-16268-3_21

nity significantly improves evacuation process considering that, in general, community has little knowledge available about the evacuation points?

Answering those questions may shed the light on important but often overlooked aspects of preparing emergency evacuation on community level, namely cultural differences regarding cooperation and selfishness. The most efficient strategy in Japan will not work properly in Europe, as people are in general more self-oriented.

The rest of this paper is organized as follows: Section 2 contains the summary of related work. Section 3 describes simulation model. Section 4 encloses the experimental setup. The results are presented in Section 5 followed by conclusions in Section 6.

2 Related Work

Although we are not aware of any other work that provides a direct, comparative analysis of evacuation effectiveness influenced by two different social behaviors of actors, number of researches have been made in the field of emergency evacuation.

For instance, there are psychological studies like Drury et al. [4] where authors analysed *post hoc* interviews with people who survived an event in which they shared the threat of death, to compare solidarity andoccurrence of supportive behavior among members in two groups of survivors with low and high identification with others. Psychological aspects of social behavior in response to emergency event were previously described in Mawson [5] who notes that references to mutual help and support should be found more often than acts driven by self-preservation. Some research focus on general reaction of community to a tsunami alert, without considering social aspects of its members' behavior. Kanai et.al [6], after Chilean tsunami in 2010, conducted a survey among citizens of Japanese coastal city, where evacuation order also was announced. The aim was to describe people's risk perception about tsunami, reaction to the official warning and evacuation scheme.

On the emergency management side, Lammel et al. [7] proposed traffic optimization for tsunami evacuation in the Indonesian city of Padang. Authors used agent based simulation to estimate the evacuation process, detect potential hindrances and locations where tsunami proof shelters would be absolutely necessary to allow a successful evacuation of citizens living in its area. In the other work, Zagorecki [8] focused on the aspect of information exchange between emergency response organizations. Zheng et al. [9] proposed a game-theoretical approach to simulate how evacuation urgency affects arising of cooperative behavior and what consequences it has for overall efficiency. Important issue mentioned also in [6] is that reaction to the emergency alert is often delayed, because citizens wait for additional confirmation. Tyshchuk et al. [10] used Natural Language Processing and Social Network Analysis to process Twitter messages published during tsunami in Japan in 2011 and automatically found leaders of communities, key players who were able to successfully urge others to take action. Arai [11] studied efficiency of information spreading from the linguistics perspective – how to compose the most persuasive warning.

Another important aspect in emergency management is an optimal utilization of rescue service. Gelenbe et al. [12] developed an algorithmic solution based on Random Neural Network that could solve optimization problem for simultaneously dispatching emergency teams to different locations. Presented approach allows us obtaining solutions for large-scale problems; hence, it could be used in real-time also during evacuation management process.

3 Model Description

3.1 World Representation

Model was implemented in NetLogo language and its source code is available on the Internet.[1] The terrain shape used in the model lowers the probability of reaching safe spot by moving in random direction and maintains realism what improves reliability of the results. It represents actual landscape of 4 km^2 of Kamaishi, Japanese coastal city, is based on the terrain map available in *Google Maps* service and divided into squares called patches. Every patch corresponds to 100 m^2 in reality. Altitude is marked with different colors; it helps to determine if given agent reached safe spot. Considering the fact that the region is surrounded by mountains seemingly any knowledge about available safe spots is necessary for an effective evacuation. However, photographs of the place reveal that there are many obstacles like high fences, concrete blocks preventing landslides on slopes and canals which significantly lower chances for successful evacuation of individuals without adequate knowledge what in this case is the knowledge about the location and route to at least one of spots specified by the Kamaishi officials and presented on the city homepage[2]. The model takes into account inaccessible terrain mentioned above.

Time in the model is counted in ticks. One tick represents 5 seconds in reality. Evacuation process begins immediately after the start of the simulation. Tsunami reaches the land after 180 ticks i.e. 15 minutes from the start of evacuation and moves with the speed 7 m/s. The maximum height, up to 40 m may be reached with 33% probability only after the whole terrain with latitude below 20 MASL has been flooded.

3.2 Agents Knowledge

In 2012 officials of Yuasa, another Japanese coastal city, organized evacuation training and conducted the survey with its 556 participants [13]. The results show that 86.9% of respondents knew at least one evacuation point. At the same time, 79% of them declared that they had already decided to which point they will evacuate in case of emergency. In the model, each agent knows given number which is a Poisson distributed random integer from 0 to 10 of available evacuation points. Agents who know more than one evacuation point always choose a spot, one of which they know, situated in the nearest location.

---

1 http://modelingcommons.org/browse/one_model/4115#model_tabs_browse_procedures
2 http://www.city.kamaishi.iwate.jp/index.cfm/6,18417,34,180,html

3.3 Agents Speed

The results presented in [13] show also that 81.8% of respondents plan to evacuate by walk (earthquakes usually cause infrastructure damages). Consequently, in the model every agent moves with walking speed which based on the research of Bohannon [14] is a double precision random number from normal distribution with mean of 1.4 m/s and standard deviation of 0.15 m/s (some agents may run instead of walk but it required a sufficient fitness). Seemingly, walking speed should not apply in case of emergency. However, the results of surveys conducted by Kanai [6] and Yuasa city [13] show that after official tsunami alert, without further confirmation, citizens often do not perceive the risk adequately and start evacuating with substantial delay. In 2010, when Kamaishi officials announced evacuation order at 9:34 am, predicting first wave coming at 1:30 pm, only 8% of 822 participants of the survey decided to evacuate immediately after announcement.

3.4 Behavior Types

In the model there are represented two opposite types of possible behaviors. In one setup, all the agents are eager to form a group and share the information about available evacuation points that they have, regardless being able to evacuate individually. In this case, after the start of the simulation every agent continuously tries to find the biggest group of other agents that are nearby. As the research of Helbing et al. [15] shows, in emergency situation people tend to show herding behavior. Joining the group with the greatest number of other participants is also the most advantageous in regard to information dissemination, because of the highest probability that at least one of its members knows location of one or more evacuation points.

In the other setup, all agents who know at least one evacuation point go there immediately after the start of the simulation. Agents without any knowledge about location of evacuation points try to follow random agent in a given radius, yet they do not exchange any information.

Agents may also try to help relatives. Every agent is assigned to a randomly selected group represented by a given number. If the agent notices relative behind him, in a given range, he moves toward the him and shares the information. Every agent may be helped only once during the simulation. In addition to information sharing, both the agents change their own speed to the speed of the faster one as we consider possibility of psychical help and greater motivation for moving faster.

3.5 Decision Process

The agent's internal decision process is presented in details in Appendix A. In general, it may be divided into three mains steps:

1. Agent chooses the nearest evacuation point that is known to him. If this process takes place after he shared information with another agent, he chooses given number of evacuation points, compare their distances with the location he has already chosen and heads to the closest one. If agent does not know any evacuation point, he approaches another, random agent in a given radius.

2. If the given agent do cooperate, he tries to locate another cooperative one in a defined radius, one who is surrounded by the greatest number of other agents (surrounding agent is defined as an agent located in 10 m radius). If such agent exists, he becomes a group center and has to change his speed to the mean speed of surrounding agents. All agents within a group share the knowledge about evacuation points. Additional parameter which determines size of a group that satisfy individuals and make them not to try to join bigger one, can be used to prevent forming too big groups.
3. An agent checks if behind, in distance of 6 to 15 m there is another agent whose group number difference is lower than given threshold and who has not been helped yet. If such agent, called relative exists, agent heads towards him, changes his own or relative's number of known evacuation points to the number known by better informed one and lastly changes speed of both to the speed of the faster one.

4 Experimental Setup

In order to test the influence of different behaviors on the efficiency of evacuation it is necessary to run multiple simulations with various setups where the key parameters are as follows.

- Number of evacuation points known by average citizen: [1; 4] - *this parameter is the λ coefficient for Poisson distribution and represents number of evacuation points locations known by average citizen. For the value 1 approximately 65% of all agents should know at least one evacuation point. For the value 4 this number grows to nearly 98%.*
- Percentage of cooperative agents: [0; 25; 50; 75; 100] – *it determines how many agents will try to form groups following the mechanism described in Section 3.4.*
- Group difference threshold: [0;1] – *determines maximum difference between numbers representing groups of two agents to consider them as relatives.*
- Radius: [50] – *determines radius in which agents can search for the other ones. Model does not directly take into account any buildings as a potential hindrance for the evacuation. However, considering existence of buildings and other objects we assume that mean range of vision could narrow to 50 meters on average.*

Every simulation for those sets of parameters was be repeated 30 times with initial number of agents equal to 300 and then averaged. Output value represents time in seconds from the start of each simulation to the state in which there is not any agent left in the model world as well as the percentage of agents who reached the evacuation point. Additionally, time was measured also in state where 10, 30, 50, 80 and 95% of agents evacuated.

5 Results

Simulations with setup in which agents do cooperate and exchange information show substantial difference in comparison with the opposite setup. In case of cooperative behavior, we may observe that agents quickly form well organized groups which head towards optimal, considering the distance, evacuation point.

In the opposite scenario agents also form groups. However, they are not organized and due to the lack of information dissemination, there are groups in which every agent knows at least one evacuation point's location. Such groups usually are not able to successfully evacuate. Fig. 1. presents the state in the 30th step of simulation for both scenarios.

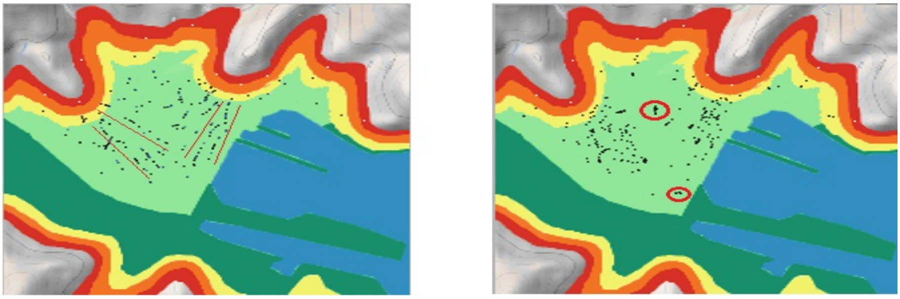


Fig. 1. Comparison simulation states for cooperative (left) and selfish community (right). Lines indicate well organized agents. Groups which do not face any evacuation point are encircled.

Output of simulations for different values of key parameters is presented in the tables below. First one shows the results for scenario of 0% of cooperative agents.

Table 1. Results of simulations where agents did not cooperate

No of evac. points known by agent	Group diff. thresh.	Mean of rescued	Mean time
1	0	84.07%	1084 s
1	1	98.81%	942.16 s
4	0	99.82%	693.67 s
4	1	99.97%	631 s

The second table presents the results of simulations for the opposite scenario where all agents did cooperate.

Table 2. Results of simulations where agents did cooperate

No of evac. points known by agent	Group diff. thresh.	Mean of res-cued	Mean time
1	0	98.39%	979.83 s
1	1	98.84%	930.52 s
4	0	99.94%	692.67 s
4	1	99.87%	721.79 s

Chart below presents time measured when given percentage of agents successfully reached one of evacuation points for communities with little knowledge about evacuation points and not eager to help their relatives. It is important to note that measures ends on the value of 95%. Final measure of time regards to the state in which all agents was rescued or died, hence cannot be included in the graph.

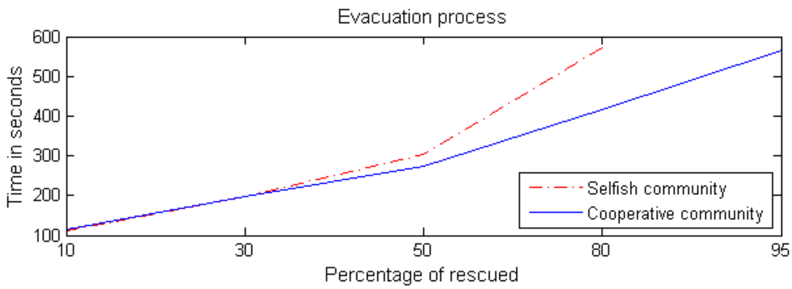


Fig. 2. Time measured when given percentage of agents with generally little knowledge evacuated

Similar chart was created to compare evacuation process of communities with good knowledge about available evacuation points.

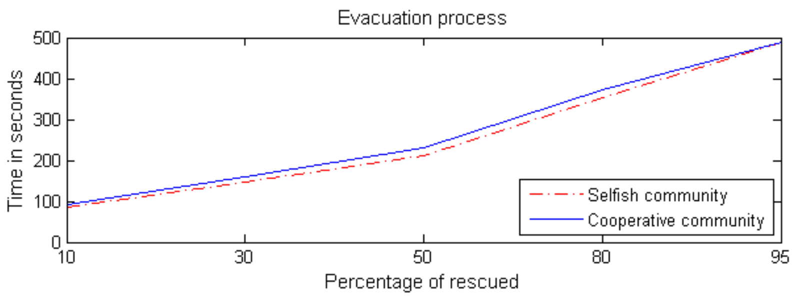


Fig. 3. Time measured when given percentage of agents with generally good knowledge evacuated

Means were compared with Student's t-test with 0.05 level of significance. Number of degrees of freedom was estimated with Welch–Satterthwaite equation.

Answering our research questions, tests showed that both mean of rescued and mean of time for scenario where members of a community had a little knowledge about evacuation points was significantly worse for the selfish community. As Fig. 2 shows, time when 50 or more percent of population reach safe spot is dramatically worsening for this community. What is more selfish community has not reached threshold of 95% rescued in any simulation. Tests show also that advantage of that 30% of selfish community who managed to reach safe spot on the beginning of simulation is not significant in comparison to results of cooperative community. Cooperative behavior that allows people better dissemination of information, substantially improves efficiency of evacuation process. Potential loss required for forming groups is compensated by its influence on community knowledge and better organization. Results for different number of cooperative agents show linear dependence of increase of that number and evacuation effectiveness improvement. Therefore awareness of importance of cooperation during emergency situation, which would lead to better information exchange, could help to increase evacuation efficiency to the level comparable with results of well informed community evacuation.

As expected, better knowledge significantly improved evacuation efficiency in comparison to any setup where agents had little knowledge about evacuation points. It emphasizes value of accurate information in the case of emergency.

Differences between results for two considered scenarios where average community member has good knowledge about available evacuation points are not significant when comparing overall results and time when community reached threshold of 95% rescued despite the fact that cooperative community performed little worse than selfish one until that threshold was reached as shows fig. 3. It is another confirmation that potential loss of time required for organization at the beginning of evacuation process is compensated even for communities with good knowledge in which most of the members could evacuate independently.

Surprisingly helping other individuals had not any noticeable influence on the evacuation efficiency, assuming that it would not be the only way of obtaining information.

6 Conclusion

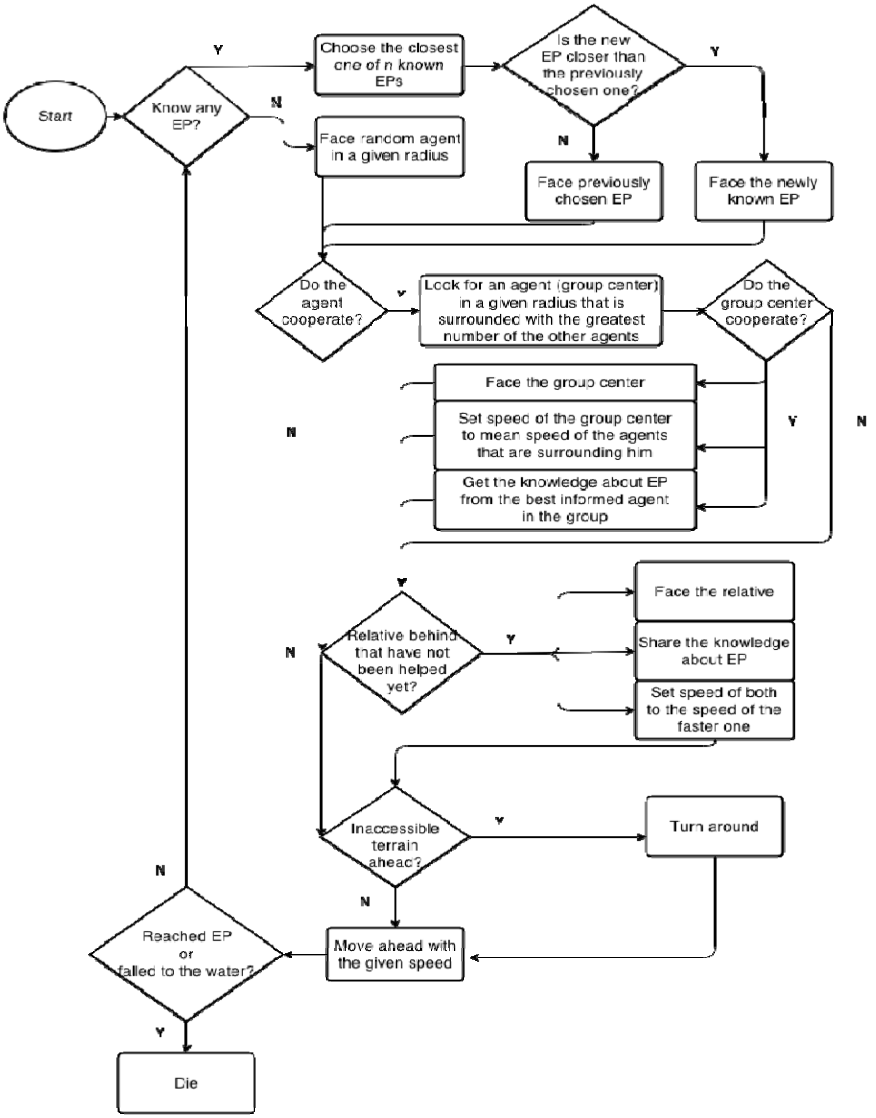
We have proposed a multi-agent system approach to compare the influence of two different types of behavior, cooperative and selfish, on evacuation efficiency. Model used in the experiment allowed us to focus on knowledge about terrain and safe spots as key factor for successful evacuation.

The results confirmed that cooperative behavior and consequently sharing of information leads to a substantially higher rate of rescued people in less time, considering that given community, in general, has little knowledge about evacuation points. Therefore, experiment proved the importance of further research regarding improvement of information efficiency, including information provided by officials, dissemination between community members in case of emergency.

Finally, our model also highlighted problem of the lack of adequate signs warning that terrain ahead may be inaccessible for pedestrians or signs leading to the nearest evacuation point.

Appendix A

Diagram of agent's behavior in tsunami model



Acknowledgements. This work is supported by Polish National Science Centre grant 2012/05/B/ST6/03364.

References

1. Shaw, R., Takeuchi, Y.: East Japan Earthquake and Tsunami: Evacuation, Communication, Education and Volunteerism. Research Publishing Service (2012)
2. Report of Shiminkatsudou Information Center. The lesson we should learn from information dissemination and citizens' cooperation during 2011 earthquake off the Pacific coast of Tōhoku (2012). http://sicnpo.jp/saigai110311/imase-urado2012.pdf (retrieved)
3. Satoh, J.: Tragedy of Okawa's primary school (2012). http://www.geocities.jp/kxbrb316/report-20.htm (retrieved)
4. Drury, J., Cocking, C., Reicher, S.: Everyone for themselves? A comparative study of crowd soladarity among emergency survivors. British Journal of Social Psychology **48**(3), 487–506 (2009)
5. Mawson, A.: Understanding mass panic and other collective responses to threat and disaster. Psychiatry: Interpersonal and Biological Process **68**(2), 95–113 (2005)
6. Kanai, M., Katada, T.: Issues of Tsunami Evacuation Behavior in Japan: Residents Response in Case of Chilean Earthquake in 2010. In: Solutions to Coastal Disasters 2011, pp. 417–423. ASCE Publications (2011)
7. Lammel, G., Rieser, M., Nagel, K., Taubenbock, H., Trunz, G., Goseberg, N., Schlurmann, T., Klupfel, H., Setiadi, N., Birkmann, J.: Emergency preparedness in the case of tsunami evacuation analysis and traffic optimization for the Indonesian city of Padang. In: Pedestrian and Evacuation Dynamics 2008, pp. 171–183. Springer (2010)
8. Zagorecki, A., Ko, K., Comfort, L.K.: Interorganizational Information Exchange and Efficiency: Organizational Performance in Emergency Environments. Journal of Artificial Societies and Social Simulation **13**(3) 3 (2010)
9. Zheng, X., Cheng, Y.: Modeling cooperative and competitive behaviors in emergency evacuation: A game-theoretical approach. Journal Computers & Mathematics with Applications **62**(12), 4627–4634 (2011)
10. Tyshchuk, Y., Li, H., Ji, H., Wallace, W.A.: Evolution of communities on twitter and the role of their leaders during emergencies. In: Proceedings of the 2013 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining, pp. 727–133 (2013)
11. Arai, K.: How to Transmit Disaster Information Effectively: A Linguistic Perspective on Japan's Tsunami Warnings and Evacuation Instructions. International Journal of Disaster Risk Science **4**(3), 150–158 (2013)
12. Gelenbe, E., Timotheou, S., Nicholson, D.: Random neural network for emergency management. In: The Workshop on Grand Challenges in Modeling, Simulation and Analysis for Homeland Security (2010)
13. General Affairs Department of Yuasa City. Report of the results of evacuation training (2012). http://www.town.yuasa.wakayama.jp/bousai/hinankunren.pdf (retrieved)
14. Bohannon, R.W.: Comfortable and maximum walking speed of adults aged 20-79 years: reference values and determinants. Age and Ageing **26**, 15–19 (1997)
15. Helbing, D., Johansson, A.: Pedestrian, Crowd and Evacuation Dynamics. Encyclopedia of Complexity and Systems Science **16**, 6476–6495 (2010)