Micro-Simulation Model for Modeling Freight Agents Interactions in Urban Freight Movement

Wisinee Wisetjindawat
Department of Civil and Environmental Engineering
Nagaoka University of Technology
1603-1 Kamitomioka-Machi, Nagaoka, Niigata, 940-2188, Japan
Phone: +81-2-58-47-1611 (Ext. 6635)
Fax: +81-2-58-47-9650
Email: wisinee@stn.nagaokaut.ac.jp

Kazushi Sano
Department of Civil and Environmental Engineering
Nagaoka University of Technology
1603-1 Kamitomioka-Machi, Nagaoka, Niigata, 940-2188, Japan
Phone: +81-2-58-47-9616
Fax: +81-2-58-47-9650
Email: sano@nagaokaut.ac.jp

Shoji Matsumoto
Department of Civil and Environmental Engineering
Nagaoka University of Technology
1603-1 Kamitomioka-Machi, Nagaoka, Niigata, 940-2188, Japan
Phone: +81-2-58-47-9615
Fax: +81-2-58-47-9650
Email: shoji@nagaokaut.ac.jp

Pairoj Raothanachonkun
Department of Civil and Environmental Engineering
Nagaoka University of Technology
1603-1 Kamitomioka-Machi, Nagaoka, Niigata, 940-2188, Japan
Phone: +81-2-58-47-1611 (Ext. 6635)
Fax: +81-2-58-47-9650
Email: pairoj@stn.nagaokaut.ac.jp

Paper Number: 07-2224
Submission Date: 1st August 2006
Re-Submission Date: 15st November 2006
Word Count: Text (5,183) + Figures/Tables (6*250) = 6,683

86th Annual Meeting of the Transportation Research Board
January 21-25, 2007. Washington D.C.

ABSTRACT

This paper proposes a micro-simulation model for urban freight movement, in which the behavior of freight agents and their relationship in supply chains are incorporated. The proposed model is a modification of the traditional four-step approach in that it considers the behavior of each freight agent individually. This paper covers three of the four steps of the traditional approach, including commodity production and consumption, commodity distribution, and conversion of commodity flows to truck flows. The results from the model will be truck OD matrices and the approximated VKT of trucks by each truck type. The proposed model utilizes the concepts on logistics and operation research to explain the behavior of each freight agent while dealing with freight movement. This paper will discuss the issues on the model framework, model formulations, and validation results of the model applying to analyze the urban freight movement in the Tokyo Metropolitan Area.

Keywords: Micro-Simulation, Supply Chain, Urban Freight Movement

INTRODUCTION

Transportation planers typically use a freight demand model as a tool to assess the decision making on freight transportation systems. However, the challenge of modeling freight transportation system has been widely known since freight transportation systems involve very complex linkages among many freight agents, including shippers, customers, and carriers. The heterogeneity of freight transportation also includes the characteristics of commodities those vary in volume, weight, and shape.

A number of attempts have been made to describe freight transportation systems for decades. The earliest models estimated freight transportation as the percentage of passenger trips from the traditional four-step approach. The current freight demand modeling tends to model truck flows explicitly. This type of models can be categorized into two groups: trip-based and commodity-based approaches (*1*). Trip-based approach mostly deals with truck trips at the aggregate level. The truck trips are generated directly from the factors such as number of employees, floor area, and any other related factors without concerning the amount of commodity production and consumption. The example of this approach is the work of Park and Smith (*2*), which developed the model for truck estimation at statewide level. The model applied the traditional four-step approach including trip generation, trip distribution, and traffic assignment. Trip rate technique was used in the trip generation model together with truck traffic volumes for adjustment of trip production and attraction to be matched to the actual volumes. List and Turnquist (*3*) estimated the truck trips matrices by different truck classes with multi-time period in urban area from the counted truck volume on the network. The model attempts to deal with various kinds of input data, including link volumes, partial OD estimates for various zones, and originating and terminating data, in order to improve the accuracy of estimates. Eriksson (*4*) discussed the empirical approach to freight transport forecasting in urban area. The model generated OD matrices from the traffic flow by considering the changes of demographic variables and time variation of traffic over day and year. In addition, the model included the effects of economic control (such as road pricing, and change of fuel price). Matt and Visser (*5*) utilized a geographic information system (GIS) for simulation model of urban freight transportation. The simulation was able to incorporate trip chain of freight transport using GIS. The GIS was used as a tool for route simulation which resulted in the sequence of visits for picking up or delivery at the optimum distance, time, or cost. However, the limitation of trip-based approaches is that it is difficult to evaluate logistic policies because the trips are derived directly from the empirical data. In addition, it should be noted that the freight transportation is originated from the movement of commodities.

To overcome the drawback of trip-based approach, commodity-based approach focuses on the movement of commodities. At the stage of trip generation, instead, the approach generates the level of commodity production and consumption. Consequently, they require the additional stage for the conversion of the commodity flows to vehicle tours. Applied examples of the approach are shown as follows. Sivakumar and Bhat (*6*) applied the fractional split distribution model at the statewide level. The model focused on only the stages of trip generation and distribution. They determined the consumption level at the trip generation stage and used the fractional split distribution model which is similar to a multinomial logit model. They stated that the consumption demand at the destination was the key factor to generate the freight movement. In addition, the model could include the impact of spatial patterns at the commodity production. Boerkamps et al. (*7*) proposed an urban freight movement model, which integrated the behavior of the freight decision makers in the supply chain including shipper, carrier, receiver, and politics. The model predicted the commodity flow based on the consumption demand of end users. The demand was linked to the supply according to the spatial distribution and market share resulting in commodity flow. Once the commodity flow was estimated, the commodities were allocated to vehicle tours and modes. Then, tours were assigned to the infrastructure network. His remarkable is that the logistic concepts are incorporated within the model and better reflect the actual behavior of freight movement. Garrido and Mahmassani (*8*) developed the distribution of a freight transportation demand model over space and time. They modeled the distribution of the choices of shipments (defined as commodity type, origin, destination, mode, and time) taken place using multinomial probit model. The model was able to define the origin-destination by commodity type, mode, and time simultaneously. It was validated to the actual shipment in Texas at the variation of seasons. The recent development on microscopic freight models can also be seen in the works of Liedtke (*9*) and Wisetjindawat (*10*).

Up to present, in the field of freight demand models, most models have not yet considered the concepts in operation research in modeling of freight movement. There are, in fact, several models developed in the field of operation research and logistic sciences (such as vehicle inventory, routing and scheduling) that should be incorporated into the modeling of freight movement in order to improve the model to be close to the actual situations.

The model presented in this paper is, therefore, a micro-simulation model focusing on the behavioral level of freight transportation in which freight agents interact in supply chains. This paper aims to propose the model framework and to show the application of the model to analyze the urban freight movement in the Tokyo Metropolitan Area. In the next section, the proposed model framework is discussed and the details on model formulations are provided. The results of the proposed model applied to analyze the freight movement in the Tokyo Metropolitan Area are further explained. The final section provides conclusions and recommendations on the proposed model.

MODEL FRAMEWORK

The proposed model is a microscopic type model, which is a modification of the traditional four-step approach. The model reproduces each firm individually rather zone-based traditional four-step approach does. The structure of the proposed model is depicted in Figure 1. The model structure consists of four main stages including:

1) Commodity production and consumption,
2) Commodity distribution,
3) Conversion of commodity flows to truck flows, and
4) Traffic assignment.

A micro-simulation model was developed in the way that the behavior of each freight agent is individually considered to determine the characteristics of each freight movement. As the model considers the behavior of each firm individually, the necessary attributes of each firm were generated using micro-simulation technique based on the aggregate data of the database of the establishments and enterprises in the study area. The attributes of each firm, such as location, number of employees, and floor area from their distributions, are generated using Monte Carlo simulation technique. At the first modeling stage, commodity generation, the amounts of commodity production and consumption of each firm are estimated using regression techniques with the firm's attributes generated from micro-simulation. The generated commodities are then linked from consumption points to production points according to the attractiveness of each production point resulting in commodity flows between consumption and production points. Fundamentally, it is the demand at consumption points that determines the amount of commodity that should be supplied at production points. Discrete choice models are selected to explain customer's behaviors on their purchasing choices. Commodities are then distributed from firms to firms over the entire area according to their relationships in supply chains. Customer's purchasing choice is derived from the multiplication of three probabilities including probability of distribution channel, probability of shipper location, and probability of selecting each shipper. Probability of distribution channel explains the structure of supply chain for each commodity type.

In a supply chain, there are many possible distribution channels, which are defined as the paths connecting customers and shippers of a commodity. For example, retailers can select to purchase a commodity from other retailers, wholesalers, or the higher levels. The probability of shipper location explains the choice behaviors of customers on selection of the location of a commodity from which will be purchased. For example, customers might prefer to purchase food products from the nearer location while traveling farther to purchase electronic products. The probability of selecting each shipper describes the attractiveness of a shipper to customers. Bigger shops or companies would attract more number of customers comparing with the smaller ones. These probabilities can be directly derived from the empirical data as same as it is done in discrete choice models. At this stage, the spatial correlation among customers also is included in the modeling system. This is because the firm's choice decisions are commonly impacted by the interactions among other firms.

The commodity flows resulted from the former stage are converted to freight flows through three stages: the delivery lot size and frequency, vehicle choice selection and vehicle routing models. The commodity flows will be divided into a small lot size to be delivered at a time. The key behavior of freight decision makers considered in the delivery lot size and frequency model is that customers and shippers both attempt to minimize their costs comprising inventory and transportation costs. Then, each lot size is assigned to a truck and carrier using a vehicle choice model, which is also a discrete choice model. In this sub-model, shippers make most important decisions on vehicle and carrier selection so that the choice model is based on the minimization of total transportation costs occurred to the shippers. Finally, lot sizes that have been assigned to trucks and carriers will then be converted to vehicle tours. The delivery tours of each truck are decided in that way, that it is aimed at the minimization of the total delivery costs to the carrier of that truck.

At this stage, the model results in truck trip OD matrices by truck type. The truck trip OD matrices resulted from the former stage are then together assigned with passenger trip OD matrices to a road network through traffic assignment resulting in network loads and changes in link travel times. Link travel times are, in fact, the factors having the most significant influence on freight movement characteristics. The changes in link travel times do not only affect route choice (as generally considered by traffic assignment) but also delivery lot size and frequency, vehicle choice selection, and especially to delivery routing. To capture the interaction between the network availability and the decision-making process of the freight decision makers (including shippers, customers, carriers, and truck drivers), an iterative process is used to update the value of link travel times and to recalculate the freight movement characteristics. The values of link travel times resulted from traffic assignment are again integrated to the model at the stage of delivery lot size and frequency. Vehicle and carrier choices and vehicle routing are then consequently recalculated. Then, the recalculated truck trip OD matrices are again assigned to the road network. This process will be continued until there are small changes in the values of the truck OD matrices. The criterion to stop iteration is shown by the following equation (*11*).

$$\max\left(\frac{\left|x^{n}-x^{n-1}\right|}{x^{n}}\right) \le \varepsilon \tag{1}$$

where, x^n is element of the OD matrix at iteration n. x^{n-1} is element of the OD matrix at iteration $n-1$. ε is stopping criterion, in this case uses 0.01

MATHEMATICAL FORMULATIONS

Commodity Generation

At first, the model generates the total monthly amounts of commodity production and consumption by each firm. Regression models are used to estimate the amounts of commodity production and consumption by firm size indicators such as number of employees and floor area as shown in Equations (2) and (3).

$$G_i^k = \alpha_1^k x_{i1} + \alpha_2^k x_{i2} + \ldots + \alpha_n^k x_{in}, \quad G_I^k = \sum_{i \in I} G_i^k \tag{2}$$

$$A_j^k = \chi_1^k y_{j1} + \chi_2^k y_{j2} + \ldots + \chi_m^k y_{jm}, \quad A_J^k = \sum_{j \in J} A_j^k \tag{3}$$

Where, G_i^k is the amount of commodity k produced by shipper i. α_n is a parameter for production indicator n of commodity k. x_{in} is the production indicator n of firm i. G_I^k is the total amount of commodity k generated in zone I. A_j^k is the amount of commodity k consumed by firm j. χ_n is a parameter for consumption indicator m of commodity k. y_{jm} is the consumption indicator m of firm j. A_J^k is the total amount of commodity k attracted into zone J.

Commodity Distribution

The generated commodities are distributed from firm to firm throughout the study area. Starting from the consumption firm, the firm selects suppliers for each commodity according to the attractiveness of the suppliers and the relationship between the firms in the supply chain of commodity. The attractiveness of suppliers is derived from the distance between supplier and customer and the amount of commodity produced by each supplier. Commodity distribution derived from the commodity flow between shipper and customer is calculated by multiplying the fraction of a customer purchasing a commodity from a shipper by the total consumption amount of the customer as follows:

$$Q_{ij}^k = P_j^k(i) \cdot A_j^k \tag{4}$$

where Q_{ij}^k is the commodity flow between shipper i to customer j for commodity k. $P_j^k(i)$ is the probability of shipper i being selected by customer j for buying commodity k. A_j^k is the total consumption amount of customer j for commodity k.

Distribution channels express the relationship between the customers and shippers of a commodity in a supply chain. The typical supply chain shown in Figure 2 demonstrates that there are relationships between industries such as the relationship between supplier and manufacturer, between manufacturer and wholesaler, and between wholesaler and retailer. Therefore, the distribution model consists of three parts: probability of distribution channel, probability of shipper location, and probability of selecting each shipper. The product of all three parts yields the probability of a given shipper being selected. The mathematical form of the model can be shown as follows:

$$P_j^k(i) = P_j(C^k) \cdot P_j(z|C^k) \cdot P_j(i|C^k, z), \quad i \in C^k, z \tag{5}$$

where $P_j(C^k)$ is the probability of distribution channel C being used for commodity k. $P_j(z|C^k)$ is the probability of zone z being selected, given distribution channel C. $P_j(i|C^k, z)$ is the probability of shipper i is selected by customer j, given distribution channel C and zone z.

Distribution Channel Choice

The probability of a distribution channel being selected for purchasing a commodity,

$P_j(C^k)$, is determined from the percentage of each distribution channel being used to distribute each type of commodity.

Zone Choice

A customer's decision is often influenced by spatial interactions with other customers in the nearby zones. The proposed model incorporates the spatial interaction into this choice probability. The model predicts the probability of consumption by each customer to purchase a commodity originating from each production zone. Each individual firm is assumed to choose a zone for purchasing a commodity according to the attractiveness of each zone, represented by the utility function of alternative zones. The sum of the fraction over all production zones for each customer's firm must be equal to one, and the fraction should satisfy the following constraints.

$$\sum_{z \in Z} y_{zj} = 1 \quad \text{and} \quad 0 \le y_{zj} \le 1 \tag{6}$$

Where, y_{zj} is the fraction of commodity consumed by customer j and supplied from zone *z*. Z is the total number of zone alternatives. Therefore, the probability that zone z, given distribution channel C^k, is selected for purchasing commodity *k* for customer's firm *j* can be expressed as follows:

$$P_j(z|C^k) = \frac{\exp(V_{zj})}{\sum_{z' \in Z} \exp(V_{z'j})} \tag{7}$$

Where, V_{zj} is the zonal attractiveness of zone *z* to customer *j*.

The model incorporated spatial dependences proposed by Mohammadian et al (*12*) to explain housing choice behavior considering the interactions among decision makers by adding the interaction part into the deterministic part of the choice model. The application of the model shows an interesting improvement of the results with the spatial interaction over those without the spatial interaction. The spatial commodity distribution model developed by Wisetjindawat et al (*13*) confirms that customer decision making is significantly influenced by the decision of the other customers. We, therefore, apply this concept to explain the interaction among customers. The specification of distance decay functions utilized in this paper is an inverse distance function. For the deterministic part (V_{zj}), the model after adding the interactions becomes

$$V_{zj} = X_{zj}\boldsymbol{\beta} + \phi_{zj} = \sum_{k=1}^{K} \beta_{zk} x_{zjk} + \lambda \sum_{s=1}^{S} y_{zs} \frac{1}{d_{js}^{\ \delta}} \tag{8}$$

where β_{zk} is a parameter corresponding to the observed characteristic x_{zjk} of alternative zone z and customer j. λ is a scalar unknown parameter. y_{zs} is the consumption fraction of alternative zone z of customer s when S is the total number of customers. d_{js} is the distance between customers j and s, where customer j is the decision maker and customer s is another customer. δ is a scalar unknown parameter.

The estimation of the model is used the same method as for general multinomial logit by using the maximum likelihood method. The paper performs model calibration using the GAUSS programming language

Shipper Choice

Shipper choice, $P_j(i|C^k, z)$ is the probability of a shipper being selected. Shipper choice probability is used to identify the shippers from which a customer purchases. However, due to the limitation of the survey data that does not allowed to identify the exact shipper from which each customer makes purchases, we assume that the larger the amount of commodity that the shipper produce, the bigger the market share from customers are. Based on the above assumption, the shipper probability can be derived directly from the exponential of the production amount of a shipper divided by the sum of the exponential of all shippers in the given distribution channel and zone, as shown by Equation (9). The conditional probability that shipper i is chosen by customer j, given C^k and z, is

$$P_j(i|C^k, z) = \frac{\exp(G_i^k)}{\sum_{i' \in C_j} \exp(G_{i'}^k)} \tag{9}$$

where G_i^k is the amount of commodity k produced by shipper i. i' is a shipper in C_j, which is the set of shippers in the given C^k and z.

The details on model formulations, model calibration, and model estimation of commodity generation and distribution models are provided in the paper of Wisetjindawat et al (*11*).

Conversion of Commodity Flows to Truck Flows

The methodology to convert the commodity flows to truck flows includes three steps: Delivery lot size and frequency, Carrier and vehicle choices, and vehicle routing. The process starts with deciding the delivery lot size and frequency for each commodity flow. Then, carrier and vehicle choice are assigned to each lot size. Then, the customers of each shipper, who have the same delivery frequency, carrier and vehicle type, will be grouped together to be delivered at the same time by a vehicle routing model. The vehicle routing model results the route travel time, which will be used as an input to the carrier and vehicle choice model to improve the results to be more realistic. The process will be continued until the choices are stable.

Delivery Lot Size and Frequency

Assuming that, lot sizes are the same at every delivery for each customer. The delivery lot size and frequency has the following relationship:

$$Q_{ij}^{k} = L_{ij}^{k} \cdot F_{ij}^{k} \tag{10}$$

where, Q_{ij}^{k} is the monthly amount of commodity type k that flows between shipper i and customer j. L_{ij}^{k} is the delivery lot size of commodity type k between shipper i and customer j. F_{ij}^{k} is the delivery frequency of commodity type k between shipper i and customer j.

Delivery lot size and frequency mainly depends on two types of costs: inventory costs and transportation costs. Inventory cost is proportional to the amount of lot size; on the contrary, transportation cost is proportional to delivery frequency and distance. This paper assumes the delivery lot size is a function of distance between shipper and customer of a commodity. The model is calibrated separately by industry type of shipper and commodity type. The sign of parameter b will be positive or negative depending on the shipper mainly focusing on either inventory or transportation costs.

$$L_{ij}^{k} = a + bD_{ij} \tag{11}$$

Where, a, b are the parameters to be estimated. D_{ij} is the distance between shipper i and customer j.

Carrier and Vehicle Choices

Shippers play a major role in the selection of carrier and vehicle choice. The characteristics of the shippers, customers, transported commodities, and firm spatial distribution strongly influence the decision on carrier and vehicle choices. The characteristics of shippers and customers can be represented by type of firms (retailer, wholesaler, or manufacturer), number of employees, and other characteristics. Attributes of transported commodities include commodity type, delivery lot size and frequency, and other characteristics related to the commodities.

This research utilizes a nested logit model to describe the choice decision process. The model is structured on two levels: carrier choice and vehicle choice, as shown in Figure 3. The type of carriers significantly impacts vehicle choice. Whenever the shipper decides to deliver by using a carrier, the decision makers are immediately changed to the selected carrier. Carriers mainly include private truck, rental truck, share truck, and delivery service truck. The decision maker of private and rental trucks is still the shipper itself and the truck will be used to deliver only the customers of the shipper. On the other hand, share truck or delivery service truck is a kind of consolidation truck, which will be used to deliver customers of the shippers that are shared together.

For vehicle choice, this research categorizes truck size into two types: small truck and large truck. The small truck category covers trucks that have a maximum carrying weight less than five tons, including light truck, small truck, and pickup truck. In contrast, the large truck category covers the trucks that have more than five-ton maximum carrying weight including large truck and special truck.

Shippers are assumed to select the choice that minimizes the total delivery cost to customers. The total cost is calculated differently for each type of truck and carrier and from the total route distance resulted from vehicle routing model.

Vehicle Routing

When the vehicle type has been decided, vehicle routing simulation is performed in order to converse the commodity flows to vehicle tours. Vehicle routing simulation will provide a sequence to visit customers or a trip chain of each truck. The delivery route is decided in the way that will minimize the route travel time, which is constrained by the maximum working hours of a truck driver and limited carrying weight of a truck.

RESULTS

Data Sets

The Tokyo Metropolitan Area (TMA) is selected for analysis in this paper. The area covers five prefectures including Tokyo, Kanagawa, Chiba, Saitama, and the southern part of Ibaraki. The area is divided into 56 zones according to the A-zone classification of the Tokyo Metropolitan Goods Movement Survey (TMGMS) comprising 52 zones within the study area and 4 zones for the prefectures nearby the study area for analysis of external trips.

There are three sources of data set used for model calibration, model input, and model validation. First, the data of TMGMS survey was used for model calibration. This data was collected from the firms throughout the TMA by the City and the Regional Development Bureau of the Japanese Ministry of Construction every five years. We utilize mainly the database of 1982 since this database provide the most complete information required for model calibration and use the database of 1994 for projection to 1999 for the purpose of model validation. The data delivers information from approximately 46,000 firms, corresponding to three percent of all firms in the study area. The data consist of records on commodity movement and truck movement of each firm. Each record provides information about firm characteristics, commodity movement, and truck movement. The information of firm characteristics includes industry type, number of employees, floor area, and other related information. In the same way, the information on commodity movement and vehicle movement includes commodity type, weight carried in and out, delivery frequency, truck type, carrier type, and other related information.

Second, the Establishment and Enterprise Census data (EEC) were collected by the Statistics Bureau in the Japanese Ministry of Public Management, Home Affairs, Posts and Telecommunication in 1999. This data covers all the enterprises in Japan. The data provide the general information about firms, for example, industry type, location, number of employees, and other related issues.

Third, the Road Traffic Census (RTC) data was conducted covering the whole area of Japan by the Road Bureau of the Ministry of Land, Infrastructure and Transport in the Japanese Government. The survey aims to characterize the usage of automobiles and road traffic volumes in Japan. The survey is usually conducted every five years and the survey data utilized in this paper is the one that was conducted in 1999. The data consist of two parts: the link traffic volume and OD survey data. The survey range covers all types of vehicles including passenger cars, buses, and trucks. Link survey data includes road characteristics, traffic volumes classified by vehicle type, travel time, and other related items. OD survey data includes vehicle trips OD (passenger cars, buses, and trucks), commodity OD by commodity type, and other related items.

Prior step before model development is the proper classification of commodities and industries. We categorize the commodities into 8 groups including 1) Agricultural Products, 2) Forestry Products, 3) Mineral Products, 4) Metal and Machinery Products, 5) Chemical Products, 6) Light Industry Products, 7) Other Products, and 8) Wastes and Scraps. Agricultural products include all unprocessed foods. Forestry products are wood, timber, charcoals, and other related products. Mineral products include natural gas, petroleum, sand, rock, and other related products. Metal and machinery products are metal materials (such as aluminum and steel) and machines. Chemical products include cement, glass, gasoline, plastic, asphalt, and other related products. Light industry products are all processes foods, paper, thread, and other related products. Other products include newspapers, magazines, cloths, furniture and daily use commodities. Wastes and scraps include all type of wastes such as industrial and residential wastes.

In the same way, the industry types are grouped into 13 groups including 1) Agriculture, Forestry, and Fishery, 2) Mining, 3) Construction, 4) Chemical Manufacturer, 5) Metal Manufacturer, 6) Machinery Manufacturer, 7) Other Manufacturer, 8) Material Wholesaler, 9) Product Wholesaler, 10) Retailer, 11) Warehouse, 12) Electricity, Gas, and Water Supplier, and 13) Service and Government Work.

Validation Results

The 87,446 virtual firms and their attributes generated by the Monte-Carlo simulation from the EEC data were used for model validation. This number corresponds to 5 percent of the firms that operate in the study area and the nearby prefectures. The virtual firms were integrated through the three stages of the model (commodity production and consumption, commodity distribution, and conversion of commodity flows to truck flows) resulting in the estimated daily truck origin and destination matrices by truck type. In step of model validation, the virtual firms are integrated to the model to estimate truck origin and destination volumes, which are compared with the actual volumes from the survey data, which were collected by the Road Traffic Census.

Figures 4 and 5 show the comparing results between the actual number of truck trips and the estimated number of truck trips for large truck and small truck respectively. In terms of the total number of truck trips, the model estimates quit similar results to the actual number of truck trips. However, in terms of the OD pair, there are some estimation errors, in particular, in the zones within the center of Tokyo. These zones are particularly distinct from the other zones because the characteristics of freight movement in the center of Tokyo are much different from those in other locations.

Table 1 compares the estimated number of truck trips to the actual number of truck trips from the Road Traffic Census survey. In addition, total VKT per day resulted from traffic assignment is compared with the results from the Road Traffic Census survey. There are some overestimations of the number of VKT. One of the reasons is that the present model for vehicle routing still not consider more variations in pick up and delivery and delivery with time window constraints.

CONCLUSION

The proposed model is a comprehensive approach to model freight transportation in a way that systematically reflects the individual behavior of freight agents. The model incorporates individual behaviors by considering the largest influence of each freight agent at each stage. The model takes into account the fundamentals of commodity movement, which is the outcome of commodities flowing through supply chains. Each individual is assumed to behave rationally in freight movement activities (such as commodity purchasing, carrier and truck size selection, and vehicle routing) by trying to minimize the total costs in each activity. The proposed model was applied to analyze the freight movement in the Tokyo Metropolitan Area through the simulation of activities of the generated firms. The results of model application suggest the development of the freight demand model given that this concept is very promising.

The present model for vehicle routing is still rather simple and considers only the distribution purpose while pick-up purpose is not yet incorporated. Vehicle routing with time window constraint is also suggested for an improvement of the model. The variations in the pattern truck routing are needed to be considered in the future.

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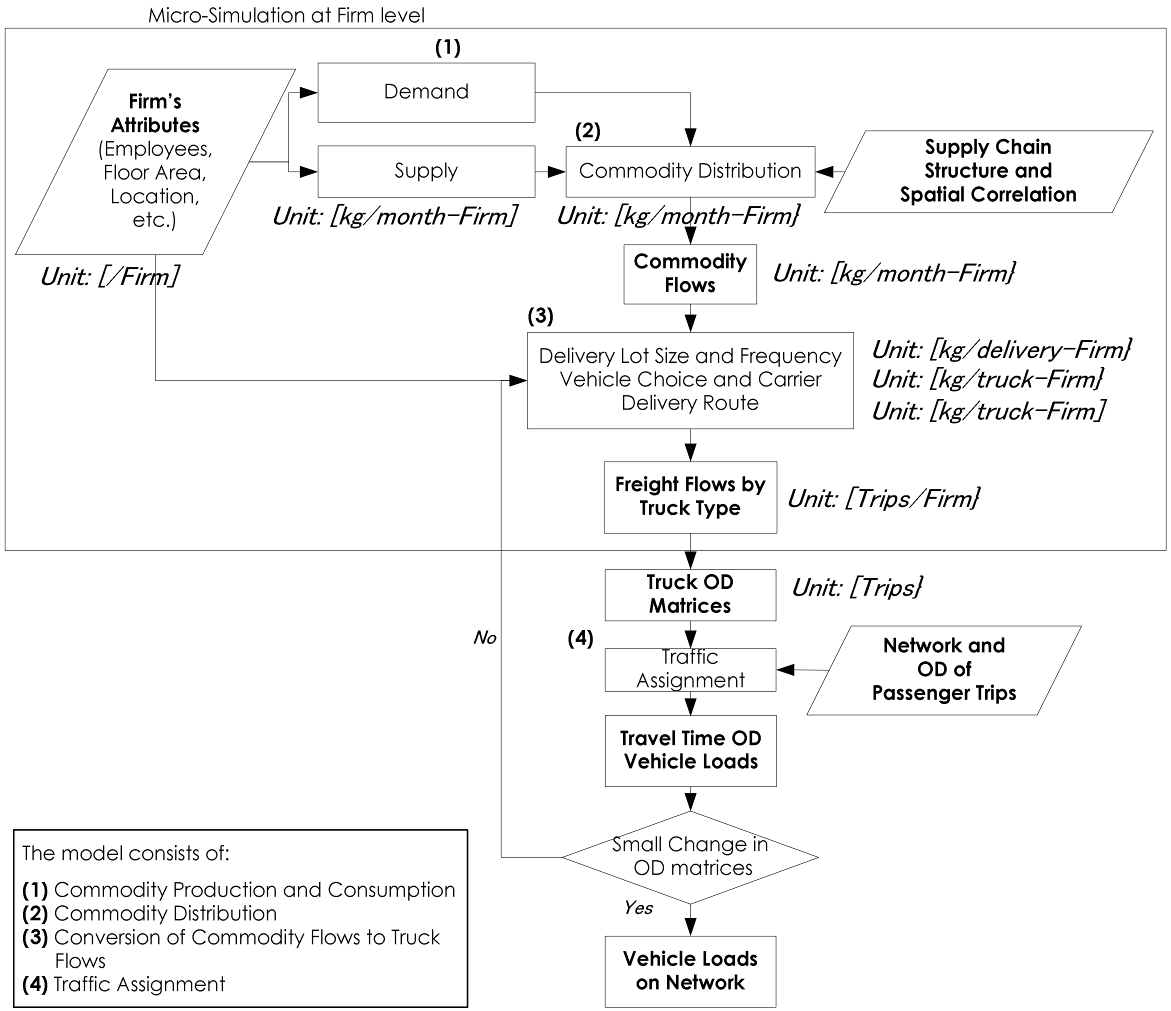

FIGURE 1 Model Structure

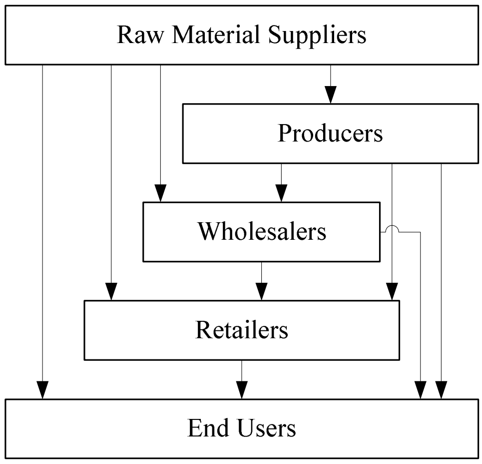

FIGURE 2. Supply Chain Structure

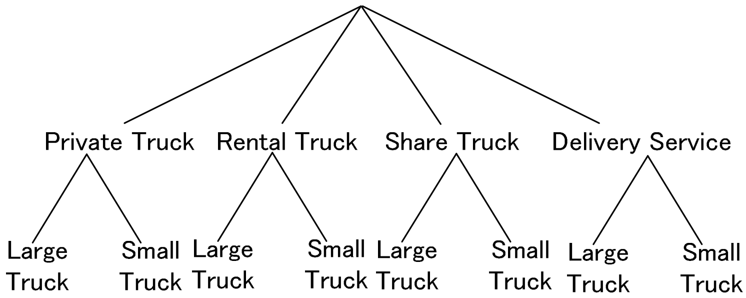

FIGURE 3. Carrier and Vehicle Choice Model

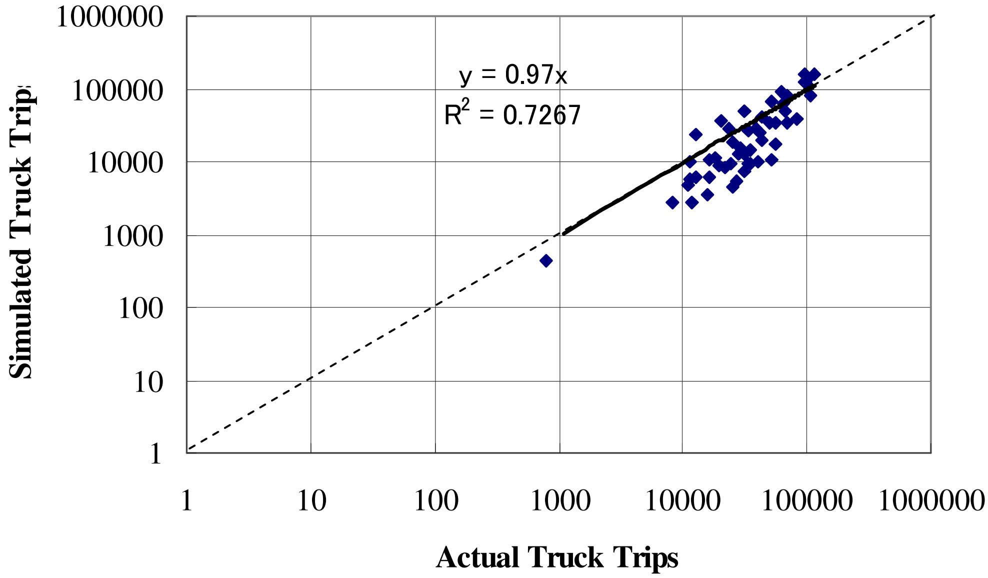

FIGURE 4 Generated Freight Movement Pattern from Simulation Comparing with the Actual Pattern for Large Truck

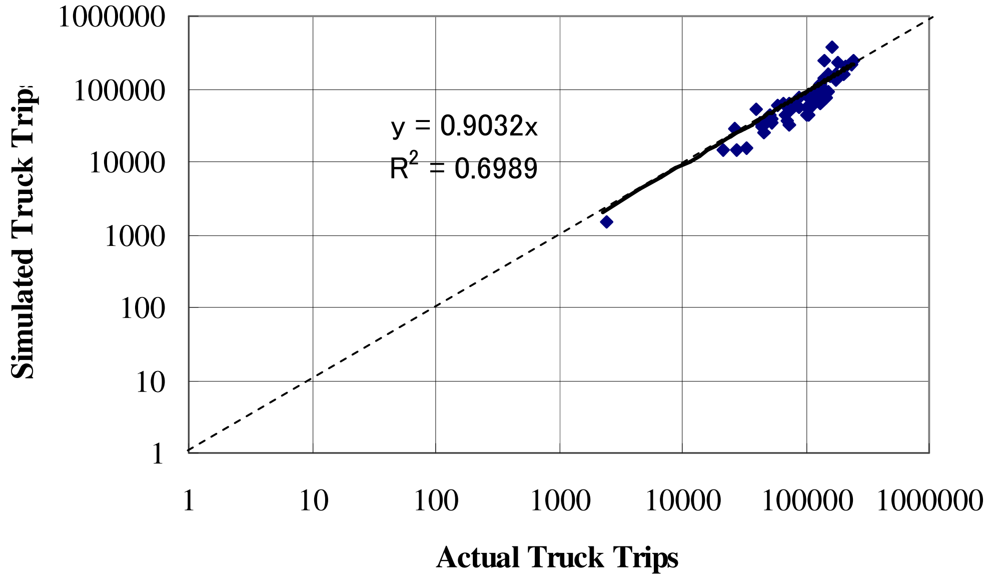

FIGURE 5 Generated Freight Movement Pattern from Simulation Comparing with the Actual Pattern for Small Truck

TABLE 1 Comparing Number of Truck Trips per Day and VKT per day from Simulation and RTC data

	Truck Trips per Day (1,000 Trips/Day)		VKT per Day (1000 VKT/Day)	
	Large Truck	**Small Truck**	**Large Truck**	**Small Truck**
Simulation	2,258	4,651	217,090	169,906
RTC	2,120	5,135	174,875	122,517