EVALUATION OF LOGISTIC POLICIES IN THE TOKYO MRTROPOLITAN AREA USING A MICRO-SIMULATION MODEL FOR URBAN GOODS MOVEMENT

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Abstract: In general, macroscopic evaluation models of logistic policies are less concerned with individual firm's behavior than microscopic models. Microscopic models of this kind usually have limitations, such as a relatively small study area or few policies. Therefore, the purpose of this study is to develop a model that can evaluate several logistic policies for the metropolitan area considering individual firm's behavior and their characteristics. Three policies were evaluated by vehicle-kilometer-traveled (VKT) and nitrogen oxide (NOx). When large-size truck ban and road pricing were implemented, the exhaust NOx decreased approximately 30 tons. Firms are charged minimum additional cost to decrease 1kg of NOx by road pricing. Therefore, road pricing was regarded as the most efficient policy in this simulation. It is certainly possible to examine other conditions, and this simulation exists to judge which policy is the most efficient or effective by comparing VKT, NOx and costs.

Key Words: Logistic Planning, Goods Movement, Logistic Policy Evaluation

1. INTRODUCTION

1.1 Background

The movement of goods is one of the most substantial factors that maintains socio-economic activities as well as the movement of passengers. In 1999, domestic distribution of goods was approximately 6,446 million tons in Japan and more than 90% were transported by truck. It is estimated that most urban goods movement is conducted by trucks. Although the number of trucks was less than 30% of registered vehicles, truck shares in terms of vehicle-kilometer-traveled (VKT) exceeded those of passenger car.

Since customers request frequent and small lot delivery for saving inventory cost, shippers have to use many trucks with a low carrying weight ratio. This causes negative impacts such as traffic congestion, long transport time, and increased energy consumption. Exhaust amounts of nitrogen oxide (NOx) from a large truck is several times that of a passenger car.

And the amount increased when the velocity is less due to traffic congestion. Efficient logistics indicate less negative impacts and logistic costs, while keeping a certain standard in delivery service. These efficient logistics should be considered not only for individuals and firms, but also for the whole of society.

The efficiency of logistics is reflected by social conditions, such as infrastructures and economic activities. Since logistics and its environment strongly affect each other, it is necessary to improve both of them, especially in large cities like Tokyo, which has many complex logistic systems. Therefore, various logistic policies have been examined and enforced all over the world.

Before implementation of these policy measures, it is necessary to estimate freight traffic and evaluate planned measures. It is generally utilized a traditional four-step travel-demand estimation process for person base traffic prediction. The four steps are as follows:

- trip generation and attraction,
- trip distribution,
- modal split, and
- traffic assignment.

This process can be applied for goods-base traffic estimation; however, there are some conspicuous differences between personnel and goods movement. One difference is to change the shape or unit of goods according to transport stages. This characteristic makes surveys difficult according to the increase in the number of distribution channels. The estimation of passenger-car traffic considers the characteristics of people moving behavior that is obtained by the Person-Trip Survey or other traffic surveys. The estimation of truck traffic rarely considers the characteristics of a firm’s logistic behavior. The reasons for this problem may come from the difficulty in obtaining logistic data because of a firm's privacy and complex characteristics of goods movement. However, the characteristics of a firm’s logistic behavior should be considered for the accuracy of traffic estimation.

A firm's logistics can be divided into inter-city logistics and intra-city logistics (urban goods movement). For inter-city logistics, a transport system is well examined and characteristics are considered for each transport mode, such as a modal-mix to reduce environmental impacts. New inter-city logistic systems for securing inter-base transportation are also examined. For urban goods movement, most goods are transported by trucks. Although cooperative delivery and securing loading/unloading facilities are frequently examined, a logistic base for temporary storage is rarely examined. Transport systems that include road network construction are also rarely examined. These logistic policy measure variables must be considered.

In previous studies, these policy measures were evaluated as individual truck units. However, when any logistic policies are examined whether it is implemented or not, it is required to estimate their effects and evaluate them comprehensively. Total VKT and exhaust amounts of NOx and carbon dioxide (CO_2) in study areas are considered as evaluation indicators. To estimate these values, truck volume for each link must be predicted by the amount of goods generated from each shipper. Existing studies relating to urban goods movement systems mainly focus on individual transport styles to be adequately efficient, therefore, few examine the relationship with road traffic. Although some studies discuss urban goods movement by road traffic systems, they have not sufficiently discussed efficient behavior mechanisms classified by industry and goods. Few have examined running characteristics and route choice characteristics for large trucks and small trucks in road networks.

1.2 Purpose and Objectives

As mentioned above, macroscopic evaluation models of logistic policy measures were less concerned with individual firm’s behavior in past studies. On the other hand, microscopic models of this kind usually have limitations, such as a relatively small study area or few policy measures.

Therefore, the purpose of this study is to develop a model that can evaluate several logistic policy measures for metropolitan areas considering individual firm’s behavior and their characteristics. The objectives of this study are as follows:

(1) To propose an improved traffic estimation method for trucks in a metropolitan area. Although conceptually this estimation method follows a four-step aggregate traffic estimation process, realistically it employees disaggregate models and micro-simulations, so the estimation truck OD volume reflects each individual firm's behavior.
(2) To determine the characteristics of firms' freight transport such as the structure of firm's logistic costs when logistic policies are implemented, and to build a disaggregate model that accurately estimates their logistic behavior. These characteristics include.
(3) To forecast the change of road traffic situations before and after policies are enforced, and to evaluate these policies with respect to traffic volume along with emission load of air pollutants.

1.3 Scope of the Study

This study deals with urban goods movement in the Tokyo Metropolitan Area. It includes Tokyo-To, Kanagawa Prefecture, Chiba Prefecture, Saitama Prefecture, and the southern part of the Ibaragi Prefecture. The population of this area is approximately 36 million, the area size is 20,000[km^2], and the population density is 1,800[persons/km^2]. In other words, approximately 30% of Japan's total population lives in this area which totals only 5% of Japan. Severe traffic congestion occurs not only in the morning and evening, but also during the daytime because of an over concentration of socio-economic activities.

Same industry firms have similar logistic characters, such as commodities to generate, parameters to decide goods quantity and delivery frequency. Therefore, this study analyzes these characteristics by each industry. Tokyo Metropolitan Goods Movement Survey (TMGMS) (MLIT, 1982) classified industries into 13 types:
1) agriculture, forestry and fishery
2) mining,
3) construction,
4) chemical manufacture,
5) metal manufacture,
6) machinery manufacture,
7) other manufacture,
8) material wholesaler,
9) product wholesaler,
10) retailer,
11) warehouse,
12) electricity, gas and water supplier, and
13) service and governmental work.

This study utilizes this classification. The following three policies were evaluated by VKT and NOx before and after policy enforcement:
- large size truck ban,
- road pricing, and
- construction of logistic center.

2. METHODOLOGY

Figure 1 shows the flow chart of the methodology for this study. It has two main parts. The first part addresses the development and validation of the traffic estimation model. The traffic estimation method conceptually follows the traditional four-step travel-demand estimation process. Although this process generally utilizes an aggregate model, this study utilizes a disaggregate model because it considers the individual behavior of firms' logistic managers and truck drivers.

Truck volumes, amounts of goods generation, and number of delivery points can be estimated for the industry type and firm size for each shipper. Delivery frequency is determined by the minimization of logistic costs including transport costs and inventory costs. Delivery routes were determined by minimizing total travel time, limitations for carrying weight and driver working time. Departure time was determined by current distribution. Truck OD volumes were computed by aggregation of individual trucks.

After developing an estimation model, it was validated by current traffic volume. When truck OD volumes were estimated by current input data, estimation results were compared with observed data from the Road Traffic Census (MLIT, 1999) and TMGMS (MLIT, 1982). If there is a large difference between the estimated results and observed data, it is necessary to examine the methodology of estimation or each model again.

Another important part of the methodology is the evaluation of how effective the logistic policies are when data is changed. The evaluated policies in this study are as follows: large-size truck ban, road pricing, and construction of a logistic center. When these policies are enforced, each firm may select the lowest alternative cost. These policies are evaluated in terms of VKT and the exhausted amount of NOx. The present state of firms' logistic behavior and goods movement are analyzed in detail from the results of several statistical surveys.

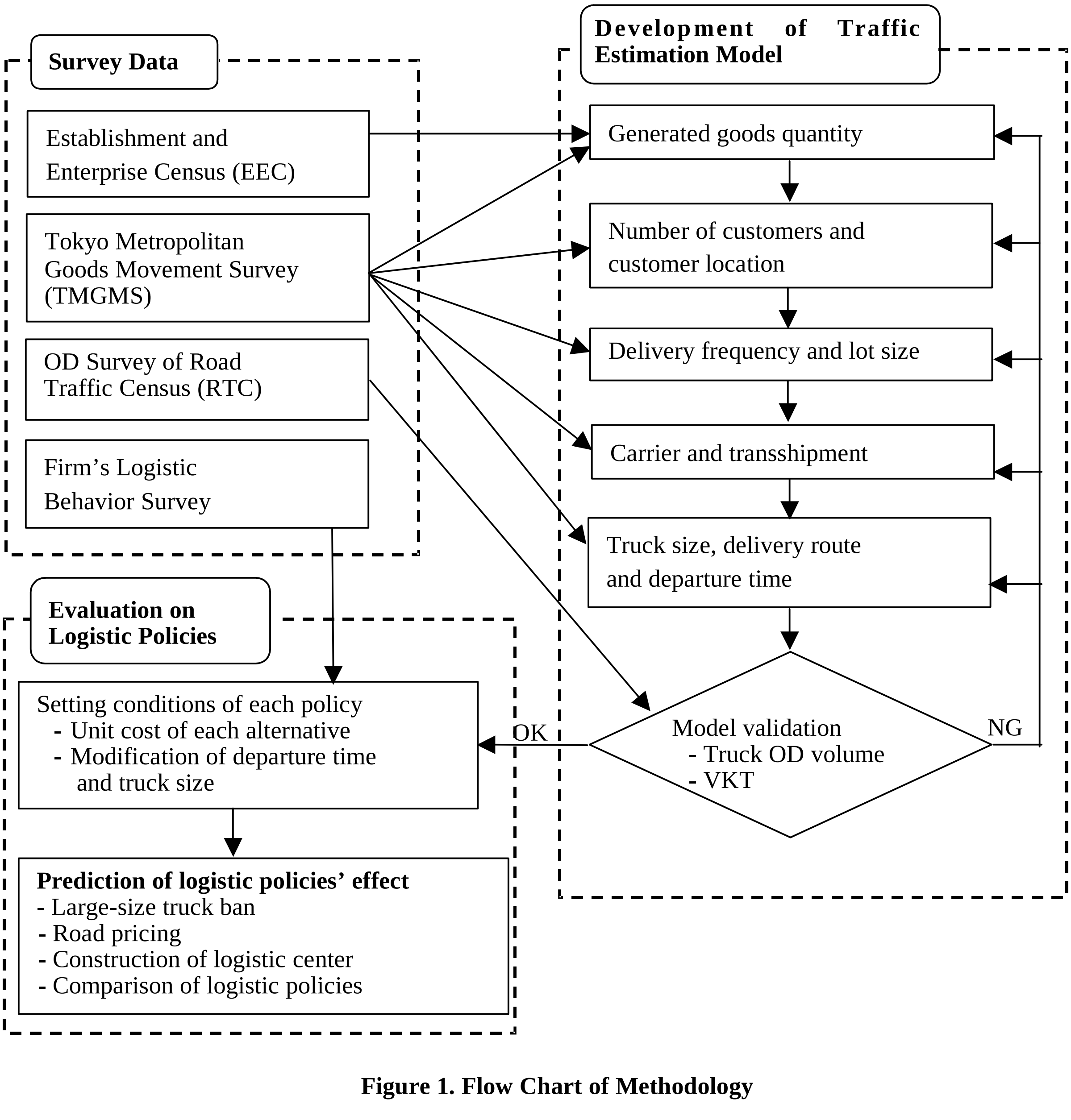

Figure 1. Flow Chart of Methodology

3. DEVELOPMENT OF TRAFFIC ESTIMATION MODEL

The traffic estimation model has been developed as mentioned above. Then traffic volume was estimated by using this developed model. Estimated traffic OD volume was compared to the values of Road Traffic Census (MLIT, 1999), TMGMS (MLIT, 1982) and Statistic Survey of Transportation (MLIT, 1998) for model validation. Table 1 shows the comparison of OD volume generated from the study area.

Since this simulation was based on data from the TMGMS (MLIT, 1999), the estimated value was similar to TMGMS. The value of TMGM was for the year 1982. If this value is multiplied by 1.125, which is the growth factor from the year 1982 to 1999, the total of TMGMS is 5,810. One possible reason for the difference between RTC and TMGMS might be due to the different sampling methods.

Table 2 shows the value of vehicle-kilometer-traveled (VKT). It is a summation of OD traffic volume multiplied by OD distance. The reason that VKT of the simulation is larger than the survey values might be that the TMGMS does not have enough data to obtain distribution pattern from a shipper to customers.

Table 1. Traffic OD Volume Generated from Study Area [unit: *1000 trips]

	Small Truck	Large Truck	Total
RTC*	5,320	2,580	7,900
TMGMS	3,879	1,285	5,164
Simulation	4,065	1,371	5,436

* RTC: Road Traffic Census (MLIT, 1999)

Table 2. Vehicle Kilometer Traveled [unit: 1000 VKT]

	Small Truck	Large Truck	Total
RTC*	61,100	63,800	124,900
SST**	49,641	85,784	135,425
TMGMS	42,502	29,845	72,347
Simulation	73,266	99,165	172,431

* RTC: Road Traffic Census (MLIT, 1999)
** SST: Statistic Survey of Transportation (MLIT, 1998)

4. EVALUATION OF LOGISTIC POLICIES

4.1 Large-size Truck Ban

This study assumed an enforcement following condition because the Firm's Logistic Behavior Survey (PWRI, 2001) addressed each firm's behavior under these conditions. The assumed conditions are as follows:

- Regulated area: inside the 7th ring road
  (Large trucks are allowed to run on the 7th ring road.)
- Regulated date: from 7:00 a.m. to 10:00 a.m. on weekdays
- Regulated vehicle type: large trucks and large special usage trucks

When it was assumed to execute the large-size truck ban with these conditions, firms mainly selected the following alternatives in the Firm's Logistic Behavior Survey (PWRI, 2001):

- Alternative 1: Change delivery time (40%)
- Alternative 2: Change truck size (60%)

There are two cases for changing truck sizes: from one large truck to two small trucks, and from one large truck to one small truck. Therefore, it is assumed that each firm would select the minimum cost alternatives among the following three alternatives:

- Alternative 1: Change delivery time
- Alternative 2: Change truck size from one large truck to two small trucks
- Alternative 3: Change truck size from one large truck to one small truck

There are two cases for changing delivery time: changing to before-regulated time, and changing to after-regulated time. However, this study focuses on only changing to after-regulated time due to the extra labor costs that occur when changing to before-regulated time. Alternative 1 is regarded as requiring a risk cost for interference of business because of changing delivery time. This risk cost is assumed to be proportional to travel time as follows:

$$AC1_{kj} = T_{kj} \cdot Vt \cdot Rt \quad (1)$$

where, $AC1_{kj}$: additional cost for alternative 1 [yen[1]],

T_{kj}: travel time from shipper k to customer j [hours],

Vt: value of time [yen/hour],

Rt: risk ratio of changing delivery time.

The value of time (Vt) comes from driver's cost. Driver's cost for a small truck is assumed to be 600,000 yen per month per one driver. This includes monthly salary, bonus, social insurance, pension saving, and other costs that a firm pays to employ a driver. If working days are 20 per month and working time is eight hours per day, driver's cost for a small truck is 3,750 yen per hour. While driver's cost for a large truck is assumed to be 5,625 yen per hour, which is the driver's cost for a small truck multiplied by 1.5. The risk ratio of changing delivery time (Rt) is set at 5 %.

Alternative 2 sums truck re-purchase cost and other additional costs to present transport cost as expressed by the following equation:

$$AC2_{kj} = Cf_{kj} + Cd_{kj} + Ct_{kj} + Ci_{kj} \quad (2)$$

where, $AC2_{kj}$: additional cost for alternative 2 [yen],

Cf_{kj}: additional fuel cost from shipper k to customer j,

Cd_{kj}: additional drivers' cost from shipper k to customer j,

Ct_{kj}: additional truck re-purchase cost from shipper k to customer j,

Ci_{kj}: additional truck insurance cost from shipper k to customer j.

The fuel cost of one small truck is set as 10 yen per carrying ton and per transport kilometer. The cost of a large truck is assumed to be 1.5 times that of a small truck. Thus, additional fuel cost (Cf_{kj}) is obtained by –5 yen multiplied by the carrying weight and travel distance.

As explained in Alternative 1, the driver's cost for a small truck is 3,750 yen per hour and for a large truck it is 5,625 yen per hour. Under this assumption, additional drivers' cost (Cd_{kj}) is obtained by 1,875 yen multiplied by travel time.

The purchase cost of a small truck is set to 3.3 million yen. If a truck is employed for 10 years and 240 days per year, the cost is 1,375 yen per day. While for a large truck it is assumed to be 2,063 yen per day, which is the cost for a small truck multiplied by 1.5. Therefore, the additional truck re-purchase cost (Ct_{kj}) is 687 yen per day.

Vehicle insurance cost of a truck is assumed to be half of the purchase cost. Thus, this cost is 688 yen per day for a small truck and 1,032 yen per day for a large truck. Additional truck insurance cost (Ci_{kj}) is 344 yen per day.

For the case of Alternative 3, although it needs truck re-purchase cost at the beginning of enforcement, fuel cost and other costs decrease. Thus, these can be regarded to be negative someday. However, when one large truck is changed to one small truck, the risk cost of leaving goods occurs because the margin space decreases. This risk cost is assumed to be proportional to the average quantity of carrying goods as follows:

$$AC3_{kj} = Al_{kj} \cdot Rl \quad (3)$$

where, $AC3_{kj}$: additional cost for alternative 3 [yen],

Al_{kj} : average quantity of carrying goods from shipper k to customer j [kg],

Rl : risk ratio of leaving goods (setted as 0.5 yen per carrying goods kilogram).

When the choice probability is estimated under these conditions, the following results are obtained:

- Alternative 1: 43 %

[1] US$1 is about 130 yen. (1st March, 2002) Source: Yahoo Japan, Market Information.

- Alternative 2: 54 %
- Alternative 3: 3 %

This proportion is similar to the Firm's Logistic Behavior Survey (PWRI, 2001). Table 3 and 4 shows the comparison before and after the enforced large-size truck ban in terms of VKT and NOx in the regulated area.

Table 3. VKT Comparison Before and After Enforced Large-size Truck Ban

1000VKT / day	Small Truck	Large Truck	Total
Before (B)	31,459	51,134	82,593
After (A)	90,389	19,994	110,383
(A) / (B)	2.87	0.39	1.34

Table 4. NOx Comparison Before and After Enforced Large-size Truck Ban

kg / day	Small Truck	Large Truck	Total
Before (B)	32,145	142,216	174,361
After (A)	89,823	55,570	145,393
(A) / (B)	2.79	0.39	0.83

VKT and NOx of the large truck obviously decrease by the large-size truck ban. However, these values of small trucks increase because of Alternative 2 and 3 (changing truck size). Thus, the total VKT volume increases by 34% and the total NOx amount decreases by 17%. This is because the exhaust unit of a large truck is bigger than that of a small truck.

Figure 2 shows the time series of NOx. Since the regulation time is assumed from 7:00 a.m. to 10:00 a.m., large trucks do not generate before 10:00 a.m. If the regulation time is longer than this assumption, the exhaust amount of NOx must decrease even more.

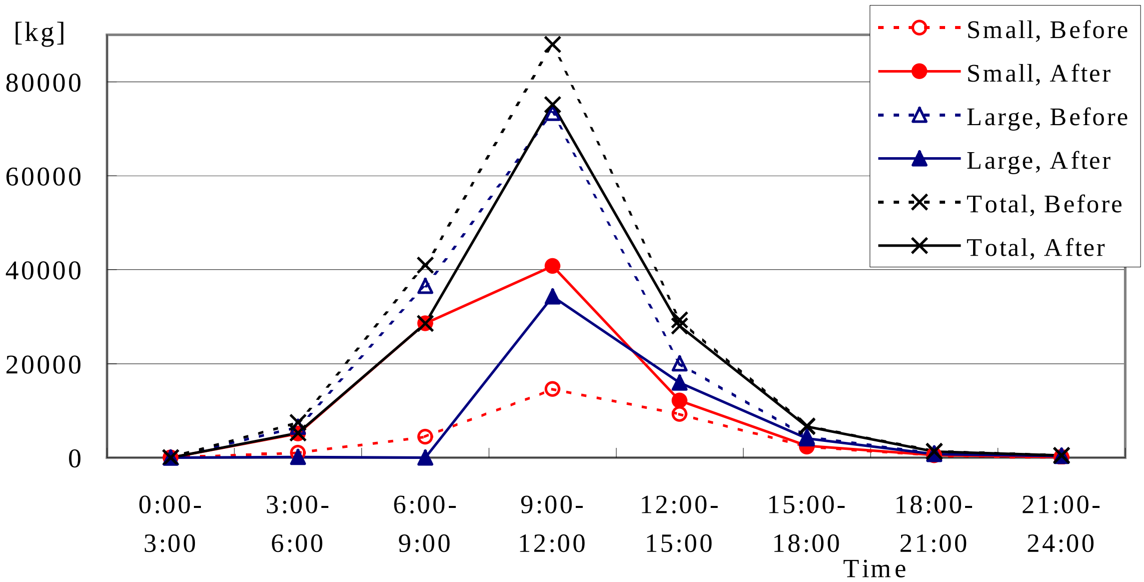

Figure 2. NOx Before and After Large-size Truck Ban

4.2 Road Pricing

This study assumes the following enforcement condition because of the Firm's Logistic Behavior Survey (PWRI, 2001), which characterized each firm's behavior under these conditions. The assumed conditions are as follows:

- Pricing area: inside the 7th ring road (The 7th ring road is free.)
- Pricing time: from 7:00 a.m. to 7:00 p.m. on weekdays
- Pricing method: Each vehicle has to pay a price every time it drives into pricing area

during pricing time.
- Price and ratio of saving travel time is set to five cases as shown in Table 5.

Table 5. Examined Cases for Road Pricing

	Price for Small Vehicle	Price for Large Vehicle	Ratio of Saving Travel Time
Case 1 (basic case)	2,000 yen	4,000 yen	5 %
Case 2	1,000 yen	2,000 yen	5 %
Case 3	3,000 yen	6,000 yen	5 %
Case 4	1,000 yen	2,000 yen	3 %
Case 5	3,000 yen	6,000 yen	8 %

When it was assumed to execute the road pricing under basic case conditions, firms mainly selected the following alternatives in the Firm's Logistic Behavior Survey (PWRI, 2001).
- Alternative 1: Not change delivery style (64%)
- Alternative 2: Change delivery time (18%)
- Alternative 3: Change truck size (18%)

It is assumed that each firm would select the minimum cost alternative among these three alternatives. When a firm selects Alternative 1, they have to pay the pricing cost. However, they may decrease travel time and transport cost because other firms change truck size and delivery time. Saved transport cost is assumed to be proportional to the quantity of goods to carry:

$$BC1_{kj} = Cp_m + L_{kj} \cdot Vt \cdot T_{kj} \cdot Rs \quad (4)$$

where, $BC1_{kj}$: additional cost for alternative 1 [yen],
Cp_m: pricing cost for vehicle size m [yen],
L_{kj}: lot size from shipper k to customer j [kg/time],
Vt: value of time [yen/hour],
T_{kj}: travel time from shipper k to customer j [hours],
Rs: ratio of saving travel time.

The same as the large-size truck ban, the value of time (Vt) utilized for a small truck is 3,750 yen per hour, and for a large truck is 5,625 yen per hour.

There are two cases for changing delivery time: changing to before-regulated time, and changing to after-regulated time. Both cases need extra labor cost since these are not regular working times. Thus, the additional cost for alternative 2 is expressed as follows:

$$BC2_{kj} = Cr \cdot Rx \cdot T_{kj} \quad (5)$$

where, $BC2_{kj}$: additional cost for alternative 2 [yen],
Cr: labor cost in regular working time [yen/hour],
Rx: ratio of labor cost for extra working time,
T_{kj}: travel time from shipper k to customer j [hours].

The same as the value of time, labor cost for regular working time (Cr) of a small truck is 3,750 yen per hour, and 5,625 yen per hour for a large truck. The ratio of labor cost for extra working time (Rx) is set at 20 %.

Alternative 3 considers only the case that one large truck is changed to one small truck. This is because if one large truck is changed to two small trucks, this cost is always higher than Alternative 1. The additional cost for Alternative 3 is expressed as follows:

$$BC3_{kj} = Cp_m + Cc + L_{kj} \cdot Vt \cdot T_{kj} \cdot Rs \quad (6)$$

where, $BC3_{kj}$: additional cost for alternative 3 [yen],
Cp_m: pricing cost for vehicle size m (small truck) [yen],
Cc: additional cost of truck re-purchase and truck insurance [yen],
L_{kj}: lot size from shipper k to customer j [kg/time],
Vt: value of time [yen/hour],

T_{kj}: travel time from shipper *k* to customer *j* [hours],

Rs: ratio of saving travel time.

The unit costs for truck re-purchase and truck insurance are the same cost utilized for the case of a large-size truck ban.

When choice probability is estimated under these conditions, the following results are obtained. Case 1 is the same condition as the Firm's Logistic Behavior Survey (PWRI, 2001), and this proportion is similar to the results of this survey. From Table 6, it can be seen that 1,000 yen for small truck and 2,000 yen for large truck is not a sufficient difference in price to change the delivery style.

Table 6. Choice Probability for Each Alternative

Case	Price for Small Truck	Price for Large Truck	Ratio of Saving Travel Time	Alt. 1	Alt. 2	Alt. 3
Case 1 (Basic Case)	2,000 yen	4,000 yen	5 %	61 %	21 %	18 %
Case 2	1,000 yen	2,000 yen	5 %	94 %	3 %	3 %
Case 3	3,000 yen	6,000 yen	5 %	26 %	54 %	20 %
Case 4	1,000 yen	2,000 yen	3 %	87 %	3 %	10 %
Case 5	3,000 yen	6,000 yen	8 %	32 %	48 %	20 %

Table 7. VKT Comparison Before and After Enforced Road Pricing (Case 1)

1000VKT / day	Small Truck	Large Truck	Total
Before (B)	31,459	51,134	82,593
After (A)	43,144	39,449	82,593
(A) / (B)	1.37	0.77	1.00

Table 8. NOx Comparison Before and After Enforced Road Pricing (Case 1)

kg / day	Small Truck	Large Truck	Total
Before (B)	32,145	142,216	174,361
After (A)	41,639	104,243	145,882
(A) / (B)	1.30	0.73	0.84

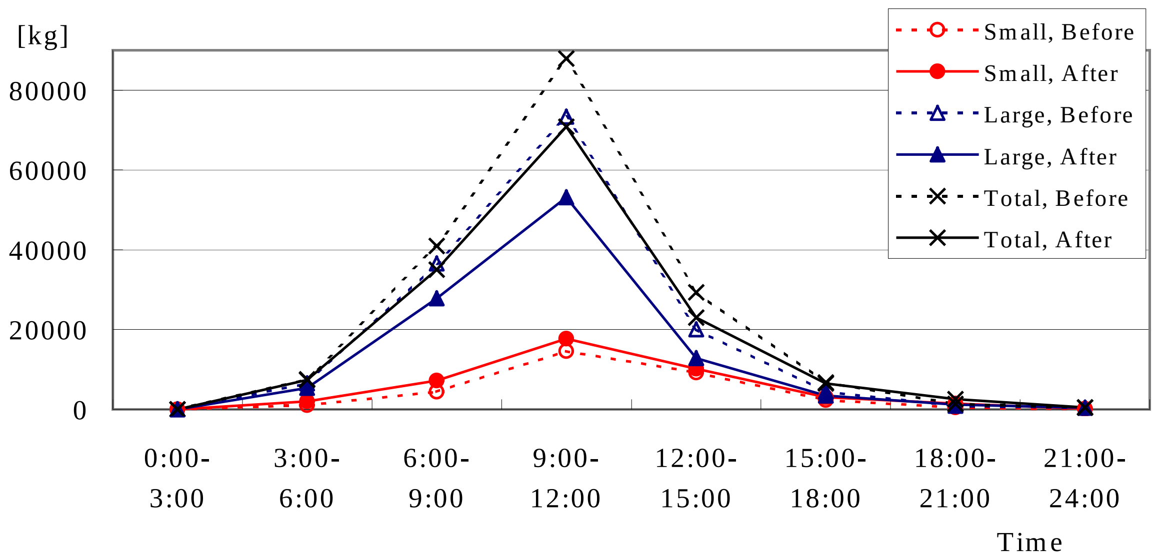

Figure 3. NOx before and after Enforced Road Pricing (Case 1)

Table 7 and Table 8 shows the comparison before and after enforced road pricing in terms of VKT and NOx in the regulated area for case 1. VKT and NOx for large trucks decrease by the road pricing. However, these amounts of small trucks increase because of Alternative 3 (to change truck size). Although the large truck ban assumed the alternative "to change truck size from one large truck to two small trucks", the road pricing dose not assume this alternative but assumes only "to change from one large truck to one small truck ". Thus, total VKT does not change and total NOx decreases by 16%. Figure 3 shows the time series of NOx.

4.3 Logistic Center Construction

The following factors are considered as the different cost between using and not using logistic center:
- construction and maintenance costs of logistic center,
- labor costs for transshipment, and
- different costs of transport.

If the total of these costs is less than zero, it means that using logistic center is less expensive than not using it. Thus, firms prefer using a logistic center for this case. Each firm should have already calculated these costs in the present state, and have decided whether to use or not to use a logistic center. This study, therefore, examines what percentage of firms change to using a logistic center if construction and maintenance costs of a logistic center are decreased by a subsidy.

If the customers' locations are close enough to each other compared to the distance between the shipper and the customer, the proportion of using logistic center becomes high. Thus, this study examined the case of a shipper who is located outside the 23 wards of Tokyo sends goods to customers who is located inside the 23 wards of Tokyo. The location of logistic centers is provided in the Table 9. It reflects to existing truck terminals and logistic centers. In Figure 4, diamond-shape marks express the location of assumed logistic centers.

Table 9. Shipper Location and Location of Logistic Center

Shipper's Location	Location of Logistic Center
Ibaraki and Saitama	Adachi-ward
Chiba	Edogawa-ward
Tokyo except 23 wards	Itabashi-ward
Kanagawa	Kanagawa-ward

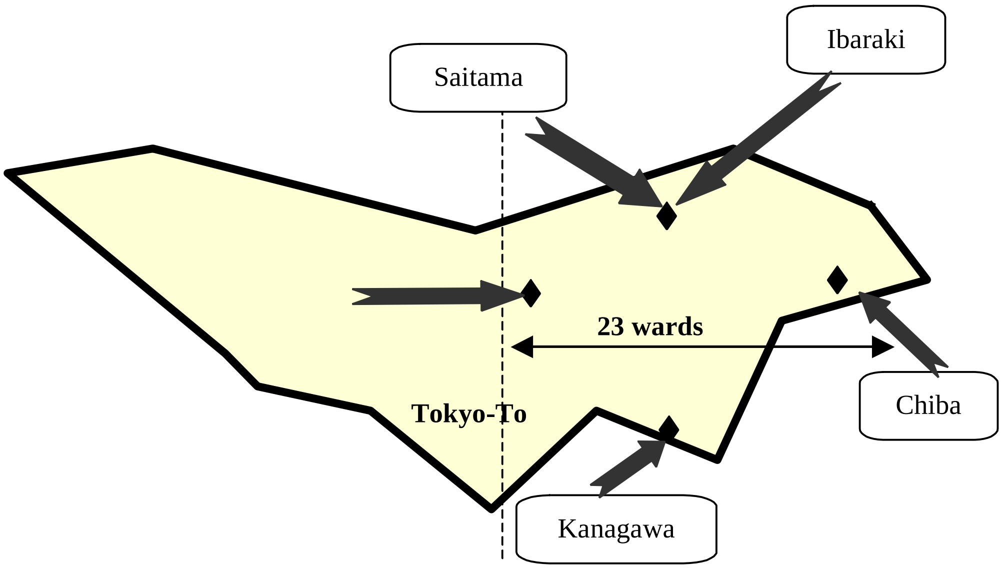

Figure 4. Location of Logistic Centers

In this policy measure, it was examined that whether or not a firm uses logistic center when construction and maintenance costs of a logistic center are decreased by subsidy. Here, the following factors are considered as different costs between using and not using a logistic center:

- Construction and maintenance cost of a logistic center:
  This was set as 10,000 yen per day per ton of carrying out goods when there was no subsidy. This value is an average from the Firm's Logistic Behavior Survey (PWRI, 2001).
- Labor cost for transshipment:
  This was set as 5,000 yen per day per ton of carrying out goods. This value was also obtained from the Firm's Logistic Behavior Survey (PWRI, 2001).
- Different cost of transport:
  Unit costs to compute this cost were the same value utilized for the large-size truck ban.

When choice probability is estimated under these conditions, the following results are obtained.

Table 10. Choice Probability for Each Alternative

Percentage of Construction and Maintenance Cost of Logistic Center that a Firm Pays	Not to use Logistic Center	Use the Logistic Center
100 % (Case 1)	98.3 %	1.7 %
75 % (Case 2)	97.2 %	2.8 %
50 % (Case 3)	96.6 %	3.4 %
25 % (Case 4)	95.5 %	4.5 %

Table 11. VKT Comparison Before and After Construction Logistic Center (Case 3)

1000VKT / day	Small Truck	Large Truck	Total
Before (B)	37,712	57,458	95,170
After (A)	37,712	57,456	95,168
(A) / (B)	1.00	1.00	1.00

Table 12. NOx Comparison Before and After Construction Logistic Center (Case 3)

kg / day	Small Truck	Large Truck	Total
Before (B)	38,535	159,858	198,393
After (A)	38,535	159,854	198,389
(A) / (B)	1.00	1.00	1.00

The theoretical percentage of not using a logistic center for the first case was 100 %. This suggests that 1.7 % of firms do not use a logistic center because of some reasons, though the cost is low. From Table 10, only 4.5 % of firms change to using a logistic center even if the construction and maintenance costs decrease by 25 %. This may be because the same carrying ratio of truck is utilized for both cases of using and not using of a logistic center. Thus, if the carrying ratio increases when it uses logistic center, the percentage using logistic center must increase as well. Since only 3.5% changes to use a logistic center in case 1, VKT and NOx decreases little in shown Table 11 and 12.

4.4 Comparison of Logistic Policies

The logistic policies are evaluated using VKT and NO_X. If the values of these indicators are increased by a logistic policy, it suggests that the policy is inappropriate. Table 13 and 14 show the comparison three logistic policies with respect to VKT and NOx. In these tables, the values of non-enforcement are the current values inside of the 7^{th} ring road, which is the regulation area for the large-size truck ban and the road pricing. On the other hand, the examined area for the construction of logistic center was the 23 wards of Tokyo. Thus, it is not adequate to compare between the construction of logistic center and two other policies directly. However, these tables show some tendencies.

From Table 13, the VKT of a large-size truck ban greatly increased though the values of the other two policies did not change from non-enforcement. The reason for this is the alternative to change truck size from one large truck to two small trucks. However, the NOx of a large-size truck ban decreased the most among three policies as shown in Table 14. This is because exhaust unit of a large truck is much larger than that of a small truck.

Table 13. Comparison of Logistic Policies by VKT in Examined Area

1000VKT / day	Small Truck	Large Truck	Total
Non-enforcement	31,459	51,134	82,593
Large-size Truck Ban	90,389	19,994	110,383
Road Pricing (Basic Case)	43,144	39,449	82,593
Construction of Logistic Center (Case 3)	37,712	57,456	95,168

Table 14. Comparison of Logistic Policies by NOx in Examined Area

kg / day	Small Truck	Large Truck	Total
Non-enforcement	32,145	142,216	174,361
Large-size Truck Ban	89,823	55,570	145,393
Road Pricing (Basic Case)	41,639	104,243	145,882
Construction of Logistic Center (Case 3)	38,535	159,854	198,389

Table 15. Comparison of Logistic Policies by NOx and Cost

	Difference of NOx [kg] (A)	Difference of cost [1000yen] (B)	(B) / (A) [1000yen / kg]
Large-size Truck Ban	-28,968	1,438,876	-50
Road Pricing (Basic Case)	-28,479	669,365	-24
Construction of Logistic Center (Case 3)	-4	-129,387	32,347

Table 15 comparatively shows the three logistic policies with respect to NOx and cost. In this table, (A) is the difference of NOx between before and after an enforced logistic policy. For instance, when a large truck ban is implemented, 28968kg of NOx is decreased compared to before implementation. (B) is the difference of cost for firms between before and after enforced logistic policies. This was computed by summing up minimum additional costs. Thus, when a large truck ban is implemented, total additional cost is approximately 1439 million yen. This implies that firms have to pay an additional 50,000 yen to decrease 1kg of NOx by a large size truck ban. On the other hand, firms are charged with only an additional 24,000 yen to decrease 1kg of NOx by road pricing.

For construction of a logistic center, firms can decrease their logistic cost by about 129 million yen because they have to pay only half of the logistic center cost and they can save transport cost by using the logistic center. However, NOx is decreased by only 4kg.

Therefore, road pricing is the most efficient policy by this comparison. It is possible to compare other cases with this methodology. This method is available to judge which policy is the most efficient or effective by comparing VKT and NOx.

5. CONCLUSIONS

This study developed a micro-simulation model to evaluate several logistic policy measures in metropolitan areas considering individual firm's behavior and their interaction. This model applied the traditional four-step travel-demand estimation process. Although the traditional four-step travel-demand estimation process commonly utilizes an aggregate model, this study employs disaggregate models and micro-simulations in order to reflect each firm's characteristics. Disaggregate models for each step were developed by using data from the Tokyo Metropolitan Goods Movement Survey (TMGMS) (MLIT, 1982), which had approximately 46,000 samples of firms. The developed models were applied to all firms in the Tokyo Metropolitan Area.

When the current data was applied to this model and truck OD volumes were estimated, the simulation results were similar to the survey results, and the VKT estimated by simulation was larger than the survey results. Although each estimation model was not completely sufficient in accuracy, this study shows the framework of a methodology to predict future traffic states.

This methodology could determine the characteristics of firms' freight transport when estimation models are developed. For instance, goods generated for most industries are directly proportional to the number of employees. Retailers generated approximately half the number of all fleets, and their delivery frequency has increased over the past 20 years. It was also possible to grasp the structure of firm's logistic costs, especially when logistic policies were implemented. The following three policies were evaluated by VKT and NOx before and after policy enforcement:

- large size truck ban,
- road pricing, and
- construction of logistic center.

When a large-size truck ban and road pricing were implemented, traffic volume for small trucks increased because of changing the truck size from large trucks to small trucks. Thus, the total VKT did not change or increase when these policies were enforced. However, the total exhaust amount of NOx decreased approximately 30 tons, which corresponds to 20% of all exhaust in the regulated area. This is because the unit exhaust amount of a large truck is much more than that of a small truck. In addition, the construction of the logistic center was not very effective under these examined conditions.

From the cost comparison, firms have to pay an additional 50,000 yen to decrease 1kg of NOx with a large-size truck ban. However, firms are charged only an additional 24,000 yen to decrease 1kg of NOx by road pricing. Therefore, road pricing was regarded as the most efficient policy among these three policies in this simulation. It is certainly possible to examine other conditions, and this simulation is available to judge which policy is the most efficient or effective by comparing VKT, NOx and costs.

Since road pricing is a strict policy compared with the other two policies, it proved to be the most effective policy in this simulation. However, it was not considered the cost to collect fees for the government. If this cost were included in the simulation, the results would be distorted because the cost is substantial especially in urban area. When a road pricing is enforced, it is necessary to examine the method of fee collection and to explain the purpose of this policy to road users. Although this simulation showed that construction of a logistic center was not effective, it is true that the effectiveness must increase if the carrying ratio increases when using the logistic center.

Some ideas are recommended for future study:

- This study did not compute traffic assignments on the road network. However, it may be possible to obtain more real travel time and travel speed. Furthermore, it is possible to evaluate other logistic policies such as recommended truck routes and road construction by using traffic assignment.
- This study did not examine a re-allocation model of firms. It is only a model that considers firms that stay in their present location or move to another location when

logistic policies are implemented. For example, if road pricing is enforced, firms may move their office or factory to avoid paying a higher pricing fee. This model would be important for long term planning.

- As mentioned in the conclusion section, each estimation model has yet to be improved. The data of TMGMS, which is mainly utilized for model building in this study, was satisfactory in terms of survey items and number of samples. However, it was surveyed 20 years ago, and some states have changed, such as industry proportions and delivery frequencies. Therefore, more recent data is necessary to re-estimate the model's parameters.
- The mechanism and unit costs of the logistic costs are not characterized enough because of a lack of samples from the Firm's Logistic Behavior Survey (PWRI, 2001). This needs to be surveyed again to obtain more precise data.

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