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Method for Extracting Vulnerable Accessibility Roadside Areas after a Large Earthquake

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Abstract—
In order to reduce human casualty after a large earthquake, it is important to secure the smooth and rapid activities of emergency vehicles (e.g., ambulance services). However, there is a risk that road blockages will obstruct emergency activities and lead to the secondary damage. In this paper, we propose new accessibility indices to evaluate the accessibility to base facilities after a large earthquake. Moreover, performing the simulation that we have previously constructed, we extract the vulnerable roadside areas with poor accessibility to disaster base hospitals in Tokyo Metropolitan. Finally, we discuss the effective countermeasures to improve the accessibility indices.

I. Introduction

As it is predicted that there is a 70% possibility of an earthquake directly hitting Tokyo metropolitan within the next 30 years, it is an urgent issue to ensure the traffic function of emergency transportation roads (hereafter called "ETR"), which is an important infrastructure that supports emergency activities at the time of a large earthquake (e.g., transportation of disaster relief supplies, firefighting activities, ambulance services, etc.). In previous paper, we discussed about the transportation function of ETR after a large earthquake by evaluating the accessibility of ETR and the effects of quake-resistant-conversion of roadside buildings (Osaragi and Kishimoto, 2019). In this paper, we propose the method for extracting vulnerable accessibility roadside areas, which have high possibility to hinder emergency activities after a large earthquake.

II. Estimation Method of The Accessibility Indicies

A. Definition of Accessibility Indices

To extract the vulnerable roadside areas with poor accessibility, we propose novel indices, Link Isolation ratio (hereafter called "LI ratio", (1)) and Network Isolation ratio (hereafter called "NI ratio", (2)). LI ratio is the index to evaluate the accessibility to base facilities by road scale; NI ratio is the index to evaluate the accessibility to base facilities by regional scale.

$$\mathrm{LI}(j,d) = 1 - \frac{\sum_{k\in K}\delta(k,j,d)}{K}, \qquad (1)$$

$$\mathrm{NI}(d) = 1 - \frac{\sum_{k}^{K}\left(\sum_{j\in R_A} l(k,j) / \sum_{j\in R_A} L(j)\right)}{K}, \qquad (2)$$

where K is the number of simulation run, $\delta(k,j,d)$ is the arrival status at the k-th time with a value of 1 when emergency vehicle can access to base facilities from link j at the k-th time and 0 when not, R_A is the set of link in Region A, L_j is the length of link j (m), and $l(k,j)$ is the passable length of link j at the k-th time (m).

B. Overview of Emergency Activity Simulation Model

To evaluate the accessibility to base facilities, it is necessary to estimate the movements of emergency vehicles at the time of a large earthquake. We improve a simulation model, which we had previously constructed. This simulation model is consist of the following two sub-models.

1) *Property Collapse Model*: We estimate the property collapse—building collapse and street blockage—using models proposed by Murao and Yamazaki (2000) and Ministry of Land, Infrastructure and Transport (2003).

2) *Emergency Behaviour Model*: We describe the emergency behaviour of each vehicle (e.g., ambulance service). We assume that emergency vehicles know the street network and the location on street blockages initially and choose the time-dependent shortest route to a destination. Emergency vehicles are also presumed to be trapped in a street if there are no routes to a destination.

III. Accessibility Assessment to Disaster Base Hospitals in Tokyo Metropolitan Area

A. Study Area and Assumptions in Simulations

Performing the emergency activity simulation model, we evaluate the accessibility to disaster base hospitals (total 80 bases) using ETR in Tokyo metropolitan (Figure I). We assume that the medical relief activities are conducted at disaster base hospitals in the corresponding secondary healthcare service areas (Figure 1, ①-⑫). We examine the simulation results with the accessibility indices, LI ratio and NI ratio.

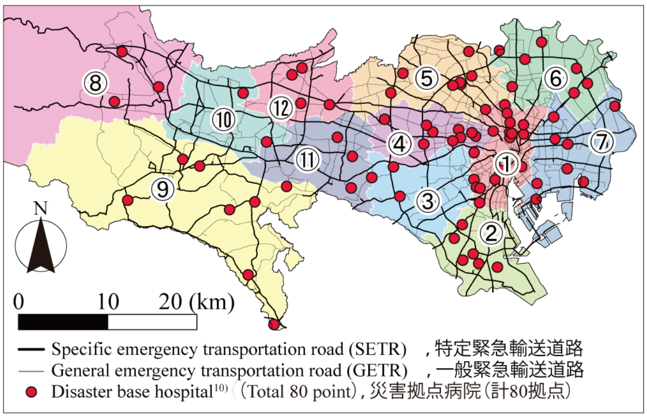


FIGURE I Spatial Distributions of Secondary Healthcare Service Area and Disaster Base Hospital

B. Spatial Distribution of Road Blockage Risk

Figure II shows the spatial distribution of road blockage ratio—the ratio of the number of times road blocked to total number of simulation runs—. There are road-links with high road blockage ratio in Arakawa-ku, Taitou-*ku*, and the west side of 23 special wards (Area I). However, since Tokyo metropolitan government has designated wider street as ETR, its value of road blockage ratio tends to be low.

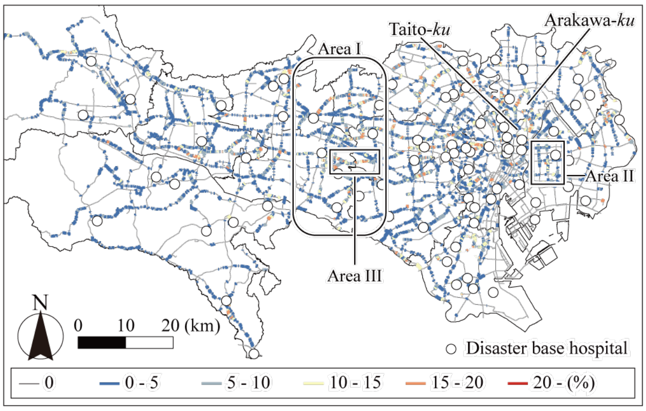


FIGURE II
SPATIAL DISTRIBUTION OF ROAD BLOCKAGE RATIO

C. Spatial Distribution of Link Isolation Ratio

Figure III shows the spatial distribution of LI ratio—the impossibility of an emergency vehicle can access to any disaster base hospital—. From the spatial distribution of the LI ratio, we can grasp vulnerable roadside areas with poor accessibility to disaster base hospitals. For instance, isolated links tend to occur over a wide area range in an area with sparse road network (Figure III, Area III). In those roadside areas , it is possible that patients may not be able to receive medical relief activities.

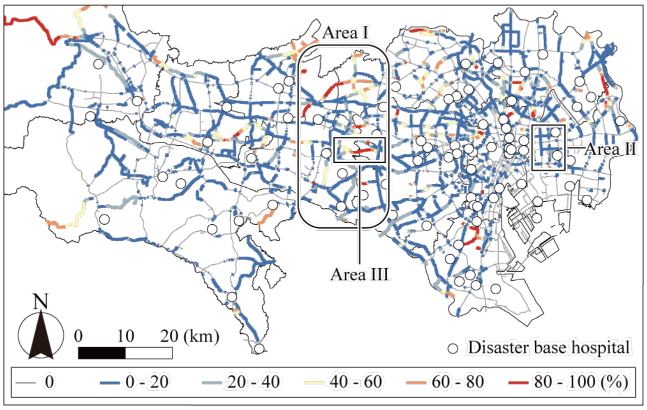
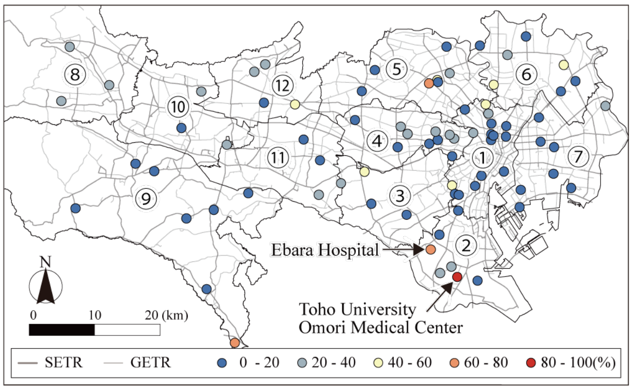


FIGURE III
SPATIAL DISTRIBUTION OF LI RATIO

D. Network Isolation Ratio of Disaster Base Hospital

Figure IV(a) shows the spatial distribution of NI ratio of each disaster base hospital—the ratio of the total length of road links, which is unreachable to the disaster base hospital, to total length of road links—. NI ratios exceeds 50.0% at 7 disaster base hospitals (Figure IV(b)). In the secondary healthcare service areas with those hospitals, there is a high possibility that the medical relief function is biased toward hospitals with high accessibility. Therefore, there is an urgent need to consider the countermeasures to improve NI ratios of those areas (e.g., quake-resistant-conversion of buildings around disaster base hospitals or road links with high LI ratios).



(a) Spatial distribution of NI ratio of each disaster base hospitals

No.	Hospital name	NI ratio
1	Toho University Omori Medical Center	93.9%
2	Ebara Hospital	78.7%
3	Nihon University Itabashi Hospital	70.1%
4	Minami Machida Hospital	61.9%
5	Tokyo Women's Medical University Medical Center East	58.7%
6	Tokyo Metropolitan Komagome Hospital	57.6%
7	Sassa General Hospital	54.1%
8	Tokyo Metropolitan Matsuzawa Hospital	49.9%
9	Toshima Hospital	46.5%
10	Tobu Chiiki Hospital	44.7%

(b) List of disaster base hospital (The bottom 10 hospitals of NI ratio)

FIGURE IV
SPATIAL DISTRIBUTION OF NI RATIO OF EACH DISASTER BASE HOSPITALS

IV. SUMMARY AND CONCLUSION

In this paper, we proposed the method for extracting vulnerable accessibility roadside areas, which have high possibility to hinder emergency activities after a large earthquake. First, we proposed the accessibility indices; Link Isolation ratio (LI ratio) and Network Isolation ratio (NI ratio). Then, performing the emergency activity simulation we have constructed, we evaluated the damage of each building/street and calculated the accessibility indices in Tokyo Metropolitan Area. From the LI ratio, we can grasp vulnerable roadside areas with poor accessibility to disaster base hospitals; From the NI ratio, we can grasp the secondary healthcare service areas with a high possibility that the medical relief function is biased toward certain hospitals.

ACKNOWLEDGMENT

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