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Advanced simulation model in the region of Tokyo metropolitan urban expressway rings

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Abstract

In the near future, Tokyo metropolitan region will be covered by urban expressway network with ring and radial roads after the completion of three ring roads. The connectivity provided by networked expressways will provide many route choice options for many Origin-Destination patterns, and the needs for effective and real time dynamic traffic management become much more important. In addition, the significance to complete rings exists in the function to guide commercials trucks to ring road routes rather than radial routes. For the development of the advanced function of such effective and dynamic traffic management scheme, the existing network traffic simulation SOUND shall be modified to accommodate commercial truck typical behavior based on the analysis of real behavior of commercial trucks. The model framework to estimate Origin-Destination demands of commercial trucks based on land use model which is also affected by network traffic operation efficiency is proposed and established.

Keywords:

network traffic simulation, commercial truck, truck terminal location.

Introduction

The Olympic and Paralympic games in 2020 will be held in Tokyo. Tokyo road network will be changed in the near future and will have possibility to accommodate traffic demand much more smoothly and efficiently than before the completion of the three ring expressways. Tokyo metropolitan region, in the near future, will be covered by urban expressway network with three ring roads including the Central Circular Route (the 1st ring road), Tokyo Outer Loop Road

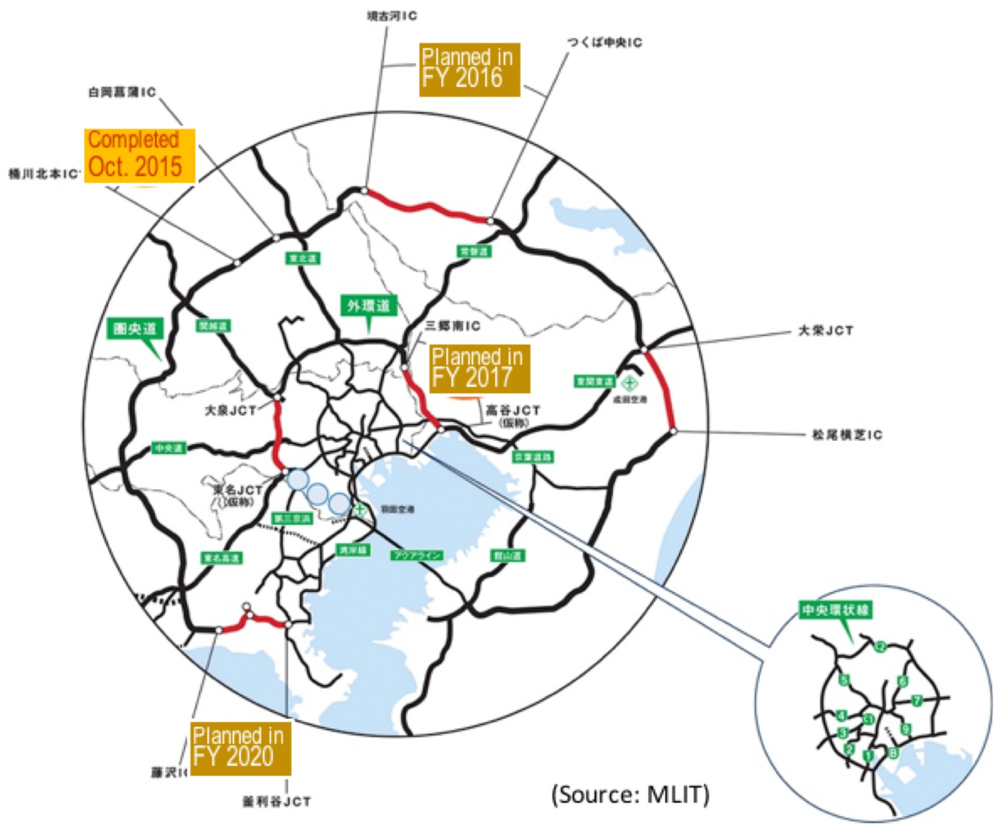

Figure 1 - Urban expressway network of three ring roads and radial roads in Tokyo metropolitan region

(Gaikan: the 2nd rind road), and National Capital Region Central Loop Road (Ken-o-do: the 3rd ring road), and radial roads as shown in Figure 1. The connectivity of expressway network will provide many route choice options for many Origin-Destination patterns and the needs for effective and real time dynamic traffic management become much more important.

In other words, even after completion of urban expressway network, traffic congestion cannot be avoided because of the existence of several traffic capacity bottlenecks, and the congestion effects caused by traffic accidents cannot be also. The intelligent traffic management scheme is needed to utilize these bottlenecks and real time monitoring system of sensors including probing technology and volume detection as well as sophisticated and real time estimation model framework, such as 'now-cast' traffic simulator [Hanabusa, et. al. 2013a, b], will be able to provide several alternatives for the most effective management of all the road network of the Tokyo metropolitan region covered by urban expressway network.

In addition, the significance to complete rings exists in the function to guide commercials trucks to ring roads rather than radial and through routes is high. For the development of the advanced function of such effective and dynamic traffic management scheme, the existing model "SOUND" [Horiguchi, et. al., 2015] shall be modified to accommodate commercial truck typical behavior based on the analysis of real behavior of commercial trucks. The model framework to estimate Origin-Destination demands of commercial trucks based on land use model which is also affected by network operational efficiency is proposed and established.

Commercial Truck Behavior

Background

One of the important aims of developing ring roads surrounding an urban area is that to reduce through-traffic in the central area of Tokyo. Thus, understanding drivers' route choice decision, that is, whether they use inner or outer ring road, is crucial for traffic management. One problem applying the conventional logit model to this practical work is to explicitly generate alternative routes prior to the choice model development, known as the choice set generation problem. This is particularly problematic in the current study, since the road network in the central area of Tokyo is quite dense, providing a large number of competitive routes which are difficult to be enumerated.

Because of this difficulty, the authors employ the recursive logit model where the route choice problem is formulated as a sequence of link choices, and thus alternative routes do not need to be enumerated [Fosgerau, et. al., 2013, Mai et. al., 2015].

Note that, although the recursive logit model can avoid the route enumeration, there are two main remaining issues. First, the correlation across routes is not dealt with in the conventional recursive logit model. For this issue, Mai et al., (2015) proposed the nested version of the recursive logit model. Second, the perception variance of generalized travel cost is assumed to be constant. The larger perception variance on travel time may exist when they choose whether or not the 3rd ring road is used, while it would be smaller they choose whether or not the 1st ring road is used [Chikaraishi et. al., 2015]. This is because travel time in the 1st ring road is far shorter and its estimation may be easier for drivers, resulting in the smaller perception variance. Though the conventional recursive logit model is used in this paper as a first trial, the above mentioned two limitations need to be addressed in future.

Empirical analysis

Commercial truck route choice behavior was never known before "Commercial Truck Probe Data" comes to be available. A private data provider has made it available. Data used in the empirical analysis of this study is freight vehicle GPS data provided by FUJITSU Ltd., collected from July 25 to 31 in 2015. In total, 164 trips which destination is off-ramp "Haneda Airport Central", Westbound (Out-bound) on the Bay-line of Tokyo Metropolitan Expressways. The observed total number of link choice is 8,362.

The utility function used in this analysis is assumed as below.

$$v(a|k) = \beta_{time}x_{time} + \beta_{cost}x_{cost} + \beta_{pena}x_{pena} + \beta_{RC}x_{RC} - 20x_{Uturn}$$

Where, x_{time}: travel time [minutes], x_{cost}: monetary travel cost [100 JPY], x_{pena}: 1 (which implies that the generalized cost caused by running on multiple links), x_{RC}: right turn dummy (1: 70-170 degree right turn, 0: others), x_{Uturn}: U-turn dummy (1: 175-185 degree turn, 0: others), and β_{time}, β_{cost}, β_{pena}, β_{RC} are parameters to be estimated. Travel time here is set according to static road network information based on the types and width of roads. Monetary travel costs are set based on fuel costs 20 JPY per kilometer, toll fare on expressways 26 JPY per kilometer with terminal charge 150 JPY. Note that all of the expressways in Japan are generally toll roads.

Table 1 - Results of recursive logit model estimation

	parameters	t-value
β_{time}	-0.681	-11.89
β_{cost}	-1.504	-7.11
β_{pena}	-0.680	-155.6
β_{RC}	-2.502	-9.13
sample size (number of trips)	164	
sample size (link choice numbers)	8,362	
final log-likelihood	-1279.05	

Table 1 shows the estimation results of proposed recursive logit model using the data. All the explanatory parameters show logically acceptable positive/negative values. From the results, the value of time for commercial trucks is estimated as 45.3 JPY per minute and the value of right turn is estimated as 166.4 JPY per turn, or 3.5 minutes per turn. The value of right turn shows rather higher costs which imply that commercial trucks, especially those trucks which may transport relatively valuable goods, may prefer to go through rather than make turns.

By the way, the results are only obtained using very limited trips which destination is the off ramp "Haneda Airport Central" so that the generalized analysis with rather wide variation of Origin-Destination patters is needed in the near future. The utility function may need to be modified; for example, considering left turn costs, direction difference to the destination, and so forth.

Land use

The construction of expressway network surrounding Tokyo Metropolis is considered to change the place of commercial truck terminals so that the Origin-Destination truck volume will be changed significantly. The authors try to utilize the data and the model framework of land use estimation model established by the "Tokyo Metropolitan Freight Survey, 2014"[Tokyo Metropolitan Area Council for Transport Planning, 2015].

Land use is estimated with a logit model proposed by the authors using the obtained land use data " Tokyo Metropolitan Freight Survey, 2014". The land use potential for physical distribution facilities is estimated with this model after the construction of the three ring roads. The result shows that the land use potential of physical distribution facilities will be higher along with the ring roads, especially along with the National Capital Region Central Loop Road (Ken-o-do; 3rd ring road). The proposed model to estimate the land use potential is represented as below.

$$P_i^r = \frac{\exp(V_i^r)}{\sum_j \exp(V_i^r)}\ , \qquad V_i^r = \sum_k \beta_k^r x_{ki}^r + \ln S_i$$

where, P_i^r is selection probability of area i, sample r; V_i^r is selection utility of the area i, sample r; x_{ki}^r is k-th explanatory variables of the area i, sample r; S_i is a variable to represent the size of the area i as livable land area size; and β_k^r is a parameter. The explanatory variables for selection utility used in this model are those such as; population density, commutable labor force, accessibility to manufacturing industries, accessibility to business district, industrialized-use purpose land use ratio, and travel time to the nearest expressway interchange. The last variable "travel time to the nearest expressway interchange" is provided by the calculated output from the network traffic simulator introduced in this research as those for morning and evening peak-hour travel time.

Given the land use potential of physical distribution facilities by the estimation model described above, the number of commercial truck trips generated from each estimated area is calculated by the model as below. This model is proposed with empirical analysis.

$$P_{tr}{}_i^r = \alpha D_i^{r\beta}$$

where, $P_{tr}{}_i^r$ is the land use potential of physical distribution facility of area i, sample r, D_i^r is truck trip generation demand of area i, sample r. α and β are parameters estimated as $2.08*10^{-5}$ and 5.10 with t-value of 0.95 and 19.94 respectively.

Figure 2 shows an example of the estimated results of the commercial truck demand increase obtained by the comparison between current land use potential and estimated future land use potential caused by the completion of three ring roads construction. It is found that the truck trip generation is increased in the areas along with the National Capital Region Central Loop Road (Ken-o-do; 3rd ring road) such as the vicinities of "Atsugi city" of Kanagawa prefecture, "Ichikawa city" of Chiba prefecture, "Kuki-city" of Saitama prefecture, and "Sakai town" of Ibaraki prefecture, on the other hand truck trip generation is decreased in other areas. This results in that the commercial truck trip efficiency will be improved after the completion of the three ring roads construction.

Implementation of commercial truck route choice model to network traffic simulator

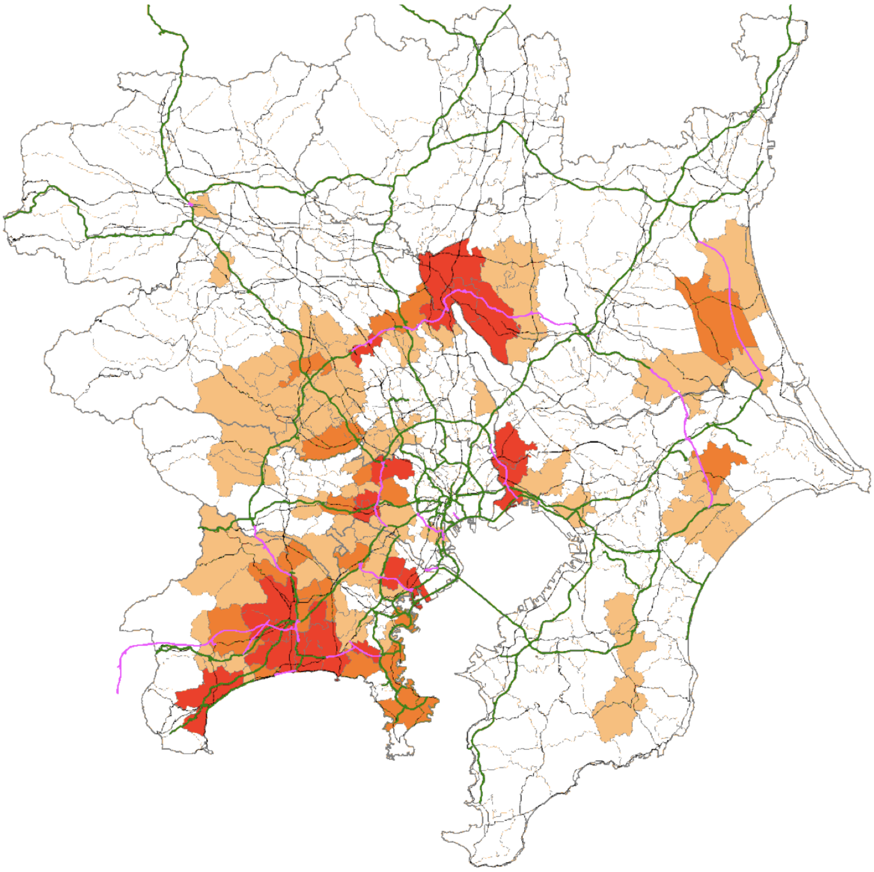

Figure 2 - Truck demand increase affected by the three rings completion

Parameter settings

The authors have already proposed to construct a prototype of a network simulation model to describe network traffic flow surrounding Tokyo Metroplitan area (Tokyo, Kanagawa, Chiba, Saitama, Ibaraki, Tochigi, and Gumma) based on 'SOUND' as presented last year [Horiguchi, et. al., 2015]. The route choice model parameters not only for small cars but also for trucks (based on the analysis described above) are set to describe the difference of their behavior.

The formula describing route choice model in SOUND is as below in the case of binary choice between choice 1 and 2. The probability to choose choice 1 p_1 is given by the equation below.

$$p_1 = \frac{1}{1 + \exp(\theta(c_1 - c_2))}$$

where θ is logit sensitivity parameter, c_1 and c_2 is the generalized cost for route 1 and 2 respectively. The generalized cost in SOUND is calculated by the equation below.

$$c = 3.6C_D\frac{D}{V_F} + C_T T + C_L N_L + C_R N_R + 60\frac{M}{E}$$

where D [m] is distance to the destination, V_F [km/h] is free speed without traffic congestion, T [sec] is travel time to the destination, N_L is number of left turns to the destination, N_R is number

of right turns to the destination, M [JPY] is total toll price to the destination, E [JPY/minute] is value of time, and C_D, C_T, C_L, C_R are parameters for distance, time, left-turn penalty, right-turn penalty, respectively.
The route choice parameters for small cars are shown in table 2 [Murakami et. al., 2002] as presented last year [Horiguchi et. al., 2015].

Table 2 - Route choice parameters for small cars used in the simulation model

parameters	values	unit
C_D	0.5	
C_T	0.5	
C_L	30	second
C_R	60	second
E	90	JPY/minute
θ	0.01	

The route choice parameters for trucks are set based on the derived values of model parameters β_{time}, β_{cost}, β_{pena}, β_{RC} shown in table 1 as following. C_D is calculated as the fraction of the parameters for number of links (β_{pena}) divided by the average link length in the study area (330 [m], derived by taking average of Digital Road Map data). C_T is given just converting the value β_{time} in minute to the value in second. E is derived by the fraction of travel time parameter (β_{time}) divided by monetary travel cost parameter (β_{cost}). C_R is estimated as the fraction of right-turn parameter (β_{RC}) divided by monetary travel cost parameter (β_{cost}), and converted with value of time E. C_L is set to about the half of C_R. The summary of the estimated parameters for trucks are shown in table 3.

Table 3 - Route choice parameters for trucks used in the simulation model

parameters	values	unit
C_D	0.0020	
C_T	0.0114	
C_L	100	second
C_R	219	second
E	45.3	JPY/minute
θ	1	

To compare route choice behavior of cars and commercial trucks, table 4 shows the normalized value of parameters divided by time parameter C_T and multiplied by the logit sensitivity parameter θ. The interpretation of the results shown in the table can be summarized as below.

- Commercial trucks are more sensitive to travel time instead of travel distance than cars, therefore, they tend to select route without congestion and faster route.
- Commercial trucks are very sensitive to the monetary travel cost (toll price) compared with cars so that they try not to use toll roads (expressways).
- Commercial trucks have higher penalty costs for turning right and left than cars so that they try to go straight and try to avoid turning right or left.

Table 4 - Comparison between cars and trucks

parameters	Cars	Trucks
normalized C_D	1	0.17
normalized C_T	1	1
normalized C_L	60	8800
normalized C_R	120	19000
normalized sensitivity*	0.022	1.9

* The "normalized sensitivity" here is the reciprocal of value of time.

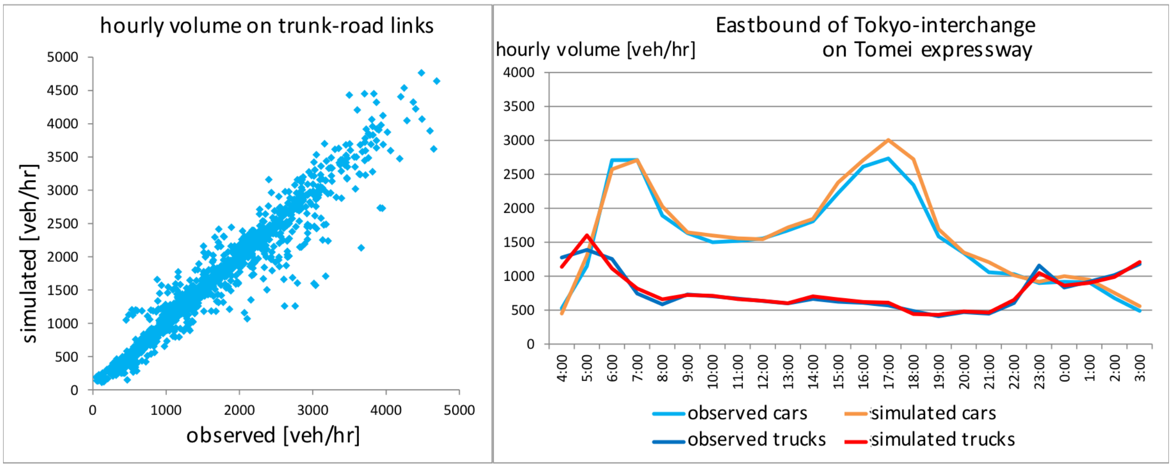

Figure 3 - Example of validation checks
(left: correlation between observed and simulated;
right: time change comparison at an example location)

The Origin-Destination demands are modified to adjust hourly volume of trunk road links calculated by the simulation and observed (Figure 3) with the route choice parameters for cars and commercial trucks identified above. The obtained land use potential of physical distribution facilities is applied to modify the Origin-Destination truck volume which will be fed for the network simulation model.

Case studies

The simulation systems have huge potential to evaluate the impact of the introduction of several types of traffic operation policy. Here, one example to evaluate the impact of a toll fare policy change as already noted that all of the expressways in Japan are generally toll roads. To introduce higher demand of ring roads, the scenario that the National Capital Region Central Loop Road (Ken-o-do; 3rd ring road) is set to be free of charge rather than existing toll fare based on Origin-Destination distance was set to the simulation system and the calculated results are compared with that of existing toll fare scheme both after the completion of three ring roads. Figure 4 shows the comparison results of daily truck volume for each links.

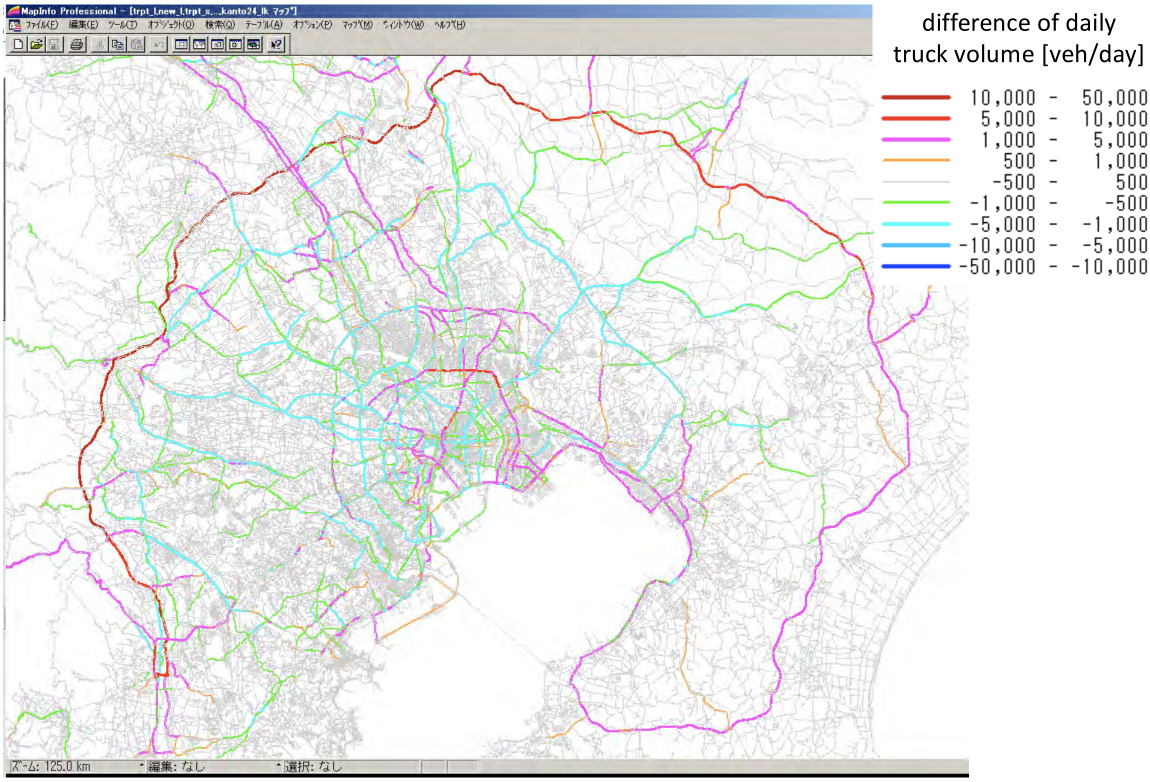

Figure 4 - Difference of truck volume between two scenarios

From the figure, the increase of traffic volume on the 3rd ring road and access road to this ring road definitely increased because of the introduction of free fare scheme on this ring road. The traffic volume on inner trunk roads including expressway network than the 3rd ring road is basically decreased. The simulation model frame reveals the capability to describe and evaluate the impact of change of traffic and/or transport management policy properly.

Conclusions

The developed model is sophisticated and advanced so that it can provide reliable picture of network dynamic traffic flow with reasonable sensitivity of any kinds of traffic management schemes. It is very useful for road authorities. For the future study, land use change, truck route choice behavior models should be modified. In addition, the parameters of traffic network simulator should be calibrated much more systematically, and the validity of the simulation results shall be increased. Comprehensive and systematic discussion for several types of traffic management scheme introduction should be conducted based on the proposed simulation.

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