Effect of evacuee on contagion of evacuation

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ABSTRACT
This paper deals with evacuation decision making of people in the disaster area. In previous papers, the cascade model is discussed contagion of evacuation decision making. The work finds that local neighborhood and their connection of the sub network are necessary to contagion. In this paper, we deal with effect of evacuee on contagion or propagation of evacuation. We found that if agents watch the agents who evacuate for shelter, many agents come to evacuate because evacuating agents for shelter comes in field of vision for many agents.

Categories and Subject Descriptors
I.6.4 [Computing Methodologies]: Simulation and Modeling-Model Validation and Analysis

General Terms
Human Factors

Keywords
Tsunami, evacuation, multi-agent simulation.

1. INTRODUCTION
The Great East Japan Earthquake was a 9.0 magnitude undersea mega thrust earthquake that occurred on Friday, March 11, 2011. The damage is less than the last great earthquake, it is believed that various disaster prevention methods take effect [10]. Since there were many people who were unable to effectively evacuate, damage was considered to have spread seriously.

Contagion or propagation is said to occur if one behavior can spread from a finite set of agents to the whole population. What are the conditions that initially adopted by only a finite set of agents spread to the whole population? In our former work [4], we analyzed that the collective behavior of population is stochastic, although decisions of agents are deterministic. We find that collective behavior is affected in the structure of the social network and threshold. In our previous work [5], we adopted a multi-agent simulation that focused on psychological conditions at time of disaster. We supposed that all agents evacuate and agents move to shelter. Then, we confirm that it takes more time to finish evacuations if psychological conditions exist at the time of disaster. And we find evacuation time are shortens that all agents finish evacuation when another agents in a hurry to evacuate. In previous papers [5], the cascade model is discussed contagion of evacuation decision making. The work finds that local neighborhood and their connection of the sub social network are necessary to contagion. In this paper, assuming that not all agents evacuate, we deal with effect of evacuee on contagion of evacuation. That is, we investigate whether evacuating agents for shelter effect on staying agents or not. In fact, it has been reported that not all people in the affected area evacuated in the Great East Japan Earthquake [3]. According to questionnaire [11], the ratio of evacuated are 55.8 % in Tokachi Oki Earthquake of 2003. And among the evacuated people, 23.4 % of people started to evacuate within five minutes and 60.3 % of people did within ten minutes. One third of finished evacuation people within fifteen minutes started to evacuate after an earthquake in hurry within about five minutes.

2. SIMULATION MODEL

2.1 Kure City
We supposed that the Nankai Trough Earthquake occurred in the day-time on Sunday. It is estimated that the magnitude of the earthquake was 6+ and the resulting tsunami with waves of up to 4 m in height reached the city 161 min after the earthquake. We deal with the area forecasted to be flooded [2]. In this paper, we model the contagion of evacuation in Kure city. There ten towns and thirty shelters [7] as shown in Figure 1. We deal with an area of 3,683 m in width and 1,881 m long.

We set each agent aims the nearest shelter in the same town. In the previous experiment, we compared cases in which agents go to the nearest shelter in the city and to the nearest shelter in the same town. We found that it is more effective when resident agents go to the nearest shelter in the same town. Based on questionnaires [3], the majority of residents evacuated to a shelter in their own towns.

Figure 1. Town, shelters and network of roads.

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2.2 Agents

According to Drabek [1], many people evacuated by family unit. By the basic resident register of March 31, 2013[8] in Kure city, the number of residents per household averaged 1.937. So, we set an agent as two people, which is the average number of a household.

The simulation model consists of two layers. The first layer stands for walking layer, which are shown in Figure 1. At the first time step, agent is generated on an intersection node, which means residents are at home. We set 213 nodes and network of roads in Kure city. And each agent walks on the road for each shelter. Table 2 shows population, number of agents and shelters in each town.

Table 1. Town identification (TID), population (POP), number of agents (NRA), and shelter ID (SID)

TID	POP[8]	NRA	SID
0	67	33	0
1	2,292	1,146	1-3
2	64	32	4-5
3	2,430	1,215	6-9
4	987	493	10-13
5	2,960	1,480	14-15
6	4,375	2,187	16-23
7	1,506	753	24-25
8	4,323	2,161	26-27
9	1,173	586	28-29
SUM	20177	10086	30

The second layer stands for social layer, which is different from last one as shown in Figure 2. Each agent decides to evacuate or not to with depending on the layer.

2.3 Decision of an Agent

Decision of an agent consists of two stages. Each agent perform the two stages each time step. The first stage builds a visibility social network on the city, which represents network of neighbors. The second stage applies the threshold model of social contagion.

2.3.1 Social network

Each agent can watch the neighbor agents within the circle view field of radius *R*. Then, each agent has links with the neighbor agents as shown in Figure 2. Here, we set radius *R* as 60 pixel (115 m), 90 pixel (173 m) and 120 pixel (230 m). In this simulation, one pixel means 1.92 m. In this paper, each agent builds the social network each time step because each agent can walk.

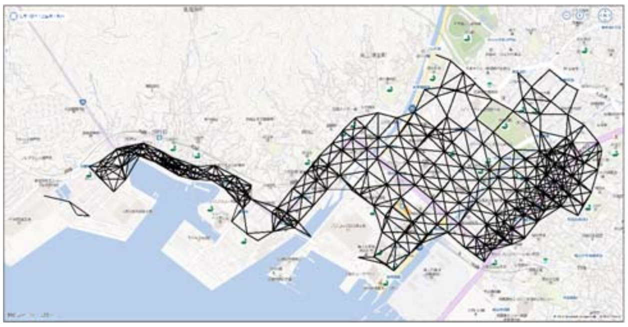
2.3.2 Threshold model

In this simulation, we deal with whether each agent decides to evacuate or not to. Each agent is given a fixed threshold value 0.05, monotonously. There are two possible states 0 (Not evacuated) and 1 (Decided to evacuate) for each agent. Each agent observes the proportion of its neighbors in state 1 and calculate the proportion of neighbors who have evacuated at time step *t* as $p_i(t)$. Then, the agent switches to 1 if the proportion $p_i(t)$ exceeds its threshold *theta*. That is,

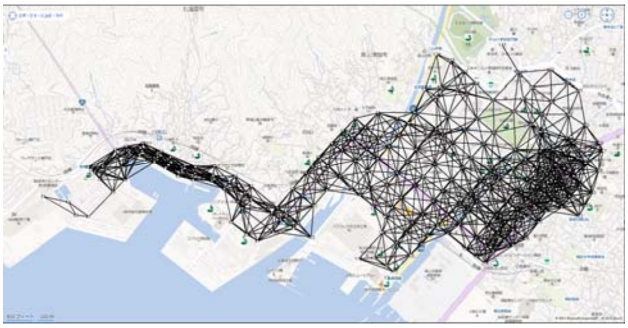
if $p_i(t) \geq theta$, Agent *i* chooses 1.

The case with the value of *theta* is 0.0 means that the agent always changes the state to 1. And the case with the value of *theta* is 0.05 means that agent changes the state to 1 only when proportions of the neighbors who have evacuated at time step *t* are greater equal than 0.05.

(a) When radius *R* is 115 m.



(b) When radius *R* is 173 m.



(c) When radius *R* is 230 m.

Figure 2. Social network of neighbor agents at first time step.

After all agents decided whether to evacuate or not to at time *t*, each agent recalculates the proportion of its neighbors in state 1 at next time *t+1*. Then, at time *t+1*, if the proportion $p_i(t+1)$ exceeds its threshold *theta*, agent *i* chooses 1.

In traditional cascade model, only one randomly chosen agent permits to make decision a time step. In former work [4], we set the timing of decision as simultaneously, that is, all agents can decide each time step to save the resources of simulation.

2.4 Walking of an Agent

Each agent starts to walk for shelter who decided to evacuate. In this model, we set one time step as one second and each agents as two people. The walking speed is assumed to be group speed since it has been shown that the walking speed of a group is slower because people tend to adjust their walking speeds to match slower individuals within the group. Moreover, the walking speed of a group of elderly people compared to that of younger people can be extremely different. We set the walking speed [9] of a young agent as 0.98 m/s (standard deviation 0.20 m/s) and the speed of an elderly agent as 0.84 m/s (standard deviation 0.13 m/s) as shown Table 2. According to the basic resident register, elderly people (65 years or older) make up 34 % of Kure city's population.

Table 2. Walking speed and ratio of agetns

Age	Ratio %	Walking speed m/s [9]	
		average	SD
Under 65	66	0.98	0.20
Over 65	34	0.84	0.13

2.5 Evaluation

We compared three patterns of radius *R* (115 m, 173 m and 230 m) and evaluated simulation results by collective behavior. We define collective behavior *p(t)* as the proportion of agents having chosen 1 (Decided to evacuated) in whole population at time *t*. We set initial collective behavior *p*(0) as 0.01, where agents randomly are state 1. There, only one percent of agents decide to evacuate at first time step. Then, we investigate the final collective behavior *p**.

3. SIMULATION RESULTS

3.1 Transition of Collective Behavior

Figure 3 shows a simulation result when radius *R* is 60. Agents decide to evacuate or not to each time step and their collective behavior *p(t)*, the proportion of agent who chosen 1, gradually changes. In Figure 3, upper line means number of evacuating agents. Then, number of evacuating agents increase to about 8,000, that is collective behavior converges around 0.8 in 100 time steps, which means 100 seconds. Another line means the number of finished evacuating agents. We found that the agents decided to evacuate for shelter come to finish evacuating in 900, which means fifteen minutes.

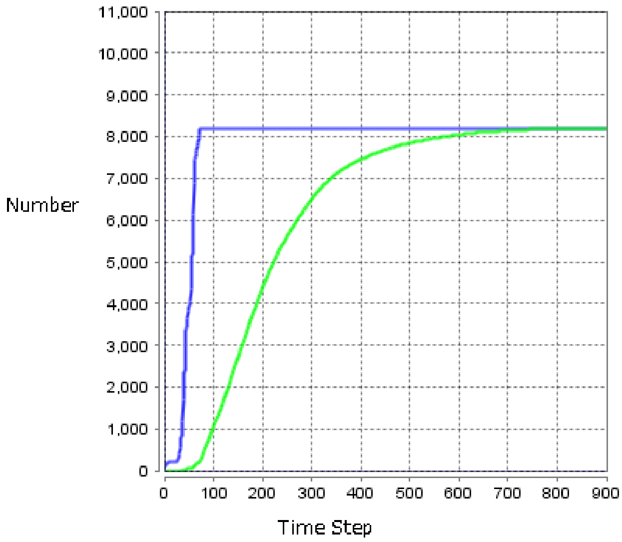
In this simulation, about four times as many agent as questionnaire [11] evacuate within five minutes. There, 13.1 % of people evacuated within 5 minutes and 18.6 % of people finished evacuating within 15 minutes. So, *theta* may be a little high value. We carry forward to a future work.

3.2 Results of collective behavior

By the last result, we simulate until 100 time step, what we call as a trial, and execute 100 trials for each pattern. Table 3 shows the histogram of the final proportion *p** of agents who decide to evacuate when *theta* is 0.05.

Final collective behavior can be high value. When radius *R* is 115 m, final collective behavior becomes 0.01 forty four times and only initially agents remain to evacuate. And final collective behavior becomes about 0.1 fourteen times, becomes about 0.2 three times, becomes about 0.3 once, becomes about 0.4 twice, becomes about 0.5 once, becomes about 0.6 three times, becomes about 0.8 twenty three times, becomes about 0.9 eight times and becomes 1.0 once of 100 trials.

When radius *R* is 173 m, final collective behavior becomes 0.01 fifty eight times and only initially agents remain to evacuate. And final collective behavior becomes to 1.0 forty twice of 100 trials. When radius *R* is 230 m, final collective behavior becomes 0.01 seventy twice and only initially agents remain to evacuate. And final collective behavior becomes 1.0 twenty eight times of 100 trials.



---: Number of evacuating agents,

---: Number of finished evaluating agents.

Figure 3. Transition of collective behavior when radius *R* is 115 m and *theta* is 0.05.

Table 3. The histogram of final collective behavior.

Final collective behavior when *theta* is 0.05	*R*		
*p**	**115 m**	**173 m**	**230 m**
0.00-0.05	44	58	72
0.05-0.15	14	0	0
0.15-0.25	3	0	0
0.25-0.35	1	0	0
0.35-0.45	2	0	0
0.45-0.55	1	0	0
0.55-0.65	3	0	0
0.65-0.75	0	0	0
0.75-0.85	23	0	0
0.85-0.95	8	0	0
0.95-1.00	1	42	28
SUM	100	100	100

4. Discussion

We found that when radius *R* is 173 m or 230 m, collective behavior tends to go to extreme, that is final collective behavior become 0.01 or 1.0. And when radius *R* is 115 m, collective behavior can be moderate. Then, if an agent can observe far agents, contagion of evacuation depends on trials, but the possibility is low that all agents evacuate. Otherwise an agent can observe only near agents, contagion of evacuation tends to occur, but it is difficult to evacuate all agents because there are some isolated sub social networks. These properties are similar to the last paper [5]. Then, when agent can observe the narrow neighbors, contagion of evacuation is possible and it is needed the sub social networks are connected each other to more large contagion.

By comparing this result and the last paper [5], the proportion of agents who decided to evaluate for the shelter in this results is more than that in the last paper. This is because an evacuating agent for shelter comes in a field of vision for many agents. That is, walking agents tend to be witnessed by other agents. Then, we found that if agents watch the evacuating agents for the shelter, many agents come to evacuate.

5. CONCLUSION

In this paper, we dealt with evacuation decision making of people in the disaster area. Homogenously wide interaction isn't effective for contagion of evacuation. And we found that if agents watch evacuating agents for shelter, because many agents come to evacuate because evacuating agent for shelter comes in field of vision for many agents.

In the future works, we will adopt that people decide to evacuate with depending on TV news, communication media and so on.

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