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DISASTER EVACUATION SIMULATION CONSIDERING EXCHANGE OF SHELTER INFORMATION BY SNS

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Abstract. *In recent years, SNS has become widespread. Then, it has easily been possible to spread and collect the information to the unspecified number of people. In particular, in the case of disasters, the information of safety confirmation, damage status and evacuation sites (shelters) is frequently exchanged. In the case of disaster evacuation in the urban areas, in order to solve the shortage of shelter capacity, it is necessary to appropriately guide the evacuees by spreading the information. For this purpose, it is necessary to consider the voluntary information exchange by SNS besides the conventional evacuees' guidance. As the first step of considering the exchange of the shelter information by SNS, in this paper, we conduct a simulation of disaster evacuation on the assumption that evacuees use SNS to spread and collect the congestion information of the shelters. The result of our simulation suggests that the exchange of the information by SNS shortens the time taken for the evacuation action and the effect of the exchange of information by SNS balances the number of evacuees among the evacuation sites.*
Keywords: Disaster evacuation, Multi-agent simulation, SNS, Evacuation behavior

1. Introduction.

By the spread of SNS in recent years, it is easily possible to spread and collect the information sent by the unspecified number of people. In the case of Kumamoto earthquake that occurred in April 2016, the safety confirmation using SNS was performed actively. Especially, at Kumamoto University, the safety confirmation of the students was performed using LINE, etc. As the result, it was reported that the time required for the safety confirmation of the students was significantly reduced [1]. On the other hand, it was also reported that the false rumors, such as "a lion escaped from a zoo" were spread by SNS, and the staff of zoo were busy with the inquiry response [2]. From these facts, we can easily understand that SNS helps the people to exchange the information at the disaster, and there is also the possibility of causing the confusion.

In the case of disaster evacuation in the urban areas, the lack of the capacity of evacuation sites (shelters) is a problem. According to the result of the inquiry of the Central Disaster Prevention Council to the local public entity, which carried out in 2007 [3], assuming that the Tokyo Bay Northern Earthquake, the capacity of the primary shelters will be insufficient for $\sim$ 560,000 people within Tokyo area. However, if a wide area evacuation across Tokyo is possible, there will be possibility to satisfy it. Thus, it is necessary and important to guide the evacuees according to the situation after the disaster. In addition to the conventional method of guiding the evacuees, such as the wireless-activated disaster warning system, and mass media, there is a possibility that it is effective for evacuees to spread and collect the information by SNS.

Many simulation researches of disaster evacuation have been conducted since the 1970s and the multi-agent simulation of disaster evacuation has been used since the 2000s (e.g.,

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Yasufuku [4]). As the model considering the exchange of information, Matsushima et al. [5] and Osaragi and Tsuchiya [6] have been performing the multi-agent simulation that considered the exchange of information of the evacuation routes. In addition, Fujioka et al. [7] have also built the multi-agent model to select the evacuation action based on the various information including the congestion of the evacuation routes. These simulations have considered the information exchange by the wireless-activated disaster warning system, the guidance by the persons on the evacuation routes and the direct information exchange by nearby evacuees. There is one research that considered the information exchange by SNS (Minami and Kato [8]). Toward more realistic simulation, as the first step, we develop a disaster evacuation simulator considering the exchange of shelter information by SNS, following the research of Minami and Kato [8]. By using our developed disaster evacuation simulator, the efficiency of the evacuation is evaluated, and we clarify how the information transmission and diffusion through SNS affect the evacuation behavior. To investigate the impact of the spread of SNS on evacuation behavior, we do not consider the specific disaster content, roads and cities.

In this paper, Section 2 explains an overview of our simulations and two models we set up for them: SNS model and local media model (LM model), Section 3 shows the results and discussions of our simulations, and Section 4 is the summary.

2. **Overview of Simulation.** We developed and implemented two kinds of simulation models: SNS model and local media (LM) model, in order to investigate the effects of information exchange by SNS on evacuee behaviors.

2.1. **Overall design of simulation.** We simulated the evacuation behavior of how evacuees make their shelter choice knowing the capacity and congestion information by SNS or LM to get there. Figure 1 shows an example of the arrangement for the evacuees and shelters. The simulation space (city) is 500×500 in which we have 5,000 evacuees and 25 shelters with the capacity of 100 persons, with periodic boundary conditions. To produce the deviation of the distribution of the population, we set more evacuees in the center than that in the edge. 10 patterns of the distribution of shelters are predetermined and we simulate for each arrangement. When a disaster occurs at time $t = 0$, the evacuees decide the destination shelter and move to their direction (described in Section 2.5.2) at a speed of 1 space per unit time (1 step). If the evacuees receive the information of the degree of congestion of the shelter by SNS (described in Section 2.3) or LM (described in Section 2.4), they can change their destination shelter (described in Section 2.5.1). When an

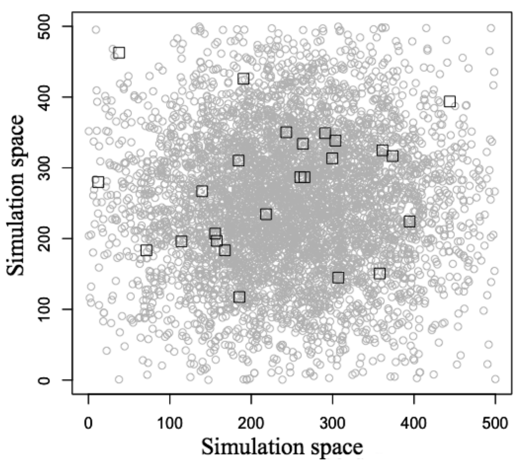


FIGURE 1. An example of the arrangement for the evacuees and shelters (evacuation sites). The squares represent the shelters and the circles represent the evacuees.

Table 1. Definition of the parameters for SNS model and LM model and the variables related to the evacuee i and shelter j

Parameter	
R_{use}	Ratio of SNS user among the evacuees
r_{LM}	Reception range of LM
Variable	
O_i	Set of the candidate of evacuation destination for the evacuee i
o_i	Current destination shelter of the evacuee i
$D_i(j)$	Distance between the evacuee i and shelter j
$C_j(t)$	Overcapacity rate of the shelter j at time t
$I_i(j)$	Information of the shelter j obtained by the evacuee i

evacuee arrives within 1 space from the destination shelter, the evacuee judges whether the evacuee enters the shelter or not (described in Section 2.5.3). We assume all evacuations complete and finish the simulation when 99% of evacuees complete evacuations.

In the remaining of this section, we explain more details of the arrangement and condition of our simulation.

2.2. **Parameters and variables.** We use the index i ($i = 1, 2, \ldots, 5{,}000$) for an evacuee and j ($j = 1, 2, \ldots, 25$) for a shelter, respectively. The definition of the parameters for SNS model and LM model is shown in Table 1. R_{use} means the ratio of SNS user among the evacuees and r_{LM} means the reception range of LM such as the wireless-activated disaster warning system, and mass media. These two parameters play an essential role in our simulation.

The definition of the variables related to the evacuee i and the shelter j is also shown in Table 1. O_i is the set of the candidate of evacuation destination for the evacuee i. At the initial state, all shelters are the elements of O_i. o_i is the current destination shelter of the evacuee i. If the destination shelter of the evacuee i is undecided, the value of o_i is 0. $D_i(j)$ means the distance between the evacuee i and shelter j and $C_j(t)$ means the overcapacity rate of the shelter j at time t, i.e., $C_j(t) =$ (the number of the evacuees entering at shelter j until time t)/(100: the capacity of shelter j). $I_i(j)$ is the information of the shelter j obtained by the evacuee i. In this simulation, the evacuees exchange the following three kinds of information to simplify the simulation:

$$I_i(j) = \begin{cases} 0: & \text{Shelter } j \text{ is crowded,} \\ 1: & \text{Shelter } j \text{ is somewhat crowded,} \\ 2: & \text{Shelter } j \text{ is NOT crowded.} \end{cases} \tag{1}$$

2.3. **SNS model.** We define R_{use} ($0 \leq R_{\text{use}} \leq 1$) as the ratio of SNS users of all evacuees. Our SNS model has the following four functions like "Twitter": Tweet, Retweet, Timeline, and Tweet search.

2.3.1. *Tweet.* Tweet is a function to post the information $I_i(j)$. An example of the information posted by the tweet function is shown in Figure 2. The posted information is stored in the data frame shown in Figure 2: information number in the first column, shelter name j in "Shelter", information of shelter $I_i(j)$ in "Information", the posted time in "Time", the evacuee name i in "Evacuee" and information number of the information source in "Source". Note that in the case of the information posted by the tweet function, 0 is stored in "Source". For example, the first line of Figure 2 shows that "at time 1, the evacuee 2041 posts the information that the shelter 3 is NOT crowded".

	Shelter	Information	Time	Evacuee	Source
1	3	2	1	2041	0
2	6	2	1	3433	0

FIGURE 2. Example of the information posted by the tweet function

2.3.2. *Retweet.* Retweet is a function to repost an existing information posted by other person. An example of the information posted by the retweet function is shown in Figure 3. The information posted by the retweet function is also stored in the same data frame in Figure 2, but the information number of the information source is stored in "Source". For example, the first line of Figure 3 (information number 8) shows that "at time 2, the evacuee 2367 reposts the information that the shelter 1 is NOT crowded. The source of this information is the information number 6".

	Shelter	Information	Time	Evacuee	Source
8	1	2	2	2367	6
9	1	2	2	4237	8
10	1	2	2	3183	9
11	1	2	2	776	10

FIGURE 3. Examples of the information posted by the retweet function. The data frame is same as the tweet function (Figure 2) except for "Source".

2.3.3. *Timeline.* Timeline is a function to view the information from other SNS users that the SNS user is following. In this paper, we assume that each SNS user follows other 500 users. According to Minami and Kato [8], there was no significant difference of the simulation results with and without users who have many followers. Thus, in this paper, the number of followers is constant for all evacuees. The timeline shows the information of the SNS user whom SNS user is following and in order from the latest. When the evacuee of SNS user obtains the information by the timeline function, the evacuee decides how much updated information to view from the latest. Then, SNS user browses the information one by one and copies the obtained information to $I_i(j)$. Note that we assumed that the timeline function is available at $t \geq 30$ because during the beginning of the evacuation the only information of "Shelter is NOT crowded." may be posted.

2.3.4. *Tweet search.* Tweet search is a function to acquire the information about the congestion information of the current destination shelter o_i. If the evacuee i of SNS user searches for the information about o_i, the evacuee i gets the latest information about o_i and copies its information to $I_i(j)$. Tweet search function is available when at least one piece of information of o_i is posted.

2.4. **Local media (LM) model.** To compare the results between SNS model and the conventional method of guiding the evacuees, such as the wireless-activated disaster warning system, and mass media, the LM model is used in our simulation. The LM model transmits the congestion information of the shelter j within the radius of r_{LM} from the shelter j. The transmission of the information is performed every 10 steps. Though the evacuees can copy the shelter information $I_i(j)$ to their own data frame in Figure 2, they cannot spread it to others.

2.5. **Evacuation behavior.** The evacuees keep moving for shelters until they finish evacuation. If the set of the candidate of evacuation destination for the evacuee i is empty ($O_i = \emptyset$), the evacuee i moves one step for their direction described in Section 2.5.2. Other evacuees take the following actions at each step (t).

2.5.1. *Obtaining the information of the shelter.* If SNS or LM is available, the evacuees can obtain the information. In this paper, we assume that the evacuees, who are SNS users outside of the LM reception range, obtain information by SNS with 10% probability. SNS user selects which function to use from two functions: timeline and tweet search. The evacuees who use SNS access one of the functions, timeline or tweet search, at random with 50% probability when both of them are available, and repost the information with 10% probability.

If the evacuee i obtains the information, the evacuee i makes the following decision based on $I_i(j)$:

- If shelter j is the current destination shelter of the evacuee i ($j = o_i$):
  - If shelter j is crowded ($I_i(j) = 0$):
    the evacuee i removes j from O_i and changes o_i with 50% probability.
  - If shelter j is somewhat crowded or shelter j is not crowded ($I_i(j) = 1$ or 2):
    the evacuee i changes nothing.

- If shelter j is not the current destination shelter of the evacuee i ($j \neq o_i$):
  - If shelter j is crowded ($I_i(j) = 0$):
    the evacuee i removes j from O_i with 10% probability.
  - If shelter j is somewhat crowded ($I_i(j) = 1$):
    the evacuee i changes nothing.
  - If shelter j is not crowded ($I_i(j) = 2$):
    the evacuee i changes o_i to j with $1/(D_i(j) + 1)$ probability.

2.5.2. *Evacuees' behavior.* At the time of evacuation start ($t = 0$), we assume that 20% of the evacuees (i.e., 1,000 persons) know the location of their nearest shelter as the destination shelter. The other evacuees take following actions depending on their situation:

- If the evacuee finds another evacuee within a radius of 5, who knows destination shelter or has an evacuee to follow (defined as a leader), he/she decides the evacuee ahead as his/her own leader to follow.
- If the evacuee does not find anyone to follow, the evacuee changes direction ahead slightly by within ±5 degrees.

Determination of arrival at the shelter is made as follows:

- If the evacuee i already decided the destination shelter ($o_i \neq 0$):
  if a shelter exists within the radius 1, we assume that the evacuee i arrived at the shelter and performed the judgement of evacuation completion described in Section 2.5.3. Otherwise, the evacuee i moves one step his/her direction.
- Even though an evacuee i is more than 1 away from any destination shelters and does not have a destination shelter ($o_i = 0$), if one of the shelters exists within a radius of 5 from the evacuee i, the evacuee decides the shelter as the destination shelter o_i. Otherwise, the evacuee i moves one step forward.

2.5.3. *Judgement of evacuation completion.* The judgement of evacuation completion is made by whether the evacuee i decides to enter the shelter or not when the evacuee i reaches the shelter. Though the capacity of each shelter is 100 persons, evacuees more than the capacity are allowed to enter if it stays under the limit allowable congestion, $\overline{C}_i(t)$. For each evacuee i, the limit allowable congestion as the function of time $\overline{C}_i(t)$ is defined, which indicates how congestion is allowed for the shelter capacity:

$$\overline{C}_i(t) = \overline{C}_{i0} \times 2^{\frac{t}{k}}, \tag{2}$$

where $\overline{C}_{i0}$ is the initial value of the limit allowable congestion and this is the different value for every evacuee; moreover, k for representing the evacuees' tolerance to the congestion twice as much as $\overline{C}_{i0}$. In this paper, the value of $\overline{C}_{i0}$ for the evacuee i is given by the normal distribution with the mean of 1.5 and the standard deviation of 0.1, and we set $k = 1000$.

As an evacuee i arrives at the shelter j at the time t, then the evacuee i compares the actual overcapacity rate $C_j(t)$ with his/her limit allowable congestion $\overline{C}_i(t)$ and makes a decision whether entering the shelter or not as follows:

- If the evacuee i allows the congestion state of shelter j $\left(C_j(t) < \overline{C}_i(t)\right)$: the evacuee i enters the shelter j.
- If the evacuee i does not allow the congestion state of shelter j $\left(C_j(t) \geq \overline{C}_i(t)\right)$: the evacuee i does not enter the shelter j. And the evacuee i excludes j from O_i and defines the nearest shelter among the remaining shelters in O_i as the new destination shelter o_i. Then, the evacuee i continues his/her evacuation.

And if the evacuee i is SNS user and the evacuee i performs the judgement of the evacuation completion, then the evacuee i posts the congestion information of the shelter j with 30% probability. In this case, by comparing $C_j(t)$ and $\overline{C}_i(t)$, the following information is posted:

$$I_i(j) = \begin{cases} 0: & 0.8 \times \overline{C}_i(t) \leq C_j(t), \\ 1: & 0.2 \times \overline{C}_i(t) \leq C_j(t) < 0.8 \times \overline{C}_i(t), \\ 2: & C_j(t) < 0.2 \times \overline{C}_i(t). \end{cases} \tag{3}$$

In Equation (3), we consider that the posted information is not the objective congestion rate but the subjective from the SNS user's viewpoint.

3. **Result and Discussion.** Our simulation code is developed by R [9]. We prepared 10 cities with 10 different distributions of shelters for the evacuation simulations conducted by our SNS model and LM model. We have 5,000 evacuees and 25 shelters each city.

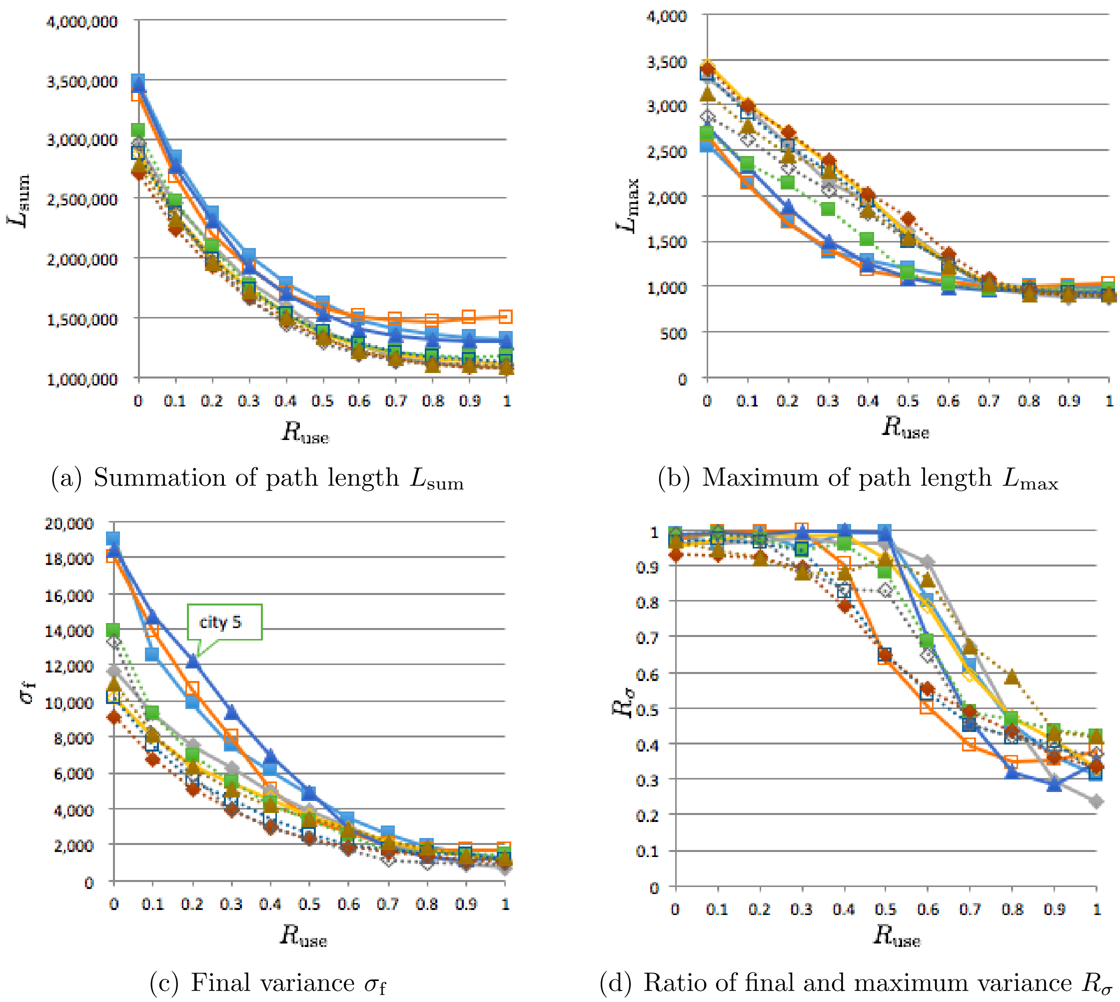
We calculated the following four evaluation indices based on the previous research [8], two of which, L_{sum} and $L_{\max}$, are related to path length that is equivalent to evacuation time, and the other two of which, σ_{f} and R_σ, are related to variance of the number of evacuees at shelters.

- Related to path length (= the evacuation time):
  - L_{sum}: Summation of path length of all evacuees (i.e., average completion time for evacuation),
  - $L_{\max}$: Maximum of path length (i.e., (longest) completion time for evacuation).
- Related to the balance of the number of evacuees between the shelters:
  - σ_{f}: Final variance (i.e., variance of the number of evacuees at shelters at the end of simulation),
  - R_σ: Ratio of the final and maximum variance (i.e., σ_{f}/(the maximum variance during simulation)).

3.1. **SNS model.** The value of the ratio of SNS user R_{use} was changed from 0 to 1 in the increments of 0.1. Then the four evaluation indices were calculated. Figure 4 shows the average value of four evaluation indices of 10 simulations in each city.

From Figures 4(a) and 4(b), we find that, in the all cities, L_{sum} and $L_{\max}$ decrease as R_{use} increases. This result indicates that the spread of SNS reduces the summation and maximum of path length. In other words, the spread of SNS reduces the average completion time for the evacuation.

From Figure 4(c), in all cities, σ_{f} decreases as R_{use} increases. In particular, in city 5 where the final variance σ_{f} is large when $R_{\text{use}} = 0$, because the decrease is larger than other cities. These results suggest that the spread of SNS tends to bring the balance of the number of the evacuees among the shelters.



(a) Summation of path length L_{sum}

(b) Maximum of path length L_{max}

(c) Final variance σ_f

(d) Ratio of final and maximum variance R_σ

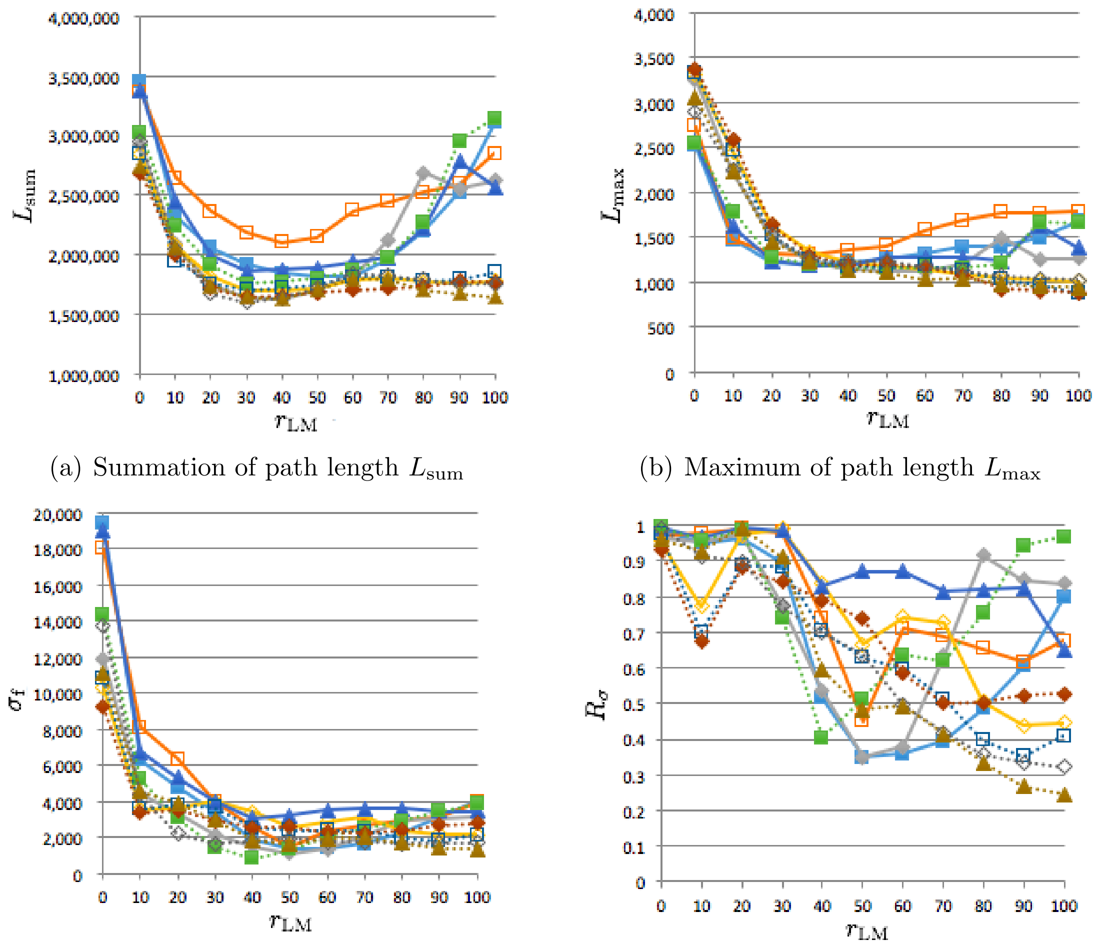
FIGURE 4. Result of the SNS model. The horizontal axes show R_{use}, and each line corresponds to the result of each city.

From Figure 4(d), R_σ decreases as R_{use} increases from 0.4 to 0.9. This result is consistent with the results of the previous research [8]. On the other hand, in the case where R_{use} is between 0 and 0.3, R_σ is close to 1 in all cities. This is because that the judgement of evacuation completion is not same in the previous research [8]. By definition of R_σ, we find that the final and maximum variance is almost same value. Thus, it may be also important to examine the relationship between R_σ and the judgement of evacuation completion in future.

3.2. **Local media model.** The value of reception range of LM r_{LM} was changed from 0 to 100 in the increments of 10. The four evaluation indices were also calculated. Figure 5 shows the average value of four evaluation indices of 10 simulations in each city. These cities are same cities in Figure 4.

From Figure 5, we can find that, when r_{LM} is between 50 and 100, there are two tendencies of the cities: the values of L_{sum}, L_{max} and R_σ increase and these values decrease or maintain. On the other hand, in any city, these three values have local minimum between 20 and 50.

From Figure 5(d), when r_{LM} is between 50 and 100, the change of R_σ is more complicated than that of σ_f. From Figure 5(c), when r_{LM} is between 50 and 100, the change of σ_f is stable. By definition of R_σ and the result of Figure 5(c), the complicated change of R_σ depends on the change of the maximum variance.



(a) Summation of path length L_{sum}

(b) Maximum of path length L_{max}

(c) Final variance σ_{f}

(d) Ratio of final and maximum variance R_σ

FIGURE 5. Result of LM model. The horizontal axes show r_{LM}, and each line corresponds to the result of each city. These cities are same cities in Figure 4.

These results suggest that the optimal value of r_{LM} exists. In other words, these results indicate that the effect of LM worsens if r_{LM} is too large i.e., the transmission of information by LM to a wide area caused the confusion in evacuation's behavior.

4. **Summary.** To consider the exchange of the shelters' information by SNS, we conducted a disaster evacuation simulation on the assumption that evacuees use SNS to spread and collect the congestion information of the shelters. Moreover, in order to compare the result between SNS and the conventional method of guiding the evacuees such as the wireless-activated disaster warning system, and mass media, the LM model was also used in our simulation. From our simulation results of Section 3.2, we found that the transmission of the information by LM to a wide area might cause the confusion in evacuation's behavior. On the other hand, from the results of Section 3.1, we found that the exchange of the information by SNS shortens the time taken for the evacuation action and the effect of the exchange of the information by SNS balances the number of evacuees among the evacuation sites. Though this was one ideal case study, our result was consistent with the result of the previous research [8].

We will perform more realistic simulations, e.g., the combination of SNS and LM. We will also perform the simulation considering the realistic characteristics of SNS containing incorrect information, etc. We will report elsewhere.

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