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DISASTER EVACUATION SIMULATION CONSIDERING TRANSMISSION OF FALSE AND FACT-CHECKING INFORMATION BY SOCIAL NETWORKING SERVICE

Hirotaka Takahashi[1], Chie Uenae[2], Yasushi Sumitani[2]
Yohei Kakimoto[3] and Yuto Omae[3]

[1]Research Center for Space Science, Advanced Research Laboratories
Tokyo City University
8-15-1, Todoroki, Setagaya, Tokyo 158-0082, Japan
hirotaka@tcu.ac.jp

[2]Department of Information and Management Systems Engineering
Nagaoka University of Technology
1603-1, Kamitomioka, Nagaoka, Niigata 940-2188, Japan
uc31113620@gmail.com; sumitaniy@aol.com

[3]Department of Industrial Engineering and Management
College of Industrial Technology
Nihon University
1-2-1, Izumi, Narashino, Chiba 275-8575, Japan
{ kakimoto.youhei; oomae.yuuto }@nihon-u.ac.jp

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Abstract. *As social networking services (SNSs) have become widespread in recent years, it has become possible to collect information from and broadcast it to an unspecified number of people with ease. In particular, in the case of disasters, information regarding safety confirmation, damage status, and evacuation sites (shelters) is frequently exchanged. In this study, we design a disaster evacuation simulation that takes account of the exchange of information on shelters, transmission of false information on shelters, and fact-checking information by SNS. Furthermore, we investigate the effect of the transmission of false information and fact-checking information on the disaster evacuation behavior. The simulation results pertaining to the transmission of false information and fact-checking information, suggest that it is very important to thoroughly check the source of the information and spread accurate information, when evacuees voluntarily spread information using SNS.*

Keywords: Disaster evacuation, Evacuation behavior, Multi-agent simulation, Social networking service

1. **Introduction.** With the expansion of social networking services (SNSs) in recent years, it has become possible to broadcast and collect the information sent by an unspecified number of people, with ease. In case of the Kumamoto earthquake that occurred in April 2016, safety confirmation was proactively performed using SNSs. In particular, at Kumamoto University, safety confirmation of the students was provided using platforms such as LINE. Therefore, it was reported that the time required for the confirmation of the safety of the students was significantly reduced [1]. However, it was also reported that false information (rumors), such as "a lion escaped from a zoo", was also spread by SNSs, and the staff of the zoo were kept busy with inquiry responses [2]. SNS users may broadcast misinformation during a disaster when unfounded discourse is sent out or when

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false information is published owing to malicious intent (e.g., the above case of "a lion escaped from a zoo"). In both cases, it is important to investigate the veracity of the messages and then disseminate the results (which is known as fact-checking).

The lack of storage capacity in evacuation sites (shelters) is a problem in disaster evacuation in urban areas. According to the results of the inquiry of the Central Disaster Prevention Council, implemented in 2007 [3], it was assumed that in the case of Tokyo Bay Northern Earthquake, the capacity of the primary shelters would prove insufficient for the ∼560,000 people residing within the Tokyo area. However, if a wider area evacuation across Tokyo was implemented, the need would be satisfied. Therefore, it becomes very crucial to guide evacuees according to the situation in times of a disaster. In addition to the conventional methods for guiding evacuees, such as wireless-activated disaster warning systems and mass media, it may be effective for the evacuees, to spread and collect information through SNSs.

Although SNSs can aid people in exchanging information following a disaster, it can also cause confusion.

Many simulation studies on disaster evacuation have been conducted since the 1970s and multi-agent simulations of disaster evacuation have been used since the 2000s (e.g., Yasufuku [4]). As models considering the exchange of information, Matsushima et al. [5] and Osaragi and Tsuchiya [6] performed multi-agent simulation that considered the exchange of information regarding evacuation routes. Furthermore, Fujioka et al. [7] constructed a multi-agent model to select the evacuation actions based on various information, including, congestion of the evacuation routes. These simulations considered information exchange by wireless-activated disaster warning systems, guidance by people on the evacuation routes, and direct information exchange by nearby evacuees.

One study had previously considered information exchange by SNS [8]. We developed the disaster evacuation simulator considering the exchange of shelter information by SNSs [9], following the research of Minami and Kato [8]. By using the disaster evacuation simulator, developed by us, the efficiency of the evacuation was evaluated, and we showcased how the information transmission and diffusion through the SNS affect the evacuation behavior. To investigate the impact of the spread of information through SNSs on the evacuation behavior, we did not take account of the specific disaster contents, roads, and cities.

However, Minami and Kato [8] and Uenae et al. [9] did not consider the effects of the transmission of false information and fact-checking information on the disaster evacuation behavior. In this study, based on Uenae et al. [9], we extended the disaster evacuation simulation, to take account of the exchange of information on shelters, the transmission of false information on shelters, and fact-checking information by SNSs.

The remainder of this paper is organized as follows. Section 2 provides an overview of our simulations. Section 3 presents the simulation results of three cases: case A: the transmission of only congestion information; case B: the transmission of congestion information and false information; case C: considering fact-checking in addition to the transmission of congestion information and false information. Moreover, the effects of the transmission of false information and fact-checking information on the disaster evacuation behavior are discussed. Section 4 presents a summary of the work.

2. **Overview of Simulation.** We developed and implemented a multi-agent simulation that considers the transmission of false information regarding shelters and fact-checking to investigate the effects of information exchange by SNS on evacuee behavior.

2.1. **Overall simulation design.** We simulated the evacuation behavior of evacuees making a shelter decision by considering the capacity, congestion information, and information regarding the availability of food at the shelter, by SNS. Figure 1 presents an example of the arrangement for the evacuees and shelters. The simulation space (City) consists of 500×500, that is, 5,000 evacuees and 25 shelters with a capacity of 100 persons each, as well as periodic boundary conditions. To produce the deviation of the population distribution, we set more evacuees in the center than at the edge. In total, 10 patterns of the shelter distributions ($\mathrm{City1}, \mathrm{City2}, \ldots, \mathrm{City10}$) were predetermined and we conducted a simulation for each arrangement. When a disaster occurs at time $t = 0$, the evacuees decide on the destination shelter and move accordingly (as described in Section 2.4.2) at a speed of 1 space per unit time (1 step). If the evacuees received information regarding the degree of congestion of the shelter and the availability of food at the shelter by SNS (Section 2.3), they could change their destination shelter (Section 2.4.1). Moreover, certain evacuees transmitted false information through SNSs (Section 2.5.1). Some evacuees also verified the facts of the information and transmitted this through SNSs (Section 2.5.2).

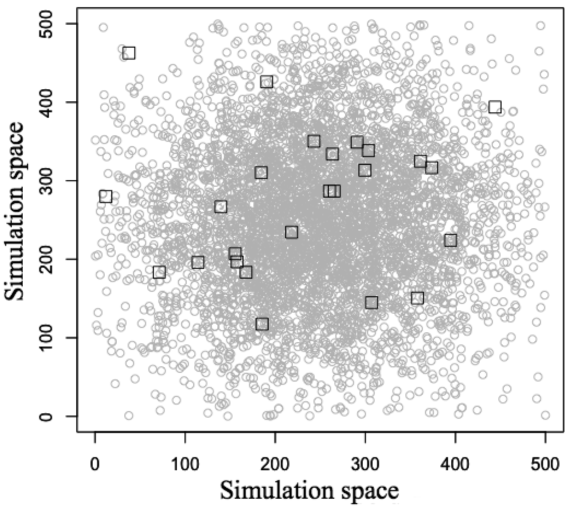


Figure 1. Example of arrangement of evacuees and shelters (evacuation sites). The squares represent the shelters and the circles represent the evacuees.

When an evacuee arrived within 1 space from the destination shelter, they decided whether to enter the shelter (Section 2.4.3) or not. We assumed that all evacuations had taken place and completed the simulation when 99% of evacuees had completed their evacuations.

As the purpose of this study was to investigate the effects of the transmission of false and fact-checking information by SNSs on the evacuation behavior, we assumed that all evacuees could use SNSs with certain probabilities. In the remainder of the sections, we explain additional details of the arrangement and conditions of our simulation.

2.2. **Variables.** We used the index i ($i = 1, 2, \ldots, 5{,}000$) for an evacuee and j ($j = 1, 2, \ldots, 25$) for a shelter.

The definitions of the variables related to evacuee i and shelter j are displayed in Table 1. O_i is the set of candidates for evacuation destinations for evacuee i. In the initial state, all shelters are elements of O_i. o_i is the current destination shelter of evacuee i. If the destination shelter of evacuee i is undecided, the value of o_i is 0. $D_i(j)$ means the distance between evacuee i and shelter j, whereas $C_j(t)$ means the overcapacity rate of shelter j at time t; that is, $C_j(t) =$ (the number of evacuees entering at shelter j until time t)/(100: the capacity of shelter j). $I_i(j)$ is the information of shelter j obtained by evacuee i. In this simulation, the evacuees exchanged the following five types of information to simplify the simulation:

$$I_i(j) = \begin{cases} 0: & \text{Shelter } j \text{ is crowded,} \\ 1: & \text{Shelter } j \text{ is somewhat crowded,} \\ 2: & \text{Shelter } j \text{ is NOT crowded,} \\ 3: & \text{Shelter } j \text{ is serving food,} \\ 4: & \text{Information that shelter } j \text{ is serving food is incorrect.} \end{cases} \tag{1}$$

F_i indicates the state of receipt of false information and fact-checking information for evacuee i. F_i is used to define the following three states:

$$F_i = \begin{cases} 0: & \text{Evacuee } i \text{ does not read the false information or fact-checking} \\ & \text{information,} \\ 1: & \text{Evacuee } i \text{ reads only the false information,} \\ 2: & \text{Evacuee } i \text{ reads the fact-checking information.} \end{cases} \tag{2}$$

Finally, U_i is the probability that evacuee i will use an SNS.

TABLE 1. Definition of variables related to evacuee i and shelter j

Variable	
O_i	Set of candidates for evacuation destination for evacuee i
o_i	Current destination shelter of evacuee i
$D_i(j)$	Distance between evacuee i and shelter j
$C_j(t)$	Overcapacity rate of shelter j at time t
$I_i(j)$	Information of shelter j obtained by evacuee i
F_i	State of receipt of false information and fact-checking information for evacuee i ($F_i = 0$ for all evacuees in initial state)
U_i	Probability that evacuee i will use an SNS (Initially, all users have a 10% probability of using an SNS.)

2.3. **SNS model.** Our SNS model includes the following four functions similar to "Twitter": tweet, retweet, timeline, and tweet search.

2.3.1. *Tweet.* The tweet is a function to post information $I_i(j)$. An example of information posted by the tweet function is presented in Figure 2. The posted information is stored in the data frame illustrated in Figure 2: the information number in the first column, shelter name j in "Shelter", information of shelter $I_i(j)$ in "Information", posted time in "Time", name of evacuee 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 indicates that "at time 1, evacuee 2041, posts information that 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 information posted by tweet function

2.3.2. *Retweet.* The retweet is a function to repost existing information that was posted by another person. An example of the information posted by the retweet function is depicted in Figure 3. The information posted by the retweet function is 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) indicates that "at time 2, evacuee 2367, reposts information that shelter 1 is NOT crowded. The source of this information is 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 information posted by the retweet function. The data frame is the same as in the tweet function (Figure 2) except for "Source".

2.3.3. *Timeline.* The timeline is a function for viewing the information from other SNS users, which the concerned SNS user, is following. In this study, we assumed that each SNS user followed 500 other users. Minami and Kato [8] demonstrated that there was no significant difference in simulation results with and without users who had many followers. Thus, in this study, the number of followers was constant for all evacuees. The timeline displays the information of the SNS users that the concerned SNS user, is following, in the order, of the most recent. When the evacuee, who is an SNS user, obtains the information using the timeline function, the evacuee decides how much updated information to view. Thereafter, the SNS user browses the information individually and copies the obtained information to $I_i(j)$. Note that we assumed that the timeline function was available at $t \geq 30$ because only the information of "Shelter is NOT crowded" may be posted at the beginning of the evacuation.

2.3.4. *Tweet search.* The tweet search is a function to acquire information about the congestion of the current destination shelter o_i. If evacuee i, who is an SNS user, searches for information regarding o_i, evacuee i will obtain the latest information regarding o_i and copy its information to $I_i(j)$. The tweet search function is available when at least one set of information regarding o_i is posted.

2.4. **Evacuation behavior.** The evacuees continue to move towards shelters until they complete the evacuation. If the set of the candidates for evacuation destinations for evacuee i is empty ($O_i = \emptyset$), evacuee i moves one step in their direction, as described in Section 2.4.2. The other evacuees take the following actions at each step (t).

2.4.1. *Obtaining information of shelter.* If SNS is available, the evacuees can obtain information. In this study, we assumed that the evacuees obtain information by SNS with a 10% probability. The evacuees select the function to use from the timeline and tweet search at random with a 50% probability when both are available, and repost the information with a 10% probability.

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

- If shelter j is the current destination shelter of evacuee i ($j = o_i$):
  - If shelter j is crowded ($I_i(j) = 0$):
    evacuee i removes j from O_i and changes o_i with a 50% probability.

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

2.4.2. *Behavior of evacuees.* At the evacuation starting time ($t = 0$), 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 the following actions depending on their situation.

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

The determination of arrival at the shelter is performed as follows.

- If evacuee i has already decided the destination shelter ($o_i \neq 0$): if a shelter exists within a radius of 1 unit, we assume that evacuee i has arrived at the shelter and performs the judgment of evacuation completion, as described in Section 2.4.3. Otherwise, evacuee i moves one step in his/her direction.
- Although evacuee i is more than 1 unit away from any destination shelters and does not have a destination shelter ($o_i = 0$), if a shelter exists within a radius of 5 units from evacuee i, the evacuee selects the shelter as the destination shelter o_i. Otherwise, evacuee i moves one step forward.

2.4.3. *Judgment of evacuation completion.* The judgment of evacuation completion is performed according to whether or not evacuee i decides to enter the shelter on reaching the shelter. Although the capacity of each shelter is 100 persons, evacuees are allowed to enter above the capacity, provided that the number remains, under the limit of allowable congestion $\overline{C}_i(t)$. For each evacuee i, the limit of allowable congestion is defined as a function of time $\overline{C}_i(t)$, which indicates the congestion that is allowed for the shelter capacity:

$$\overline{C}_i(t) = \overline{C}_{i0} \times 2^{\frac{t}{k}}, \tag{3}$$

where $\overline{C}_{i0}$ is the initial value of the limit of allowable congestion and this value differs for every evacuee. Moreover, k represents the tolerance of evacuees to the congestion that is twice as much as $\overline{C}_{i0}$. In this study, the value of $\overline{C}_{i0}$ for evacuee i was given by the normal distribution with a mean of 1.5 and standard deviation of 0.1, and we set $k = 1{,}000$.

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

- If evacuee i allows the congestion state of shelter j $\left(C_j(t) < \overline{C}_i(t)\right)$: evacuee i enters shelter j.
- If evacuee i does not allow the congestion state of shelter j $\left(C_j(t) \geq \overline{C}_i(t)\right)$: evacuee i does not enter shelter j. Furthermore, 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. Subsequently, evacuee i continues his/her evacuation.

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

$$I_i(j) = \begin{cases} 0: \ 0.8 \times \overline{C}_i(t) \leq C_j(t), \\ 1: \ 0.2 \times \overline{C}_i(t) \leq C_j(t) < 0.8 \times \overline{C}_i(t), \\ 2: \ C_j(t) < 0.2 \times \overline{C}_i(t). \end{cases} \tag{4}$$

In Equation (4), it is considered that the posted information is not the objective congestion rate, but the subjective perspective of the SNS user.

2.5. **Transmission of false information and fact-checking.** The simulation takes account of sending out false information and fact-checking tweets on the SNS. During the simulation, evacuees send out false information according to Section 2.5.1 and fact-checking the tweets according to Section 2.5.2.

2.5.1. *Transmission of false information and evacuee behavior.* One evacuee i, who has not completed evacuation, tweets the following false information only once:

$$I_i(j) = 3\text{: Shelter } j \text{ is serving food,} \tag{5}$$

where shelter j in Equation (5) is randomly determined from shelters that are a distance of 100 or more units from the perspective of the false information sender i, regardless of the elements of O_i. Let j_{fake} be the target shelter where the false information was sent. The time of tweeting is set to the early stage of the disaster occurrence (the start of evacuation); that is, the time of tweeting false information is randomly determined between $t = 30$ and $t = 100$. It is assumed that the evacuee who sends out the false information obtains the information by some other means and sends it out on the SNS without checking the facts. Therefore, the sender is also deceived by the false information ($F_i = 1$). Even if the sender is within a distance of 1 unit from the shelter, when the evacuee tweets the false information, the evacuation is continued by changing the destination of the shelter to j_{fake}, without making a judgment on the evacuation completion.

An evacuee i who sees the tweet of false information changes the destination shelter O_i to j_{fake} with a probability of $3/(D_i(j_{\text{fake}}) + 3)$ (let j_{prev} be the destination shelter before the change). This probability is based on [8]. When the destination shelter is changed to j_{fake}, the value of F_i is changed from 0 to 1. Based on the information stored in $I_i(j)$, the following decision is made.

- If shelter j is the current destination shelter of evacuee i ($j = o_i$):
  - If shelter j is crowded ($I_i(j) = 0$):
    evacuee i removes j from O_i with a 50% probability and reselects O_i. Furthermore, if $F_i = 1$, the probability U_i of using the SNS is changed from 1% to 10%.
  - If shelter j is serving food ($I_i(j) = 3$):
    change the probability U_i of using the SNS from 10% to 1% and then set $F_i = 1$.
  - Otherwise, evacuee i changes nothing.
- If shelter j is not the current destination shelter of evacuee i ($j \neq o_i$):
  - If shelter j is crowded ($I_i(j) = 0$):
    evacuee i removes j from O_i with a 10% probability.
  - If shelter j is not crowded ($I_i(j) = 2$):
    evacuee i changes o_i to j with a $1/(D_i(j) + 1)$ probability.

  - If shelter j is serving food ($I_i(j) = 3$) and $F_i = 0$:
    evacuee i changes o_i to j_{fake} with a $3/(D_i(j)+3)$ probability and then sets $F_i = 1$. Furthermore, the probability U_i of using the SNS is changed from 10% to 1%.
  - Otherwise, evacuee i changes nothing.

An evacuee, who sees the tweet of false information, retweets the false information tweet with a 30% probability (normal tweets regarding shelter congestion have a 10% probability of being retweeted).

2.5.2. *Fact-checking.* When an evacuee i, who has seen a misinformation tweet (an evacuee with $F_i = 1$), arrives at shelter j_{fake}, the following fact-checking tweet will be sent with a 50% probability following the evacuation completion decision:

$$I_i(j) = 4\text{: Information that shelter } j \text{ is serving food is incorrect.} \tag{6}$$

When an evacuee i with $F_i = 1$ arrives at shelter j_{fake} or sees a fact-checking tweet, evacuee i changes $F_i = 2$. An evacuee, who changes the destination shelter to j_{fake} owing to a false information tweet ($F_i = 1$) and who also sees a fact-checking tweet, changes the destination shelter from j_{fake} to j_{prev} with a probability $1 - \{3/(D_i(j_{\text{fake}}) + 3)\}$. If evacuee i has changed the destination shelter from $O_i = 0$ (no destination shelter) to j_{fake}, evacuee i sets the destination shelter to $O_i = 0$. Moreover, the probability that the evacuee uses the SNS, U_i, is changed from 1% to 10%. In summary, evacuee i makes the following decisions based on the information stored in $I_i(j)$.

- If shelter j is the current destination shelter of evacuee i ($j = o_i$):
  - If shelter j is crowded ($I_i(j) = 0$):
    evacuee i removes j from O_i with a 50% probability and reselects O_i. Moreover, if $F_i = 1$, the probability U_i of using the SNS is changed from 1% to 10%.
  - If shelter j is serving food ($I_i(j) = 3$):
    the probability U_i of using the SNS is changed from 10% to 1% and $F_i = 1$ is set.
  - If the information that shelter j is serving food is incorrect ($I_i(j) = 4$):
    evacuee i changes o_i to j_{prev} with a $1 - \{3/(D_i(j) + 3)\}$ probability and then sets $F_i = 2$. Furthermore, the probability U_i of using the SNS is changed from 1% to 10%.
  - Otherwise, evacuee i changes nothing.
- If shelter j is not the current destination shelter of evacuee i ($j \neq o_i$):
  - If shelter j is crowded ($I_i(j) = 0$):
    evacuee i removes j from O_i with a 10% probability.
  - If shelter j is not crowded ($I_i(j) = 2$):
    evacuee i changes o_i to j with a $1/(D_i(j) + 1)$ probability.
  - If shelter j is serving food ($I_i(j) = 3$) and $F_i = 0$:
    evacuee i changes o_i to j_{fake} with a $3/(D_i(j)+3)$ probability and then sets $F_i = 1$. Furthermore, the probability U_i of using the SNS is changed from 10% to 1%.
  - If the information that shelter j is serving food is incorrect ($I_i(j) = 4$) and $F_i = 0$:
    evacuee i sets $F_i = 2$.
  - Otherwise, evacuee i changes nothing.

Evacuee i who sees a fact-checking tweet will retweet the fact-checking tweet with a 30% probability (a normal tweet has a 10% probability of being retweeted). If evacuee i with $F_i = 2$ finds a tweet of false information in a tweet search or timeline, evacuee i will not read the tweet of false information, but will read the next tweet. Moreover, if evacuee i with $F_i = 2$ finds a fact-checking tweet in a tweet search or timeline, evacuee

i will retweet the fact-checking tweet only once. Thereafter, evacuee i will read the next tweet without reading the fact-checking tweet.

3. **Results and Discussion.** Our simulation code was developed using R [10]. We prepared 10 cities with 10 different shelter distributions for the evacuation simulations. There were 5,000 evacuees and 25 shelters in each city. The simulations were conducted for three cases: case A: the transmission of only congestion information, case B: the transmission of congestion information and false information, and case C: the consideration of fact-checking in addition to the transmission of congestion information and false information.

We calculated the following four evaluation indices based on previous research [8, 9]. The first two, namely L_{sum} and $L_{\max}$, are related to the path length, which is equivalent to evacuation time, and the other two, σ_{f} and R_σ, are related to the variance of the number of evacuees at shelters.

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

As an example of the results, Figure 4 presents the mean values of the four evaluation indices for 10 simulations in each case of City1. To investigate whether there was a significant difference between the mean values of the evaluation indices for cases A, B, and C, a statistical test of the difference between the mean values was performed using the Games-Howell method.

It can be observed from Figures 4(c) and 4(d) that when false information was transmitted (case B), the mean values of the final variance σ_{f} and final/maximum variance ratio R_σ increased significantly compared to case A. This was because evacuees were directed to the shelter with false information, and the number of evacuees that were accommodated in the shelter was not balanced. Therefore, when the evacuees performed fact-checking of the information (case C), these values, namely σ_{f} and R_σ, would settle at almost the same level as in case A.

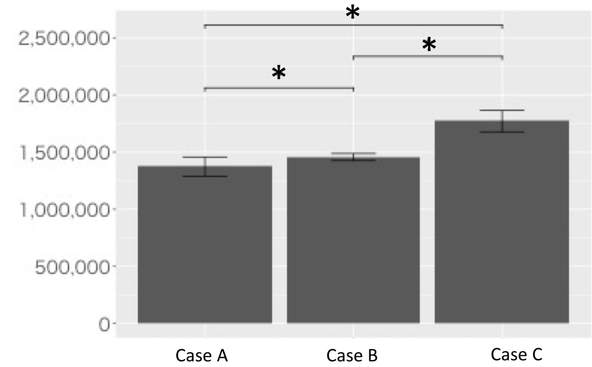
According to Figure 4(b), when false information was transmitted (case B), the mean value of $L_{\max}$, that is, the maximum time required for evacuation, decreased significantly compared to cases A and C.

As illustrated in Figure 5, a longer time was required to evacuate the last several dozen people in cases A and C.

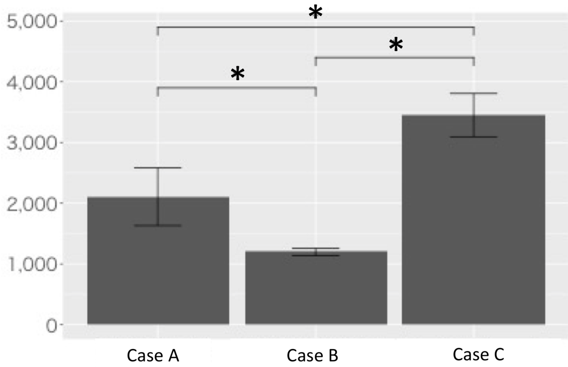
The evacuees who saw tweets of false information were more likely to change their evacuation destination and to retweet than those who saw tweets of congestion information (Section 2.5.1). This suggests that the time taken by the evacuees to decide on their evacuation destination and leader was shorter when false information was tweeted. Therefore, $L_{\max}$ in case B was smaller than that in cases A and C.

Moreover, the same tendency as that in cases A and C was evident. However, the number of evacuees, who were undecided about the destination shelter and leader of the evacuees, decreased slower in case C than in case A.

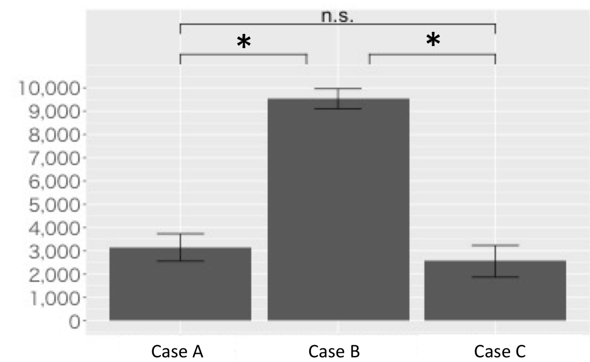
The evacuees who read the fact-checking tweets reverted their evacuation destination shelter according to the distance from j_{fake}, including the case in which the destination



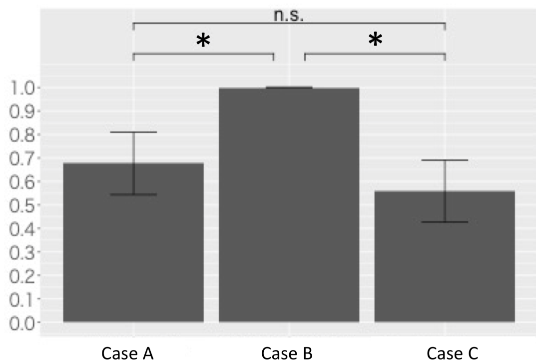
(a) Summation of path lengths L_{sum}



(b) Maximum path length L_{max}



(c) Final variance σ_{f}



(d) Ratio of final and maximum variance R_{σ}

FIGURE 4. City1 results as an example of simulation results. The mean values and standard deviations of the four evaluation indices for 10 simulations were obtained in each case. Moreover, a statistical test of the difference between the mean values was performed using the Games-Howell method. $*$ means $p < 0.05$ and n.s. means not significant.

evacuation shelter was reverted from j_{fake}, to no destination evacuation shelter ($o_i = 0$) (Section 2.5.2). Let i_{fc} be an evacuee who has changed the destination shelter from j_{fake} to no destination shelter ($o_i = 0$) and who has no leader.

According to Section 2.4.2, the requirements for an evacuee to be a leader are that, the destination shelter is known ($o_i \neq 0$) or he/she has another evacuee as his/her leader. Evacuee i_{fc} will no longer satisfy the requirements for leader. Therefore, the evacuees who were following i_{fc} will not be able to find the leader and are considered to have wandered around the area aimlessly with i_{fc}.

We confirmed that L_{max}, σ_{f}, and R_{σ} exhibited a similar tendency for all cities. However, the summation of the path lengths of all evacuees (i.e., the average completion time for evacuation), L_{sum}, exhibited a different tendency in each city. This was owing to the structure of the city. In the case of the city where the average distance between the center of the city and each shelter was small, the mean value of L_{sum} tended to decrease significantly in case B. However, in the case of the city where the average distance between the center of the city and each shelter was large, the mean value of L_{sum} tended to increase significantly, as indicated in Figure 4(a).

4. **Summary.** To consider the exchange of information regarding shelters by SNSs, we conducted a disaster evacuation simulation based on the assumption that evacuees used

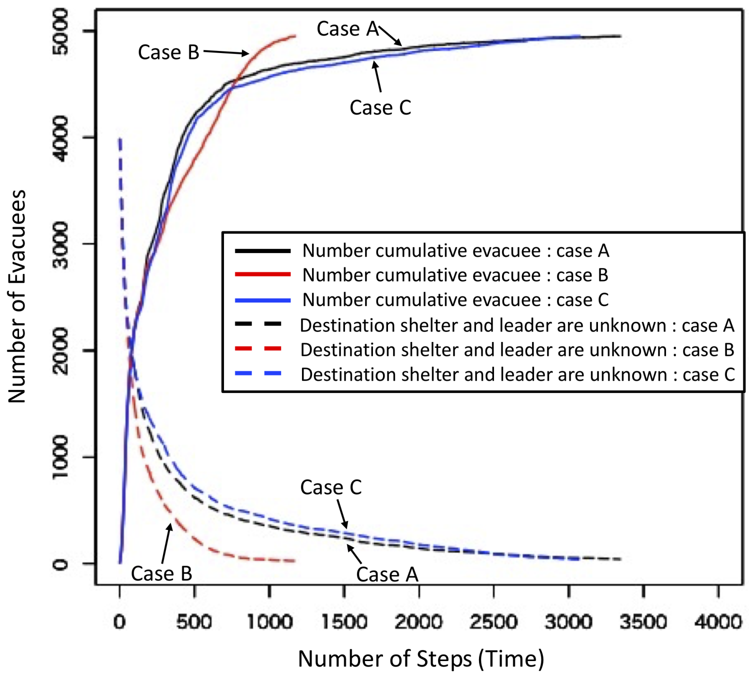


FIGURE 5. Number of cumulative evacuees, and number of evacuees whose destination shelter and leader are unknown. This is an example result of a simulation case of City1.

SNSs to spread and collect congestion information of shelters, transmit false information, and fact-checking information.

The results demonstrated that, compared to the case of only spreading and collecting congestion information, the mean value of the longest completion time for evacuation decreased in the simulations that considered the transmission of false information. Moreover, the number of evacuees, that were accommodated, was not balanced among the evacuation shelters.

In the simulations that considered fact-checking transmission, the aforementioned problem of imbalance in the number of evacuees that were accommodated was eliminated by fact-checking, although the longest completion time for evacuation increased, compared to the case in which only congestion information was transmitted. This indicates that when evacuees use SNSs to send and obtain information voluntarily, they need to verify the source of the information and send accurate information.

Regarding the average completion time for evacuation, as the results exhibited a different tendency in each city, it may be necessary to consider the relationship between the average completion time for evacuation and the location of evacuation shelters in each city.

In this study, based on [8] and [9], we assumed some fixed probabilities for the sake of simplicity, i.e., we used the fixed probabilities discussed in Section 2 (e.g., the possibility that the evacuees obtain information by SNS). Though the obtained results might not change significantly, it is important to confirm the results, obtained by changing these assumptions, quantitatively.

We did not consider the structures of specific cities or roads as we investigated the impact of the transmission of information using SNSs on the evacuation behavior. However, it can easily be observed that the structure of specific cities or roads is related to the evacuation behavior based on the results of the average completion time for evacuation in our simulations. This should be considered in future work.

Moreover, we will perform more realistic simulations, e.g., a combination of SNSs and the method of guiding evacuees, such as wireless-activated disaster warning systems and mass media.

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Author Biography

Hirotaka Takahashi received the D.Sci. degree from the Graduate School of Science and Technology, Niigata University, Japan, in 2005. He was a Postdoctoral Researcher with the Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Germany, from September 2005 to August 2007. He has been a Faculty Staff Member at various universities. He has been a Professor with the Research Center for Space Science, Advanced Research Laboratories, Tokyo City University, Japan from September, 2020. His research interests include adaptive data analysis methods, information theory, and gravitational wave physics and astronomy (general relativity). He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE), the Information Processing Society of Japan (IPSJ), the Operations Research Society of Japan (ORSJ), the Japan Society for Fuzzy Theory and Intelligent Informatics (J-SOFT) and the Physical Society of Japan (JPS), among others.

Chie Uenae received the M.Eng. degree from the Department of Information and Management Systems Engineering, Nagaoka University of Technology, Japan, in 2021. Her research interests include the development of the multi-agent systems and operations research.

Yasushi Sumitani received the B.Eng. degree in Mechanical Engineering in 1991, and the M.Eng. degree in Mechano Informatics in 1993, respectively, from University of Tokyo, Japan, and he obtained the M.A. degree in International and Development Economics from Yale University, United States, in 2001. He worked in the Ministry of Economy, Trade and Industry, the Japanese Government, from 1993 to 2018, and he was a full-time professor at the Nagaoka University of Technology from 2013 to 2015. His current research interests include operations research, optimization, game theory, value of information and decision-making.

Yohei Kakimoto received the B.Eng. and the M.Eng. degrees from Nagaoka University of Technology, Japan, in 2016 and 2018, respectively. He is currently an Assistant of the College of Industrial Technology, Nihon University, Japan. His research interests include operations research and geographic information science. He is a member of the Operations Research Society of Japan (ORSJ).

Yuto Omae received the D.Eng. degree from the Department of Information Science and Control Engineering, Nagaoka University of Technology, Japan in 2016. He was a Postdoctoral Researcher at Japan Institute of Sports Sciences and an Assistant Professor at National Institute of Technology, Tokyo College. He is currently an Assistant Professor of Department of Industrial Engineering and Management, College of Industrial Technology, Nihon University, Japan from April 2019. His research interests are intelligent informatics, machine learning, mathematical model and so on. He is a member of the Institute of Electrical and Electronics Engineers (IEEE), the Institute of Electronics, Information and Communication Engineers (IEICE), the Japanese Society for Artificial Intelligence (JSAI), the Japan Society for Fuzzy Theory and Intelligent Informatics (J-SOFT), among others.