https://doi.org/10.20965/jdr.2020.p0520

Paper:

Traffic Impacts of On-Street Parking Cars on Secondary North-South Streets in Downtown Yangon

Yudai Honma† and Kimiro Meguro

The University of Tokyo
4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan
† Corresponding author, E-mail: yudai@iis.u-tokyo.ac.jp
[Received November 28, 2019; accepted March 24, 2020]

The downtown area in Yangon city, Myanmar, frequently experiences heavy traffic; one of the reasons is rampant illegal parking of cars on the streets. It has been pointed out in several studies that this area would be severely affected when a disaster occurs, and hence it is essential to clarify the effect of such undesirable parking behavior on the reduction in capacity of the Yangon road network. The purpose of this research is to illustrate the unfavorable traffic conditions that would result from on-street parking in downtown Yangon. We studied the mathematical relationship between travel distance and flow volume, and clarified the following mechanism. (i) On-street parking reduces the speed of vehicles on the streets. (ii) The unbalance of speed causes deviation of the shortest-time route from the shortest-distance route. (iii) An increase in total travel distance results in an increase in flow volume. We have also presented numerical results based on the detailed GIS data for downtown Yangon, and examined two scenarios that describe both evacuation and normal-life situations.

Keywords: downtown Yangon, on-street parking car, deviation, shortest-distance, shortest-time

1. Introduction

Several traffic congestions occur all over the world, and they are the major elements that reduce the capacity of road networks. Traffic congestions occur because of various reasons associated with the properties of road networks, such as narrow road width, steep slope, long tunnel, and unfavorable network topology. It is inevitable that human factors can also cause traffic congestions. One of the factors is unfavorable driving behavior; if many drivers do not follow the traffic signal, the throughput of vehicles at the intersections would be reduced.

Yangon city, Myanmar, has a large road network that carries heavy traffic. Notably, the downtown area in Yangon city always suffers from heavy traffic, and it takes a long time to move within the area. The road network in the downtown area is a typical grid-like network with hierarchical road types, and it is difficult to move smoothly on the narrow secondary streets. As shown in **Fig. 1**, the main reason is rampant illegal parking of cars on the streets by road users.

Fig. 1. Street parking cars in downtown, Yangon.

In several studies, it has been pointed out that the downtown area of Yangon would be severely affected when a disaster occurs. For example, Tint et al. presented a liquefaction map in Yangon when an earthquake occurs, and the downtown area was categorized as a high-potential zone [1]. Bhattacharya et al. analyzed the land-use risks in case of emergency and disaster, and the downtown area was classified as a high-risk zone [2]. If such a serious phenomenon occurs, the residents in the downtown area will have to evacuate, but the cars parked on the streets would become major obstacles for movement. On-street parking reduces the link capacity of the streets and reduces the travel speed on the secondary streets. This serious phenomenon will affect not only the evacuation process, but also the normal life. It is essential to clarify the effect of such undesirable parking behavior on the reduction in capacity of the Yangon road network.

Several earlier studies have focused on disaster management of transportation networks. Literature reviews on this topic can be found in the work by Hoyos et al. [3] and Zheng et al. [4]. As discussed in these studies, the operations research field has effectively tackled the transportation network issues related to disaster management. Designing of networks is an important topic related to this issue. The emergency transportation network design problem can be treated as an integer programming problem to identify the optimal emergency transportation network. Nikko et al. [5] presented a three-objective problem on this topic. The transportation protection problem identifies the optimal links and routes to preserve the network performance after the disaster that caused capacity degradation [6].

Performance metrics to evaluate the effects of a disaster on the transportation network is another important topic. Though there are several measures to analyze the effects of a disaster, such as vulnerability, flexibility, and robustness [7], they normally consist of a combination of basic network parameters, such as connectivity, travel distance, travel time, flow volume, and OD demands [8]. Therefore, in this study, we consider travel distance, travel time, and flow volume as the major factors, and analyze the theoretical relationship between the factors; numerical examples related to traffic situations in the downtown, Yangon are also presented.

It may be noted that travel distance and flow volume have a clear theoretical relationship [9]. As the travel distances in an area increase, the flow volumes also increase; this is normal, because both changes indicate an increase in traffic flow. Several earlier studies have focused on distances and/or flow volumes on road networks [10–13]. For example, Fujita and Suzuki focused on an idealized circular-radial network, and analytically derived both the average distance and flow volume [14]. In some other studies, other types of networks have been considered. One example of a grid network is reported by Koshizuka [15], and an analysis based on Euclidian distance was conducted by Ghosh [16]. Furthermore, Kurita assumed a circular disk city and compared several types of idealized road patterns [17]. Similarly, Ukai and Toriumi defined n-directional distance and theoretically analyzed the distance distribution in a circular region [18]. Further, some studies focused on the relationship between road distance and Euclidian distance [19]. Miyagawa has assumed hierarchical road networks in his studies [20].

The purpose of this research is to illustrate the unfavorable traffic conditions that would result from on-street parking in downtown Yangon. We focus on both distance and flow volume on the road network in downtown Yangon. We assume hierarchical structure of the road network, and consider the difference in travel speeds in arterial streets and secondary streets. Then, we calculate both the distance for the shortest-time route and the time taken for the shortest-distance route with various speed settings. We approximately incorporate the reduction in link capacity based on the decrease in speed; in other words, each speed corresponds to the extent of on-street parking. To consider both evacuation and normal-life scenarios, we prepare two different OD patterns. The calculations show that unfavorable driving behavior increases as the speeds in the secondary roads decrease. The results show an increase in travel time based on the time taken for the shortest-distance routes. Thus, it is clear that the presence of cars parked on secondary streets would lead to a significant reduction in the network capacity in downtown Yangon.

In actual situations, the travel speed of each link is endogenously determined by the flow volume on the link. The well-known BPR function [21] is used to express such a relationship, and the equilibrium assignment model is a sophisticated method to describe the situation [22]. In this research, though link capacity and flow volume are the main issues, we introduce a more straightforward approach. The travel speed of each link is exogenously determined, and it is assumed that people use the shortest path. There are two important reasons for adopting a simple mathematical model. First, the data accuracy in calculating the equilibrium assignment model is insufficient. The detailed personal trip data in Yangon city is not open to public, and hence we cannot obtain the data on OD demands at the required level to adopt the equilibrium assignment model. Even the BPR function depends on the region, and the calibration of the parameters in a developing country is a challenging issue [21]. If the equilibrium assignment model is applied using many uncertain parameters, the result would be distorted. Secondly, and more important reason is for the real readers of this research. While the equilibrium assignment model can make predictions when more data and parameters are used, it is uncertain whether the local residents of Yangon can understand the model. Through the results of this research work, we should notify the Yangon residents of the disadvantage of parking illegally on the streets. To convince them, instead of presenting only the result, it would be better to explain the mechanism related to the phenomenon also. We are confident that our mathematical expressions can be broadly accepted by Yangon residents; this is another important purpose of this study.

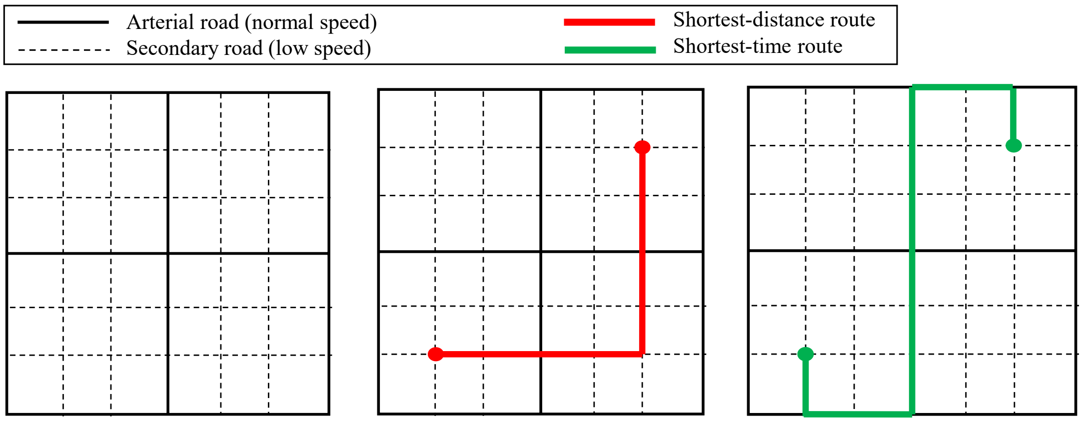
The contents of this paper are as follows. In Section 2, we state the basic concepts of this study and formulate mathematical models for the shortest-time route and the shortest-distance route. We discuss the inequality relationship between the two routes theoretically. In Section 3, we present the numerical results based on the detailed GIS data for downtown Yangon. In particular, we prepare two patterns of OD demands to describe both evacuation and normal-life situations. In Section 4, we conclude the study and summarize the mechanism of impact on traffic based on two simple mathematical expressions.

2. Formulation

In this section, we describe the basic concepts of this study. In particular, we formulate two types of routing behaviors in road networks and state the difference between them.

2.1. Basic Concepts

The downtown area of Yangon city can be regarded as a typical grid network. In the grid network, the route that connects two points with the shortest-distance is simple.



(a) Hierarchical grid network (b) Shortest-distance route (c) Shortest-time route

Fig. 2. Shortest-distance route and shortest-time route in a hierarchical grid network.

Normally, it consists of two-directional and orthogonalized movements with only a few turnings, as shown in **Fig. 2(b)**. Notably, even if we assume a hierarchical grid network as shown in **Fig. 2(a)**, the characteristics of the shortest-distance route is still simple.

Conversely, the route that connects the origin and the destination in the shortest-time is more complicated. As it is closely related to the travel speed of each link, it becomes important in a hierarchical grid network. As shown in **Fig. 2(c)**, this route also consists of two-directional and orthogonalized movements, but the number of turns is more.

It may be noted that these two routes are different, and that the difference increases when the travel speed of each link is different, as in the hierarchical road network. The shortest-distance route is not the shortest in terms of time. Likewise, the shortest-time route is not the shortest in terms of distance. Thus, we cannot simultaneously optimize both time and distance. In the following subsection, we formulate these phenomena and examine the unfavorable influences on the road networks. Hereafter, we abbreviate the shortest-distance route as the SD route and the shortest-time route as the ST route.

2.2. Mathematical Models

Let us suppose a directed graph $G(N,E)$ as a road network, where N is a set of nodes, and E is a set of links. We denote each link as $e \in E$, the travel-distance of link e as d_e, and the travel time of link e as t_e.

A mathematical problem for solving the SD route from origin $o \in N$ to destination $d \in N$ is defined by the following equations.

$$\text{min.} \sum_{e \in E} d_e x_e^{\text{SD}} \quad \text{(1)}$$

$$\text{s.t.} \sum_{I(i)} x_e^{\text{SD}} - \sum_{O(i)} x_e^{\text{SD}} = \begin{cases} -1 & (i = o) \\ 0 & \forall i \in N \setminus \{o,d\} \\ -1 & (i = d) \end{cases} \quad \text{(2)}$$

$$x_e^{\text{SD}} = \{0,1\} \quad \forall i \in N \quad \text{(3)}$$

where $x_e^{\text{SD}} = 1$ if link e is used as a part of the SD route, and 0 otherwise. Furthermore, $I(i)$ is a set of inflow links of node i, and $O(i)$ is a set of outflow links of node i.

Expression (1) is the objective function, and it calculates the distance of the route. Expression (2) shows the flow constraints, and it ensures route connectivity. Expression (3) shows the constraints for variables 0 and 1.

Similarly, the following equations define the problem for solving the ST route from origin $o \in N$ to destination $d \in N$.

$$\text{min.} \sum_{e \in E} t_e x_e^{\text{ST}} \quad \text{(4)}$$

$$\text{s.t.} \sum_{I(i)} x_e^{\text{ST}} - \sum_{O(i)} x_e^{\text{ST}} = \begin{cases} -1 & (i = o) \\ 0 & \forall i \in N \setminus \{o,d\} \\ -1 & (i = d) \end{cases} \quad \text{(5)}$$

$$x_e^{\text{ST}} = \{0,1\} \quad \forall i \in N \quad \text{(6)}$$

where $x_e^{\text{ST}} = 1$ if link e is used as a part of the ST route, and 0 otherwise.

2.3. Relationship Between SD and ST Routes

It may be noted that the shortest route under any condition does not pass through the same link twice. Therefore, we can express both the SD route and ST route as a set of links as given below.

$$R_{od}^{\text{SD}} = \left\{ e \middle| \forall e \in E,\ x_e^{\text{SD}} = 1 \text{ for OD pair}(o,d) \right\} \quad \text{(7)}$$

$$R_{od}^{\text{ST}} = \left\{ e \middle| \forall e \in E,\ x_e^{\text{ST}} = 1 \text{ for OD pair}(o,d) \right\} . \quad \text{(8)}$$

In addition, we define a function to calculate the total distance and time as functions of route R_{od} as follows.

$$Distance\left(R_{od}\right) = \sum_{e \in R_{od}} d_e x_e \quad \text{(9)}$$

$$Time\left(R_{od}\right) = \sum_{e \in R_{od}} t_e x_e \quad \text{(10)}$$

Now, we obtain two inequalities which are important in this study:

$$Distance\left(R_{od}^{ST}\right) \geq Distance\left(R_{od}^{SD}\right) \quad \text{(11)}$$

$$Time\left(R_{od}^{ST}\right) \leq Time\left(R_{od}^{SD}\right) \quad \ldots\ldots\ldots (12)$$

Expression (11) indicates a situation that can occur in real life. In general, people tend to use the ST route than the SD route, because they can empirically recognize the travel speed of each link. Thus, the above expression indicates that people need to travel more distance than the distance corresponding to the SD route. Such a deviation from the SD route increases the traffic volume. Expression (12) corresponds to another scenario in which people single-mindedly use the SD route. In this case, people are obliged to bear more travel time than the time taken for the ST route.

2.4. Relationship Between Travel-Distance and Flow Volume

At the end of the mathematical section, we summarize here a theoretical relationship between the travel distance and the flow volume. The following formula gives the relationship between the total distance and total time.

$$\sum_{od} Distance\left(R_{od}\right) = \sum_{e \in E} d_e Flow\left(e\right) = T \quad \ldots (13)$$

where $Flow(e)$ is the aggregated flow volume of link e, and T indicates the total traffic volume in the region. The continuous version of this formula was introduced by Koshizuka [9].

The left side of the above inequality shows the total travel distance, and the right side shows the total flow volume. In other words, this formula shows how the total amount of traffic can be defined using the travel distance and flow volume. In addition, using this formula, we can prove that the flow volume in the region will increase if the travel distance in the region increases. However, the formula does not consider the travel time because it covers only physical movements. It shows the importance of focusing not only on travel time but also on travel distance.

The discussions in Sections 2.2–2.4 are valid in any normal road network. In the next section, we numerically examine the additional burden that would be created in downtown Yangon.

3. Numerical Results Based on GIS Data for Downtown Yangon

In this section, we present the numerical results based on detailed GIS data for downtown Yangon.

3.1. Network and Demand Data

The road network we used for the downtown area of Yangon is shown in **Fig. 3**. It shows a typical grid-like network, but the efficiencies in west-east movement and north-south movement are very different. It may be noted that there are many narrow and secondary north-south streets that are not recorded in our GIS Data (only recorded roads are illustrated in **Fig. 3**). As the spans of the arterial north-south streets are long, these secondary roads are frequently used to help the north-south movement. However, several cars are parked on the secondary roads, and the travel speed on these roads is very low. The span of the arterial west-east streets is relatively short, and there are no secondary streets. As a result, the ST and SD routes often become very different. Examples of the ST and SD routes in downtown Yangon are also shown in **Fig. 3**. It can be seen that the SD route uses more secondary streets, and the ST route involves deviations.

In this numerical example, we prepared the following two scenarios: evacuation scenario and normal-life scenario. In the evacuation scenario, we regarded the exact locations of buildings as the origin points. When people evacuate from downtown, they have to evacuate to the north side, because the other three sides of the downtown area are surrounded by rivers. Therefore, in this scenario, we defined seven main intersections connected to the outer regions as evacuation points, and assumed that people evacuate to the nearest evacuation point. The location of the buildings and evacuation points are shown in **Fig. 4**. In the evacuation scenario, there are 5,558 buildings in total, and thus the total number of OD patterns is 5,558.

It is also important to analyze the effect of cars parked on the streets on the normal movements within the downtown, and hence we prepared a scenario to describe the normal-life condition. In this scenario, we regarded all 5,558 buildings as both origin and destination (OD) points and considered all combinations of movements. In the normal-life scenario, the total number of OD patterns is $(5{,}558 \times 5{,}557)/2 = 15{,}442{,}903$.

In both scenarios, to describe the movement using secondary north-south streets, we assume that each OD point can vertically access the nearest arterial west-east streets, as shown in **Fig. 5**. Thus, the movements are idealized, but it can be considered that it simulates the real-life situations well.

We performed calculations for both ST routes and SD routes for all the pairs. For the arterial roads, we assume that the travel speed is $v_1 = 20$ km/h. To examine the impact of slowing down in the secondary north-south streets because of the cars parked on the streets, we prepared the following six cases, i.e., $v_2 = \{20, 10, 8, 6, 4, 2, 1\}$ km/h.

3.2. Results Based on the Route for the Shortest Time

First, we discuss the results based on the route for the shortest time.

Figures 6 and **7** show the results corresponding to the OD pattern for the evacuation scenario. **Fig. 6** shows the distribution of distance for the ST route at various speeds (v_2). Similarly, **Fig. 7** shows the aggregated flow volumes on the network. It can be seen that the distance distribution has a longer tail as the speed on the secondary roads decreases (see **Figs. 6(b)** and **(c)**). At the same time, the central part of the distribution does not change by a large amount. This implies that the deviation would not be very long for many people, but some people will have very

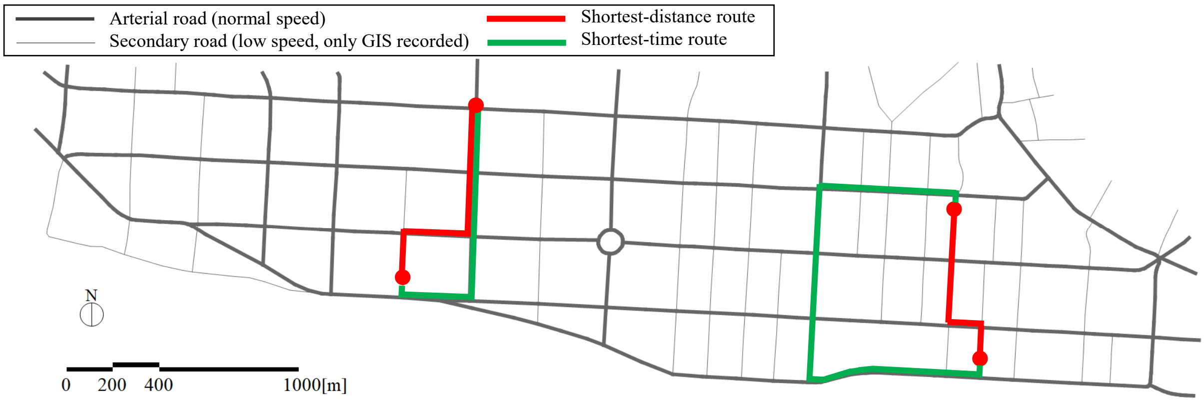


Fig. 3. Example of shortest-distance route and shortest-time route in the downtown, Yangon (Case of $v_2 = 4$ km/h).

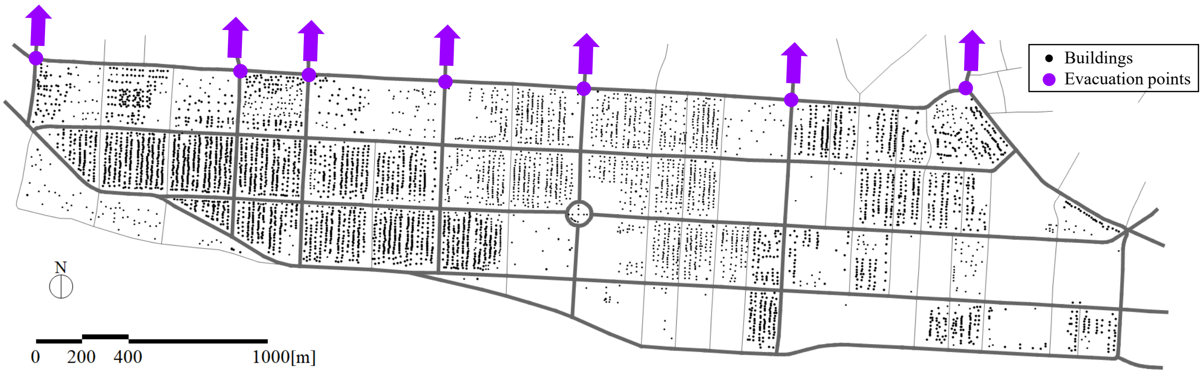


Fig. 4. Locations of buildings (OD points) and evacuation points in downtown area.

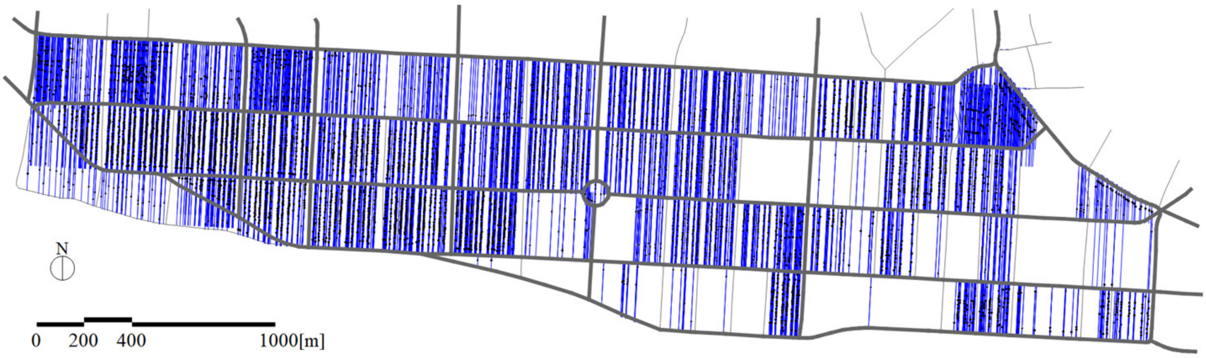
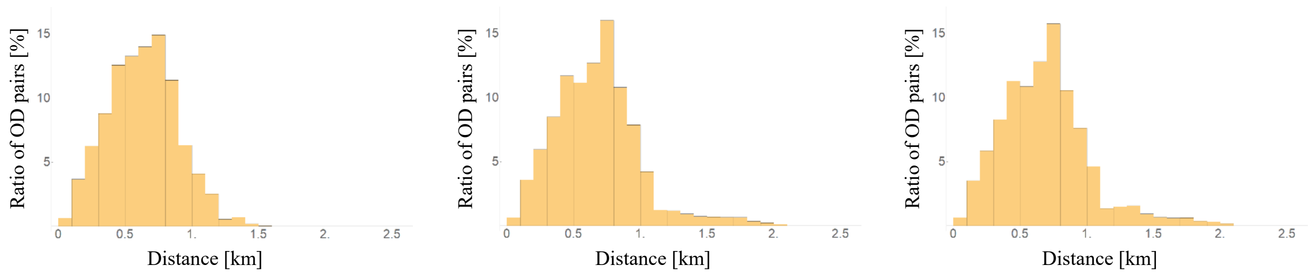


Fig. 5. Idealized access to arterial west-east streets.

long detours.

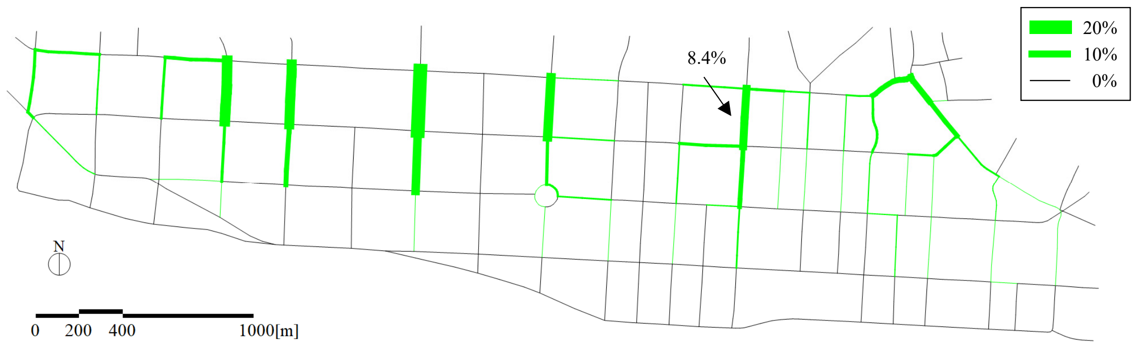
The impact on the flow volume is very drastic. As people are expected to evacuate to the north side, the north-south arterial roads that connect to the evacuation points are highly used. The flow volume on the street that connects to the second evacuation point from east has more than doubled; it is only 8.4% in **Fig. 7(a)**, but 17.7% in **Fig. 7(b)**, and 19.1% in **Fig. 7(c)**. This is understandable, because people could use the secondary roads for the north-south movement when $v_2 = 20$ km/h, but would not use them when v_2 decreased. In fact, the street we focused on is the only arterial road that exists in the east part of the downtown region. In contrast, more than three arterial streets exist in the west part, and hence their flow volumes have not changed as much as in the east part. Thus, we can conclude that the slowing down of the vehicles by the cars parked on the secondary street would severely affect evacuation from the east part of the downtown area.

Next, we discuss the result based on the OD pattern of the normal-life scenario. **Fig. 8** shows the distance distribution of the shortest time route at various speeds of v_2. Similarly, **Fig. 9** shows aggregated flow volumes on the networks. The distance distribution generally shifts to the

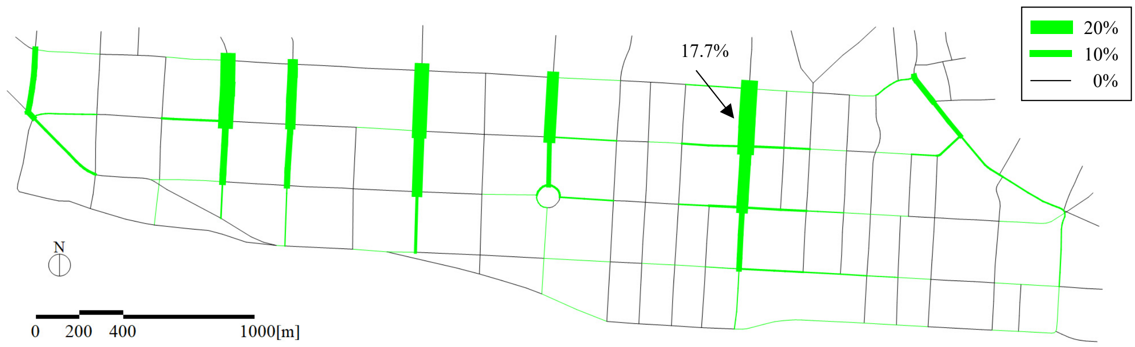


(a) Case of $v_2 = 20$ km/h (b) Case of $v_2 = 4$ km/h (c) Case of $v_2 = 1$ km/h

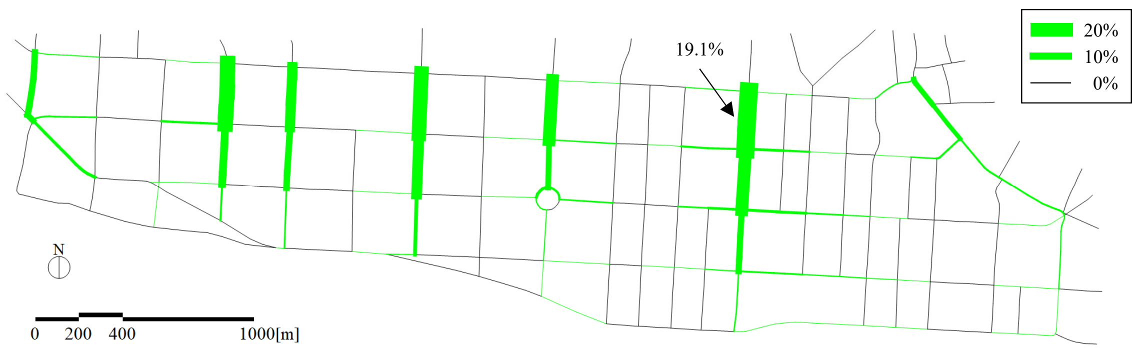
Fig. 6. Distance distributions in various cases for the ST routes (evacuation scenario, $v_1 = 20$ km/h).



(a) Case of $v_2 = 20$ km/h



(b) Case of $v_2 = 4$ km/h

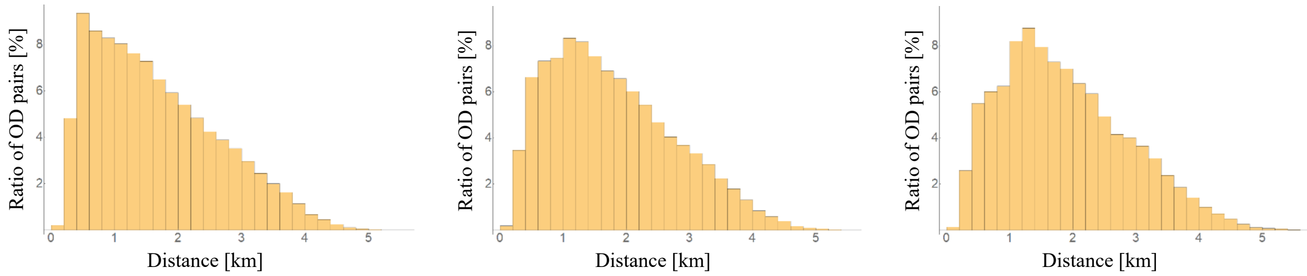


(c) Case of $v_2 = 1$ km/h

Fig. 7. Aggregated flow volumes in various cases regarding the ST routes (evacuation scenario, $v_1 = 20$ km/h).

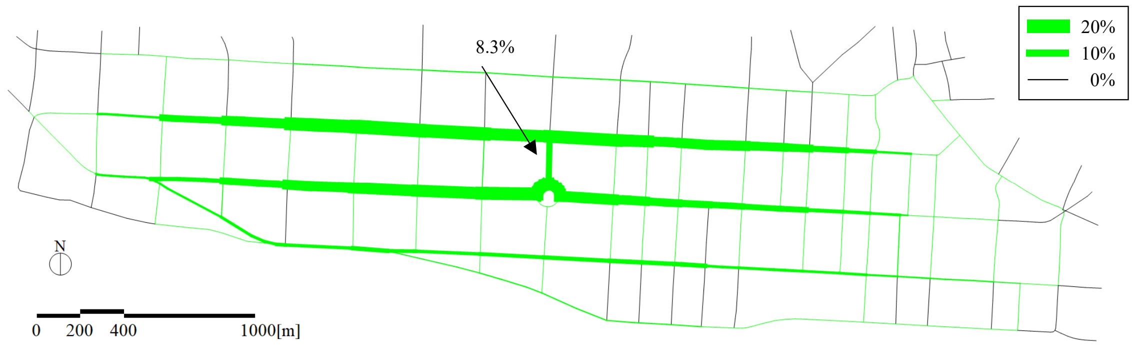
right, and its characteristic is different from that of the evacuation scenario. The reason is apparent that all OD patterns have to use secondary roads twice for both access and egress.

Next, we discuss the results based on the OD pattern for the normal-life scenario. **Fig. 8** shows the distance distribution in the ST route at various speeds (v_2). Similarly, **Fig. 9** shows the aggregated flow volumes on the network. The distance distribution generally shifts to the right, and its characteristic is different from that in the

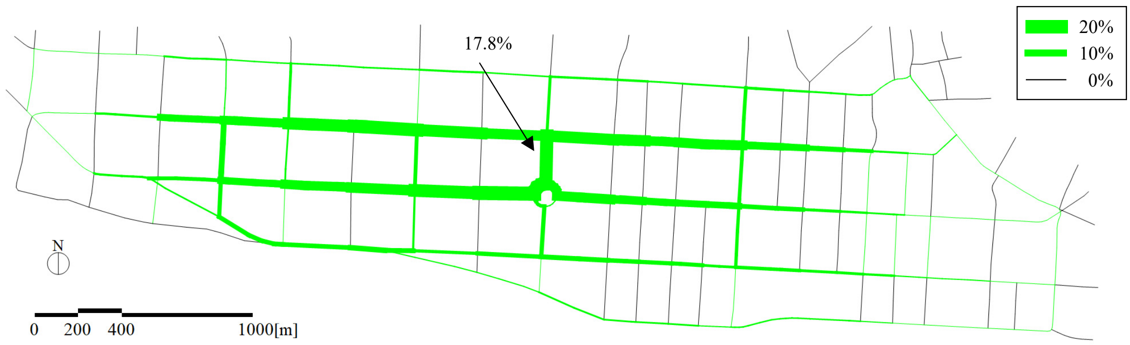


(a) Case of $v_2 = 20$ km/h (b) Case of $v_2 = 4$ km/h (c) Case of $v_2 = 1$ km/h

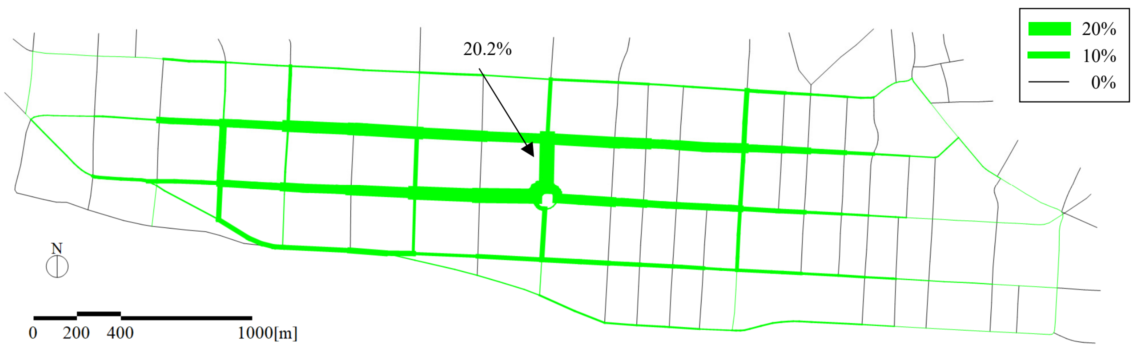
Fig. 8. Distance distributions in various cases for the ST routes (normal-life scenario, $v_1 = 20$ km/h).



(a) Case of $v_2 = 20$ km/h



(b) Case of $v_2 = 4$ km/h



(c) Case of $v_2 = 1$ km/h

Fig. 9. Aggregated flow volumes in various cases regarding the ST routes (normal-life scenario, $v_1 = 20$ km/h).

case of the evacuation scenario. This is because all OD patterns have to use the secondary roads twice for both access and egress.

The impact on flow volume is also of interest. It is known that the ST route is equivalent to the SD route when all the link speeds are the same ($v_1 = v_2 = 20$ km/h). **Figs. 8** and **9(a)** show the minimum case for both travel distance and flow volume (refer the theoretical relationship between travel distance and flow volume, given earlier). As shown in **Figs. 8**, **9(b)**, and **(c)**, both travel dis-

Table 1. Statistics of travel distance, traffic amount and travel time (evacuation scenario).

Speed [km]	Travel distance of ST route [m]				T of ST route [$\times$ 10^6 people·m]		Travel time of SD route [min]			
	Min.	Median	Ave.	Max.	T1	T2	Min.	Median	Ave.	Max.
$v_2 = 20$	44	636	633	1,513	2.28	1.40	0.13	1.81	1.80	4.54
$v_2 = 10$	44	652	655	2,006	2.61	1.01	0.13	1.94	1.94	5.08
$v_2 = 8$	44	655	663	2,063	2.79	0.91	0.13	1.99	2.00	5.42
$v_2 = 6$	44	664	671	2,076	2.94	0.79	0.13	2.06	2.11	6.01
$v_2 = 4$	44	671	678	2,076	3.00	0.78	0.13	2.13	2.32	7.17
$v_2 = 2$	44	675	686	2,076	3.05	0.89	0.13	2.22	2.97	10.66
$v_2 = 1$	44	678	690	2,113	3.08	0.77	0.13	2.26	4.26	18.06

Table 2. Statistics of travel distance, traffic amount and travel time (normal-life scenario).

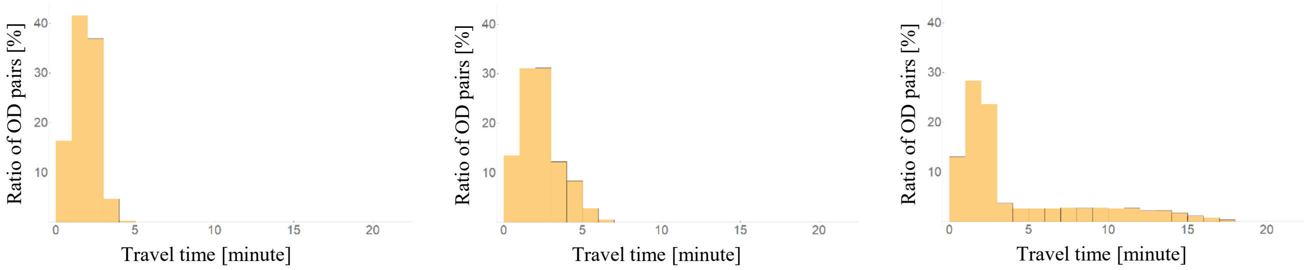
Speed [km]	Travel distance of ST route [m]				T of ST route [$\times$ 10^{10} people·m]		Travel time of SD route [min]			
	Min.	Median	Ave.	Max.	T1	T2	Min.	Median	Ave.	Max.
$v_2 = 20$	45	1,485	1,663	5,334	2.14	0.43	0.14	4.39	4.92	16.00
$v_2 = 10$	45	1,512	1,687	5,422	2.27	0.40	0.14	4.83	5.36	16.88
$v_2 = 8$	45	1,531	1,704	5,444	2.30	0.31	0.14	5.06	5.59	17.40
$v_2 = 6$	45	1,562	1,731	5,507	2.35	0.25	0.14	5.45	5.96	18.34
$v_2 = 4$	45	1,627	1,785	5,626	2.43	0.23	0.14	6.26	6.69	20.21
$v_2 = 2$	45	1,698	1,845	5,772	2.52	0.22	0.14	8.72	8.91	27.49
$v_2 = 1$	45	1,728	1,874	5,775	2.56	0.21	0.14	13.36	13.34	42.85

tance and aggregated flow volumes have increased as a result of the decrease in the secondary link speed v_2. These are the results of deviation from the SD route. Especially from **Fig. 9(c)**, we can confirm that the center of the arterial north-south street is much more congested than the situation shown in **Fig. 9(a)** (the flow volume in the link increased from 8.3% to 20.2%). Several other arterial north-south streets are also used to a greater extent.

These results indicate that the presence of cars parked on secondary streets will be a critical factor for the deviation behavior and the increase in traffic on arterial streets. The summary of the statistics of travel distance related to the ST routes for different values of v_2 is presented on the left side in **Tables 1** and **2**. From the tables, we can confirm that the travel distance will increase by approximately 55 m in the evacuation scenario and 210 m in the normal-life scenario, if v_2 decreases from 20 km/h to 1 km/h. The traffic volume given in expression (13) is also summarized in **Tables 1** and **2**. Here, T_1 and T_2 indicate the traffic volumes on the arterial roads and secondary roads, respectively. It can be seen that T_1 increases and T_2 decreases as v_2 decreases. Thus, we can conclude that the slowing down on the secondary streets will increase the traffic volume on the arterial roads.

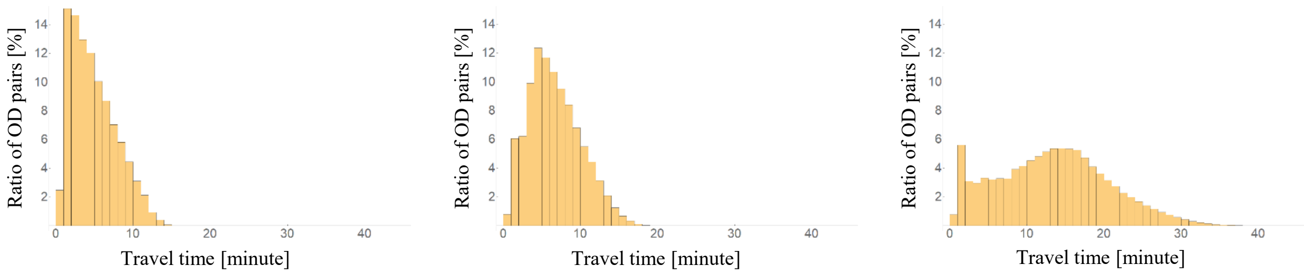
3.3. Results Based on the Route for the Shortest Travel Distance

Finally, we discuss the results based on the SD routes. In this case, no deviation would occur, and alternatively, the travel time increases with the slowing down on the secondary streets. **Fig. 10** shows the travel time distribution for the SD routes in the evacuation scenario, and **Fig. 11** shows the corresponding distribution in the normal-life scenario. In both scenarios, we can confirm that the travel time on the SD routes increases as the speed on the secondary streets decrease. It may be noted that the flow volumes are always the same in the case of the SD routes. More detailed statistics of the travel time related to the SD routes for different values of v_2 are summarized on the right side in **Tables 1** and **2**. From the tables, we can confirm that the travel time increases by approximately 2.5 min in the evacuation scenario and 9 min in the normal-life scenario, if v_2 decreases from 20 km/h to 1 km/h. The result in this section indicates that people will be at a disadvantage even if they do not follow the ST route and use the SD route.



(a) Case of $v_2 = 20$ km/h (b) Case of $v_2 = 4$ km/h (c) Case of $v_2 = 1$ km/h

Fig. 10. Travel time distributions in various cases regarding the SD routes (evacuation scenario, $v_1 = 20$ km/h).



(a) Case of $v_2 = 20$ km/h (b) Case of $v_2 = 4$ km/h (c) Case of $v_2 = 1$ km/h

Fig. 11. Travel time distributions in various cases regarding the SD routes (normal-life scenario, $v_1 = 20$ km/h).

4. Conclusion

In this study, we numerically analyzed the influence of cars parked on secondary north-south streets in downtown Yangon from the viewpoints of travel time, travel distance, and flow volume.

As the road network is a typical grid-like network with a hierarchical road type, the ST route and the SD route would be different. When we assume that people would prefer the ST route for their movements, the results showed the fact that the presence of cars parked on the secondary north-south streets promotes deviation behavior and increase in traffic volumes. Even when people follow the SD route, the slowing down of vehicles on the secondary streets contributes to an increase in travel time.

We demonstrated the unfavorable impact of on-street parking of cars on the traffic condition using two mathematical expressions, (11) and (13). The mechanism is as follows. (i) On-street parking reduces the speed on the secondary streets. (ii) The unbalance of speed induces deviation in the ST route from the SD route; this is mathematically shown in expression (11). (iii) The increase in total travel distance results in an increase in flow volume, because there it has a theoretical relationship with traffic volume, as given in expression (13). This mechanism is normal, and can be applied to any region. Therefore, we believe that it will be possible to convince the local residents in many developing countries, where serious traffic congestion prevails because of cars parked on the streets. Even if multiple shortest routes on the grid network are considered and flow volumes of each link in **Figs. 7** and **9** are changed, the aforementioned characteristics are still satisfied.

It is certain that the traffic congestion as indicated in (iii) will affect the speed on the streets, as mentioned in point (i). Thus, (i)–(iii) forms a feedback loop; this is the basic idea of the equilibrium assignment models. When local residents understand both the above mechanism and the importance of equilibrium assignment models, there will be a strong motivation to get ready for more detailed GIS data.

Acknowledgements

This study was supported by the Science and Technology Research Partnership for Sustainable Development (SATREPS) program, which is funded by the Japan Science and Technology Agency (JST) and Japan International Cooperation Agency (JICA).

References:

[1] Z. L. Tint, N. M. Kyaw, and K. Kyaw, "Development of Soil Distribution and Liquefaction Potential Maps for Downtown Area in Yangon, Myanmar," Civil Engineering J., Vol.4, No.3, pp. 689-701, 2018.

[2] Y. Bhattacharya, T. Kato, T. Matsushita, E. Tun, and T. Aye, "Response-Capacity Analysis of Urban Systems to Support Emergency and Disaster Response in a Developing City: The Case of Yangon, Myanmar," J. Disaster Res., Vol.13, No.1, pp. 138-151, 2018.

[3] M. C. Hoyos, R. S. Morales, and R. Akhavan-Tabatabaei, "OR models with stochastic components in disaster operations management: a literature survey," Computers & Industrial Engineering, Vol.82, pp. 183-197, 2015.

[4] Y.-J. Zheng, S.-Y. Chen, and H.-F. Ling, "Evolutionary optimization

for disaster relief operations: a survey," Applied Soft Computing, Vol.27, pp. 553-566, 2015.
[5] N. Nikko, M. Babaei, and A. S. Mohaymany, "Emergency transportation network design problem: Identification and evaluation of disaster response routes," Int. J. of Disaster Risk Reduction, Vol.27, pp. 7-20, 2018.
[6] A. S. Mohaymany and M. Babaei, "Optimal resource allocation in urban transportation networks considering capacity reliability and connectivity reliability: a multi-objective approach," Int. J. of Civil Engineering, Vol.11, pp. 33-42, 2013.
[7] R. Faturechi and E. Miller-Hooks, "Measuring the performance of transportation infrastructure systems in disasters: a comprehensive review," J. of Infrastructure Systems, Vol.21, No.1, doi: 10.1061/(ASCE)IS.1943-555X.0000212, 2014.
[8] J. C. Chu and S.-C. Chen, "Optimization of Transportation Infrastructure-System Protection Considering Weighted Connectivity Reliability," J. of Infrastructure Systems, Vol.22, No.1, doi: 10.1061/(ASCE)IS.1943-555X.0000264, 2015.
[9] T. Koshizuka, "Comparison of Road Network Patterns with Respect to Travel Distance and Passing Volume," J. of the City Planning Institute of Japan, Vol.34, pp. 763-768, 1999 (in Japanese).
[10] C. E. M. Pearce, "Locating Concentric Ring Roads in a City," Transportation Science, Vol.8, No.2, pp. 142-168, 1974.
[11] E. M. Holroyd, "Theoretical average journey lengths in circular towns with various routeing systems," Road Research Laboratory Report, No.43, 1966.
[12] E. M. Holroyd, "Routing traffic in a square town to minimize route-crossings," Beiträge zur Theorie des Verkehrsflusses: Strassenbau und Strassenverkehrstechnik, Vol.86, pp. 175-183, 1968.
[13] K. Tamura and T. Koshizuka, "An analytical method to derive the distributions of distances and flow volumes on networks," J. of the City Planning Institute of Japan, Vol.35, pp. 1021-1026, 2000 (in Japanese).
[14] S. Fujita and T. Suzuki, "Average Trip Length and Traffic Flow in a Disk City with Multi-ring Routes," J. of the City Planning Institute of Japan, Vol.38, pp. 421-426, 2003 (in Japanese).
[15] T. Koshizuka, "Comparison between Low and High Buildings with Respect to Travel Distance," J. of the City Planning Institute of Japan, Vol.31, pp. 31-36, 1996 (in Japanese).
[16] B. Ghosh, "Random distances within a rectangle and between two rectangles," Bulletin of the Calcutta Mathematical Society, Vol.43, pp. 17-24, 1951.
[17] O. Kurita, "Theory of Road Patterns for A Circular Disk City –Distributions of Euclidean, Recti-Linear, Circular-Radial Distances–," J. of the City Planning Institute of Japan, Vol.36, pp. 859-864, 2001 (in Japanese).
[18] T. Ukai and S. Toriumi, "Distribution of n-directional distance in a circular region," J. of the City Planning Institute of Japan, Vol.52, pp. 1327-1334, 2017 (in Japanese).
[19] K. Tamura, T. Koshizuka, and Y. Ohsawa, "Relationship between Road Distance and Euclidean Distance on Road Networks," J. of the City Planning Institute of Japan, Vol.36, pp. 877-882, 2001 (in Japanese).
[20] M. Miyagawa, "Optimal allocation of area in hierarchical road networks," The Annals of Regional Science, Vol.53, No.2, pp. 617-630, 2014.
[21] D. Nobel and S. Yagi, "Network Assignment Calibration of BPR Function: A Case Study of Metro Manila, the Philippines," J. of the Eastern Asia Society for Transportation Studies, Vol.12, pp. 598-615, 2017.
[22] M. C. J. Bliemer, M. P. H. Raadsen, L. J. N. Brederode, M. G. H. Bell, L. J. J. Wismans, and M. J. Smith, "Genetics of traffic assignment models for strategic transport planning," Transport Reviews, Vol.37, pp. 56-78, 2017.

Name:
Yudai Honma

Affiliation:
Associate Professor, Institute of Industrial Science, The University of Tokyo

Address:
4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan

Brief Career:
2007-2008 Research Fellow, Japan Society for Promotion of Science
2008-2010 Assistant Professor, Tokyo Metropolitan University
2010-2014 Assistant Professor, Waseda University
2014- Lecturer, The University of Tokyo
2017- Associate Professor, The University of Tokyo

Selected Publications:
• "Node-based vs. path-based location models for urban hydrogen refueling stations: Comparing convenience and coverage abilities," Int. J. of Hydrogen Energy, Vol.44-29, pp. 15246-15261, 2019.

Academic Societies & Scientific Organizations:
• Institute for Operations Research and the Management Sciences (INFROMS)
• Operations Research Society of Japan (ORSJ)
• Architectural Institute of Japan (AIJ)

Name:
Kimiro Meguro

Affiliation:
Professor, Institute of Industrial Science, The University of Tokyo

Address:
4-6-1-Be604, Komaba, Meguro-ku, Tokyo 153-8505, Japan

Brief Career:
2008- Visiting Professor, The Open University of Japan
2010- Professor, Graduate School of Interdisciplinary Information Studies, The University of Tokyo
2015- Director, The Japan Association for Earthquake Engineering
2016- Special Advisor of Cabinet Office, Government of Japan

Selected Publications:
• M. Kohiyama, A. S. Kiremidjian, K. Meguro, and M. Ohara, "Incentives and Disincentives Analysis for Improving Policy for Seismic Risk Management of Homeowners in Japan," Natural Hazards Review, Vol.9, No.4, pp. 170-178, 2008.
• K. Meguro and H. Tagel-Din, "Applied Element Simulation of RC Structure under Cyclic Loading," J. of Structural Engineering, Vol.127, No.11, pp. 1295-1305, 2001.

Academic Societies & Scientific Organizations:
• Japan Society of Civil Engineers (JSCE)
• Institute of Social Safety Science (ISSS)
• Japan Association for Earthquake Engineering (JAEE)
• International Association for Earthquake Engineering (IAEE)
• World Seismic Safety Initiative (WSSI)
• Japan Society for Natural Disaster Science
• Japan Society for Active Fault Studies (JSAF)