SIMULATING TSUNAMI EVACUATION WITH MULTI-AGENTS AND DETERMINING A COUNTERMEASURE WITH AHP

Kazuhira Kohara
Chiba Institute of Technology
Japan
k-kohara@jcom.zaq.ne.jp

Takuya Sugiyama
Chiba Institute of Technology
Japan
kohara.kazuhiro@p.chibakoudai.ac.jp

ABSTRACT

We propose an integration method that uses agent-based modeling to simulate tsunami evacuation and the Analytic Hierarchy Process (AHP) to make a decision on a countermeasure. First, we created multiagent coast models that include a tsunami agent, shelter agents, road agents and evacuee agents. Second, we divided the coast into several districts and predicted the tsunami evacuation success/failure number of each district by using a computer simulation with multiagent coast models. Third, we considered several countermeasures (adding a shelter, adding an evacuation route) using that prediction. Fourth, we estimated the effects of each countermeasure. Finally, we use AHP to determine the best countermeasure against a tsunami disaster.

Keywords: agent-based modeling; tsunami disaster; countermeasure decision making

1. Introduction

Multiagent-based social simulations have been extensively investigated, and various attempts have been made to apply them to the layout design of supermarkets, stock markets, sales prediction and tsunami evacuation (Yamane et al. 2012; Panayi et al. 2012; Kohara et al. 2014; Saito et al. 2005). The Analytic Hierarchy Process (AHP) has been widely used for economic, political, social and corporate decision making (Saaty, 1980; Saaty et al. 1994; Saaty, 2001; Ginda et al. 2016).

Previously, we investigated the real-world problem of predicting sales for stores and using that prediction to determine where to locate a new store (Kohara et al. 2014). We proposed an integrated method that uses agent-based modeling and the AHP to predict sales and to choose a new store location. First, we created multiagent town models that included store agents and consumer agents. We then estimated the predicted sales for each store by using a computer simulation based on multiagent town models. Finally, we used AHP to determine the location of a new store.

In this paper, we investigate another real-world problem of predicting the tsunami evacuation success/failure number and using that prediction to determine countermeasures against a tsunami disaster. We propose an integrated method that uses agent-based modeling and the AHP to predict the evacuation success/failure number and determine the countermeasure. First, we created multiagent coast models that consist of a tsunami agent, shelter agents, road agents and evacuee agents. Then, we estimated the predicted evacuation success/failure number by using a computer simulation with multiagent coast models. Finally, we used AHP to decide the best countermeasure against a tsunami disaster.

The main features of our method are as follows: (1) We introduced a tsunami into the coast models as an agent. (2) We divided the coast into several districts, predicted the tsunami evacuation success/failure number of each district and considered several countermeasures (adding a shelter, adding an evacuation route) using that prediction. (3) We estimated the effects of each countermeasure. (4) We determined the countermeasure using the results of a multiagent simulation and AHP.

2. Multiagent coast models

We created a multiagent coast model based on a popular coast in Shizuoka Prefecture where it is predicted that a large earthquake will occur in the near future. The width of the coast is 2 km. Since the size of the coast model is 100 cells by 200 cells, one cell corresponds to 10 m in each direction. Evacuees move one cell per step and 100 m per minute, so a minute corresponds to 10 steps. Evacuees move one cell per two steps on a sloping road. The tsunami moves two cells per step. Here, we assumed that a 10 meter high tsunami arrives 10 minutes after the earthquake, and that 60% of evacuees start to evacuate immediately, 30% of evacuees start at 5 minutes after the earthquake, and 10% of evacuees start at the time of the arrival of the tsunami. These assumptions are based on results from a questionnaire carried out after the large earthquake that occurred in Japan on March 11, 2011. There are four kinds of agents: a tsunami agent, shelter agents, road agents and evacuee agents. The number of evacuee agents is 3000, based on the published number of people bathing at the coast. The number of shelters is 10, based on the actual information. Evacuee agents move to a higher location in the same way as in the related work (Saito et al., 2005). When evacuees arrive at the intersection, they move according to traffic signs. If there is a shelter, they go to the shelter. Otherwise, they move to a higher location.

Figures 1 and 2 show our multiagent coast model. In Figure 1, green lines show flat roads, orange lines show sloping roads and light blue shows the sea.

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v8i3.406

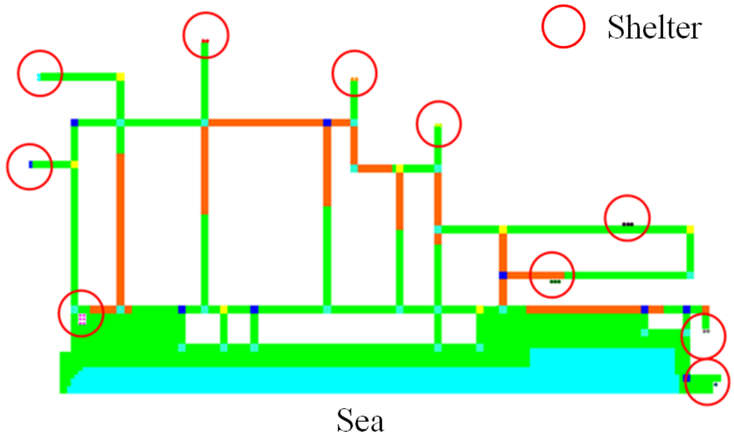

Figure 1. Multiagent coast model

In Figure 2, dark blue shows tsunami agents. The tsunami moves two cells per step.

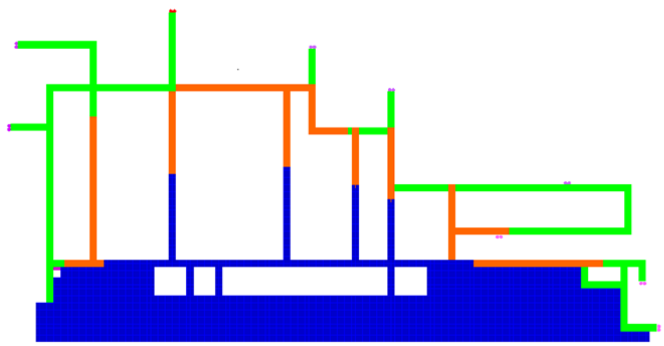

Figure 2. Multiagent coast model

3. Predicting evacuation success/failure number

First, we divided the coast into five districts (A, B, C, D and E) as shown in Figure 3. We generated 600 people in each district and estimated the evacuation success number of each district. We examined an average number of 50 trials. Table 1 shows the results. The evacuation success number of district C is comparatively small.

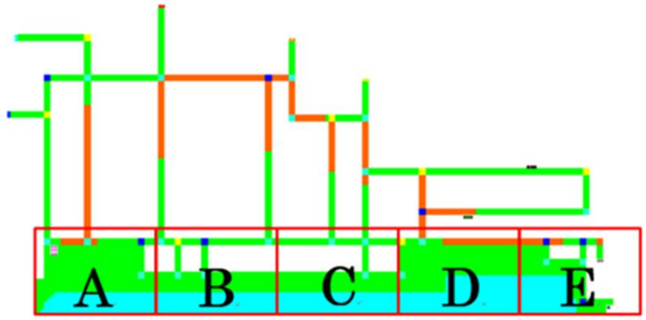

Figure 3. Dividing the coast into five districts

Table 1
Estimated evacuation success number of each district

Districts	Estimated evacuation success number
District A	472
District B	475
District C	452
District D	480
District E	483

Second, we generated 3,000 people on the coast and estimated the evacuation success number. Again, the number of shelters is ten. We assumed that a 10 meter high tsunami arrives at 10 minutes after the earthquake and leaves at 15 minutes after the earthquake. We also examined an average number of 50 trials. Table 2 shows the results. The number of evacuees who succeeded in reaching shelters was 1,397 and number of evacuees who succeeded in reaching high places was 1,076. Therefore, the total number of successes was 2,473 and total number of failures was 527.

Table 2
Results of tsunami evacuation simulation of the current state

	Estimated number
Success number to reach shelters	1,397
Success number to reach high places	1,076
Total success number	2,473
Total failure number	527

Third, we added a shelter (shelter K in district B, shelter L in district C, or shelter M in district D) or an evacuation route (route X in district A, route Y in district B, or route Z in district C) based on the above results and the actual map, as shown in Figures 4 and 5.

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v8i3.406

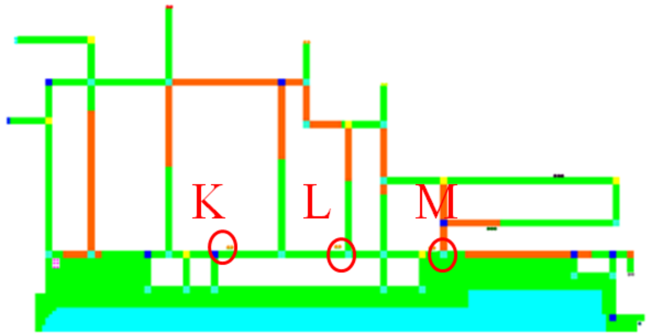

Figure 4. Adding a shelter

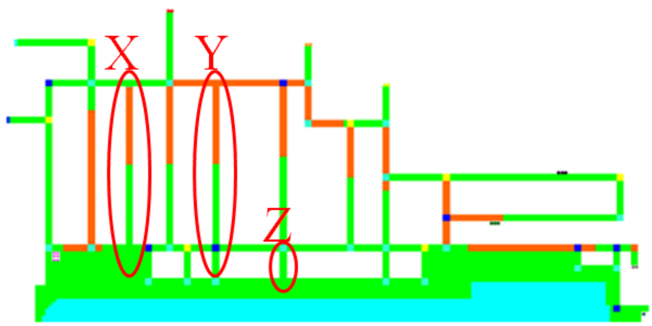

Figure 5. Adding an evacuation route

Table 3 shows the results when a shelter is added. The average failure number for the 50 trials was 449 when adding shelter K, 372 when adding shelter L, and 343 when adding shelter M. Adding shelter M was the most effective, and adding shelter L was the second most effective.

Table 3
Results of tsunami evacuation simulation in case of adding a shelter

	Success to shelters	Success to high places	Total number of success	Total number of failure
Current state	1,397	1,076	2,473	527
Adding shelter K	1,842	709	2,551	449
Adding shelter L	1,962	667	2,628	372
Adding shelter M	2,024	633	2,657	343

Table 4 shows the results when an evacuation route was added. The average failure number for the 50 trials was 236 when adding route X, 230 when adding route Y, and 164 when adding route Z. Adding route Z was most the effective and adding route Y was the second most effective.

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v8i3.406

Table 4
Results of tsunami evacuation simulation in case of adding an evacuation route

	Success to shelters	Success to high places	Total number of success	Total number of failure
Current state	1,397	1,076	2,473	527
Adding route X	2,075	690	2,764	236
Adding route Y	1,874	897	2,770	230
Adding route Z	2,392	443	2,836	164

4. Determining a countermeasure by using AHP

Figure 6 shows the relative measurement AHP model created for the task of deciding a tsunami evacuation measure. Here, we used the following four criteria: feasibility, evacuation success rate, cost, and time required to realize the countermeasure. In feasibility, a countermeasure whose feasibility is high is important. In success rate, a countermeasure whose success rate is high is important. In cost, a countermeasure whose cost is low is important. In required time, a countermeasure whose required time is short is important.

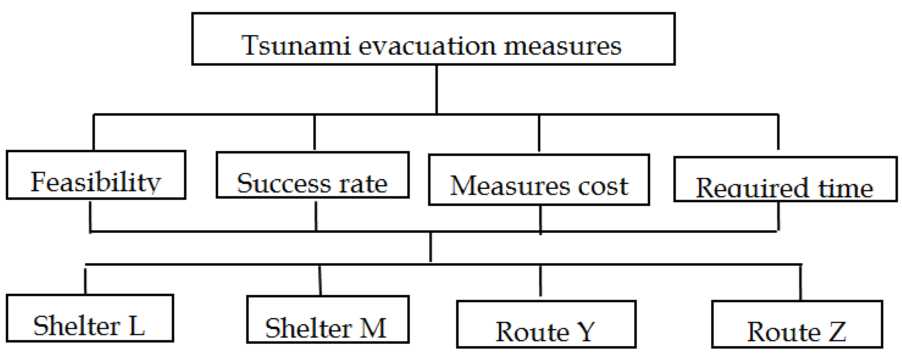

Figure 6. Determining a countermeasure with AHP

Here, we used the following four alternatives: (1) adding shelter L, (2) adding shelter M, (3) adding evacuation route Y, and (4) adding evacuation route Z. Table 5 shows four alternatives for a countermeasure against a tsunami disaster.

Table 5
Four alternatives for a countermeasure against tsunami disaster

	Success to shelters	Success to high places	Total number of success	Total number of failure
Adding shelter L	1,962	667	2,628	372
Adding shelter M	2,024	633	2,657	343
Adding route Y	1,874	897	2,770	230
Adding route Z	2,392	443	2,836	164

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v8i3.406

Table 6 shows pairwise comparisons of four criteria when feasibility and success rate are most important. In this case, the weights of feasibility and success rate are the highest (their weights = 0.342). Consistency index means whether a pair comparison matrix is consistent or not. When the index is lower than 0.10, we judge that the pair matrix is consistent. Here, the consistency index is 0.041 and the pairwise comparisons are consistent.

Table 6
Pairwise comparisons of four criteria when feasibility and success rate are most important

	Feasibility	Success rate	Measures cost	Required time	Weight
Feasibility	1	1	2	3	0.342
Success rate	1	1	2	3	0.342
Measures Cost	1/2	1/2	1	4	0.226
Required time	1/3	1/3	1/4	1	0.091

Consistency index = 0.041

Table 7 shows pairwise comparisons of alternatives with respect to predicted feasibility. We will use existing hotels for shelters L and M, and construct new evacuation routes for Y and Z. Therefore, the feasibility of shelters L and M is higher than that of routes Y and Z. Route Z is shorter than route Y; therefore, the feasibility of route Z is higher than that of route Y. The weights of shelters L and M were the highest.

Table 7
Pairwise comparisons of alternatives with respect to feasibility

	Shelter L	Shelter M	Route Y	Route Z	Weight
Shelter L	1	1	6	2	0.368
Shelter M	1	1	6	2	0.368
Route Y	1/6	1/6	1	1/5	0.054
Route Z	1/2	1/2	5	1	0.211

Consistency index = 0.011

Table 8 shows pairwise comparisons with respect to success rate. The success rate is 0.945 (2836/3000) when adding route Z, 0.923 (2770/3000) when adding route Y, 0.886 (2657/3000) when adding shelter M, and 0.876 (2628/3000) for shelter L. The weight of shelter Z is the highest.

Table 8
Pairwise comparisons of alternatives with respect to success rate

	Shelter L	Shelter M	Route Y	Route Z	Weight
Shelter L	1	1/2	1/4	1/5	0.078
Shelter M	2	1	1/3	1/4	0.125
Route Y	4	3	1	1/2	0.306
Route Z	5	4	2	1	0.492

Consistency index = 0.016

Table 9 shows pairwise comparisons with respect to the measure cost. We will use existing hotels for shelters L and M; therefore, the measure cost is comparatively low. Shelter M is smaller than shelter L. Route Z is shorter than route Y. The weight of shelter M is the highest.

Table 9
Pairwise comparisons of alternatives with respect to measures cost

	Shelter L	Shelter M	Route Y	Route Z	Weight
Shelter L	1	1	8	3	0.317
Shelter M	1	1	9	4	0.499
Route Y	1/8	1/9	1	1/6	0.043
Route Z	1/3	1/4	6	1	0.146

Consistency index = 0.012

Table 10 shows pairwise comparisons with respect to required time. As route Z is short, required time to construct route Z is short. As shelter L is larger than shelter M, comparatively many rooms can be used for evacuees immediately. The weight of route Z is the highest.

Table 10
Pairwise comparisons of alternatives with respect to required time

	Shelter L	Shelter M	Route Y	Route Z	Weight
Shelter L	1	2	5	1/2	0.289
Shelter M	1/2	1	4	1/3	0.176
Route Y	1/5	1/4	1	1/6	0.059
Route Z	2	3	6	1	0.476

Consistency index = 0.022

Table 11 shows the final results when feasibility and success rate are most important. In this case, the weight of adding route Z is highest because the weights of adding route Z with respect to feasibility and success rate are comparatively high.

Table 11
Final results of AHP when feasibility and success rate are most important

Alternatives	Results
Adding shelter L	0.250
Adding shelter M	0.297
Adding route Y	0.138
Adding route Z	0.317

5. Additional studies

5.1 Additional study on changing tsunami height

The tsunami height is based on the expected information which is between 5 and 10 meters. Table 12 shows an additional study on tsunami height. First, we assumed the

ISSN 1936-6744
http://dx.doi.org/10.13033/ijahp.v8i3.406

tsunami height is 10 meters. Then, we changed the tsunami height to 5 meters. The evacuation failure number was 169. The tsunami height is crucial for tsunami evacuation; however, a countermeasure against a 10 meter high tsunami is important.

Table 12
Additional study: changing tsunami height

Tsunami height	Success to shelters	Success to high places	Total number of success	Total number of failure
5 meters	1,420	1,411	2,831	169
10 meters	1,397	1,076	2,473	527

5.2 Additional study on changing tsunami arrival time

The tsunami arrival time is based on actual information. Tsunamis have arrived at 10 minutes after the earthquake on average over the past hundred years. Table 13 shows an additional study on tsunami arrival time. First, we assumed the tsunami arrives 10 minutes after the earthquake. Then, we changed tsunami arrival time to 20 minutes or 30 minutes after the earthquake. The evacuation failure number was 508 for 20 minutes or 461 for 30 minutes. Anyway, evacuate immediately!

Table 13
Additional study: changing tsunami arrival time

Tsunami arrival time	Success to shelters	Success to high places	Total number of success	Total number of failure
10 minutes	1,397	1,076	2,473	527
20 minutes	1,860	632	2,492	508
30 minutes	1,903	636	2,539	461

5.3 Additional study on changing tsunami speed

Table 14 shows an additional study on tsunami speed. First, we assumed the tsunami moves 2 times faster than people's speed. Then, we changed it so that the tsunami moves 4 times faster than people's speed. The evacuation failure number was 922 when the tsunami moves 4 times faster than people's speed. Anyway, evacuate immediately!

Table 14
Additional study: changing tsunami speed

Tsunami speed	Success to shelters	Success to high places	Total number of success	Total number of failure
2 times faster	1,397	1,076	2,473	527
4 times faster	1,347	731	2,078	922

5.4 Additional study on changing percentage of evacuation consciousness

Table 15 shows an additional study on changing the percentage of evacuation consciousness. First, we assumed that 60% of evacuees start to evacuate immediately, 30% of evacuees start at 5 minutes after the earthquake, and 10% of evacuees start at the time of arrival of the tsunami, based on questionnaire results. Then, we changed the percentage of evacuation consciousness into 70%:25%:5% and 70%:29%:1%. The evacuation failure number was 296 for 70%:25%:5% and 123 for 70%:29%:1%. Again, evacuate immediately!

Table 15
Additional study: changing percentage of evacuation consciousness

Percentage	Success to shelters	Success to high places	Total number of success	Total number of failure
60%:30%:10%	1,397	1,076	2,473	527
70%:25%:5%	1,584	1,120	2,704	296
70%:29%:1%	1,571	1,306	2,877	123

5.5 Additional study on changing pairwise comparisons of four criteria

Table 16 shows an additional study on changing pairwise comparisons of the four criteria when required time is most important. In this case, the weight of required time is 0.549.

Table 16
Pairwise comparisons of four criteria when required time is most important

	Feasibility	Success rate	Measures cost	Required time	Weight
Feasibility	1	2	4	1/3	0.239
Success rate	1/2	1	3	1/4	0.147
Measures Cost	1/4	1/3	1	1/6	0.067
Required time	3	4	6	1	<u>0.549</u>

Consistency index = 0.020

Table 17 shows the final results when required time is the most important. In this case, the weight of route Z is highest because the weights of route Z with respect to the success rate and required time are comparatively high.

Table 17
Final results of AHP when required time is most important

Alternatives	Results
Adding shelter L	0.279
Adding shelter M	0.236
Adding route Y	0.093
Adding route Z	<u>0.394</u>

Table 18 shows another additional study on changing pairwise comparisons of the four criteria when cost is most important. In this case, the weight of cost is 0.495.

Table 18
Pairwise comparisons of four criteria when measures cost is most important

	Feasibility	Success rate	Measures cost	Required time	Weight
Feasibility	1	3	1/2	5	0.310
Success rate	1/3	1	1/4	3	0.134
Measures Cost	2	4	1	6	<u>0.495</u>
Required time	1/5	1/3	1/6	1	0.061

Consistency index = 0.026

Table 19 shows the final results when cost is most important. In this case, the weight of shelter M is highest because the weights of shelter M with respect to feasibility and measures cost are comparatively high.

Table 19
Final results of AHP when measures cost is most important

Alternatives	Results
Adding shelter L	0.299
Adding shelter M	<u>0.389</u>
Adding route Y	0.083
Adding route Z	0.233

6. Conclusion

We proposed integrating agent-based modeling with the AHP for predicting a tsunami evacuation success/failure number and making decisions about countermeasures against a tsunami disaster. First, we created multiagent coast models that include a tsunami agent, shelter agents, road agents and evacuee agents. Second, we divided the coast into five districts and estimated the evacuation success/failure number of each district by using a computer simulation with multiagent coast models. Third, we added a shelter or an evacuation route and estimated the failure number. Finally, we applied the AHP with four criteria. We applied our method to an actual coast and showed its effectiveness. We also reported additional studies on changing tsunami height, changing tsunami arrival time, changing tsunami speed, changing percentage of evacuation consciousness, and changing pairwise comparisons of four criteria. In future work, we will apply our method to other cases, other coasts and other types of AHP and ANP for decision making (Saaty, 1996; Saaty et al. 2013).

REFERENCES

Ginda, G., & Dytczak, M. (2016). A survey of AHP and ANP applications in civil engineering and urban management. *ISAHP 2016*.

Kohara, K., & Sekigawa, D. (2014). Sales prediction with multiagent town models and deciding stores location with AHP. *ISAHP 2014*.

Panayi, E., et al. (2012). Agent-based modeling of stock markets using existing order book data. *MABS'12 (13th International Workshop on Multi-Agent Based Simulation).* Doi: 10.1007/978-3-642-38859-0_8

Saaty, T. (1980). *The Analytic Hierarchy Process*. New York: McGraw-Hill. Doi: http://dx.doi.org/10.1080/00137918308956077

Saaty, T., & Vargas, L. G. (1994). *Decision making in economic, political, social and technological environments with the Analytic Hierarchy Process*. Pittsburgh: RWS Publications. Doi:10.1016/0898-1221(95)90109-4

Saaty, T. (1996). *The Analytic Network Process*. Arlington: Expert Choice.

Saaty, T. (2001). *Decision making for leaders: The Analytic Hierarchy Process for decisions in a complex world*, Pittsburgh: RWS Publications.

Saaty, T., & Vargas, L. G. (2013). *Decision making with the Analytic Network Process: Economic, political, social and technological applications with benefits, opportunities, costs and risks (Second Edition)*. Springer Verlag. Doi: 10.1007/978-1-4614-7279-7_1

Saito, T., & Kagami, H. (2005). Simulation of evacuation behavior from tsunami utilizing multiagent system. *Journal of Architecture and Planning, Transactions of AIJ, 597,* 229-234. (in Japanese) Doi: http://doi.org/10.3130/aija.74.627

Yamane, S. et al. (2012). Agent-based social simulation for a checkout layout design of a specific supermarket. *MABS'12 (13th International Workshop on Multi-Agent Based Simulation).*