Logistics Chain Modeling for Urban Freight: Pairing Truck Trip Ends with Logistics Facilities

Takanori Sakai (corresponding author)
Department of Urban Planning and Policy, University of Illinois at Chicago
412 S. Peoria St. Suite 215, Chicago, IL 60607
Tel: 312-996-5240; Fax: 312-413-2314; Email: tsakai3@uic.edu

Kazuya Kawamura
Department of Urban Planning and Policy, University of Illinois at Chicago
412 S. Peoria St. Suite 215, Chicago, IL 60607
Tel: 312-996-5240; Fax: 312-413-2314; Email: kazuya@uic.edu

Tetsuro Hyodo
Department of Logistics and Information Engineering, Tokyo University of Marine Science and Technology
2-1-6, Etchujima Koto-ku Tokyo 135-8533 Japan
Tel: +81-3-5245-7386; Email: hyodo@kaiyodai.ac.jp

Word count: 5,844 words text + 8 tables/figures x 250 words (each) = 7,844 words

TRR Paper number: 17-01357

Submission Date: March, 5, 2017

ABSTRACT
In the existing freight models, the choices of logistics facility locations and the selection of logistics facilities for routing the shipments are often treated without distinction although these two decisions are distinct and affected by different set of factors in reality. In this paper, we develop models of logistics facility choice that match truck trip ends with logistics facilities using a large urban freight survey data from the Tokyo Metropolitan Area. The models can be used to estimate truck traffic flows associated with transshipments. We categorize the urban portion of logistics chains into five types of movements and develop a total of 30 models to separately analyze six commodity groups. The results indicate that the proposed approach can capture the mechanism of the logistics facility selection by movement and commodity types. The tests for the reproducibility of the models warrant the future use of the models for urban freight demand analysis.

INTRODUCTION

One of the most challenging elements in urban freight analysis at present is the indirect shipments, which is defined as the shipments that go through one or more logistics facilities (distribution centers, warehouses, truck terminals and other intermediate facilities) on the way to the final destination. According to the 2003 Tokyo Metropolitan Freight Survey (unpublished data), about 43% of freight truck trips either originate or terminate at a logistics facility or both, underscoring the enormous role indirect shipments play on everything from congestion to carbon emissions. Understanding the decisions regarding the selection of transshipment points is highly relevant to urban freight planning and policy. For example, the growing discussions about logistics sprawl, "the movement of logistics facilities away from urban centers" (*1*), come from the concern that such trend would move the transshipment points to the outskirts of urban areas, and thus lead to an increase in truck travel. However, the lack of data and demand analysis tools has hampered the rigorous examination of the relationship between the spatial distribution of logistics facilities and transshipment patterns, which affect the lengths and the number of truck trips.

Integrating the logistic element in a freight model requires the understanding of practices and decision factors that affect both the structure and the operation of "logistics chain". In our view, the decisions regarding the operation (e.g. selection of transshipment points) are distinct from the physical system (e.g. number, size and location of logistics facilities) in practice, although they are often treated interchangeably in the existing freight models. These two different sets of choices would be motivated by the similar but not the same factors. While the decisions related to the physical system would be strongly influenced by the expected shipment demand and the costs associated with it, the decision has a long time horizon and the alternatives are constrained by the availability of suitable sites and other factors. On the other hand, the operational decisions, including the choice of logistics facilities for transshipment, would follow a shorter time horizon and each shipment has the different needs that must be met. Analyzing these two choice problems separately would reveal decision factors for each, and the estimated models are expected to give the insights that are especially beneficial for understanding the relationship between land use and truck traffic.

While logistics facility location choice has been studied in the past, the understanding of the choice of transshipment locations is rudimental at best especially for the urban portion of the logistics chain. While determining the optimum locations for logistics facilities is one of the major topics in the field of operations research, modeling tools and behavioral analysis that capture the transshipment decisions are limited. This research strives to address the knowledge gaps by 1) analyzing the factors that affect the selection of logistics facilities for transshipment in an urban area, and 2) develop and evaluate the models that can be used to estimate the truck trips associated with transshipments. The framework described in this paper partially overlaps with trip generation in the classic four-step model in the sense that the result can be used to estimate the number of inbound and outbound truck trips at the logistics facility level or zonal level. It also overlaps with trip distribution in the sense that the pairings of trip ends are carried out. This work is a part of the ongoing efforts at the University of Illinois at Chicago and Tokyo University of Marine Science and Technology to develop the freight analysis tool, called ULLTRA-SIM, for the Tokyo Metropolitan Area. The ULLTRA-SIM is a modeling tool to evaluate the logistics land use policies for their effects on logistics facility location choices, shipment patterns, and traffic impact.

INDIRECT SHIPMENTS

The objective of any freight shipment is to move the goods from the origin to the final destination, and the transshipment points that the shipment passes along the way (e.g. logistics facilities) are often treated as if they are nodes in the network. As such, the decisions associated with the transport chain, including the selection of logistics facilities, are often estimated based on the cost minimization framework (e.g. shortest path). In contrast, we will analyze the selection of logistics facilities using the discrete choice modeling framework to capture the effects of the characteristics of the facilities and the surrounding areas. We extract the records from a large freight survey conducted in the Tokyo Metropolitan Area (TMA) to focus on the shipments that have at least one trip end within the TMA and also go through at least one logistics facility (i.e. indirect shipments). As noted earlier, 43% of the truck trips recorded in the survey meet the criteria.

For our analysis, it is helpful to distinguish transshipment points from the origins and the destinations of shipments. Hereafter, we will define the beginning and the end of an entire logistics chain (e.g. a farm to a grocery store, a factory to a store, etc.) as “production” (P) and “consumption” (C) trip ends, respectively. We also call an external trip end P if it is the origin of an inbound trip, and C if it is the destination of an outbound trip. This definition does not distinguish between the transshipment points outside of the study area and the actual origins and destinations of logistics chains. Meanwhile, the trip end at a logistics facility within the study area will be called “generation” (G) for outbound trips, and “attraction” (A) for inbound trips. A and G can be the trip ends of a shipment leg between a logistics facility and an origin or a destination (e.g. from a farm in the external area to a distribution center in the study area) or between two logistics facilities in the study area. In this set up, external trip ends must be either P or C, while internal trip ends are A or G if they are transshipment points, or P or C if they are at origin or destination locations. Figure 1 depicts these definitions.

It is important to note that since we have reliable truck trip data and our ultimate interest is road traffic impact, we choose truck trip as the analysis unit. Therefore, the movements of goods between origins, destinations, and logistics facilities are represented in terms of truck trips. In this setup, a logistics chain is represented by two trip ends at the origin and destination of shipments, a production (P) and a consumption (C), and for indirect shipments, include one or more transshipment points that serve as both the attraction (A) and generation (G) trip ends (see Figure 1).

LITERATURE REVIEW

As discussed in (*2*) and (*3*), an increasing number of freight models, either proposed or already in use, are taking logistics elements into consideration. Those models vary in the level of data aggregation, scale (urban, regional, national, international), the unit of analysis (shipment-based, truck-based or mixed), and the supply chain and logistics elements that are considered. There are significant differences in the manners in which the elements such as the decisions on trading, transportation channel, shipment size and delivery/pick-up frequency, vehicle touring, and/or delivery/pick-up time window are integrated in the models. However, the models that consider the use of logistics facility for transshipments are still limited. Huber et al. (*4*), based on the review of more than a hundred freight models, argue that only a small number of models integrate the use of logistics facilities in the framework.

There are few different approaches for modeling the logistics facility use. In the models such as SAMGODS (Sweden), NEMO (Norway), SMILE (Netherlands), SLAM (EU), and

EUNET (the Trans Pennine Corridor, the UK), the selection of the logistics facility locations is taken into account in the main structure through the transportation chain generation that follows the estimation of the flows between production and consumption locations (i.e. P-C flows) (*4-7*). The recent extension of the SMILE model details a methodology of transport chain generation (*8*). Using the transportation survey data for heavy goods vehicle operators in Netherlands, they develop two sub-models, "gravity model" and "logistics chain model", for estimating freight traffic demand. The purpose of the logistics chain model is to generate trip links from P-C flows. The multinomial logit model is used for the choice among direct and indirect shipments, which is also the choice of a zone for transshipment in case of indirect shipment, taking the logistics cost (transportation and stock-related costs) into account in the utility function. Interestingly, Davydenko et al. (*9*) use the same models to evaluate the impacts of the policies of the centralization and decentralization of transshipment locations as well as the increase in transportation cost. The similar structure is also proposed for the models developed by the Los Angeles County Metropolitan Transportation Authority and the Chicago Metropolitan Agency for Planning (*10-11*). Though it is limited to food retailing companies in Germany, Friedrich (*12*) develops a national scale model (SYNTRADE) that consists of "supply path decision" and "warehouse structure decision"; the latter simulating warehouse locations based on P-C flows. In GoodTrip model, logistics facilities (distribution centers) are considered in the calculation of zonal goods attractions, but not separately in the process of goods flow formulation (*2, 13*). In the agent-based models, such as InterLog (*14*) and Wisetjindawat et al. (*15*), the use of logistics facilities is not explicitly considered.

Only a small number of works have been carried out to integrate the logistics facility use in freight models, especially at the urban scale. Even when transshipment locations are considered, most existing models treat the decisions related to logistics chain in the manner analogous to route choice and apply the cost minimization approach. Also, the structures of the existing models often do not adequately differentiate the decisions on the use of logistics facilities from the siting of the facilities, though these two decisions are actually different, especially for the shipments that are handled by for-hire fleet or associated with a large firm with an extensive network of logistics facilities to choose from for each shipment. The factors for the choice of logistics facilities are yet to be analyzed in detail at the disaggregate level. This research is, to the best of our knowledge, the first attempt to model the logistics chain through the pairing of trip ends for indirect shipments that involve transshipment(s) using disaggregate data and the characteristics of the facilities and the surrounding areas.

ANALITICAL FRAMWORK

Each indirect shipment has a P, a C, and at least one pair of A and G. As shown in Figure 1, the locations of P and C can be either outside or inside of the study area while the logistics facilities, and thus A and G, are within the study area. The numbers of As and Gs for a particular logistics facility are not necessary the same. For example, if shipment consolidations are performed at a logistics facility, As would outnumber Gs.

The problem to be tackled is as follows; given the locations and quantity of P and C and the available transshipment locations (i.e. logistics facilities), estimate the truck trips (an OD table) by matching (or "pairing") P to A and C to G, or in the case of movements between two logistics facilities, pairing A with G (or the reverse). The end product is a truck trip OD table for indirect shipments. As mentioned in the previous section, in most existing models, transshipment points are ignored (i.e. Ps and Cs are directly matched), or treated in the same manner as other facilities such as factories and retail establishments. The premise of this study is that the decisions regarding the selection of transshipment points are unique, and thus logistics facilities should be treated differently from other freight-generating entities such as factories and retail establishments. We develop the models that allow the consideration of unique roles that logistics facilities play as transshipment points. We do this by first establishing the abovementioned framework to represent truck trips that move indirect shipments between origin, destination, and transshipment points. Then, we identify the factors that influence the choice of transshipment points to route the shipment through.

For the analysis presented in this paper, the input data such as the locations of logistics facilities as well as the locations of Ps, Cs, and also As are taken exogenously from the survey data. In practice, the number of As and Gs are typically estimated using economic indicators and the scale of logistics business. The proposed framework can be easily applied to the case in which the trip ends are supplied by a trip generation model and a logistics facility location choice model. For example, it can supplement the urban freight analysis tool developed by Sakai et al. (*16*). In addition, this approach is flexible and matches the structure of typical freight survey data that collects information on truck trips. It may be ideal to analyze the logistics chains at the shipment level, but the data required to trace the movements of individual shipments through the chains are extremely difficult to obtain.

Data

The Transport Planning Commission of the Tokyo Metropolitan Region (TPCTMR) conducts a metropolitan scale freight establishment survey about every 10 years. The latest effort, 2013 Tokyo Metropolitan Freight Survey (TMFS), is arguably the largest urban freight establishment survey in the world, and was made available to us for the present research. The 2013 TMFS covers the area of 23 km^2, which is home to 42 million people and 1.6 million establishments. A total of 136,632 establishments in the TMA were recruited for the survey and the responses were obtained from 43,131 establishments (a response rate of 31.6%). The data include the information for both establishments and their shipments. The establishment data consist of location, industry type, facility type, employment size, floor area, and year of establishment. The shipment data include the locations of shipment origin and destination, facility types at origin and destination, the number of truck used, weight, and commodity type, for both inbound and outbound shipments. The establishment locations are available at the address level and the truck trip origins and destinations are available at the municipality level (there are 315 municipalities in the survey area).

While the 2013 TMFS covered establishments such as factories, wholesalers, and service industries, we only use the data obtained from logistics facilities, which include distribution centers, truck terminals, warehouses, intermodal facilities and oil terminals. A total of 4,646 logistics facilities reported facility and shipment information. The official expansion factors that are calculated by the TPCTMR based on geographical location, facility size, and type of industry are used. After the expansion, the data set includes 38,401 internal trips going from origins to logistics facilities, 111,555 internal trips going from logistics facilities to destinations, 50,883 internal truck trips between logistics facilities, and 16,835 inbound and 36,453 outbound external truck trips. Truck trips are categorized by six commodity groups: (1) food, (2) daily goods, (3) raw materials, (4) machinery, (5) chemical goods and (6) mixed goods. As we discuss later in detail, the multinomial logit modelling framework is applied. The unit of analysis are truck trip ends at origins, destinations, and logistics facilities. The choice alternatives are logistics facilities.

The independent variables considered in the models are summarized in Table 1. In addition to the 2013 TMFS, we use socioeconomic data prepared by the TPCTMR, which is organized in 1 km by 1 km polygons covering the TMA. For "Acce. est.", the types of establishments to be included in the calculation of accessibility are defined for each commodity group, considering potential association between industries (Table 2). The variables excluding "pop. dens." and dummy variables are log transformed as it improves the fit of the models. In addition, all non-dummy variables are normalized for each model estimation. In the final models, the variables that are not statistically significant at 90% confidence interval or show the opposite sign from the expected are excluded, except for "dum rr3" and "dum port" which are included into the models regardless of the sign and the significance.

Model Structure

We develop the multinomial logit models which estimate the probabilities of logistics facilities to be selected (as A or G) for being paired with each trip end (P, C or A). The models are estimated for each commodity type group. Furthermore, five model groups (MG) are defined based on trip type (see Figure 2). MG1 is for the internal trips between Ps (at the origins) and As (at logistics facilities), while MG2 is for the internal trips between Gs (at logistics facilities) and Cs (at the destinations). The third group, MG3, is for the trips between two logistics facilities in the study area. For MG3, the numbers and locations of As are exogenously determined based on the survey data and the model pairs them with Gs since that is sufficient to determine the truck trips between logistics facilities. The MG4 and MG5 pair the Ps and Cs associated with the origins and destinations located outside of the study area with As and Gs. MG4 is for the inbound trips (pairing P with A) and MG5 is for the outbound trips (pairing C with G). The models in the MG4 and MG5 would capture the selection of the logistics facilities for inter-regional shipments.

Define that i^g is a P, C or A of commodity group g and j^g is a logistics facility that handle the commodity group g. Following the multinomial logit modelling framework, the logit (or utility-like function) of a logistics facility j^g for an i^g that is seeking a logistic facility is defined as follows:

$$U_{i^g,j^g} = V_{i^g,j^g} + \varepsilon_{i^g,j^g} \qquad (1)$$

where:

V_{i^g,j^g}: the deterministic component

ε_{i^g,j^g}: the random component

Assuming that the random component follows Gumbel distribution, the probability for a logistics facility j^g to be paired with an i^g when J^g is the set of all logistics facilities that handle commodity g, is:

$$P_{i^g,j^g} = \frac{\exp(V_{i^g,j^g})}{\sum_{j^g \in J^g} \exp(V_{i^g,j^g})} \qquad (2)$$

For MG1, MG2 and MG3, the deterministic component is defined by the following function:

$$V_{i^g,j^g} = \alpha^g D_{i^g,j^g} \times \sum_{k \in K} \beta_k^g L_{j^g,k} \quad (3)$$

where:

D_{i^g,j^g}: the network distance between i^g (P, C or A) and a logistics facility j^g
$L_{j^g,k}$: the measure of the characteristics k of logistics facility j^g or its location
α^g, β_k^g: the parameters to be estimated

For MG4 and MG5, the border-point(s) is defined based on the location of P or C. For example, for a P or C that is located to the north from the study area, one or more border-point(s) which is the most likely entry point(s) for the truck trip is defined on the northern border of the TMA. For MG4 and MG5, D_{i^g,j^g} in Equation 3 is replaced by the shortest distance between the border-point(s) for a P or C and a logistics facility $j^g (D'_{i^g,j^g})$.

In this setup, the pairing of trip ends is modeled as the selection of logistics facility instead of individual A or G. For example, in MG1, for a given P of a specific commodity type, the probability of selecting a logistics facility (and thus any As at the facility) among the facilities that handle the commodity is being estimated, instead of selecting specific A to pair with.

MODEL ESTIMATION RESULTS

Using the maximum-likelihood estimation, a total of 30 models were estimated (five model groups with six commodity groups). It should be noted that, while various implications are obtainable from these estimated models, the characteristics of the estimated models or coefficients could not be summarized in a simple manner. Due to the space limitation, we focus on the performance of the models and the observed characteristics that we consider most insightful.

Internal Trips associated with Origins and Destinations (MG1 and MG2)

First, the estimated models in MG1 and MG2 are shown in Table 3. McFadden's ρ^2s range from 0.090 to 0.307. While the ρ^2 values are fairly typical for this type of model, they are noticeably higher for the mixed-goods (0.307 and 0.278), indicating the independent variables considered in the models successfully capture the factors of the logistics facility choices for mixed-goods. For all the models, “ship. dist.” is a very strong factor, indicating that logistics facilities that are closer to origin or destination makes them highly attractive. In fact, without the “ship. dist.” variable, the explanatory powers of the models diminish considerably. The result supports the conventional assumption that trip distance is an important decision factor for logistics chain formulation. Also, “floor area” contributes significantly to the model performance, though the effect is weak or does not exist for raw materials and chemical goods which include various bulk goods.

The models for mixed goods show interesting characteristics. Compared with other commodity groups, “pop. dens.” is a far stronger explanatory factor for mixed goods, especially for the trips to the destinations (Cs), which indicates that logistics facilities in lower density areas are preferred for routing mixed goods shipments, *ceteris paribus*. This makes sense as high-throughput facilities like the ones handling mixed goods may cause more conflicts with local residents. As the shipments to the customers tend to be under a greater level of delivery time window constraints, congestion associated with density may also be a factor. Furthermore, the significant effect of “land price” indicates that facility costs are important to the facility choice for deliveries to the destinations.

Finally, the dummy variable, “dum port”, shows that the preference for the logistics facilities in the industrial areas is dependent on commodity types. The logistics facilities in the port areas are preferred transshipment points for goods such as raw material, chemical goods, and machinery from the origins (Ps) while avoided for food, daily goods, and mixed goods. For the trips to the destinations (Cs), logistics facilities in the port areas are not popular across all commodity types except for food. The logistics facilities along the Ring Road 3 (the dummy variable “dum rr3”) are popular for daily goods for both trips from the origins and to the destinations.

Internal Trips between Logistics Facilities (MG3)

The estimated models for the trips between two logistics facilities are shown in Table 4. The McFadden's ρ^2 is the lowest for the model of daily goods (0.054) and the highest for mixed goods (0.129). Interpretation of this model may not be as straightforward as the ones in the other model groups, as the shipments between two logistics facilities would be strongly influenced by both the upstream and downstream legs in the supply chain. The strong effects of “ship. dist.” are again observed in this model for all commodity types. On the other hand, the effect of “floor area” is quite strong for food, but not observed for machinery and chemical goods.

The results also show that the facilities in the port area and the areas along Ring Road 3 are popular for most goods, especially for machinery, but the effect is negative for daily goods. For food, the facilities in the port area are less likely to be selected, but those along Ring Road 3 are highly desirable. Positive effects of “dum port” for raw materials, machinery and chemical goods parallel the results of MG1 (Table 3). The preference for the port area for transshipping those types of commodities can be explained by the historical development of the area for heavy industries that include the presence of supporting infrastructure and facilities that accommodate the movements of bulky and/or hazardous commodities.

The negative effects of “dum port” and “dum rr3” and the strong effect of “acce. est.” for daily goods indicate that truck trips between logistics facilities occur in the area having high accessibility to the origins of those types of goods, which are not necessarily in the port area nor the area along Ring Road 3.

External Trips (MG4 and MG5)

Table 5 shows the estimated models for the external trips. McFadden's ρ^2s are relatively modest compared against the earlier models. It is especially notable that the coefficients for the “dist. to BD”, which is the distance between the logistics facility and the border point assigned to the external trip end, are considerably lower in magnitudes than those for the “ship. dist.” variables from the models described above. Low ρ^2s indicate that the power of the model to explain the selection of the transshipment points for external trips are relatively weak. Meanwhile, the effects of facility size (“floor area”), land price, and access to establishments show consistent effects in terms of direction and magnitude, to a degree, across commodities. Logistics facilities that are larger and located in the areas with low land price and good accessibility to the businesses are preferred. Interestingly, the industrial areas in the port region or along the Ring Road 3 are less likely choices in many cases.

For mixed goods, most of the independent variables are significant with the expected signs, and many of them show stronger effects than for the other commodity groups. Especially for the outbound trips (MG5), the combination of low population density and high population accessibility is very important for the choice of logistics facilities.

REPRODUCIBILITY OF THE MODELS

Using the Monte Carlo method, we check the reliability of the models by analyzing how well they can replicate the patterns observed in the 2013 TMFS. Since the model outputs are compared against the very data used to estimate the model, the purpose of this exercise is not validation. Rather, the aim of this exercise is to assess the explanatory powers of the models and also evaluate the behavior of the probability functions.

For each of the 30 models, the probabilities for the match between each of the trip ends and the available logistics facilities are estimated using the estimated parameters. Then, the selection of the logistics facility for each P, C or A is simulated using the calculated probabilities. Aggregating the matched trip ends at the municipal level produces a 315-by-315 OD table for each of the 30 models. This exercise is repeated for 1,000 times for each model and then the average number of trip ends in each municipality is calculated and compared against the actual figure derived from the survey data. For the internal trips, the numbers of truck trips between individual ODs (a total of 99,225 = 315 × 315) are also compared. As the indicator of the prediction performance, R-squared that follows the function below is calculated:

$$R^2 = 1 - \frac{\sum_k (y_k - \widehat{y_k})^2}{\sum_k (y_k - \bar{y})^2} \quad (4)$$

where:

y_k : Observed number of trip ends or truck trips for a municipality k
$\widehat{y_k}$: Estimated number of trip ends or truck trips for a municipality k
$\bar{y}$: Average observed trip ends or truck trips

The results are shown in Figure 3. For each plot, the inset shows the magnified view of the data points near the origin for clarity. Some data points are on the y-axis since the 2013 TMFS includes records with no trip ends or truck trips (i.e. the observed values are zero). The reproducibility of the models is generally acceptable, especially for MG1 and MG2 (upper-left and upper-right) with the R^2 of 0.529 and 0.579, respectively. This suggests that the models perform well for the logistics chains with the origins or destinations within the study area. Relatively low R^2 (0.456) of the MG3 (the trips between logistics facilities) shown in the center-left panel can be attributed to one significant underestimation for the municipality that actually generates the largest number of trips. It suggests a need for examining outliers for this type of model. The R^2 for the individual OD flow comparisons, which was constructed by combining the simulation results from the MG1, MG2, and MG3, is 0.586 (center-right), which is acceptable considering the size and number of zones.

As for the external trips (lower-left and lower-right), the reproducibility for the inbound shipments (0.597) is considerably higher than that for the outbound shipments (0.409), which indicates the selection of transshipment locations for the inbound movements from the external areas has more systematic pattern that can be captured by our model than the outbound movements.

CONCLUSION

The understanding of the complex urban freight movement is a significant challenge to both researchers and practitioners. Arguably, the most challenging component of urban freight analysis is the logistics chains that involve transshipments. Especially, the use of logistics facilities has not been modeled or analyzed with the consideration of the characteristics of the facilities and their locations. The existing approaches mainly depend on the simplified decision-making assumptions based on the logistics costs that may not be applicable at the urban or metropolitan scale. Theoretically speaking, compared with national or super-regional models, variation in shipment distances within an urban area may not play as large a role in the logistics chain decisions because the variations between alternatives may be insignificant.

In this research, we propose and test a new approach to analyze and reproduce the urban freight movements that use logistics facilities for transshipment at the metropolitan scale. The logistics facility choice models described in this paper are based on the understanding that the decisions regarding the infrastructure development, e.g. locations of logistics facilities, are distinct from more short-term ones associated with the routing of the shipments through logistics chains. The models were estimated using the disaggregate data, reflecting various factors that have not been considered in the past studies.

The proposed modeling approach successfully captured the effects of facility and land characteristics on the selection of logistics facilities as transshipment points. The goodness of fit indicators suggest that the proposed approach is most effective for the mixed goods shipments, probably because the supply chains for such goods are mostly managed by major shipping companies with clear intention for cost minimization over the entire supply chains. Also, having a large network of logistics facilities, as the companies that handle mixed goods shipments tend to, gives them an opportunity to carry out such cost minimization choices regarding the routing of the shipments that can be captured in discrete choice analysis. The fits of the models for other commodity groups are lower. It is difficult to pinpoint the reason, but the lack of more detailed data on logistics facilities, such as the capacity to accommodate larger trucks or special equipment to handle certain type of commodity, may be a factor.

While the strong contribution of shipment distance for intra-metropolitan truck trips confirms the validity of the shortest path (or minimum cost) approach for estimating such trips, the models also show that other variables influence the choice of transshipment points. It is difficult to generalize the results as commodity type and also the type of movement strongly affect the model parameters, underscoring the heterogeneity present in urban freight movements and the need to develop separate models for individual freight segments.

Meanwhile, generally strong results for the evaluation of reproducibility give a confidence toward the implementation of the approach presented in this paper for demand analysis. Further research on this topic is strongly encouraged and the approach is expected to be reflected in policy evaluation tools in the future.

ACKNOWLEDGMENTS

We would like to thank the Transport Planning Commission of the Tokyo Metropolitan Region for sharing the data for this research. This study received funding from the National Center for Freight and Infrastructure Research and Education (CFIRE), and the Department of Urban Planning and Policy at the University of Illinois at Chicago. CFIRE is a national university transportation center supported by the US Department of Transportation.

REFERENCES

1. Dablanc, L., S. Ogilvie, and A. Goodchild. Logistics sprawl: Differential warehousing

development patterns in Los Angeles, California, and Seattle, Washington. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2410, 2014, pp. 105-112.
2. Chow, J. Y., C. H. Yang, and A. C. Regan. State-of-the art of freight forecast modeling: lessons learned and the road ahead. *Transportation*, Vol. 37, Issue 6, 2010, pp. 1011-1030.
3. De Jong, G., I. Vierth, L. Tavasszy, and M. Ben-Akiva. Recent developments in national and international freight transport models within Europe. *Transportation*, Vol. 40, Issue 2, 2013, pp. 347-371.
4. Huber, S., J. Klauenberg, and C. Thaller. Consideration of transport logistics hubs in freight transport demand models. *European Transport Research Review*, 2015, pp. 7-32.
5. De Jong, G., and M. Ben-Akiva. A micro-simulation model of shipment size and transport chain choice. *Transportation Research Part B: Methodological*, Vol. 41, Issue 9, 2007, pp. 950-965.
6. Tavasszy, L. A., B. Smeenk, and C. J. Ruijgrok. A DSS for modelling logistic chains in freight transport policy analysis. *International Transactions in Operational Research*, Vol. 5, Issue 6, 1998, pp. 447-459.
7. Jin, Y., I. Williams, and M. Shahkarami. Integrated regional economic and freight logistics modelling: results from a model for the Trans-Pennine Corridor, UK. Presented at the European Transport Conference. Strasbourg, France, 2005.
8. Davydenko, I., and L. Tavasszy. Estimation of warehouse throughput in freight transport demand model for the Research Netherlands. *Transportation Research Record: Journal of the Transportation Board*, No. 2379, 2013, pp. 9-17.
9. Davydenko, I. Y., L. A. Tavasszy, and H. Quak. A quantitative model for exploration of logistics sprawl of the future. Presented at 5th METRANS International Urban Freight Conference. Long Beach, California, 2013.
10. Fischer, M., M. Outwater, L. Cheng, D. Ahanotu, and R. Calix. Innovative framework for modeling freight transportation in Los Angeles County, California. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1906, 2005, pp. 105-112.
11. Cambridge Systematics, Inc. *A working demonstration of a mesoscale freight model for the Chicago Region*. 2011. http://www.cmap.illinois.gov/documents/10180/15707/CMAP_Meso_Freight_Model_Report_11-2011_final.pdf/b75fecc4-e947-4aa1-b87d-9b7ee486efc2. Accessed July 1, 2016.
12. Friedrich, H. Simulation of logistics in food retailing for freight transportation analysis. Presented at 12th World Conference on Transport Research. Lisbon, Portugal, 2010.
13. Boerkamps, J., and A. Van Binsbergen. GoodTrip – a new approach for modelling and evaluation of urban goods distribution. In *City Logistics I, 1st International Conference on City Logistics* (Taniguchi, E., and R.G. Thompson., ed.), Institute of Systems Science Research, Kyoto, 1999, pp. 175–186.
14. Liedtke, G. Principles of micro-behavior commodity transport modeling. *Transportation Research Part E: Logistics and Transportation Review*, Vol. 45, Issue 5, 2009, pp. 795-809.

15. Wisetjindawat, W., K. Sano, and S. Matsumoto. Commodity distribution model incorporating spatial interactions for urban freight movement. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1966, 2006, pp.41-50.
16. Sakai, T., K. Kawamura, and T. Hyodo. Location choice models of urban logistics facilities and the impact of zoning on their spatial distribution and efficiency. Presented at 95th Annual Meeting of the Transportation Research Board, Washington D.C., 2016.

LIST OF TABLES

LIST OF FIGURES

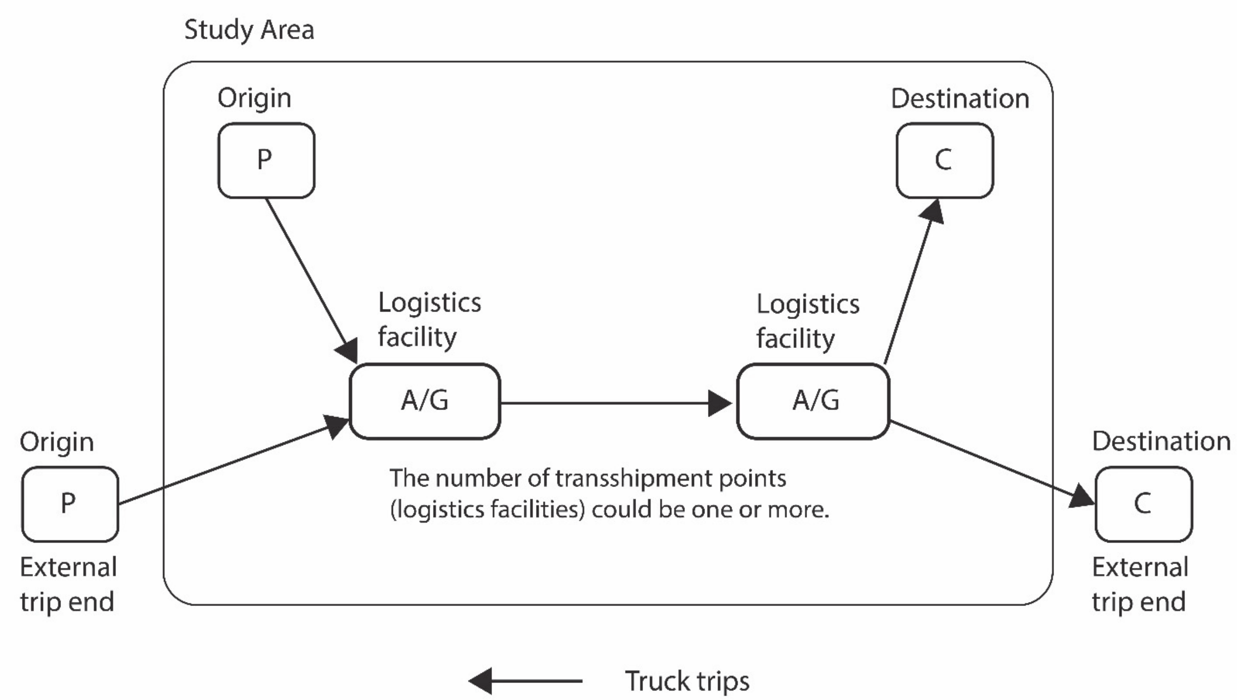

FIGURE 1 Trip ends and truck trips of indirect shipments

TABLE 1 Independent Variables for Logistics Facility Choice Model

Notation	Expected sign of effect	Description
Ship.dist.	-	Network distance between P, C or A and a logistics facility. (log transformed) (for internal trip links only)
Dist. to BD	-	Network distance between the border point that is associated with P or C and a logistics facility. (log transformed) (for external trip links only)
Floor area	+	Floor area of a logistics facility. (log transformed)
Pop. dens.	-	Population density of a 1km-by-1km polygon where a logistics facility is located.
Land price	-	Average land price of a 1km-by-1km polygon where a logistics facility is located. (log transformed)
Acce. est.	+	Accessibility to relevant establishments = $\sum_l E_l \exp(-\mu \times \log(d_l))$ where: E_l: no. of relevant establishments in location l (a 1km-by-1km polygon) d_l: network distance between a logistics facility and location l (a 1km-by-1km polygon) μ: impedance factor (=0.5)[a] (log transformed)
Acce. pop.	+	Accessibility to residential population = $\sum_l P_l \exp(-\mu \times \log(d_l))$ where: P_l: residential population in location l (a 1km-by-1km polygon) d_l: network distance between a logistics facility and location l (1km-by-1km polygon) μ: impedance factor (=0.5)[a] (log transformed) (for mixed goods only)
Dist. to Exp. IC	-	Distance from the nearest expressway interchange. (log transformed)
Dum port	+/-	Dummy variable. 1 if in port areas along Tokyo Bay; 0 otherwise. The port area is a traditional industrial zone and also used for import and export goods.
Dum rr3	+/-	Dummy variable. 1 if along Ring Road 3; 0 otherwise. Ring Road 3 is about 40-50 km away from the urban center and serves as the newly developed industrial corridor.

Note: [a] Quoted from a gravity model which is based on the OD and distance matrices developed by TPCTMR in 2003.

TABLE 2 Establishment Industry Types Considered for Accessibility Indicator (Acce. est)

	Potential attraction establishments	Potential generation establishments
Food	• Manufacture of food • Wholesale trade, general merchandise • Wholesale trade (food and beverages) • Retail trade, general merchandise • Retail trade (food and beverage) • Accommodations • Eating and drinking places • Food take-out and delivery services	• Manufacture of food • Manufacture of beverages, tobacco and feed • Wholesale trade, general merchandise • Wholesale trade (food and beverages)
Daily goods	• Printing and allied industries • Wholesale trade, general merchandise • Wholesale trade (textile and apparel) • Retail trade, general merchandise • Retail trade (dry goods, apparel and apparel accessories) • Medicine and Toiletry retailers • books and stationery retailers	• Manufacture of textile mill products • Manufacture of furniture and fixtures • Manufacture of pulp, paper and paper products • Printing and allied industries • Manufacture of plastic products, except otherwise classified • Manufacture of rubber products • Manufacture of leather tanning, leather products and fur skins • Wholesale trade, general merchandise • Wholesale trade (textile and apparel)
Raw materials	• Manufacture of textile mill products • Manufacture of lumber and wood products, except furniture • Manufacture of furniture and fixtures • Manufacture of pulp, paper and paper products • Manufacture of iron and steel • Manufacture of non-ferrous metals and products • Manufacture of fabricated metal products • Manufacture of general-purpose machinery • Manufacture of production machinery • Manufacture of business oriented machinery • Wholesale trade (building materials, minerals and metals, etc.)	• Mining and quarrying of stone and gravel • Manufacture of lumber and wood products, except furniture • Manufacture of iron and steel • Manufacture of non-ferrous metals and products • Manufacture of fabricated metal products • Wholesale trade (building materials, minerals and metals, etc.)
Machinery	• Electronic parts, devices and electronic circuits • Manufacture of electrical machinery, equipment and supplies • Manufacture of information and communication electronics equipment • Manufacture of transportation equipment • Wholesale trade, general merchandise • Wholesale trade (machinery and equipment) • Retail trade, general merchandise • Machinery and equipment	• Manufacture of general-purpose machinery • Manufacture of production machinery • Manufacture of business oriented machinery • Electronic parts, devices and electronic circuits • Manufacture of electrical machinery, equipment and supplies • Manufacture of information and communication electronics equipment • Manufacture of transportation equipment • Wholesale trade, general merchandise • Wholesale trade (machinery and equipment)
Chemical goods	• Manufacture of chemical and allied products • Manufacture of petroleum and coal products • Manufacture of plastic products, except otherwise classified • Manufacture of rubber products • Manufacture of ceramic, stone and clay products	• Manufacture of chemical and allied products • Manufacture of petroleum and coal products • Manufacture of ceramic, stone and clay products
Mixed goods	• All industries	• All industries

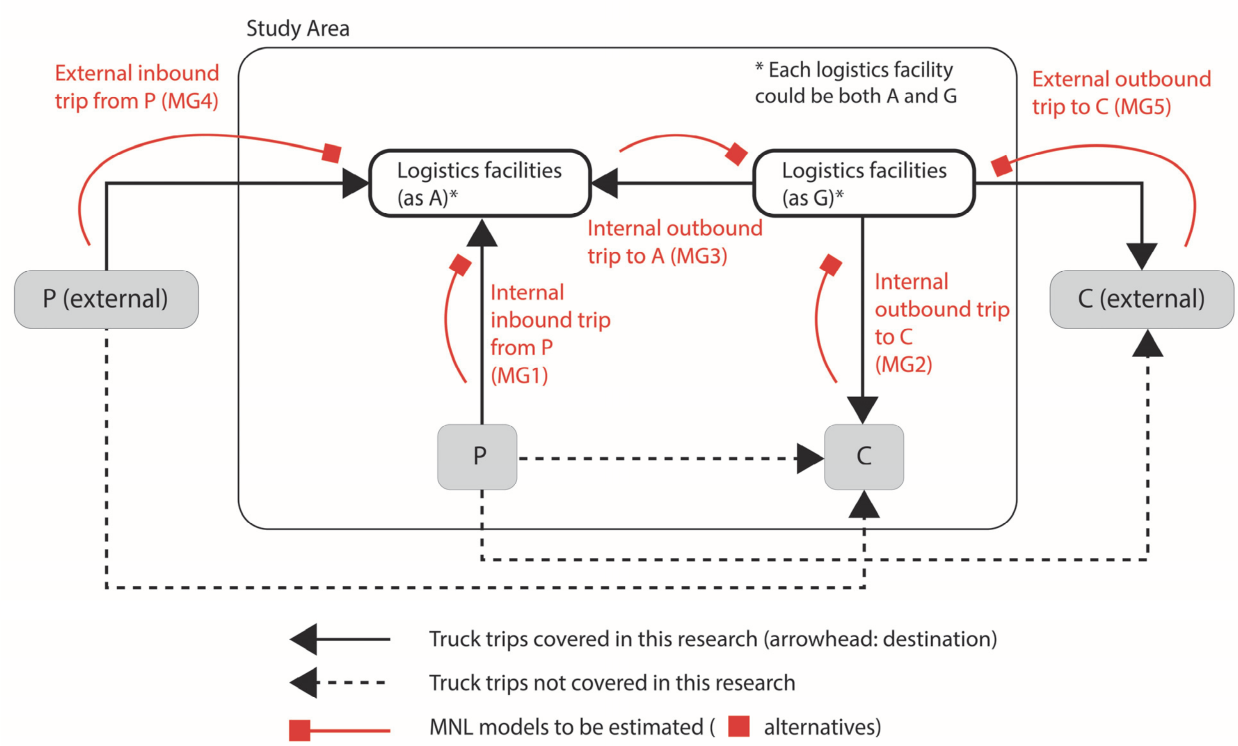

FIGURE 2 Target truck trips of five model groups

TABLE 3 Estimated MG1 and MG2

	MG1 (Internal inbound trip from P)						MG2 (Internal outbound trip to C)					
	Food	Daily goods	Raw materials	Machinery	Chemical Goods	Mixed Goods	Food	Daily goods	Raw materials	Machinery	Chemical Goods	Mixed Goods
Ship. dist.	-1.00	-0.83	-0.84	-0.76	-1.08	-1.35	-0.92	-0.81	-0.85	-0.87	-0.84	-1.39
	(-192)	(-121)	(-104)	(-107)	(-157)	(-105)	(-322)	(-213)	(-176)	(-183)	(-175)	(-138)
Floor area	0.71	0.48		0.48		0.34	0.42	0.43	0.14	0.51		0.40
	(56.2)	(36.0)		(35.5)		(16.9)	(76.0)	(60.1)	(15.4)	(54.3)		(27.5)
Pop. dens.	-0.09	-0.15		-0.16		-0.49			-0.08	-0.13	-0.07	-0.91
	(-4.70)	(-9.85)		(-8.61)		(-10.9)			(-6.30)	(-9.64)	(-4.91)	(-24.9)
Land price	-0.30		-0.36		-0.28		-0.19		-0.30	-0.31	-0.40	-0.35
	(-16.6)		(-22.5)		(-18.4)		(-30.5)		(-18.4)	(-17.4)	(-24.1)	(-10.7)
Acce. est.				0.06					0.21	0.29	0.14	0.34
				(3.15)					(12.6)	(15.1)	(8.94)	(7.58)
Acce. pop.						0.08						0.11
						(2.01)						(4.07)
Dist. to Exp. IC		-0.02								-0.07	-0.08	-0.17
		(-1.79)								(-6.53)	(-8.00)	(-9.57)
Dum port	-0.12	-0.46	0.35	0.20	0.43	-0.75	0.05	-0.44	-0.21	-0.78	-0.22	-0.16
	(-3.32)	(-12.7)	(10.4)	(5.57)	(14.2)	(-10.9)	(3.94)	(-22.5)	(-7.94)	(-25.6)	(-7.77)	(-3.59)
Dum rr3	0.07	0.63	-0.72	-0.18	-0.35	-0.83	-0.22	0.65	-0.52	-0.31	-0.11	-0.78
	(2.14)	(15.7)	(-9.64)	(-3.95)	(-6.40)	(-10.2)	(-11.3)	(31.0)	(-13.0)	(-10.4)	(-3.28)	(-13.2)
ρ^2 (adjusted)	0.234	0.099	0.096	0.090	0.170	0.307	0.111	0.092	0.094	0.132	0.110	0.278
No. of P/C	9,676	6,882	5,158	6,195	7,424	3,066	43,006	22,194	14,561	13,507	12,685	5,602
No. of alt.	10,648	11,247	7,767	7,755	7,467	4,859	10,648	11,247	7,767	7,755	7,467	4,859

Note: t values are shown in the parentheses.

TABLE 4 Estimated MG3 (Internal Outbound Trips to A)

	Food	Daily goods	Raw materials	Machinery	Chemical Goods	Mixed Goods
Ship. dist.	-0.63	-0.55	-0.85	-0.71	-0.87	-0.99
	(-150)	(-77.9)	(-96.1)	(-88.1)	(-78.0)	(-94.7)
Floor area	1.10	0.65	0.30			0.22
	(133)	(57.7)	(17.9)			(12.8)
Pop. dens.		-0.18	-0.09	-0.05	-0.05	-0.43
		(-12.2)	(-4.6)	(-2.15)	(-1.85)	(-12.8)
Land price	-0.53	-0.38		-0.49	-0.40	-0.19
	(-43.7)	(-20.6)		(-23.3)	(-14.3)	(-7.75)
Acce. est.	0.30	0.56				
	(22.8)	(30.2)				
Acce. pop.						0.26
						(8.24)
Dist. to Exp. IC			-0.14			-0.12
			(-8.14)			(-6.01)
Dum port	-0.23	-0.77	0.19	1.22	0.51	0.23
	(-12.2)	(-24.8)	(4.10)	(32.0)	(9.65)	(5.22)
Dum rr3	1.37	-0.28	0.96	0.89	0.52	-0.21
	(83.9)	(-6.05)	(19.4)	(20.4)	(8.17)	(-2.89)
ρ^2 (adjusted)	0.109	0.054	0.107	0.084	0.098	0.129
No. of A	24,319	10,672	4,268	5,081	2,876	3,667
No. of alt.	10,648	11,247	7,767	7,755	7,467	4,859

Note: t values are shown in the parentheses.

TABLE 5 Estimated MG4 and MG5

	MG4 (External inbound trip from P)						MG5 (External outbound trip to C)					
	Food	Daily goods	Raw materials	Machinery	Chemical Goods	Mixed Goods	Food	Daily goods	Raw materials	Machinery	Chemical Goods	Mixed Goods
Dist. to BD	-0.33	-0.08		-0.10	-0.20	-0.19	-0.40	-0.13	-0.31	-0.22	-0.26	-0.07
	(-24.7)	(-5.32)		(-5.56)	(-7.03)	(-5.86)	(-47.1)	(-12.8)	(-15.1)	(-21.9)	(-18.8)	(-3.14)
Floor area	0.81	1.06	0.65	0.69	0.19	0.81	0.85	0.85	0.25	0.24	0.65	0.91
	(44.8)	(61.5)	(26.2)	(36.7)	(6.82)	(20.7)	(62.0)	(75.6)	(14.2)	(21.4)	(34.6)	(30.8)
Pop. dens.			-0.09			-2.57	-0.25					-8.40
			(-2.22)			(-9.88)	(-12.7)					(-23.2)
Land price			-0.24	-0.48	-0.49	-2.18	-0.19	-0.05	-0.79	-0.21	-0.60	-1.23
			(-5.44)	(-15.3)	(-11.4)	(-24.5)	(-11.3)	(-3.16)	(-26.5)	(-10.7)	(-23.3)	(-21.4)
Acce. est.	0.06	0.38	0.16	0.39	0.33	0.65		0.29	1.15	0.18	0.09	0.36
	(3.37)	(21.0)	(4.39)	(12.4)	(8.45)	(9.13)		(17.6)	(33.9)	(8.88)	(3.90)	(7.86)
Acce. pop.						0.71						2.16
						(9.06)						(22.0)
Dist. to Exp. IC			-0.22		-0.22	-0.72			-0.20			-0.72
			(-8.56)		(-8.19)	(-20.6)			(-11.9)			(-26.4)
Dum port	0.11	-1.30	-1.20	-0.17	-0.13	0.14	0.60	-1.30	-0.95	0.20	-0.05	-1.07
	(2.96)	(-28.8)	(-13.6)	(-3.64)	(-1.74)	(1.36)	(18.3)	(-39.8)	(-18.5)	(6.00)	(-1.00)	(-10.2)
Dum rr3	-0.01	-0.27	1.02	-0.07	0.55	-1.53	-0.01	-1.11	0.44	1.57	-0.69	-2.39
	(-0.16)	(-4.47)	(18.5)	(-1.37)	(6.81)	(-10.5)	(-0.18)	(-19.7)	(8.17)	(63.7)	(-8.45)	(-16.5)
ρ^2 (adjusted)	0.038	0.052	0.046	0.030	0.013	0.176	0.060	0.038	0.034	0.038	0.038	0.178
No. of P/C	4,384	4,552	2,007	3,514	1,463	915	8,163	10,382	3,915	8,671	3,629	1,693
No. of alt.	10,648	11,247	7,767	7,755	7,467	4,859	10,648	11,247	7,767	7,755	7,467	4,859

Note: t values are shown in the parentheses.

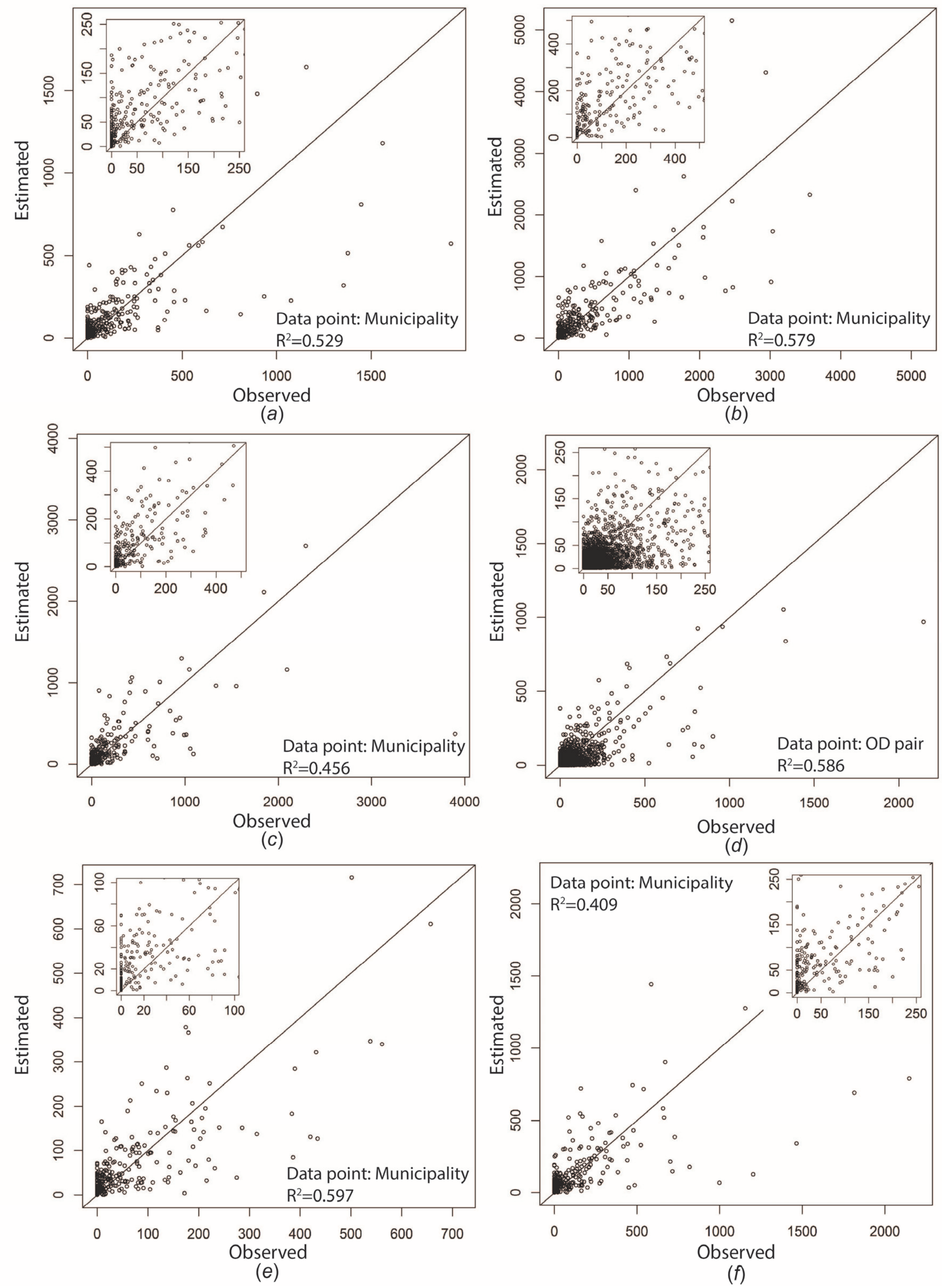

FIGURE 3 Reproducibility for number of trip ends and truck trips: (a) no. of trip ends (As) paired with Ps, internal (MG1), (b) no. of trip ends (Gs) paired with Cs, internal (MG2), (c) no. of trip ends (Gs) paired with As, internal (MG3), (d) no. of truck trips for OD pairs, internal, (e) no. of trip ends (As) paired with Ps, external (MG4), and (f) no. of trip ends (Gs) paired with Cs, external (MG5)