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Crowding of Various Facilities Relevant to Supporting People Who Have Difficulty Returning Home after a Large Earthquake

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ABSTRACT

When a large earthquake occurs, many people are presumed to have difficulty in returning home. However, no research has been achieved yet to discuss the congestion of supporting facilities for stranded people in terms of site, the number and spatial distribution. In this study, we construct a simulation model, which describes people's behavior such as returning home or going to other facilities after an earthquake occurs. Using the model, we estimate the congestion of facilities which varies according to day of the week or the time when the event occurs, and demonstrate the effective methods for reducing the congestion, which include offering information for people and cooperation of private institutions.

Keywords

Large earthquake, difficulty in returning home, temporary shelter, support station for people returning home on foot, crowding.

INTRODUCTION

The Great East Japan Earthquake (March 11, 2011) caused little material damage in the Greater Tokyo Area, but transport systems including buses and private cars were paralyzed and a large number of people had difficulty returning home. As a result, the Tokyo Metropolitan Government enacted the Ordinance on Measures for Stranded Persons (which came into effect in April 2013). This ordinance advances measures and preparations by local governments in the Greater Tokyo Area for an imminent earthquake directly beneath the capital city, including designating temporary shelters and support stations to help those trying to return home.

In simulation studies of stranded people, Osaragi (2008, 2012) estimated the spatio-temporal distribution of people in places distant from their own homes using person trip survey data (PT data) focusing on the Greater Tokyo Area, and by simulating the behavior of people returning home on foot, estimated the number of stranded people and the number of people staying in the streets according to the time that the earthquake strikes. Osaragi's study (2008, 2012) was carried out before the Great East Japan Earthquake, but it accurately estimated the chaos in the Greater Tokyo Area, including the time it took for people to return home on foot and the number of stranded people who abandoned the idea of returning home and stayed in their offices, for example. However, it was necessary to update the model by performing the survey for the people who had actually experienced East Japan Earthquake. Also, it was difficult to understand the mechanism of people's decision making of returning home, since the model was a neural network model. Hiroi et al. (2011) carried out a questionnaire survey immediately after the Great East Japan Earthquake and used the obtained trip data on people returning home on foot to carry out a disaggregated analysis and estimate the number of people who stayed and the number of people who returned home on foot according to each municipality. Osaragi (2016a) used the behavioral characteristics of people returning home on foot revealed by this survey to construct a probabilistic model (a nested logit model) for estimating the behavior of people in the city after a disaster according to their attributes, where they are, and the time at which the disaster occurs. Based on the results of estimating the number of people according to behavior type, Osaragi's study also considered the effectiveness of the Ordinance on Measures for Stranded Persons. This probabilistic model will be used to predict people's decision making on returning home behavior in this study.

Okawa et al. (2009) analyzed the number of toilets and the area of rest stops required, focusing on arterial roads from the city center to the outskirts. However, they did not examine the number, size, or positioning of facilities designated by local governments for the Greater Tokyo Area.

In the present study, we first estimate the level of crowding of various facilities (temporary shelters, support stations, and train stations) relevant to supporting people who have difficulty returning home in the Greater Tokyo Area by constructing a model to describe the movement of people and their choice behavior regarding facilities after a large earthquake, and simulating movement on foot assuming an earthquake directly beneath the capital city. Next, we consider measures for reducing crowding of facilities based on the estimation results. Specifically, in terms of soft measures, we consider the effect of reducing crowding by providing information to people returning home on foot; and in terms of hard measures, we consider the effect of opening up facilities belonging to private businesses.

CONSTRUCTION OF WALKING SIMULATION MODEL

People and Facilities Subject to Simulation

Table 1 gives a summary of the people and roads subject to this simulation. The people subject to simulation were extracted from the 2008 Tokyo Metropolitan Person Trip Survey data (hereinafter, PT data), which includes detailed personal attributes, as well as the location and time information of the departure and arrival. Also, purpose of trip, and means of transportation are also included. Specifically, in order to conduct an analysis that focuses on people returning home on foot from the city center to the outskirts of the city and the crowding of facilities in the city center and its vicinity, people passing even just once through the area within a 20 km radius of the city center (Imperial Palace) were extracted from the PT data and taken as subjects of the analysis.

Table 1. Summary of Area, People, and Roads Subject to Simulation

People/ Area/Road	Definition
Area subject to simulation	Every road in Tokyo Metropolitan, Kanagawa Pref., Saitama Pref., Chiba Pref., South part of Ibaraki Pref. (Highway and driveway are excluded).
People subject to simulation	People staying at places outside home at the assumed disaster occurrence time were extracted from the PT data. The shortest route for returning home was analyzed and those passing through the 20 km radius centered on the Imperial Palace were extracted. The PT data of non-business day were estimated by using the method shown in Osaragi (2016b).
Main road	National road, prefectural road, city road (When heading to the destination, it is assumed that main roads are preferentially used as easy-to-navigate routes).
Narrow street	Roads other than the main roads

Figure 1 shows the spatial distribution and Table 2 shows a summary of the various facilities (temporary shelters, support stations, and train stations) subject to simulation. The information about the location and type of facilities were taken from GIS-based database compiled by Tokyo metropolis. In this study, the support facilities for people who have difficulty returning home were defined as shown in Table 2, and the means of accessing the facilities from the roads were modeled according to Figure 2.

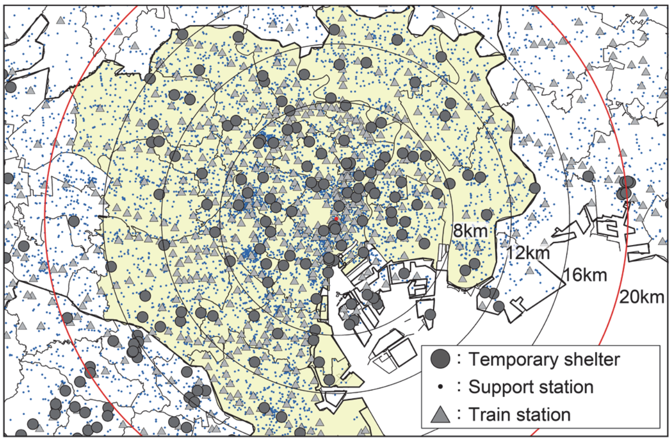


Figure 1. Spatial Distribution of Facilities to be Analyzed

Table 2. Outline of various facilities for people who have difficulty returning home

Type of facility	**Classification**	**Number of facilities**	**Number of people to be accepted for each facility**	**Number of toilets for each facility**	**Behavior of people**
Temporary shelter	Facility of Tokyo government	201	350	not specified	Temporary stay (People who visit once stay until the next morning [*1] Defined by the local governments
	Facility of other local governments	271	220 – 650 [*1]		
Support station	Municipal high school	238	400	20	Use of toilet facility (including waiting for toilet use) Taking a rest (10 to 30 minutes)
	Convenience store	13,552	20	1	
	Restaurant	2,545	40	2	
	Gas station	3,085	30	2	
	Car store	304	50	2	
Train station	Station designated for a temporary stay	210	not specified	[*2]	Stay till going to a temporary shelter or stay until the next morning [*2] Estimated from the number of people staying at the station at 8 o'clock on weekdays
	Other station	1,377			

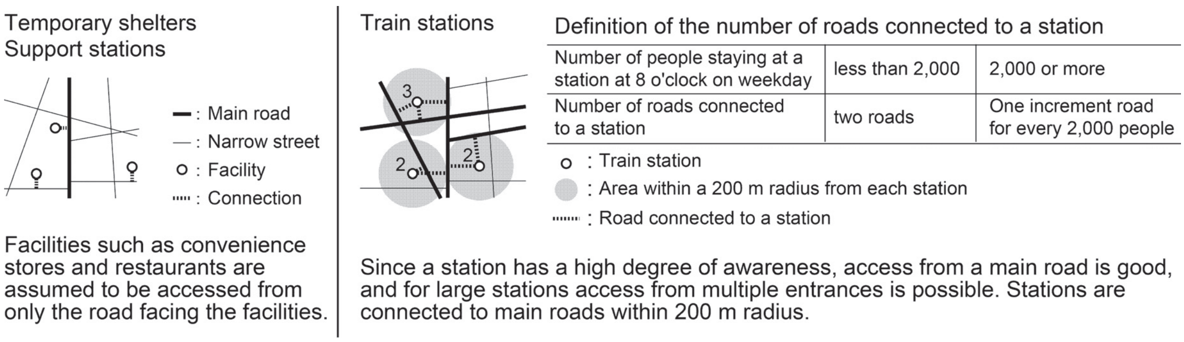


Figure 2. Modeling of Accessing Facilities from Roads

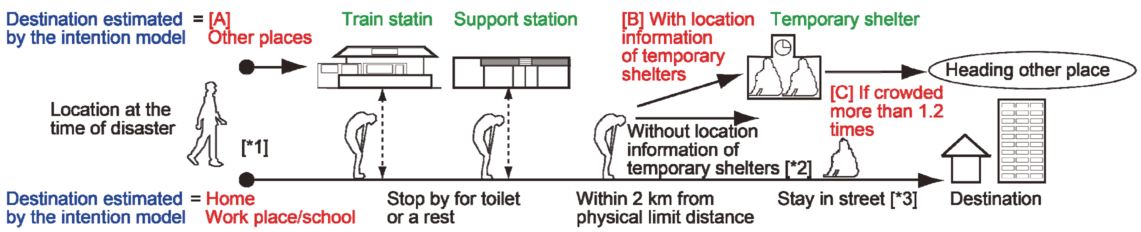
Construction of Walking Model

Table 3 and Figure 3 show a model that describes the travel behavior of people in the city after a large earthquake (walking model). Based on the intention model (Osaragi, 2016a), which describes decision-making and behavior of individuals, people who are at their place of work or school when the earthquake strikes were assumed to either stay where they are or head home. Other people were assumed to head either home, to their place of work/study, or to some another place. Among the people who head toward some other place, those who have location information of shelters were assumed to head toward a temporary shelter, whereas those who do not have location information were assumed to head toward the nearest train station (Table 3). Here, people other than those who stay at their place of work/study were defined as “walkers”, and the timing of the start of their action was established based on the results of a survey carried out after the Great East Japan Earthquake (Hiroi et al., 2011). After starting their action, they were considered to walk toward their destination, stopping at support stations and train stations along the way for a rest and to use the toilet. Also, physical limit distances (Cabinet Office, 2008) were set on the basis of sex and age. When walkers approached a place within 2 km from their physical limit distance, they were assumed to give up on going to their original destination and to change their destination to a nearby temporary shelter or train station (people who have given up on walking). Furthermore, walkers who reached their physical limit distance were assumed to stop walking and stay where they were (people staying in the street) (Figure 3).

Table 3. Outline of Modeling of Walkers' Destinations

Location at the time of disaster	Destination estimated by the intention model		
	Home	Work place/school	Other places
At their place of work/study	Heading home	Staying at work place/school (Not treat as target walkers in simulation)	
At station/ in train	Heading home	Heading to work place/school	Heading to temporary shelters [* 1]
At other facility/ outdoor	Heading home	Heading to work place/school	Heading to temporary shelters [* 2] or nearest station [* 3] (After taking a rest, heading to temporary shelters [* 1])

[* 1] Set the facility to be the destination according to the intention model.
[* 2] Heading to temporary shelters, if only walkers who have the location information before the action.
[* 3] Many people visited railway stations just after the East Japan Earthquake (2001) in order to collect the information about the restoration of transportation or the locations of temporary shelters.



[*1] The walking speed is 4 km/h, and it decreases according to the density of walkers.
[*2] Continue directly to the destination and check whether there is temporary shelters within 1km radius for each intersection. If there is a temporary shelter, change the destination to it.
[*3] Reached the physical limit distance, stop moving and stay in street.

[Assumption]
1. When walking on a road connected to a support station or station, a walker will stop by if he/she want to go to toilet or want to take a rest.
2. Waiting time for the use of toilet is assumed to be (the number of people in line / the number of toilets) multiplied 1 min. The rest time was set as a uniform random number from 10 to 30 minutes.
3. The time until a walker wants to go to the toilet is set as a uniform random number from 0 to 192 minutes for the first time of use. For the second time of use, it is set as a random number following the normal distribution with an average of 123 minutes and variance of 34.5 minutes.
4. A walker who has taken a rest more than once takes a rest after walking a distance more than half of the physical strength limit distance.
5. A walker does not stop by if he/she has to wait for more than 15 minutes. Also, he/she does not stop by for a rest if the number of people taking a rest exceeds the capacity of facility.

Figure 3. Outline of Walking Model

Construction of Facility Choice Model

Most people are thought to head toward a temporary shelter or train station after an earthquake strikes (Figure 3, [A],[B],[C]), but their preference regarding the choice of facility will differ depending on their individual situation and circumstances. Therefore, facility choice behavior was modeled under various situations and circumstances (Figure 4(1)). First, facilities located further than the reachable distance (Figure 4(2)) and severely overcrowded facilities (when information on crowding is available) were considered unlikely to be chosen, and so these facilities were excluded from the destination choices. Then, the model was created by multiplying each facility by a weighting according to each person's situation and circumstances (Nakasone et al. 2014, 2015), and assuming that people head toward the facility with the highest value. Specifically, the model assumes that people in situation [A] in Figure 3 have a relatively large amount of physical strength remaining and so they tend to choose a facility that is uncrowded, whereas people in situation [B] have little strength left and so they tend to choose a nearby facility located in the direction that they have been traveling.

Walkers [A], [B], [C] are shown in Figure 3.

(1) Reliable temporary shelters are limited to whose that satisfy both [a], [b1] or [b2] shown below.
([b1] or [b2] is used only for walkers with information about level of crowding)

[a] Located within reachable distance (see below)
[b1] Level of crowding at the time of acquiring information is 1.2 times or less (for walkers [A], [B])
[b2] Level of crowding is 0.8 times or less than current shelter (for walkers [C])
[c] In case that there is no facility which satisfies the criteria:
- People at station stays in the same station until the next morning, and others head to the nearest station (for walkers [A])
- If there is a station within reachable range, a walker stay there, if not, he/she stay in a road (for walkers [B])
- Stay in current temporary shelter (for walkers [C])

(2) Weighting of facility choice is performed according to the location classification of facilities based on the distance to each facility, the level of crowding, and the direction of destination.
A walker goes to a temporary shelter with the highest value of weighting.

[Definition of reachable distance]
People giving up on going >>> Reachable distance = 2 km - [Distance moved after giving up on going to the original destination]
People staying at a temporary shelter >>> Reachable distance = 2 km
Others >>> Reachable distance = Physical limit distance

[Facility location classification]

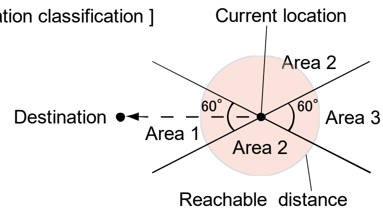


Figure 4. Outline of Facility Choice Model

Simulation Assumptions

In this study, it is assumed that an earthquake occurs directly beneath the capital city and all public transportation in the Greater Tokyo Area becomes paralyzed. However, for simplicity, outbreaks of fire and road blockages were not taken into account, and it was assumed that walkers are able to walk on the roads in an orderly way. The earthquake was assumed to occur at 9:00, 14:00, or 18:00 on either a weekday or a non-business day, and at 8:00 on a weekday only, supposing occurrence during the weekday commuter rush. The simulation period was set at 720 minutes (12 hours) from the time at which the earthquake occurs. In a Monte Carlo simulation, it is generally preferable to perform the simulation many times, but in this study, computation load constraints meant that the simulation was performed only 20 times for each case. Mean values of the simulation results were used in the analysis.

ESTIMATION RESULTS FOR CROWDING

Crowding of Temporary Shelters

The level of crowding of temporary shelters is high when the earthquake occurs at 14:00, a time at which there are many people in the city center. Particularly on non-business days, there are many people in the city center eating, shopping, and other activities, and so the level of crowding of train stations and temporary shelters becomes very high (Figure 5(a)). Crowding decreases as distance from the city center increases. However, approximately 12 to 14 km from the city center, crowding increases because many people give up on walking while returning home and the density of facilities is low (Figure 5(b)). Looking at the spatial distribution of crowding, the highest level of crowding is found in the vicinity of Shinjuku Station on a non-business day. This is followed by the areas around Tokyo Station, Ikebukuro Station, and Ueno Station, which shows that crowding is particularly severe around the main terminals (Figure 5(c)).

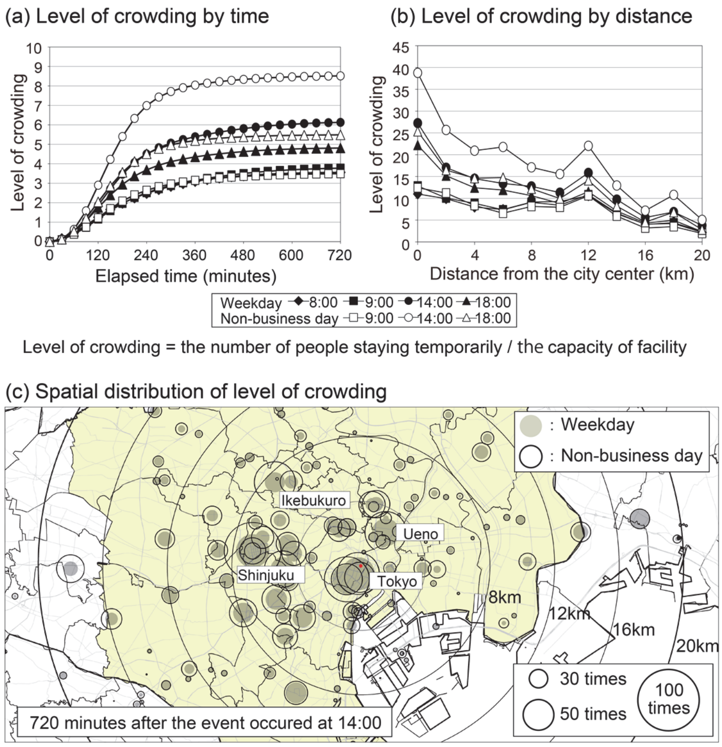


Figure 5. Estimated Level of Crowding of Temporary Shelters

Crowding of Support Stations for People Trying to Return Home

On weekdays, many people return home on foot from their place of work/study in the city center to the outskirts of the city, and so crowding of toilet facilities is found to be greater than on non-business days. In addition, the decrease in crowding is delayed because people at their places of work/study return home in a dispersed manner (Figure 6(a)).

However, because walkers take a rest after walking for a certain distance, the number of people resting reaches a peak approximately 4 hours after the earthquake on non-business days, and approximately 5 to 6 hours after the earthquake on weekdays (Figure 6(b)). Similar to the number of people using toilet facilities, the number of people taking a rest is higher on weekdays than on non-business days, and it is particularly high when the earthquake occurs at 9:00 or 14:00. Looking at the spatial distribution, there is a succession of facilities where the numbers of people taking a rest are extremely high along the main arterial roads such as National Route 6 and the Keiyo Road from the city center toward Chiba, and the Setagaya Avenue and Nakahara Street toward Kanagawa (Figure 6(c)). The numbers are particularly high approximately 8 to 20 km from the city center, and are highest along the Keiyo Road.

Focusing on the facilities along the six main arterial roads heading in various directions from the city center shown in Figure 6(c), when the earthquake occurs at 14:00 on a weekday, it is clear that the level of crowding of toilet facilities is higher than in Figure 6(a), most prominently along the Keiyo Road (Figure 6(d)). The number of people taking a rest shows a similar trend, and many people take a rest along National Route 6 and the Setagaya Avenue (Figure 6(e)).

The above results show a requirement for prioritized measures along the main arterial roads mentioned above (particularly the Keiyo Road).

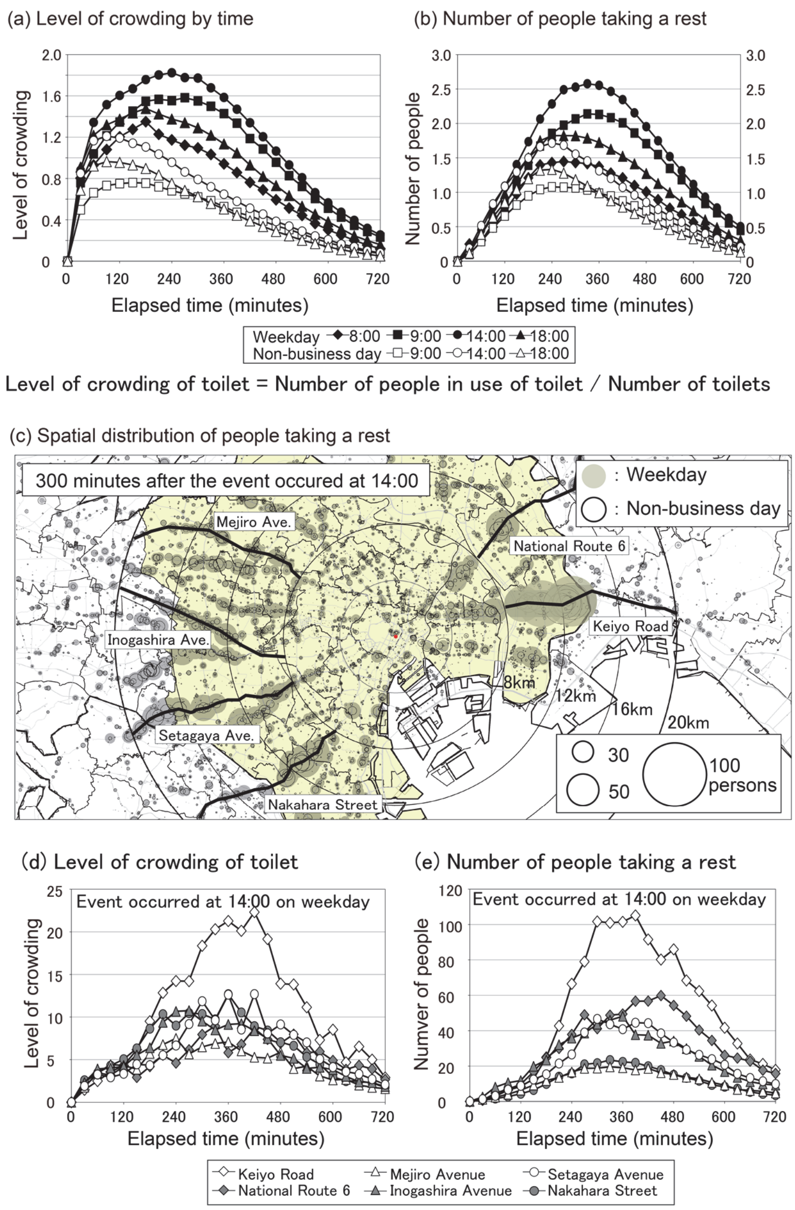


Figure 6. Level of Crowding of Support Stations for People Returning Home on Foot

Crowding of Train Stations

When the earthquake occurs at 8:00 on a weekday, a time at which many people are on their way to work or school, extremely large numbers of people stay inside train stations (Figure 7(a)). Looking at the spatial distribution, a large number of people stay at each station on Yamanote Line, particularly Shinjuku, Shibuya, and Ikebukuro Stations (Figure 7(c)). Focusing on these stations, when the earthquake occurs at 8:00 on a weekday, there are a large number of people staying at the station immediately after the earthquake. In contrast, when the earthquake occurs at 14:00 on a non-business day, people staying in the vicinity of the station gather gradually, and they become most numerous between 1 and 2 hours after the earthquake (Figure 7(b)). For example, when the earthquake occurs at 14:00 on a non-business day, the number of people staying at Maihama Station (the station closest to Tokyo Disneyland) increases to a level comparable to the city center (Figure 7(b)). This shows the importance of measures not only in the city center but also in the neighborhoods of facilities that attract large numbers of visitors.

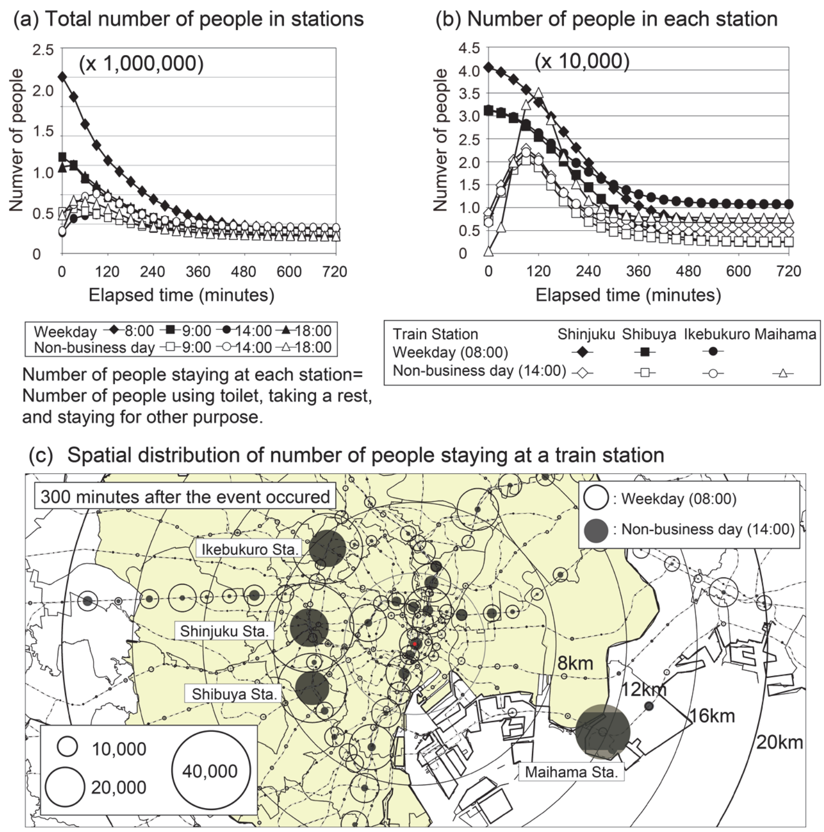


Figure 7. Spatial Distribution of Number of People Staying at Train Stations

Spatial Distribution of People Staying in the Street

The number of people staying in the street (people who have given up on walking to their destination) is highest when the earthquake occurs at 14:00 on a weekday (Figure 8(a)), and by distance, it is highest approximately 16 to 20 km from the city center (Figure 8(b)). Looking at the spatial distribution of linear density of people staying in the street (in terms of 100 m of road) when the earthquake occurs at 14:00 on a weekday, the density is high on the segments beyond 8 km from the city center of the main roads heading in various directions from the city center (Figure 8(c)). In particular, the number of walkers on National Route 6 is high, but because there are relatively few support stations in this far from the city center, they are unable to rest adequately and so end up staying in the street (Figure 8(d)).

The above results show that the existing facilities for people who have difficulty returning home are seriously insufficient for the potential numbers of stranded people, and there will be severe crowding of facilities and a large number of people staying in the street. The following sections propose and evaluate measures for reducing crowding, focusing mainly on temporary shelters as destinations taking in stranded people.

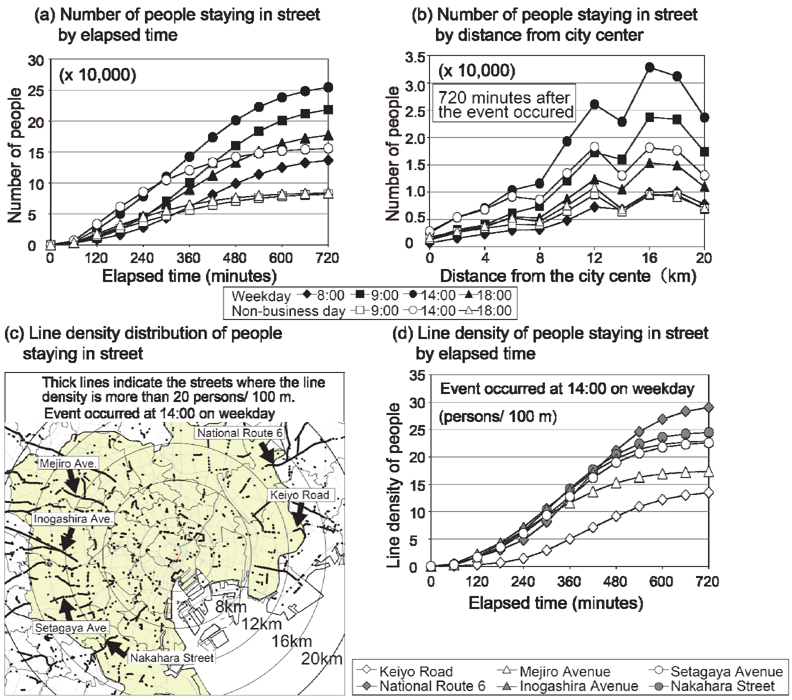


Figure 8. Number of People Staying in Street (People who have given up on walking to their destination)

ANALYSIS OF REDUCTION IN CROWDING AS A RESULT OF INFORMATION PROVISION

Assumptions about Provision of Information

This study considered the effect of providing information to people as a measure to reduce crowding at temporary shelters, specifically shelter location and crowding information (Table 4). The effects of word-of-mouth should not be ignored in a crisis situation. We have investigated it by simulating the evacuation behavior (Tsuchiya et al. 2015). We intend to combine all the related models into one big simulation model in the future. However, we omitted discussion about the effects of word-of-mouth in this paper due to the limitation of number of pages. The simulation was performed for an earthquake occurring at 14:00 on a weekday/non-business day, when crowding of facilities becomes highest, assuming the information provision probabilities shown in Table 5.

Table 4. Assumptions about Provision of Information

Information on locations of temporary shelters	Once a walker gets this information, he/she will know the location of all temporary shelters.
Information on level of crowding	Once a walker gets this information, he/she will know the level of crowding of all temporary shelters, which is updated every time.

Table 5. Assumptions about Probability of Obtaining the Information

Places where a walker is staying at the time of disaster	Probability of providing information at emergency				Probability of providing information when visiting a facility [*2]		
	Indoor			Outdoors	Temporary shelter	Support station	Train station
	Work place /school	Train station [*1]	Other facility				
Information on locations of temporary shelters	100 %	100 %	50 %	0 %	100 %	100 %	100 %
Information on level of crowding	0 %	100 %	0 %	0 %	100 %	50 %	100 %

[* 1] Including those who are riding in the train at the time of disaster.

[* 2] The latest information of level of crowding is provided at the time of departure from the facility.

Effect of Providing Information during an Earthquake Disaster

The effect of providing information at train stations and support stations during an earthquake disaster was analyzed. Simulations were performed under each of three assumptions (Figure 9(a)): Assumption (1), under which the results described in Section 3 were obtained, and Assumptions (2) and (3), under which information is provided.

The trend in the level of crowding at shelters is more crowding under Assumption (2) than under Assumption (1), for both weekdays and non-business days. This is because people who have acquired location information are better able to reach a shelter (Figure 9(b)). However, crowding is lower under Assumption (3), and this is considered to be because convergence of people on crowded shelters is reduced as a result of the acquired crowding information. Looking at the level of crowding by distance zone, the differences between Assumptions (1), (2), and (3) increase as the shelter becomes closer to the city center for both weekdays and non-business days (Figure 9(c)). Looking at the spatial distribution, crowding at the shelters near the main terminals, such as Shinjuku, Ikebukuro, and Tokyo Stations, is particularly low under Assumption (3) compared to Assumption (1) (Figure 9(d)).

(a) Assumption of providing information during an earthquake disaster

No.	Assumption of providing information
(1)	No information is provided (Location information is provided 100% only at stations / temporary shelters)
(2)	Only position information is provided (Probability of providing information is shown in Table 5)
(3)	Information on location and level of crowding is provided (Probability of providing information is shown in Table 5)

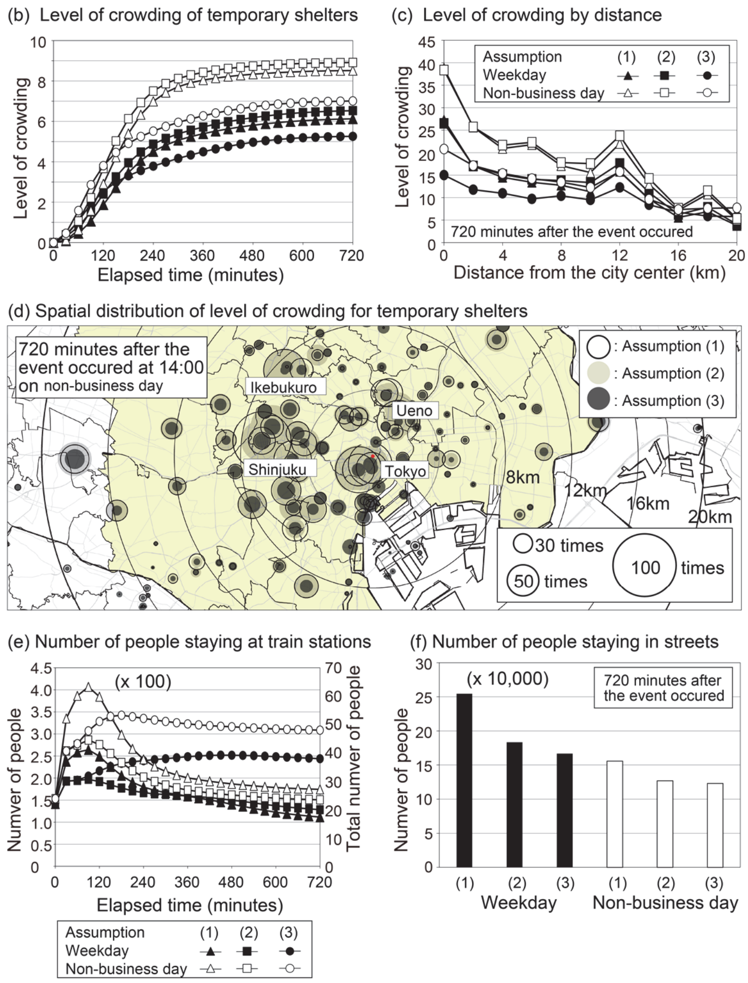


Figure 9. Effect of Providing Information during an Earthquake Disaster

In contrast, the number of people staying at train stations is greatest under Assumption (1) approximately 2 hours after the earthquake occurs in the case of both weekdays and non-business days; however, by the end of the simulation, the number is greatest under Assumption (3) because people who have acquired crowding information gather at the stations (Figure 9(e)). In addition, the number of people staying in the street is greatest in the order (1) > (2) > (3) for both weekdays and non-business days, but the difference is particularly noticeable on weekdays (Figure 9(f)).

The above results show that the provision of information on crowding in addition to location information, as in Assumption (3), could reduce crowding at temporary shelters in the city center and mitigate chaos by reducing indiscriminate travel.

Effect of Regularly Providing Information

The effect of providing information about shelters on a regular basis at places of work/study and via the Internet was analyzed. Simulations were performed separately under Assumptions (4) and (5) shown in Figure 10(a), and the results were compared with those under Assumption (3), in which information is provided only during the earthquake disaster (Figure 9(a)).

Looking at the level of crowding at shelters, crowding is greater under Assumptions (4) and (5) than under Assumption (3) because people who have acquired location information in advance are better able to reach a shelter (Figure 10(b)). Looking at the level of crowding by distance, it is evident that even in the region that shows a locally high value under Assumptions (3) and (4) (approximately 12 km from the city center), crowding is controlled to the same level as the surrounding area under Assumption (5) (Figure 10(c)).

(a) Assumption of providing information during an earthquake disaster

No.	Assumption of regularly providing information [*1]
(4)	Only position information is provided (It is assumed that everyone has information before an earthquake occurs)
(5)	Information on location and level of crowding is provided (Level of crowding after 720 minutes of temporary shelters in Assumption (3))

[*1] Assumption of providing information during the event is the same as Assumption (3)

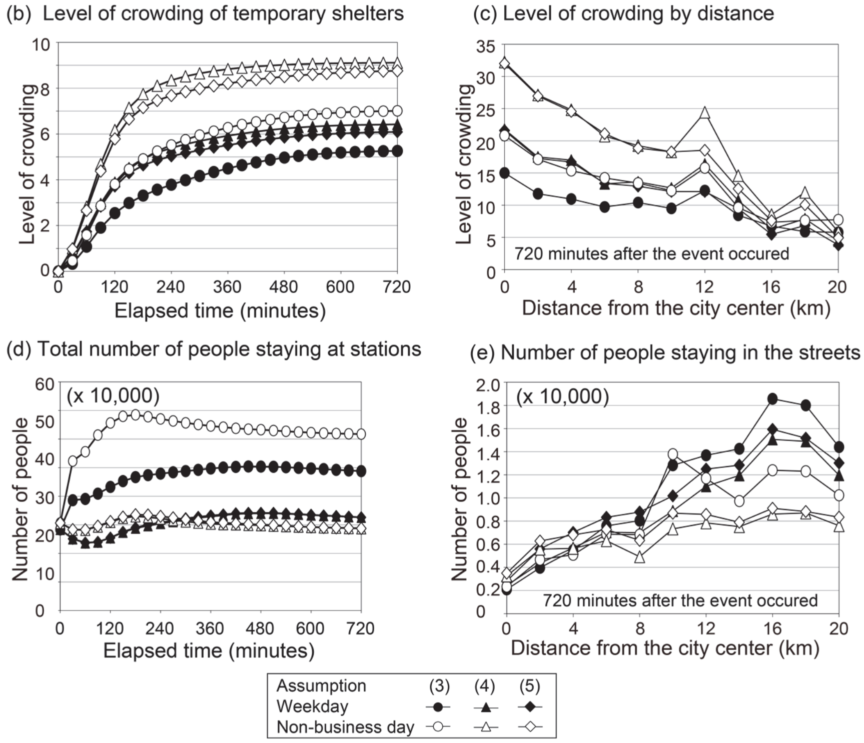


Figure 10. Effect of Regularly Providing Information

In contrast, looking at the number of people staying at train stations, crowding is greatly reduced under Assumptions (4) and (5) compared to Assumption (3) (Figure 10(d)). This is because, under Assumption (3), many people collect information at train stations, but under Assumptions (4) and (5) in which they have acquired location information in advance, people head directly to the shelters. In addition, looking at the number of people staying in the street by distance, the number is lower under Assumptions (4) and (5) compared to Assumption (3) approximately 10 to 20 km from the city center (Figure 10(e)).

The above results show that, although crowding of shelters would increase, providing information on the locations of shelters on a regular basis could reduce the number of people who are forced to stay in unsuitable places, such as in the street or at a train station. In addition, regularly providing information on the predicted level of crowding for each shelter could control imbalances in level of crowding between shelters.

ANALYSIS OF REDUCTION IN CROWDING AS A RESULT OF COLLABORATION WITH PRIVATE-SECTOR FACILITIES

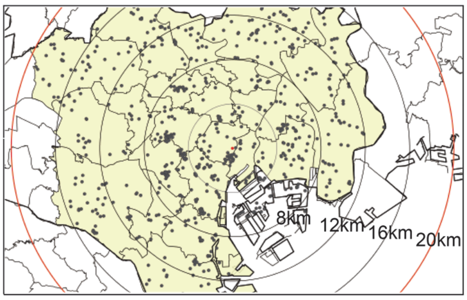
Method of Selecting Private-sector Facilities

During the Great East Japan Earthquake disaster, many private-sector facilities that were not designated as temporary shelters fulfilled the same function. In particular, accommodation facilities, large commercial facilities, and sports facilities took in many stranded people. Therefore, this study considered the effect of collaboration with private-sector facilities as a hard measure for reducing crowding. Specifically, the effect of private-sector facilities (20–100 facilities) within the 23 wards of the Tokyo Metropolis shown in Figure 11(a) taking in stranded people was examined. Three methods of selecting facilities were different in the following options: (i) arbitrary (regardless of crowding estimated by the simulation, facilities are chosen randomly from private-sector facilities whose building area is greater than 1,500 m^2), (ii) batch priority (facilities are all chosen at the same time with priority given to shelters with severe crowding estimated by the simulation), (iii) sequential priority (facilities are chosen in sequential order from shelters with severe crowding estimated by the simulation) (Figure 11(b)). The simulation was performed 10 times for each case, with 20 private-sector facilities added at a time. The earthquake was assumed to strike at 14:00 on a non-business day, which causes the most crowding of shelters, and information provision was taken to be as in Assumption (3) shown Figure 9(a).

(a) Outline of private-sector facilities and their spatial distribution

Facility Type	Number of facilities
Accommodation	109
Large commercial	433
Sports	146

- Building area of private-sector facility is greater than 1,500 m_2
- 5 people can stay for 100 m_2 of building area of each facility



(b) Method of Selecting Private-sector Facilities

(i)	Arbitrary (facilities are chosen randomly regardless of crowding)
(ii)	Batch priority (facilities are chosen at the same time according to severe crowding)
(iii)	Sequential priority (facilities are chosen in sequential order from shelters with severe crowding)

Figure 11. Outline of Private-sector Facilities

Comparison of Selection Method

Looking at the level of crowding of shelters according to number of private-sector facilities and the selection method, the difference according to the selection method is small, but crowding is lowest using Method (ii) (batch priority) (Figure 12(a)). Looking at the level of crowding of shelters by distance, crowding is lowest using Method (ii) (batch priority) until approximately 6 km from the city center, and beyond that, the difference according to the selection method is small (Figure 12(b)). Looking at the spatial distribution, compared to no private-sector facilities, both Method (ii) (batch priority) and Method (iii) (sequential priority) reduce the levels of crowding of shelters in the city center (Figure 12(c)).

However, the mean level of crowding of collaborating private-sector facilities increases in the order (i) < (ii) < (iii) (Figure 13(a)). Looking at the level of crowding by distance zone, crowding in the city center is lowest using Method (i) (arbitrary) and Method (ii) (batch priority) (Figure 13(b)), but looking at the spatial distribution, it is evident that there are facilities with extremely high levels of crowding on the outskirts of the city (Figure 13(c)). In contrast, using Method (iii) (sequential priority), there are few private-sector facilities with markedly high levels of crowding.

The above results show that the method of selection of private-sector facilities that is effective in reducing crowding of shelters may differ depending on the location. Specifically, Method (ii) (batch priority) is capable of effectively reducing levels of crowding of shelters in the city center, whereas while Method (iii) (sequential priority) is capable of stably reducing levels of crowding of shelters on the outskirts and therefore less likely to cause severe crowding of private-sector facilities. This implies that it could be more effective to select and request the collaboration of private-sector facilities using Methods (ii) and (iii) separately for the city center and the outskirts, respectively.

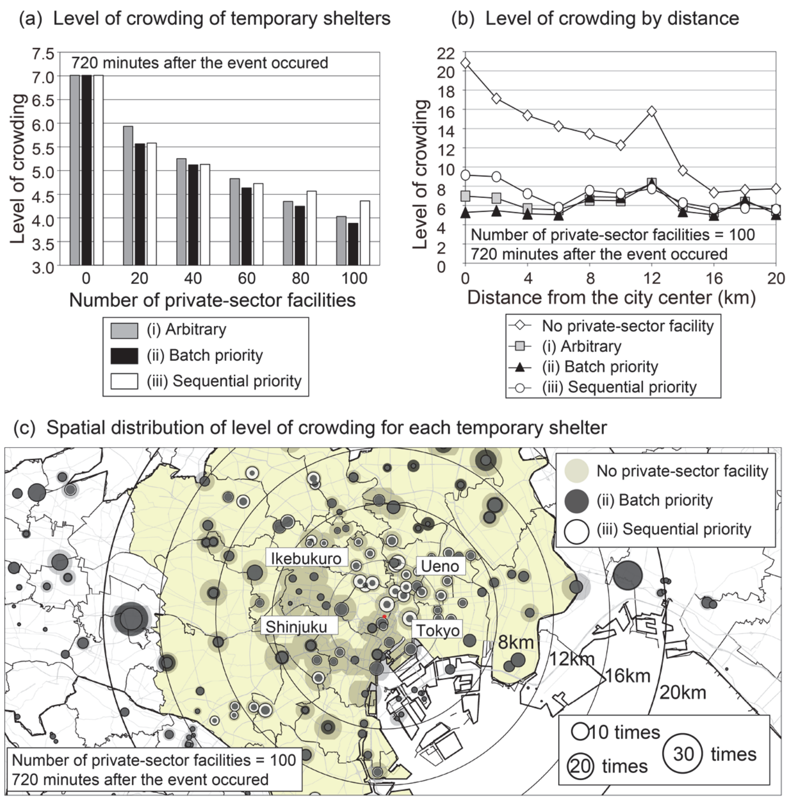


Figure 12. Cooperative Effect of Private-sector Facilities

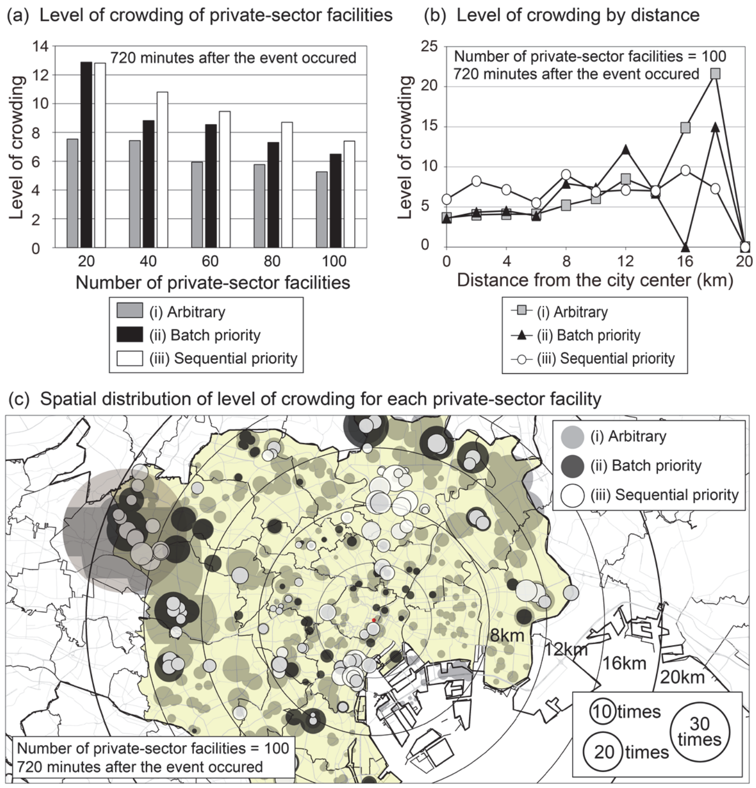


Figure 13. Level of Crowding by Cooperating Private-sector Facilities

SUMMARY AND CONCLUSIONS

In this study, the travel behavior of people in Tokyo after a large earthquake was modeled, and the levels of crowding of facilities for people who have difficulty returning home were estimated by performing simulations of people traveling on foot. The results showed that temporary shelters become most crowded when the earthquake strikes at 14:00 on a non-business day, a time at which there are many people (eating and shopping) in the city center with nowhere to shelter after the quake. The results also showed that support stations for people trying to return home become crowded when the earthquake occurs at 14:00 on a weekday, an occurrence time that generates a large numbers of walkers. The number of people staying at train stations is highest when the earthquake occurs at 8:00 on a weekday, a time at which many people are commuting to work or school. It was also found that, when the earthquake occurs at 14:00 on a weekday, many people stay in the street on the arterial roads leading in various directions from the city center (segments beyond 8 km from the city center).

Next, the effect of reducing crowding by providing people with information was analyzed. Shelters are likely to become more crowded as a result of providing people with information on the location of the shelters, whether the information is provided at the time of the earthquake or on a regular basis. On the other hand, the number of people having to spend a night at a train station or in the street is likely to be reduced. In addition, if information on crowding can be provided in real time after the earthquake, it may be possible to control rises in crowding at shelters. Further, by regularly providing information on predicted level of crowding, it may be possible to control imbalances in level of crowding between shelters.

Finally, the study analyzed the effect of reducing crowding through collaboration with private-sector facilities (opening up of facilities). The results of examining methods of selecting private-sector facilities for collaboration showed that, in the city center, it is effective to select private-sector facilities in the vicinity of shelters that are predicted to become crowded. However, on the outskirts of the city center, it is possible that private-sector facilities will become extremely crowded, and so it is preferable to perform multiple selections while checking crowding at private-sector facilities using sequential simulations.

The simulation models developed in this research can provide detailed information about the facilities to be congested and where people are most likely to strand. The civil protection authorities can use this information for increasing the capacity of the critical facilities or setting-up emergency check-points or mobile assistance.

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