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MODELING LOGISTICS LOCATION CHOICE AND TRUCK ROUTE CHOICE BEHAVIOR BY TOKYO METROPOLITAN REGION FREIGHT SURVEY

Tetsuro Hyodo, Tokyo Univ. of Marine Science and Technology, Japan
Hirohito Kuse, Tokyo Univ. of Marine Science and Technology, Japan
Yasukatsu Hagino, Institute of Behavioral Sciences, Japan
Hideki Takebayashi, Ministry of Land, Infrastructure and Transport, Japan
Kotaro Endo, LITEC CO., LTD Tokyo, Japan

Abstract

Road network and land use regulations has a great impact on logistics functions and elements particularly in elements of commodity flow such as route choice and volume, facility location and SCM structure to name a few. Accordingly, public sectors should develop appropriate demand models to describe these elements for future infrastructure plans or policies. In this paper, we studied logistics location choice model and truck route choice model in evaluating the impacts of newly constructed roads in Tokyo Metropolitan Region (TMR). The actual data of the large-scale public freight survey was applied to the model estimation and several policies were analyzed.

PROFILE OF TOKYO METROPOLITAN FREIGHT SURVEY (TMFS) IN 2003

In TMR, the decennial freight surveys were conducted in 1972, 1982 and 1993 by the Transport Planning Commission of TMR. The fourth survey was conducted in 2003. It consisted of: 1) questionnaire survey to logistics establishments (30,000 respondents) for daily commodity flow and logistics activities of their facilities, 2) questionnaire survey to large size truck drivers for actual routes, and 3) local delivery survey of loading and unloading activities in five Central Business Districts (CBD).

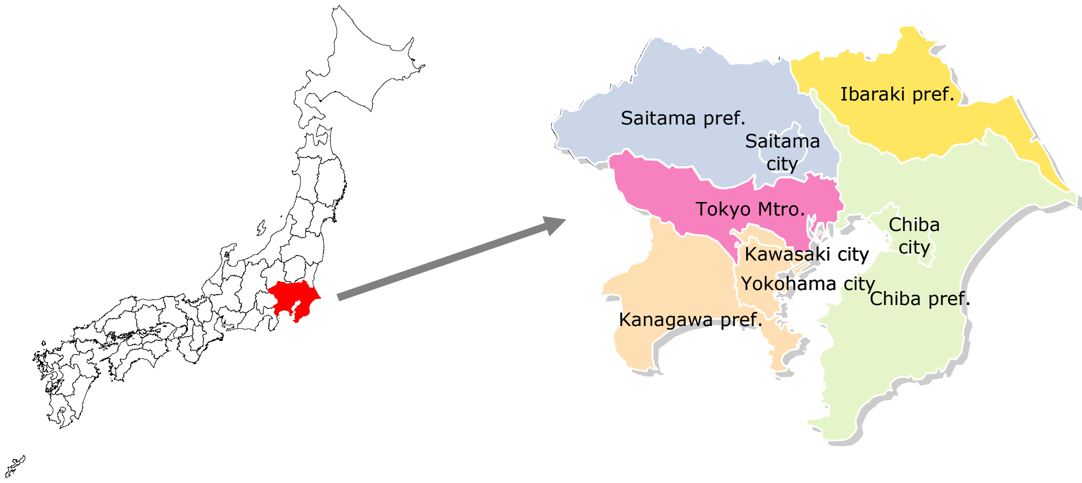


Figure 1 Tokyo Metropolitan Region

The main part of the survey was the questionnaires to logistics establishments. The survey questionnaire was primarily sent to manufacturing, shipping, warehouse, and wholesale establishments. About 120,000 questionnaires were mailed out to those establishments, and about 30,000 of them replied.

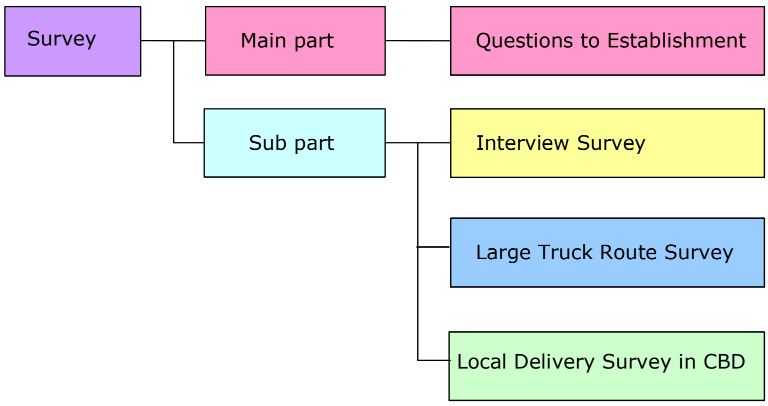


Figure 2 Structure of the Tokyo Metropolitan Freight Survey

Current situations of freight in TMR

In this section, current situations of freight in TMR are described based on the survey questionnaires. Figure 3 shows the freight distribution in TMR. The total volume of commodity flow has not changed compared to 1982, but the flow from outside to TMR has increased due to increased imports. Of the transportation modes in TMR, almost all were trucks (Figure 4). Large portions carried by trucks are goods for citizens' living necessity.

Figure 5 illustrates the goods flow from production/import to consumption based on the supplemental business objective survey as a part of the TMFS. From the urban transport perspective, the figure implies that freight measures in "regional" "city" and "local" levels and the network connecting those different levels respectively are critical to control regional freight facilities (e.g. warehouse, logistics center, etc.) as well as the leveled urban freight structure.

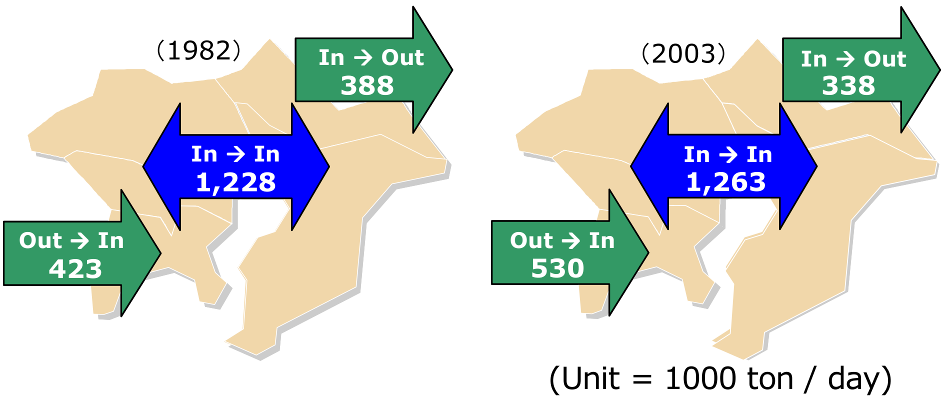


Figure 3 Daily Commodity Flow in TMR

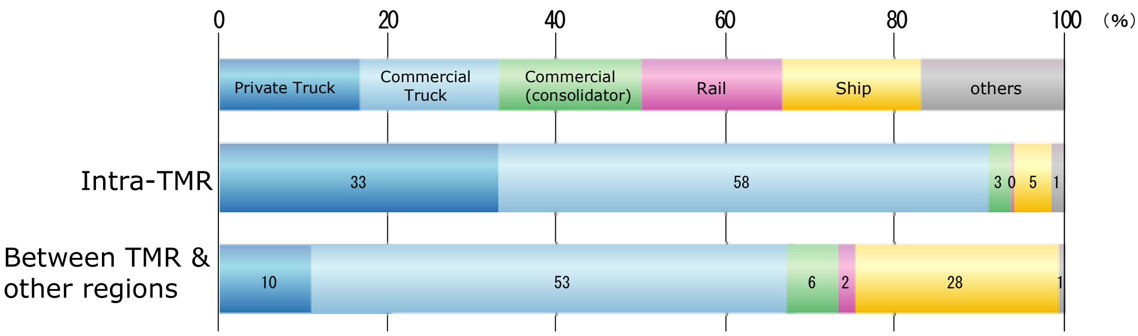


Figure 4 Commodity Flow by Modal Share

"Private Truck" is owned by shippers, "Commercial Truck" is owned by freight companies

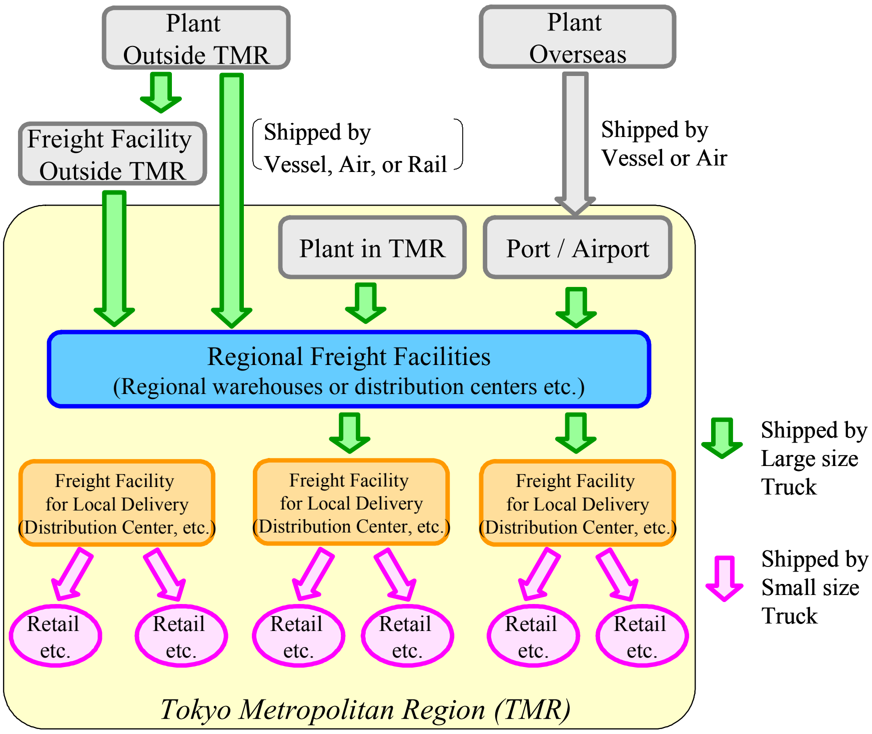


Figure 5 Schematic Diagram of Goods Flow in TMR

Four freight policies

The Commission analyzed the survey results in collaboration with many academic researchers and established various transportation policies as well as city and regional planning policies in 2005. Those are classified into four areas;

Policy A: support location of regional logistics facilities,
Policy B: control location of local delivery facilities in urban areas,
Policy C: improve road network for large trucks,
Policy D: promote effective loading/unloading activities in CBD.

The Commission developed new demand forecasting models for logistics facility's location choice, truck route choice model, and physical distribution channel pattern model. One of the major policies is to evaluate the impact of newly constructed roads on logistics activities. For the policy analyses, the location choice model for "Policy A" and the route choice model for "Policy C" are introduced in the following two Chapters.

LOGISTICS FACILITY LOCATION CHOICE MODEL FOR MEASURING IMPACT OF ROAD CONSTRUCTION

Lately, logistics facilities have grown larger through merging for cost reduction purposes. Those large facilities tend to locate in undeveloped areas where space is still available. These facilities generate flow of large-size trucks, so controlling location of those facilities has become a crucial issue in city and regional planning in TMR.
In this study, a model was developed to quantitatively estimate location choice probabilities for regional logistics facilities. The study also analyzes "Policy A" to direct locations for those facilities.

A discrete choice Logit model was estimated quantitatively for the likelihood of location of large-scale logistics facilities in 1km^2-meshes within TMR. The variables used in the model are "transportation service-level," "whether appropriate land-use for logistics," etc.

Logit model of logistics facility location was estimated in the areas around expressway interchanges (IC) currently under construction. With the location probabilities estimated, we proposed a policy to support the location for logistics efficiency near expressway ICs and limiting the location for those areas for environmental preservation purposes.

Estimation of location choice model

The Location Choice Model was established to quantitatively estimate potential areas for large-scale regional logistics facilities in TMR and the anticipated effects of location choice and guiding location for such facilities. A discrete choice Logit model was selected for location choice by 1km-mesh in TMR using the logistics establishment survey (main part) data from the 4th TMFS.

Areas and zoning for estimation
The areas for estimation were: Southern Ibaraki and 4 other prefectures (Tokyo, Chiba, Saitama, and Kanagawa). The tertiary mesh (1km mesh) of the National Land Numerical Information was used for zoning to enable microscopic analysis. The total number of mesh was 15,230 in the areas surveyed.

Location data used in the estimation and model categories/segments
Among logistics facility samples of the Logistics Survey (Main Survey), those built in 1990 or later at current location were used for the estimation. In Table 1, observations were divided into 2 categories, Regional Freight Facility and Local Distribution Center.

The study assumed to apply discrete choice Logit models and we selected the following model commonly used in zone selection[1).

Table 1 Model Categories/Segments

Regional Freight Facility	Model 1	Property w/ 3000 ㎡ and over	Freight facility with major destinations outside TMR or their prefecture, and average travel distance over 40km
	Model 2	Property w/ less than 3000 ㎡	
Local Distribution Center	Model 3	Freight, warehouse sectors	Facility other than regional freight facility
	Model 4	Other industries	

$$P_i^r = \frac{\exp\left(\bar{v}_i^r + \ln M_i\right)}{\sum_j \exp\left(\bar{v}_j^r + \ln M_j\right)} = \frac{\exp\left(V_i^r\right)}{\sum_j \exp\left(V_j^r\right)} \quad (1)$$

P_i^r : Probability of logistics facility of segment r to locate in area i (tertiary mesh)

$\bar{v}_i^r$: Utility function of the average utility for available lot in the area i and its variance

M_i : Number of available lots in the area i

V_i^r : Utility function of the area i

Since the number of available lots, M_i, is not directly observable, so, we suppose the variable S_i as the number of observable lots in the area i,

$$M_i = \alpha S_i \quad (2)$$

S_i: Scale variable of the area i (inhabitable area – residential area), α : parameter.

The utility function of Logit model then becomes

$$V_i^r = \sum_k \beta_k^r x_{ki} + \ln S_i \quad (3)$$

x_{ki}: k^{th} variable for the average location utility in a lot in the area i (location factor)

β_k^r : parameter

Explanatory variables for location choice model

Considering the location factor and data availability, explanatory variables were selected for Equation (3). The scale variable in equation (3) was obtained by subtracting the residential area from the inhabitable area.

Since the number of location options is the number of tertiary mesh 15,230 in the entire TMR, parameter estimation would be difficult with the Logit model theoretically. However, if the size of subset randomly selected from the choice set is large enough, the estimated parameters will converge. Thus, in this study, a total of 200 meshes, 199 as alternatives and one with actual facility, were selected among 15,230 for each observation, and then, estimated with maximum likelihood method, considering the capacity of personal computers and software (GAUSS) used.

Table 2 shows the estimation results which were confident for key explanatory variables. Correlation coefficient ranged between 0.6 and 0.8 when comparing the actual number of facilities and the estimate, so we concluded that the model was quite accurate.

CALIBRATION OF LOCATION POTENTIAL FOR LOGISTICS FACILITY

Definition of location potential

With the utility value calibrated for each mesh with utility function (location utility, hereafter) for location choice equation (3), the following deviation was defined as a potential value,

$$P_i^r = \frac{10 \times (V_i^r - \overline{V^r})}{\sigma^r} + 50 \tag{4}$$

where,

P_i^r : potential of segment *r*, in mesh *i* , V_i^r : location utility of segment *r*, in mesh *i* ,

$\overline{V^r}$: average location utility in segment *r*

σ^r : standard deviation of location utility in segment *r*.

Calibration of potential for large-scale regional logistics facilities

With model (regional logistics facility with area over 3,000m^2) 1 in Table 2, current location potential for regional logistics facilities with over 3,000m^2 was calibrated and compared with actual distributions of these facilities. It is presented in Figure 6 which implies that areas with high potential will be located in coastal and suburban areas. 77% of actual large-scale logistics facilities were located in the highest 20% potential meshes.

Calibration of potential changes by road development

Since beltways (expressways) are to be completed in TMR in the near future, demand for large-scale logistics facilities around future expressway ICs is expected to increase. Estimating the demand quantitatively for those facilities is essential for appropriate location guiding measures.

Location potential for prospective expressways was calibrated as in the previous paragraph. Figure 7 shows the planned expressway network in TMR and the areas with

Table 2 Estimated Results of Location Choice Model

Explantory variables		Parameters (t-value in parenthesis)	Regional Freight Facility		Distribution Center	
			Model 1	Model 2	Model 3	Model 4
			Area 3000m^2 and over	Area less than 3000m^2	Transport/ warehouse	Other industries
ln(population density ※1)		(1000persons/km^2)	-0.3634 (-4.918)	-0.2876 (-4.653)	-0.2971 (-4.715)	-0.2443 (-2.452)
ln(working population in commuting distance)		(1000persons)	0.9672 (5.401)	1.0244 (6.678)	0.7705 (5.637)	0.6214 (3.328)
ln(Accessibility to machine & assembly sectors)			0.5361 (1.404)			0.8332 -2.083
ln(Minutes to Keihin Port)		(minutes)		-0.485 (-1.777)	-0.3986 (-1.471)	
ln(Distance to expressway IC)		(km)	-0.1566 (-1.731)	-0.1575 (-2.078)	-0.1414 (-1.621)	-0.1044 (-1.017)
ln(Land price)		(1,000Yen/km)	-0.8878 (-3.932)	-0.6117 (-3.440)		-0.2761 (-1.158)
Urban control area		Yes = 1 Otherwise = 0	0.2831 (1.516)			0.2659 (1.294)
Land use category	Semi-industrial	Ratio to inhabitable area	3.1014 (7.715)	2.3507 (7.053)	3.0846 (8.918)	2.8124 (6.411)
	Industrial	Ratio to inhabitable area	3.5490 (6.922)	3.4662 (8.820)	3.8045 (9.028)	1.1305 (1.307)
	Exclusive industrial	Ratio to inhabitable area	3.6174 (11.182)	2.6897 (7.594)	3.242 (9.669)	2.0056 (3.709)
Land Attribute Dummy	Inland	Yes = 1 Otherwise = 0		-0.1695 (-0.910)		
	Coastal	Yes = 1 Otherwise = 0		-0.8910 (-3.102)		6.4518 (3.794)
	Suburb	Yes = 1 Otherwise = 0	-6.5950 (-2.419)			
ln(sample land area) x land attribute dummy	Inland				-0.0354 (-1.256)	-0.0833 (-2.165)
	Coastal				-0.1544 (-3.667)	-1.0206 (-3.970)
	Suburb		0.8501 (2.729)			
Container use dummy x land attribute dummy	Coastal					
	Suburb					-1.0952 (-1.838)
Number of employees x land attribute dummy	Coastal					
	Suburb		-0.0048 (-2.519)			
ln(road density in mesh)			0.4042 (1.748)	1.1728 (5.336)	0.4550 (2.072)	0.6022 (2.499)
ln(available area※2)			1.0000 (—)	1.0000 (—)	1.0000 (—)	1.0000 (—)
Initial maximum likelihood			-899.5	-1248.1	-1007.5	-633.7
Final maximum likelihood			-718.6	-1019.2	-796.2	-633.7
Likelihood ratio adjusted to degrees of freedom			0.201	0.183	0.209	0.129
Correlation coefficient between numbers of actual and estimated locations by local government			0.593	0.625	0.783	0.645
Sample size			168	237	189	139

※1 Population density: Night population in mesh/Inhabitable area

※2 Available area: Inhabitable area – General building area

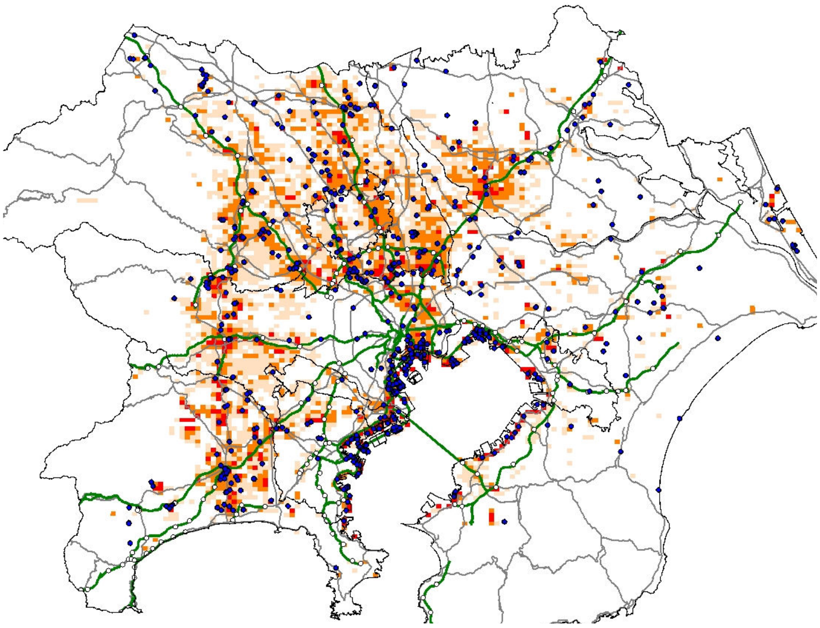


Figure 6 Calibrated Potential for Large-scale Regional Logistics Facilities

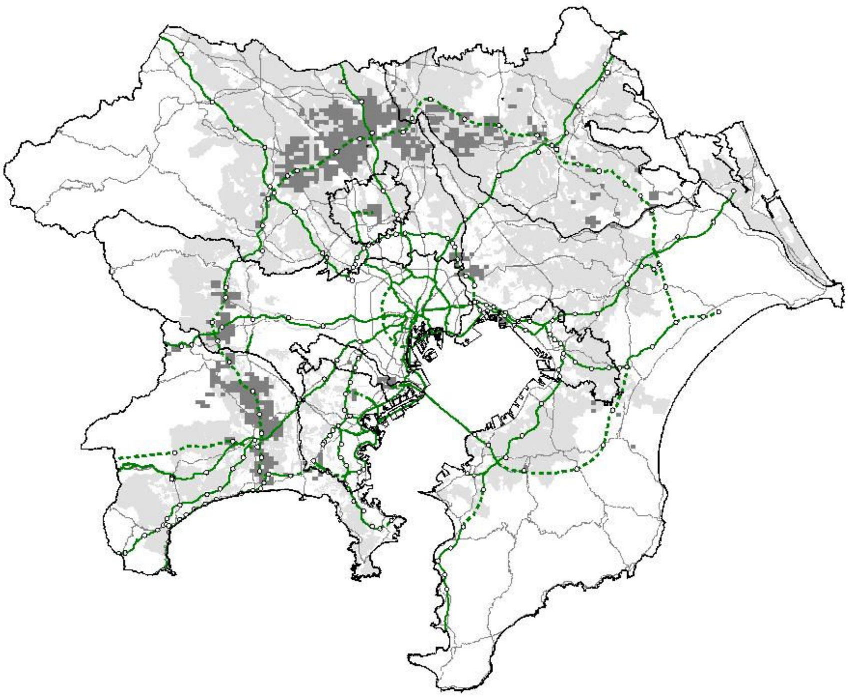


Figure 7 Planned Expressway Network (dotted line) and
Calibrated High Potential area after Road Development (dark color area)

increased potential after the expressway development. Consequently, potential for large-scale regional logistics facility will be high around suburban expressway ICs and it will increase in the future. Many of those areas are under urbanization control (green areas in both figures), so the Committee concluded that effective location control is an important issue for the future.

Calibration of demand for relocation due to guiding measures

Since this location choice equation (1) is capable of estimating the location likelihood using location utility change by mesh, as in the previous section, the effects on location demand by guiding measures were estimated for logistics facilities over 3,000km^2. Specifically, changes in location probability after the expressway development (currently under construction) in meshes where those facilities should be located, were estimated by changing the proportion of exclusive-industrial areas within mesh. The selected areas have a potential value of 57 and over, and near ICs on Ken-o-do (within 2km diameter or along weight-designated road within 5km diameter).

The ratio of exclusive-industrial area was set at 25% (average in meshes with exclusive-industrial zones in TMR) to calculate location probabilities. Then, changes in relocation demand were estimated using the current location probabilities. Major findings are summarized below:

1) The number of large-scale regional logistics facilities relocating to guided areas in suburb would be 180, 7% of total facilities
2) Of those, approximately 41% are from suburb (7% of large-scale regional logistics facilities in suburban areas)
3) Approximately 16% are from coastal area (3% of those in coastal areas)
4) Approximately 43% are from urban areas (11% of those in urban areas)

Since the model is static, the estimated results should not be implied that these changes will occur instantly upon implementing these measures. However, the estimation should be implied that the estimated number of relocation could happen due to the measures.

TRUCK ROUTE CHOICE ANALYSIS BY MAXIMUM OVERLAPPING ROUTE MODEL

Current issues on large size truck movement in TMR

The increase of international cargo causes more heavy or tall containers movement in road network. Deregulation of truck size and weight in 1990's has also raised the average truck size. In Japan, trucks over total 20 ton or 3.8 m height can be driven only "the designated link for heavy vehicle" or "the designated link for tall vehicle" without permission. However, there are many bottlenecks in road network for large size trucks because of the lack of these designated links. Figures 8 and 9 illustrate the present

networks of designated links. It is shown that the road running north-south for heavy vehicle in western region is not constructed, because some beltways in TMR have not been developed by the citizens' objections.
We supposed that some methods for evaluating the priority of road improvement or construction for truck should be required. The conventional multi-class assignment model can not follow the large truck's route choice behavior under these constraints, therefore, we examined "Maximum Overlapping Route (MOR) Model" as detailed in the next subsection.

Figure 8 Designated Link for Heavy Vehicle

Figure 9 Designated Link for Tall Vehicle

Maximum overlapping route (MOR) model for truck route choice behavior

This method was developed for describing bicycle route choice behavior by Hyodo *et al*. The objective function of this model is to maximize the overlapping link length between "cognitive minimum cost route" and actual route as follows.
First, we define the actual trip length of the *n*-th sample (X_n) as

$$X_n = \sum_a \delta_{na} \cdot l_a \quad , \tag{5}$$

where

δ_{na} : dummy variable; if the *n*-th sample passes the *a*-th link=1, otherwise=0,

l_a : the length of the a-th link.

Assuming that perceived link length is affected by the link attributes, we propose the following relationship.

$$l^*_{an}(\boldsymbol{\beta}) = l_a \cdot \prod_k \beta_k^{Z_{ank}} \tag{6}$$

$l^*_{an}(\beta)$: the cognitive length of the *a*-th link of the *n*-th sample

Z_{ank} : the dummy variable of k-th attribute for the a-th link of the n-th sample

β_k : unknown parameter for the k-th attribute

Equation (6) states that the physical attributes of a link affect the cognitive length of the link. Therefore, cognitive link length may be different for each driver. In this paper, we apply this MOR model to truck drivers' route choice under the many conditions such as travel time, travel cost, expressway toll, designated link for heavy vehicle etc. These variables can be considered by using the following general cost function instead of the cognitive length in Equation (6).

$$GC_a^*(\omega,\boldsymbol{\beta}) = (\text{Cost}_a + \omega \cdot \text{Time}_a) \cdot \prod_k \beta_k^{Z_{ak}} \tag{7}$$

"ω" is value of time (VOT) and it is also an unknown parameter. The parameters are estimated by the following process. The overlapping rate of n-th sample is defined by

$$D_n(\omega,\boldsymbol{\beta}) = \frac{\sum^{a} \delta_{na} \cdot \delta_{na}^*(\omega,\boldsymbol{\beta}) \cdot l_a}{X_n} \tag{8}$$

$\delta_{na}^*(\omega,\beta)$: dummy variable: if the n-th sample passes the a-th link of the minimum generalized cost path=1, otherwise=0

The weighted overlapping rate with whole samples is

$$D(\omega,\boldsymbol{\beta}) = \frac{\sum_n X_n \cdot D_n(\omega,\boldsymbol{\beta})}{\sum_n X_n} = \frac{\sum_n \sum_a \delta_{na}\delta_{na}^*(\omega,\boldsymbol{\beta}) \cdot l_a}{\sum_n X_n} \tag{9}$$

This objective function is not continuous with parameters, because the minimum generalized cost path is changed discretely based on $(\omega,\boldsymbol{\beta})$. Therefore, we drawn the contours of $D(\omega,\boldsymbol{\beta})$ with appropriate interval of $(\omega,\boldsymbol{\beta})$, and confirmed the maximum point. If the number of parameters is over two, this method is not feasible so that Genetic Algorithm (GA) should be applied [2)].

Estimation result and the applicability

We applied the model to the truck drivers' questionnaire survey which is a part of TMR Freight Survey in 2003. The survey provides about 700 actual large truck routes in TMR. The MOR model can involve many variables as attributes of links as mentioned before. We have already prepared digital road network data and the results of traffic assignment analysis. In this paper, we introduced the results for the parameter estimation. Table 3 is the initial overlapping rate which means all link attribute parameters (β) equal to one. Because of the variation of variables, we can define several kinds of "shortest path", minimum distance, travel time and travel cost. Hereafter, we apply "minimum actual distance route" as for the simple initial overlapping rate.

Table 3 Initial Overlapping Rate by Definition of The Shortest Path

	Weighted Overlapping Rate (Eq.(9))
1) Minimum actual distance route	0.48151
2) Minimum travel time route	0.49623
3) Minimum travel cost route	0.38662

We examined a lot of combinations of many variables. Owing to the limitation of space, the results of two variable cases are reported. Table 4 shows the six kinds of estimation results. The highest weighted overlapping rate is given by model with "Value of Time (VOT)" and "Dummy variable of designated heavy vehicle link". The estimated VOT is 74 [Yen/min.], which is similar to the more commonly used value in Japan. The parameter of the dummy variable (0.550) means that the designated link for heavy vehicle provides 45% shorter cognitive distance for drivers. Aggregate log likelihood is calculated as $\rho = 1 - (\log(0.64962)/\log(0.48151)) = 0.410$. This is very high when it is compared to the past results of bicycle route choice examples[2)].
The variables related to land use are not so significant ("Model numbers 2-5", "2-6"). However, the link condition is an important factor for truck drivers in TMR.
Figure 10 illustrates the contour of weighted overlapping rate of "Model number 2-1" in Table 4. It is confirmed that the objective function is not smooth and has several local optimum points.

Table 4 Parameter Estimation Results of Two Variable Case

Model number	Variable	Parameter	Weighted overlapping rate
2-1	Value of Time [Yen/min.]	74	0.64962
	Dummy of "heavy" link[1]	0.550	
2-2	Value of Time [Yen/min.]	88	0.63677
	Dummy of "tall" link[2]	0.775	
2-3	Value of Time [Yen/min.]	102	0.63754
	Dummy of 4 lanes[3]	0.725	
2-4	Value of Time [Yen/min.]	58	0.64372
	Dummy of expressway[4]	0.625	
2-5	Value of Time [Yen/min.]	80	0.59173
	Dummy of D.I.D.[5]	1.100	
2-6	Value of Time [Yen/min.]	86	0.58515
	Dummy of Ring Road 7[6]	0.900	

1 If designated link for heavy vehicle=1, otherwise=0
2 If designated link for tall vehicle=1, otherwise=0
3 If number of lanes equals to 4 or over=1, otherwise=0
4 If expressway=1, otherwise=0
5 If link is in D.I.D.=1, otherwise=0
6 If link is inside of Ring Road #7=1, otherwise=0

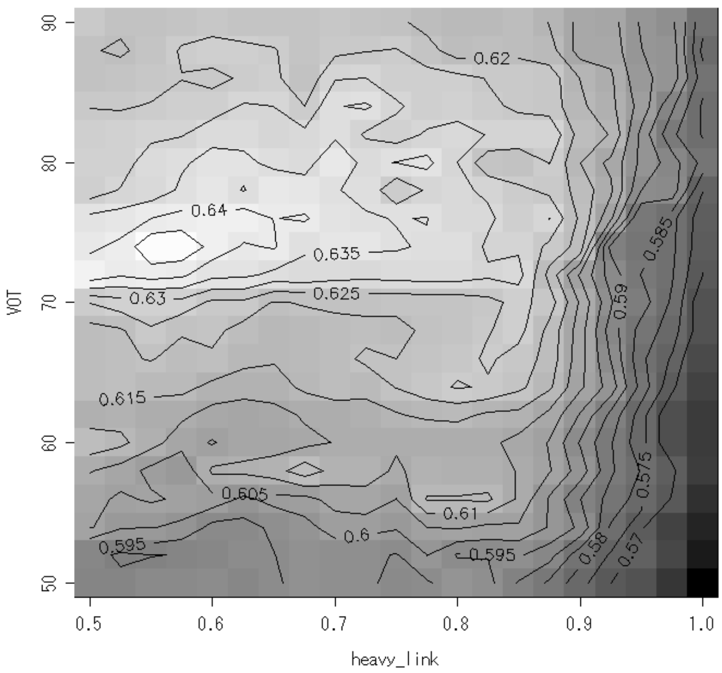
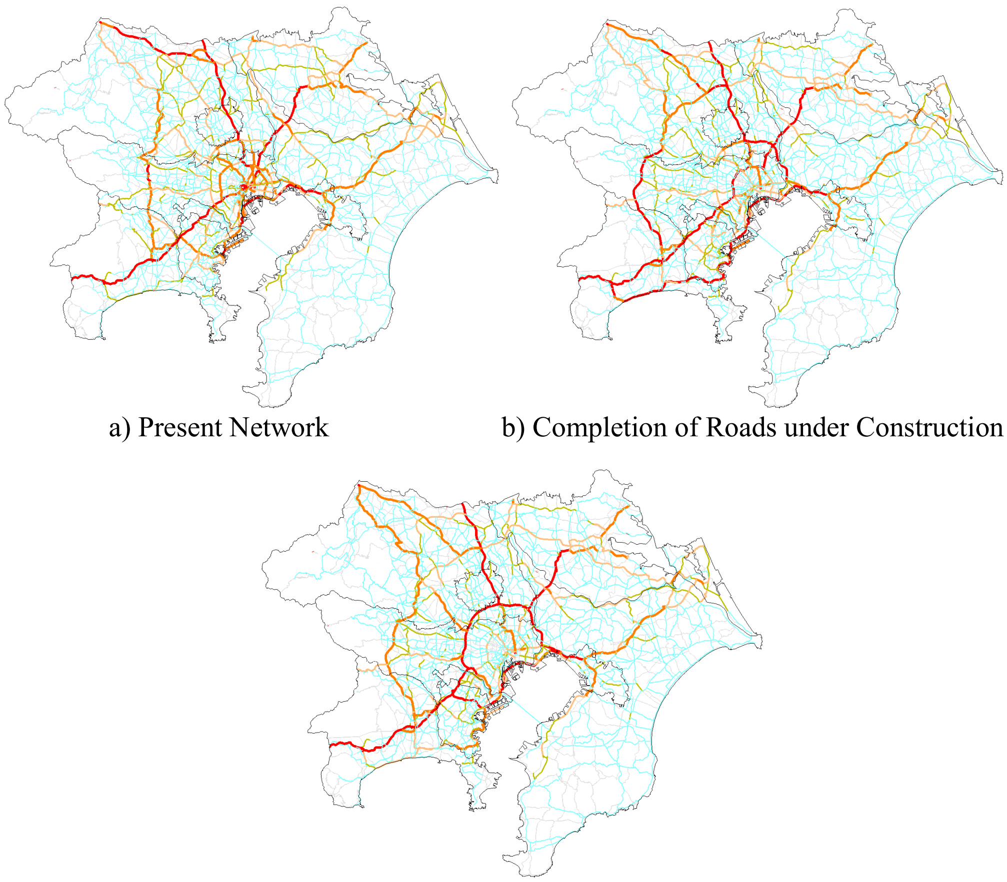


Figure 10 Contour of Weighted Overlapping Rate with Two Variables
(Horizontal axis=Dummy of "heavy" link, Vertical axis=Value of Time)

By using the truck OD tables and MOR model, we can forecast the future link volume of large sized trucks in TMR. The OD table of large sized truck was calculated by the result of TMR Freight Survey. And truck route for each OD pair was assumed that the minimum generalized cost estimated by MOR model number 2-1 in Table 4. Three cases, "Present", "Completion of roads under construction" and "Completion of Long Term road network," were examined as the case studies (Figure 11). "Present" result suggests that present network is generating excessive concentration of large sized trucks in the central area. The outer beltways are now under construction, and they will be completed in 2012. Figure 11 "b) Completion of roads under construction" displays that the new network would shift the inconvenient concentrated traffic to the suburban beltways. However, there are some missing links in TMR road network. "c) Completion of Long Term road network" case hypothesizes construction of two important sections. One section completes the inner beltway, and other connects large port and principle expressway in Japan. It is represented that these sections are important "pieces" to accomplish smooth and sustainable road network in TMR.
As we introduced in this subsection, the MOR model has applicability for demand forecasting. Now we are examining this methodology to other metropolitan areas and testing the evaluation procedure for road construction priority for large sized trucks.



a) Present Network b) Completion of Roads under Construction

c) Completion of Long Term Road Network

Figure 11 Calibrated Large Size Truck Traffic Volume

REMARKS

In this paper, logistics location choice model and truck route choice model were developed and its applicability with the actual freight survey data was examined. The advancement of internationalization and expansion of road network, especially newly constructed beltways, cause more active goods movement in TMR. These two models would give the important information for infrastructure planning to meet the increasing demand. The former model is for "node facility" and the latter model is for "link facility".

We represented two models as separate tools, however, these models and the conventional four step model should be integrated. It is one of further topics to be examined.

We reported the results to many public sectors in TMR, and several sectors launched or revised their transportation master plans or city plans based on the study results. Tokyo Metropolitan Region Freight Survey and our analyses opened the way to discuss freight policies by quantitative methods.

Further topics to improve the choice models are summarized as follows:

1) Spatial error structure for location choice model should be tested for better effective parameters (Bhat *et al.*).
2) In this paper, "Maximum Overlapping Route (MOR) Model" was applied to the network already assigned traffic volume, however, it can be utilized as an impedance term of conventional BPR function. Traffic assignment with the estimated MOR model should be examined (Prashker et al.).

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