Evaluation of the spatial pattern of logistics facilities using urban logistics land-use and traffic simulator

Evaluation of the Spatial Pattern of Logistics Facilities using Urban Logistics Land-use and Traffic Simulator

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ABSTRACT

Despite the growing research interests on the spatial restructuring of logistics facilities that occurred in many cities around the world, the relationship between the spatial pattern of logistics land use and the level of externalities is far from being elucidated. We use the Urban Logistics Land-use and Traffic Simulator (ULLTRA-SIM), developed for the Tokyo Metropolitan Area, to evaluate the level of externalities that accompany different spatial distribution patterns of logistics facilities. The ULLTRA-SIM takes a novel approach to analyze the urban freight impacts through the simulations of logistics facility locations, urban logistics chains, and truck flow. The results indicate that, while the moderate concentration and deconcentration of logistics facilities do not significantly affect the level of externalities, scarcity of logistics facilities in or near the high demand locations exacerbates negative externalities. Also, the results of the simulations underscore the need for rigorous analysis in order to reduce negative externalities through logistics land use policies.

Keywords:
Urban freight simulation; land use and transportation; logistics sprawl; city logistics

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1. Introduction

The relationship between logistics-related land use and urban freight traffic is one of the emerging issues in urban freight research (Taniguchi et al., 2016). The evolution in logistics practices have led to changes in locational preferences, functions, and operations of logistics facilities. Large, high-throughput distribution centers that facilitate pull-logistics practices (i.e. supply chain operations driven by demand-side information) have replaced the facilities with storage as their primary function. Meanwhile, the need for large, high-throughput facilities has prompted the outward migration of logistics facilities in many cities. Such spatial transformation of logistics facilities gives rise to the concern about the negative externalities that may accompany such transformation, including congestion, CO_2 emission, local air pollution, infrastructure damages and traffic accidents, and calls for land use policies to curb "logistics sprawl". However, it is difficult to develop effective policies because little is known about the relationship between the spatial distribution of logistics facilities and the level of negative externalities. The purpose of this paper is to fill such knowledge gap by obtaining high-level insights into the abovementioned relationship; we measure the level of negative externalities under several spatial distribution patterns of logistics facilities, both actual and hypothesized, using a simulation model named Urban Logistics Land-use and Traffic Simulator (ULLTRA-SIM).

The ULLTRA-SIM is developed for the simulations of logistics facility location choice, logistics chain development, and truck flow in the Tokyo Metropolitan Area (TMA). The main calibration dataset is the 2013 Tokyo Metropolitan Freight Survey (TMFS) data. Existing land use and transportation simulators that consider goods movement, such as MEPLAN (Hunt and Simmonds, 1993) and TRANUS (De la Barra and Rickaby, 1982), treat logistics facilities (or logistics land use) as trip generators, and thus do not take into account their unique function as transshipment points within logistics chains. In contrast, the ULLTRA-SIM addresses the unique mechanism of logistics facility location choices and the process of the logistics facility selection for developing logistics chains, both of which are not properly considered in the existing models. The ability of the ULLTRA-SIM allows us to analyze the impacts of the logistics land use in a more rigorous manner and compare the impacts on Vehicle Kilometers-Traveled (VKT), Vehicle Hours-Traveled (VHT), fuel consumption, and the level of emissions (CO_2, NO_X, SPM, CO and SO_2).

The rest of the paper continues as follows; Section 2 provides the review of literature that focuses on the spatial distribution of logistics facilities at the metropolitan-scale and the evaluation of its impact on negative externalities; Section 3 details the ULLTRA-SIM; Section 4 explains the study area, the data used, simulation approach, and the scenarios tested; Section 5 discusses the result of the simulations; and Section 6 concludes the paper.

2. Literature review

2.1 Spatial restructuring of logistics facilities

The last decade saw many studies that focus on the distribution of logistics facilities in a metropolitan area (Aljohani and Thompson, 2016). In those studies, it is often suspected or presumed that "logistics sprawl", which is defined as "the spatial deconcentration of logistics facilities and distribution centers in metropolitan areas" (Dablanc and Rakotonarivo, 2010), would lead to longer truck trip distances, and, as a result, exacerbate the negative externalities. The recent prevalence of studies that measure and validate the occurrence of logistics sprawl in various urban areas around the world (Dablanc and Rakotonarivo, 2010; Dablanc and Ross, 2012; Dablanc et al., 2014; Heitz and Dablanc, 2015; Sakai et al., 2015, 2017b; Todesco et al., 2016; Woudsma et al., 2016) attests to the concern over the potential association between the spatial distribution of logistics facilities and negative externalities.

Those outward migrations of logistics facilities have not occurred for their own sake. The spatial transformation of logistics land use was prompted by the structural changes in logistics systems. Hesse and Rodrigue (2004) argue that the evolution of logistics that integrates different activities in supply chain, such as "supplying, warehousing, production and distribution functions", made possible by the innovations in information and communication technology (ICT), has reshaped freight transportation system since the 1960s. One of the key changes is the emergence of pull-logistics that has contributed to the significant reduction in cycle time and inventory cost. As a result, larger facilities with high throughput are becoming increasingly more desirable or even essential for pull-logistics operations (McKinnon, 2009; Allen et al., 2012; Sakai et al., 2017b). In the TMA, the average floor area of logistics facilities just about doubled, from 2,552 m^2 to 4,808 m^2 between 2003 and 2013 (Sakai et al., 2017b). In the metropolitan areas, the changes in the needs of logistics facilities, together with the scarcity of available sites, the rise in land prices and congestion near the urban center, often drove the restructuring of logistics facility locations (Hesse, 2004; Allen et al., 2012). However, such locational restructuring does not always occur. For example, Dablanc et al. (2014) shows the "relative sprawl", i.e. the outward migration of logistics facilities that is faster than that of business establishments in general, has not occurred in the Seattle Metropolitan Area between 1998 and 2009, while it has occurred in Los Angeles during the same period. The authors point out the availability of sites for new logistics facilities in the proximity of the urban center as well as growth management policies as potential reasons for the difference between those two locations.

2.2 Impacts of the spatial distribution of logistics facilities

Despite the growing interest in the topic, the literature that quantifies the association between the spatial distribution of logistics facilities and the scale of negative externalities is limited. Wygonik and Goodchild (2016) focus on the last-mile travel and analyze the effects of the factors of urban form (e.g. road density, distances from warehouse to store, store service area, etc.) on externalities, i.e. vehicle-miles travelled (VMT), CO_2, NO_X, and PM10, for three different delivery service designs using linear regression modeling. The results show the negative effect of road density and the positive effect of the distance to warehouse on the level of externalities. Wagner (2010) conducts a scenario analysis, comparing two different spatial patterns of logistics-related land use through traffic analysis using the origin-destination matrices for Hamburg, Germany. Her analysis indicates that a concentration of logistics land use near the urban center causes less externalities (due to shorter vehicle travel distances) than the scenario with dispersed logistics-related land use. While her case study is insightful, the analysis focuses only on a subset of logistics facilities and shipments in the study area, assuming that shipments are handled at the same facility regardless of the location. Davydenko et al. (2013) use a national scale logistics chain model, i.e. SMILE (Tavasszy et al.,1998), to measure the changes in ton-kilometers traveled (TKT) and VKT caused by the centralization and decentralization of transshipments in the Randstad region in the Netherlands. The results indicate that the effects of spatial changes in transshipment locations are limited as far as the scenarios examined by the authors are concerned. While the research is a pioneering effort that uses a logistics chain model to measure the effects of spatial pattern of logistics facilities, the geographical scale of the study, the entire nation, and the spatial unit of the analysis, region, do not allow the generalization of the findings to urban areas.

Sakai et al. (2015) used the data from the 2003 TMFS to analyze the relationship between the distance from the urban center and shipment efficiency, which is measured by both the average shipment distance and the distance between the actual and optimum logistics facility locations; the optimum location is a hypothetical location where a logistics facility minimizes the total shipment distance of the associated shipments. Their cross-sectional study indicates that logistics facilities become less efficient as the distance from the urban center increases. However, their subsequent longitudinal study (Sakai et al., 2017b) using the data from 2003 and 2013 TMFS found that the efficiency of good movements by trucks, measured in truck VKT per ton of shipment, actually improved between 2003 and 2013 despite the significant decentralization of logistics facilities.

2.3 Aim of this research

Despite the growing interest in logistics sprawl and the social impacts of freight, existing literature do not provide sufficient knowledge to guide the development of effective land use policies to address the negative impacts of truck travel in an urban area. Specifically, there is a dearth of knowledge on how the spatial distribution of logistics facilities affect logistics chains, truck travel, and associated social impacts at the metropolitan level. Logistics sprawl is not always caused or accompanied by the transformation of the logistics systems. The outward migration occurred in many cities due to the lack of sites near the urban center that satisfy the conditions for developing new logistics facilities required in the emerging logistics system. The question that this research strives to investigate is as follows; given the aforementioned changes in the functional need for logistics facilities in the past several decades, how public policies should guide the locations of logistics facilities to reduce negative externalities? This research carries out a series of simulations to derive high-level insights into how logistics facilities should be distributed in an urban area to reduce negative impacts of truck traffic. We believe that in the situation that socially desirable design of freight transportation system is far from being elucidated, the present research provides useful information for policy makers and planners.

3. The ULLTRA-SIM

3.1 Settings

In this study, our definition of logistics facilities includes distribution centers, truck terminals, warehouses, intermodal facilities, and oil terminals. We simulate logistics facility locations and shipments, considering the structure of logistics chains that consist of a production point (i.e. an origin of a logistics chain), a consumption point (i.e. a destination of a logistics chain), and one or more transshipment points in between. Since the interest of the research is the evaluation of spatial distribution of logistics facilities where transshipments occur, our analysis only considers the logistics chains that include at least one transshipment point. In other words, our analyses exclude direct shipments between the production and consumption points. From the analytical perspective, this implies that the split between direct and indirect deliveries will not be affected by the scenarios. We measure the levels of externalities resulting from several spatial distribution patterns of logistics facilities while keeping constant the numbers of logistics facilities of different sizes required for logistics operations, as well as the locations and quantities of production and consumption (we refer them as "shipment demands"). Here, we fix the total supply of logistics facilities, assuming it is pre-determined by various factors, such as facility cost, demand, inventory management and consolidation strategies. We analyze the effects of changes in transshipment locations that are determined by the spatial distribution of logistics facilities. The locations of shipment demands are aggregated at the municipality level. The unit of shipment is the number of trucks used; therefore, we use the terms "shipment" and "truck trip" interchangeably in this paper. In this setting, a shipment (or a truck trip) may consist of deliveries or pickups to/from multiple locations within a municipality.

We differentiate two types of decisions relevant to a logistics chain formulation in urban setting; the choice of the logistics facility location and the choice of the transshipment facility. The former is relevant to the formulation of the spatial distribution of logistics facilities, and the latter is about the pairing between a shipment demand and a logistics facility that handles the demand. Such model design can simulate the long-term, strategic decisions of the facility development and the mid- or short-term decisions on the routing of shipments in a reasonable manner.

3.2 Flow and specifications of the ULLTRA-SIM

The flow of the ULLTRA-SIM is provided in Figure 1. The simulation model consists of three main components. First, the logistics facility location choice model (LFLCM) estimates the location of each logistics facility considering the characteristics of the candidate locations and the facility. For the simulation of some of the land use scenarios, adjustments are made to the LFLCM or to the choice probabilities produced by the model to generate specific spatial distribution patterns of logistics facilities, which are discussed in Section 4. Next, the logistics chain model (LCM) takes the logistics facility distribution generated by the LFLCM as well as the shipment demands to estimate truck trips that connect production, consumption, and logistics facilities. In other words, the LCM generates logistics chains that go through logistics facilities. Finally, the traffic flow and impact simulator (TFIS) aggregates the trips and assigns them on the road network and, then, estimate the indicators of externalities. The LFLCM and LCM are run sequentially, reflecting the assumption that the choice of the logistics chain depends on the distribution of logistics facility locations because the decision time horizon for the latter tend to be longer.

The models for each step are estimated using standard closed-form specifications such as multinomial logit (MNL) and linear regression (LR) models mainly for computational efficiency, following the practice of other large-scale simulation systems (e.g. Waddell et al., 2007). The LFLCM and LCM are originally proposed by Sakai et al. (2016) and Sakai et al. (2017a), respectively. The model specification for each component is explained below.

3.2.1. The logistics facility location choice model (LFLCM)

The LFLCM is a set of spatial discrete choice models that estimate the probabilities of the locations to be selected by each logistics facility based on accessibility, site characteristics and zoning information. The estimated probabilities are used for implementing the Monte Carlo method to simulate the logistics facility locations. The spatial unit of location alternatives are 1 km by 1 km polygons. Within the study area (mentioned in Section 4.1), 17,916 polygons are considered as potential locations.

In the LFLCM, the utility function of a location l for a logistics facility f of the size of a is defined as:

$$U_{f^a,l} = \boldsymbol{\beta}_a^{ACCESS\_LFLCM}\mathbf{ACCESS}_{f^a,l} + \boldsymbol{\beta}_a^{SITE\_LFLCM}\mathbf{SITE}_l + \boldsymbol{\beta}_a^{ZONE\_LFLCM}\mathbf{ZONE}_l + \varepsilon_{f^a,l} \qquad (1)$$

where:
$\mathbf{ACCESS}_{f^a,l}$: a vector of the accessibility indicators at location l for a logistics facility of the size a (a=1: ≤ 400 m^2, a=2: 400-3000 m^2, a=3: > 3000 m^2), f^a
$\mathbf{SITE}_l$: a vector of the site characteristics at location l
$\mathbf{ZONE}_l$: a vector of the shares of zoning types at location l
$\varepsilon_{f^a,l}$: a randomly distributed unobserved component
$\boldsymbol{\beta}_a^{ACCESS\_LFLCM}$, $\boldsymbol{\beta}_a^{SITE\_LFLCM}$, $\boldsymbol{\beta}_a^{ZONE\_LFLCM}$: vectors of the parameters

Assuming that $\varepsilon_{f^a,l}$ follows the extreme value type I distribution, the probability for a logistics facility f^a to choose a location l is:

$$P_{f^a,l} = \exp\left(V_{f^a,l} + lnA_l\right) / \sum_l \exp\left(V_{f^a,l} + lnA_l\right) \qquad (2)$$

where:
$V_{f^a,l}$: the deterministic component of $U_{f^a,l}$
A_l: the size of the developable area at location l, calculated by subtracting the total area of wasteland, forest, and water (river, lake, beach, and sea area) from the size of a polygon (1 km^2).

It should be noted that, in the simulations discussed later in Section 4, the LFLCM does not reflect the dynamic nature of land market as the land price and the variables related to land availability are exogenously given. This setting entails the assumption of partial equilibrium, that the effects of logistics facilities on land price and land availability are limited (if any) because of the demand of various other land use types (residential buildings, offices, retails, factories, etc.) that dominates the market.

3.2.2. The logistics chain model (LCM)

The function of the LCM is to estimate the probability of each logistics facility being used for routing a shipment. The details of the development and estimation of the LCM are provided in Sakai et al. (2017a) and we only present an overview of the model and highlight the features that enable simplified yet reasonably accurate simulation of various logistics land use scenarios.

For the LCM, we define four types of trip ends, Production (P), Consumption (C), Attraction (A) and Generation (G) (see Figure 2). P is the origin of an inbound trip to a logistics facility. P is either at a facility within the study area that is not a logistics facility, or an external trip end (either at a logistics or a non-logistics facility outside of the study area); C is either the destination of an outbound trip from a logistics facility, which is at a non-logistics facility in the study area, or an external trip end. P and C are the "shipment demands" mentioned earlier and exogenously given. A is the destination of an inbound trip, which is at a logistics facility by definition; and G is the origin of an outbound trip, which is also at a logistics facility. The LCM estimates P→A, G→C and G→A trips, given the locations and the characteristics of the logistics facilities and the shipment demands (i.e. Ps and Cs) (2.1 to 2.4 in Figure 1).

It is important to note that pairings between specific P and C (the beginning and the end of a logistics chain) are not fixed in the LCM. The structure of the LCM, which freely matches P, C and A with logistics facilities instead of choosing the intermediate point (i.e. a logistics facility) for an exogenously defined P-C pair, allows us to simulate the changes in the logistics chains that can occur under different scenarios in a realistic manner without requiring the data for the entire logistics chains.

The models (2.1, 2.3 and 2.4 in Figure 1) employ MNL framework to pair Ps, Cs and As with logistics facilities, which in turn serve as As or Gs for the subsequent leg of the logistics chain. The spatial unit of trip ends are municipalities. The study area (mentioned in Section 4.1) consists of 315 municipalities. Sakai et al. (2017a) shows that this modeling approach can replicate the shipment OD with a reasonable level of accuracy, taking the heterogeneity on logistics facility use by commodity and trip type in logistics chains into account.

The utility function of a logistics facility f that handles a commodity group g for a trip end t of a trip end category ec for a commodity group g is defined as:

$$U_{t^{ec,g},f^g} = \boldsymbol{\beta}_{ec,g}^{ACCESS\_LCM}\mathbf{ACCESS}_{t^{ec,g},f^g} + \boldsymbol{\beta}_{ec,g}^{FACILITY\_LCM}\mathbf{FACILITY}_{f^g} + \boldsymbol{\beta}_{ec,g}^{SITE\_LCM}\mathbf{SITE}_{f^g} + \varepsilon_{t^{ec,g},f^g} \quad (3)$$

where:
$\mathbf{ACCESS}_{t^{ec,g},f^g}$: a vector of accessibility indicators for a logistics facility f^g for a trip end in category ec (ec=1 for P, ec=2 for C, and ec=3 for A) for a commodity group g (g=1: Food; g=2: Daily Goods; g=3: Raw Materials; g=4: Machinery; g=5: Chemical Goods; g=6: Mixed Goods), i.e. $t^{ec,g}$
$\mathbf{FACILITY}_{f^g}$: a vector of facility characteristics for logistics facility f^g
$\mathbf{SITE}_{f^g}$: a vector of site characteristics for the location of logistics facility f^g
$\varepsilon_{t^{ec,g},f^g}$: a randomly distributed unobserved component
$\boldsymbol{\beta}_{ec,g}^{ACCESS\_LCM}$, $\boldsymbol{\beta}_{ec,g}^{FACILITY\_LCM}$, $\boldsymbol{\beta}_{ec,g}^{SITE\_LCM}$: vectors of the parameters

Assuming that $\varepsilon_{t^{ec,g},f^g}$ follows the extreme value type I distribution gives the probability for a trip end $t^{ec,g}$ to be paired with logistics facility f^g, which is:

$$P_{t^{ec,g},f^g} = \exp\left(V_{t^{ec,g},f^g}\right) / \sum_{f^g} \exp\left(V_{t^{ec,g},f^g}\right) \quad (4)$$

For running this model for the G→A trips, the locations (at the municipality level) and the quantities of As (for G→A trips) have to be estimated so that a trip end A can be paired with another logistics facility that in turn becomes G (2.2 in Figure 1). The number of As (for G→A trips) to be served by the logistics facilities of size a' in municipality m is estimated using the following LR model:

$$N_{A^{\mathrm{G}\to\mathrm{A}},a',m} = \beta_{a'}^{a=1} N_{f^{a=1},m} + \beta_{a'}^{a=2} N_{f^{a=2},m} + \beta_{a'}^{a=3} N_{f^{a=3},m} \quad (5)$$

where:
$N_{f^{a=1},m}$, $N_{f^{a=2},m}$, $N_{f^{a=3},m}$: The number of logistics facilities by size (a=1: ≤ 400 m^2, a=2: 400-3000 m^2, a=3: > 3000 m^2) at municipality m
$\beta_{a'}^{a=1}$, $\beta_{a'}^{a=2}$, $\beta_{a'}^{a=3}$: The parameters to be estimated.

Once $N_{A^{\mathrm{G}\to\mathrm{A}},a',m}$ is obtained, it is split for each commodity type based on the shares of commodities in the paired Gs (obtained from estimated G→C trips at 2.1 in Figure 1) at municipality m.

3.2.3 The traffic flow and impact simulator (TFIS)

This simulator consists of two components: traffic assignment and impact estimation. The shipment data from the LCM are combined and converted to truck OD data. The shortest-path assignment is conducted based on link travel times that are estimated as daily averages using the data from the 2010 Road Traffic Census (Ministry of Land, Infrastructure, Transport and Tourism, 2010). The 2010 Road Traffic Census collected traffic counts for about 16 thousand road segments in the prefectures included in the study area. The Bureau of Public Roads (BPR) function was used for the traffic-to-speed conversion. The estimated truck assignment data are then used to evaluate the externalities associated with the logistics chains that go through logistics facilities in terms of VKT, VHT, fuel consumption, and the emissions of CO_2, NO_X, SPM, CO, and SO_2. Energy consumption and emission factors are based on travel speed (in 5 km/hour increments) and vehicle size (in two categories based on load capacity). The composition of gasoline and diesel vehicles are also considered. The factors are obtained from the report of a governmental research institute (National Institute for Land and Infrastructure Management, 2010).

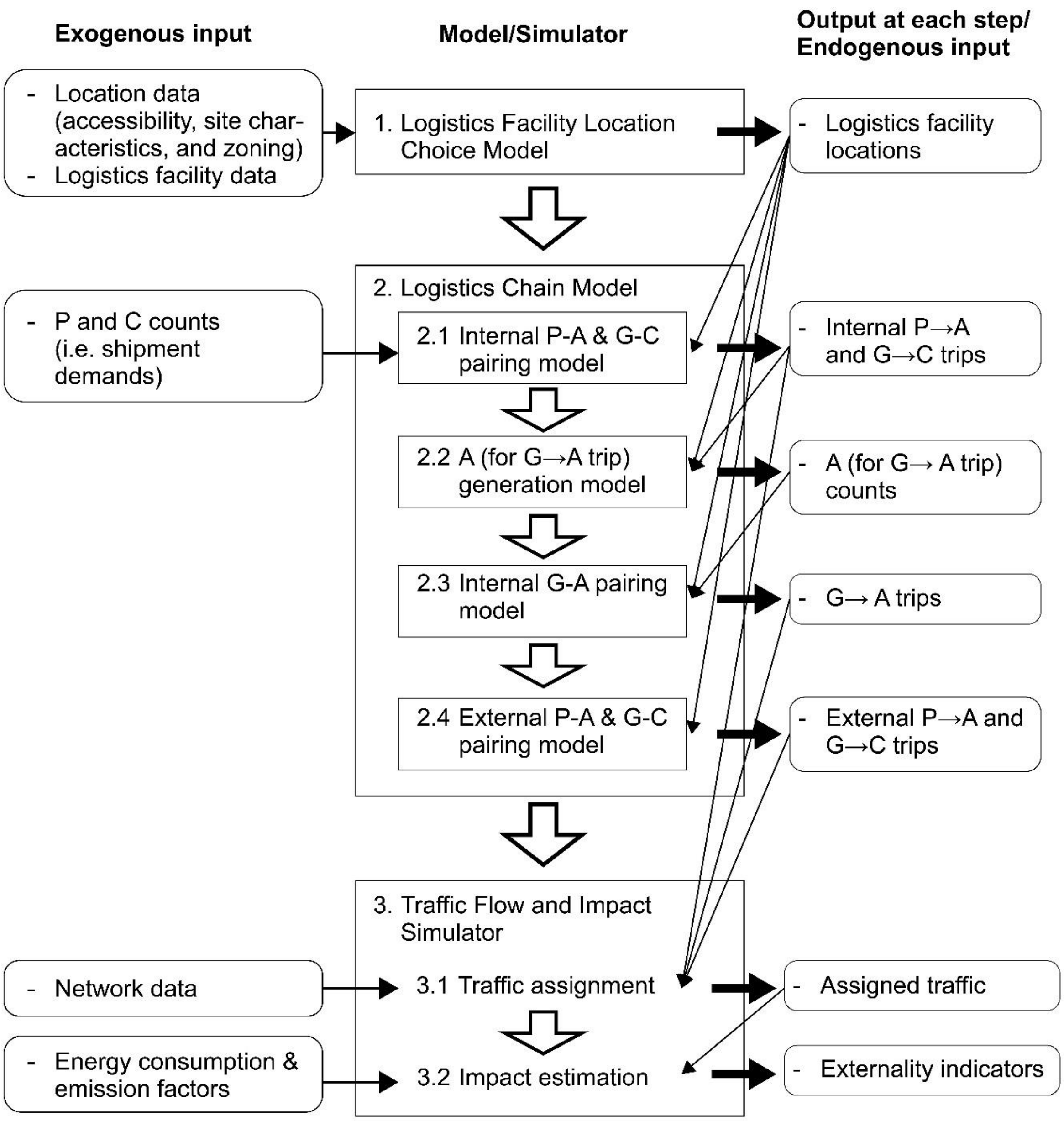

Figure 1: Flow of ULTTRA-SIM

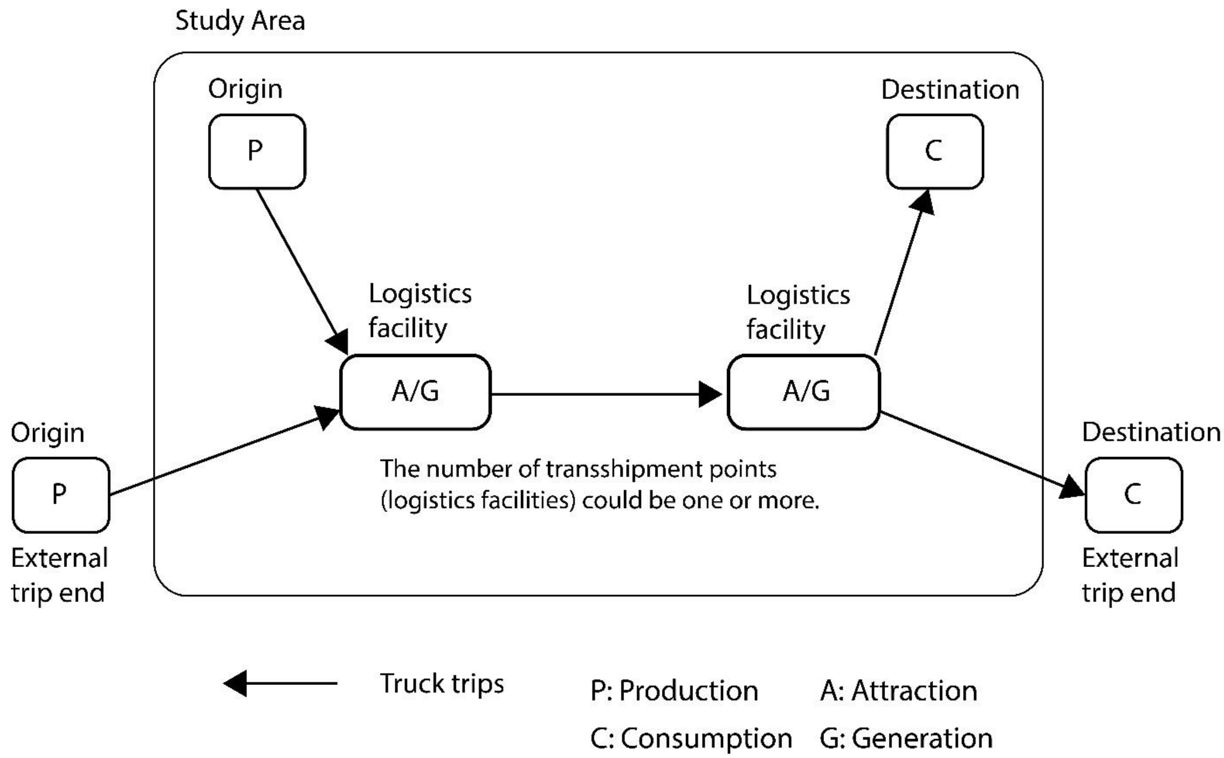

Figure 2: Trip ends and truck trips considered in LCM

4. Testing spatial distribution patterns

4.1 Study area

The analysis is conducted for the Tokyo Metropolitan Area (TMA), which covers the area of 23 thousand km^2. The TMA is by far the largest metropolitan area in Japan in terms of both population and the number of establishments, where 42 million people reside (Ministry of Internal Affairs and Communications, 2010) and 1.6 million establishments are located (Ministry of Internal Affairs and Communications, 2012). In this research, we define the area in front of the Tokyo Railway Station, the most expensive piece of land in Japan, as the urban center. The TMA has a monocentric urban structure; both population and businesses are most concentrated around the urban center. Also, the expressway system that consists of ring and radial roads has its center at the approximate location of the Tokyo Railway Station (Figure 3). The TMA is an international gateway having busiest seaports and airports in the country. Especially, the area around the ports of Tokyo, Kawasaki and Yokohama is the most significant shipment generator in the area.

Like other metropolitan areas in the North America and Europe, the TMA has experienced the outward migration of logistics facilities in recent years (Sakai et al., 2015; Sakai et al., 2017b). Given the aforementioned changes in the needs of the supply chain industry, public sector agencies have discussed policy proposals for guiding the development of new logistics facilities, including the incentives for locating large-scale logistics facilities near expressway interchanges and the restrictions on locating those facilities in so-called “Urbanization Control Area”, where the development requires a rigorous review for permission, to achieve a socially efficient spatial pattern and the logistics system (Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, 2015).

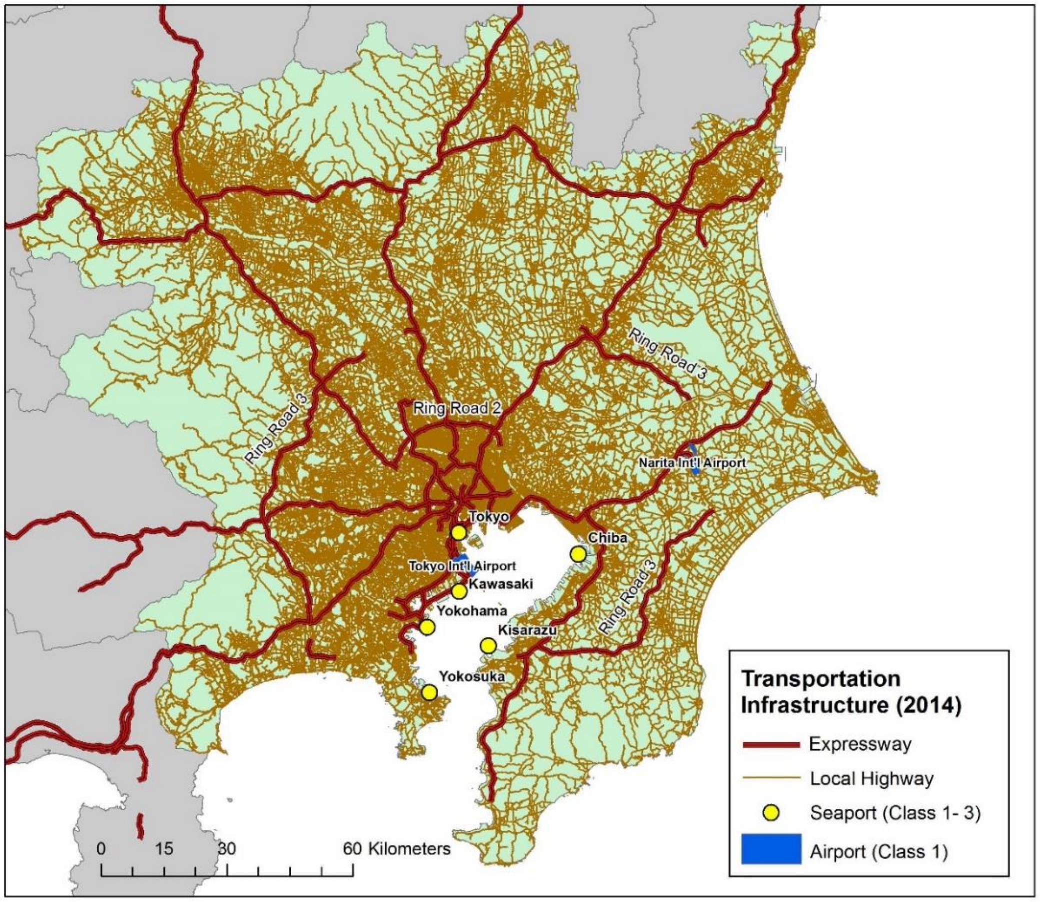

Figure 3: Transport system in the Tokyo Metropolitan Area

4.2 Data

The 2013 Tokyo Metropolitan Freight Survey (TMFS) is an establishment survey covering manufacturers, wholesalers, retailers, restaurants and service industry, conducted by the Transport Planning Commission of the Tokyo Metropolitan Region (TPCTMR). The survey reached 136,632 establishments in the TMA and 43,131 of them responded (the response rate of 31.6 %), including 4,646 logistics facilities. In this research, we use only the responses from those logistics facilities. For relating the sample to the population, the TPCTMP calculated expansion factors based on industry type, employment size, and geographic location. The data set is expanded by using those official expansion factors to represent all logistics facilities in the area. The TMFS data set covers both facility and shipment information; the facility information includes industry category, function, year of establishment, floor area, and employment size and the shipment information includes the locations of origins/destinations and their facility types, commodity types, weight, and the number of trucks used, for both inbound and outbound shipments. After the expansion, the data set includes 19,423 logistics facilities in total, and 261,902 truck shipments, of which 40,356 are P→A trips (internal), 115,867 are G→C trips (internal), 52,391 are G→A trips (internal), 16,835 are P→A trips (external), and 36,453 are G→C trips (external); these data are used to estimate the LFLCM and the LCM.

The accessibility and the site data for each of the 1 km-by-l km polygons that cover the study area were provided by the TPCTMR or calculated based on the 2013 TMFS data and the information from the archive of the Government of Japan. The lists of variables used in the models are provided in the Appendices A and B.

4.3 Estimations of LFLCM and LCM

The maximum likelihood estimation (MLE) and minimum mean-square estimation (MMSE) were implemented for

MNL and LR models, respectively. The details of the variables and the estimated models are provided in Appendices A and B. We tested the travel impedance criteria both based on network-based travel distance and travel time; it turned out that the models with the travel distance can achieve greater fit than those with the travel time. As for the LFLCM, the effects of the variables vary considerably depending on the size of logistics facilities. For example, the variables of shipment distance have stronger effects for small and medium facilities than large facilities. On the other hand, the coefficient of population density shows the strongest negative effect for large facilities. The fit of the LFLCM models measured by the adjusted Rho-square ranges between 0.280 and 0.307, which indicates good performance for this type of model. For the LCM, the effect of shipment distance on the choice of logistics facilities stands out for internal shipments, although facility size also has a strong effect for some commodity types. The fit of the LCM models varies widely between 0.013 to 0.332 depending on the trip and commodity types. In general, the models of internal trips performed better than those for external trips.

4.4 Simulation approach

The estimated models (LFLCM and LCM) are used for the simulations. All logistics facilities in the data set, regardless of their establishment years, and the associated logistics chains are taken into consideration. In the simulation, the number of logistics facilities, their floor areas, and types of commodity handled are taken directly (after the expansion) from the 2013 TMFS. Thus, we take the actual characteristics of logistics facilities, excluding locations, as given. Similarly, shipment demands, i.e. the locations and the quantities of Ps and Cs, their commodity types, and the sizes of vehicles to handle them, are taken from the 2013 TMFS. Taken together, the ULLTRA-SIM implicitly assumes that the fundamental structure of the logistics system would remain relatively stable. We believe this approach facilitates the interpretation of the outputs by highlighting the impacts of different land use policy scenarios.

We simulate several different spatial distributions (i.e. scenarios) of logistics facilities by adjusting the LFLCM model parameters and/or estimated probabilities. In the LFLCM, "average shipment distance" is used as independent variables with and without log-transformation. Initially, to compute the average shipment distance for each alternative location of a logistics facility, the observed shipment demands (from the 2013 TMFS) associated with respective facilities are used. Later, each logistics facility and the shipment demands handled by the facility are decoupled and reconstructed by the LCM. This process is necessary to reflect the dynamic nature of logistics chain formulations; if logistics facilities change their locations, then, the logistics chains should be restructured based on the new logistics facility locations. We also tested, for some of the scenarios, the simulation with a feedback mechanism between the LFLCM and LCM but the changes observed in the externality indicators are marginal, 0.3% or less, against the outputs from the runs without the feedback process. The simulation is repeated 20 times for each scenario to check the effects of random components in the LFLCM and LCM (i.e. standard deviations (SD) of the results).

4.5 Land use scenarios

Figure 4 shows the distribution of Ps and Cs in the TMA used for the simulation. Despite the strong monocentric structure of the population and the establishments, the shipment demands are not simply concentrated in the area around the urban center and the ports (the west side of Tokyo Bay). Although the urban center and the port area are the largest clusters of the demands, some concentrations of the demands are observed also in the periphery, specifically, the west, north-west and north of the TMA; this is mainly due to the locations of factories, which do not necessarily correspond to those of overall business establishments (Sakai et al., 2017b).

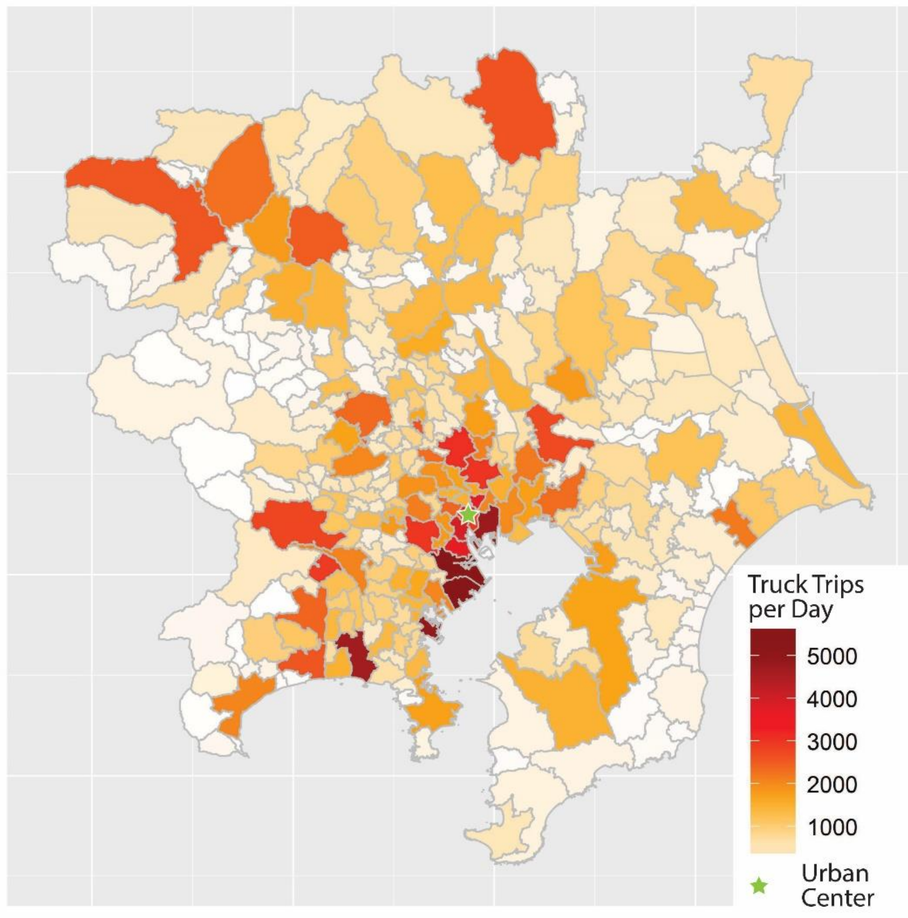

Figure 4 Distribution of Productions and Consumptions

The simulation process starts with generating the spatial distribution of logistics facilities for each of the scenarios. Before choosing the final set of scenarios, we ran a number of scenarios and checked the sensitivity of the simulation model to understand the behavior of the model, especially the interactions among the components. The six scenarios presented below were selected as they are most illustrative of the relationship between the spatial distribution of logistics facilities and externalities. While the simulation was run 20 times for each scenario, the spatial distributions of logistics facilities for a particular scenario did not differ much.

The overall approach is to first simulate the actual (Scenario I – "baseline") and the best (Scenario II – "shipment distance minimization") scenarios to establish the maximum achievable reduction in externalities through the spatial distribution of logistics facilities. Then, three scenarios, each representing a general approach to control logistics facility distribution, are simulated; the cases of centralization (Scenario III – "centralization") and decentralization (Scenario IV – "prohibition on logistics facility development in the urban core"), and a clustering of logistics facilities at locations near the urban center (Scenario V – "concentration") are simulated to estimate the impacts of those land use patterns on externalities. Finally, Scenario VI – "deconcentration", in which logistics facilities migrate to less dense areas that are away from the urban center, as in logistics sprawl, is tested. The description of each scenario is provided below and the examples of the spatial distributions for the scenarios, excluding Scenario III – "centralization", are shown in Figure 5.

(I) Baseline: This scenario replicates the spatial distribution of logistics facilities observed in the 2013 TMFS, as best as can be, by the ULLTRA-SIM. No adjustment of the model parameters or the estimated probabilities is performed in the LFLCM. The means (and the standard deviations (SDs)) of the average distances from the urban center for small, medium and large facilities are 37.3 km (SD: 0.14 km), 38.3 km (SD: 0.12 km) and 37.3 km (SD: 0.19 km), respectively.

(II) Shipment distance minimization: Given the observed shipment records, the location that minimizes the total shipment distance is selected for each facility. Once all the optimum logistics facility locations are determined, the pairings of shipment demands and logistics facilities are updated by the LCM. The average distances from the urban center for small, medium and large facilities are 34.6 km, 34.4 km and 30.2 km, respectively. The results for this scenario provide the maximum level of reduction in the externalities achievable through the spatial distribution of logistics facilities.

(III) Centralization: This scenario is the extreme mono-centric concentration of logistics facilities. Specifically, all logistics facilities are in the urban center; therefore, the distance from the urban center is zero for all facilities. For this scenario, the LFLCM is not used and the distribution of the logistics facilities is directly fed into the LCM.

(IV) Prohibition on logistics facility development in the urban core: Under this scenario, no logistics facilities are located within 30 km from the urban center. To accomplish this, the LFLCM is run with the choice set that excludes the locations in the urban core. The means (and the SDs) of the average distances from the urban center for small, medium and large facilities are 48.6 km (SD: 0.10 km), 49.0 km (SD: 0.08 km) and 50.8 km (SD: 0.16 km), respectively.

(V) Concentration: This scenario concentrates logistics facilities in the port area that has traditionally served as the major freight generator. To achieve this distribution, the choice probabilities of the LFLCM are adjusted to create a highly concentrated distribution of logistics facilities in the port area around the Port of Tokyo, which is close to the urban center. To accomplish this distribution, the probabilities of the locations in the port area are quintupled. The means (and the SDs) of the average distances from the urban center for small, medium and large facilities are 36.0 km (SD: 0.11 km), 36.7 km (SD: 0.10 km) and 32.9 km (SD: 0.16 km), respectively.

(VI) Deconcentration: Under this scenario, the logistics facilities are encouraged to deconcentrate. To achieve such effect, three changes are imposed in the LFLCM model parameters and the estimated probabilities: (1) the coefficients of the independent variables that reflect the availability of industrial zones (i.e. shares of quasi-industrial, industrial, and exclusively industrial zones) are set to zero, (2) the coefficients for population density for small and medium facilities are adjusted to be the same as the value for large facilities, and (3) the choice probabilities for locations that are in the highest 0.5 % of employment accessibility are changed to zero. Firstly, removing the effects of industrial zones that are greatly concentrated in the port area encourages the deconcentration of logistics facilities, especially that of large facilities. Secondly, the adjustment of the coefficients for the population density let the small and medium facilities avoid the locations with high population density. Thirdly, the prohibition of choosing the highest employment accessibility locations lessens the attractiveness of the urban center for placing logistics facilities, which would be very high without this adjustment. The overall effect is to encourage logistics facilities to locate in less dense areas that are outside of the urban center and the port area. The means (and the SDs) of the average distances from the urban center for small, medium and large facilities are 40.4 km (SD: 0.13 km), 40.7 km (SD: 0.11 km) and 42.6 km (SD: 0.20 km), respectively.

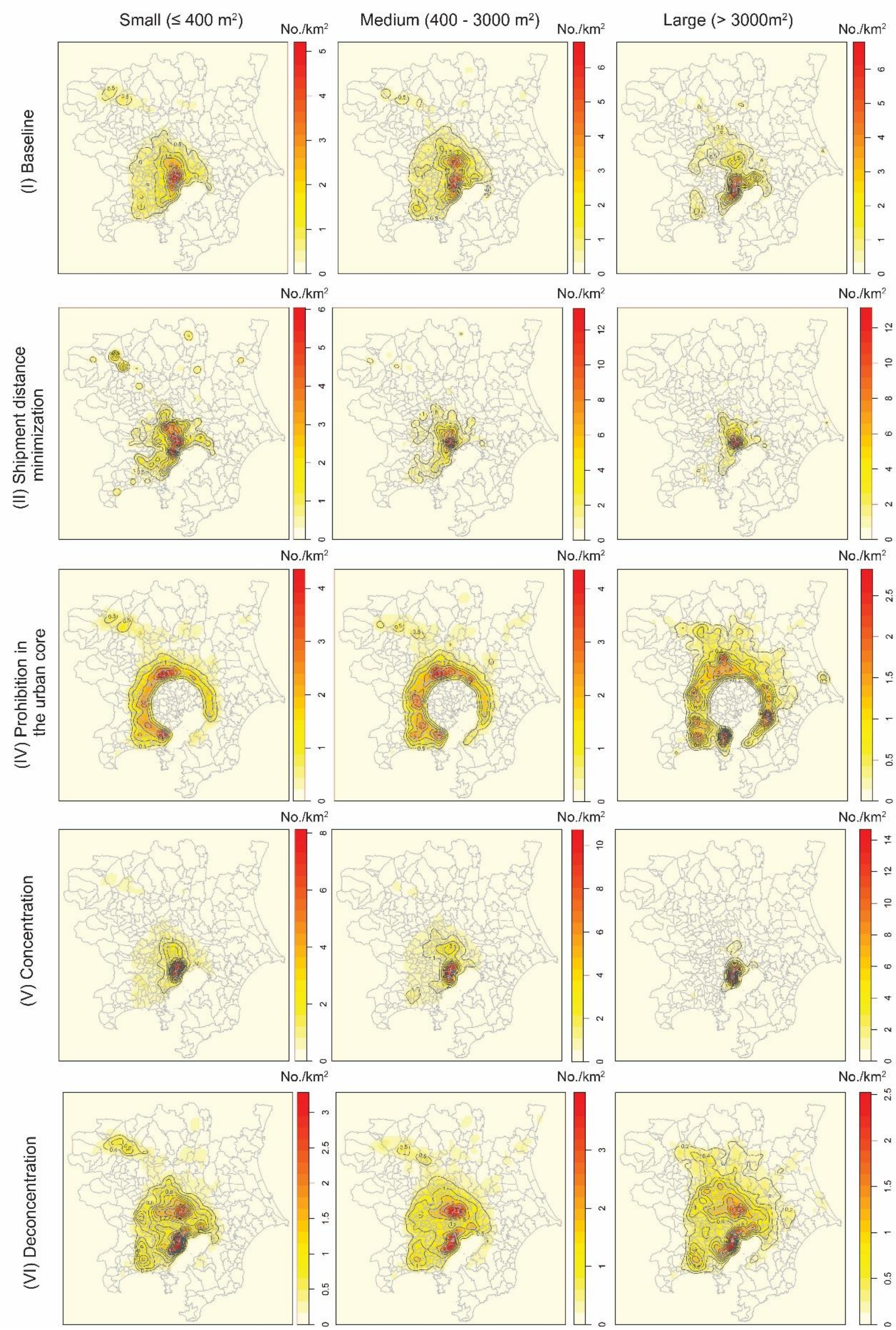

Figure 5: Spatial distribution of logistics facilities (Scenarios I, II, IV, V, and VI)

5. Result and discussion

The LCM and TFIS were run for the generated distribution patterns and the indicators of externalities were estimated as shown in Table 1. Scenario II achieves a significant mitigation of negative externalities compared with the Baseline scenario. The simulation result indicates that positioning the logistics facilities at the locations that minimize the aggregate shipment distances reduces various measures of externalities by approximately 12% compared with the Baseline scenario. The spatial distribution of Scenario II indicates that, for large facilities, the locations that minimize the shipment distance are concentrated in the urban center (as they service relatively large areas and the urban center is highly accessible to the demands), while small facilities are dispersed (as their service areas are small), some of them locating in the suburbs or even in the exurbs near the clusters of shipment demands.

The two extreme scenarios, Scenario III and Scenario IV, indicate both the perfect concentration of logistics facilities at the urban center and the absolute restriction on the logistics facilities near the urban center produce higher levels of externalities than the baseline (excluding CO under Scenario III). The results are not surprising as the shipment demands are distributed both near the urban center and the outside of the central area, and both extreme centralization and decentralization lead to a spatial mismatch. The measures of externalities are much higher under Scenario IV; traffic and emissions are about 10% more than those of the baseline. The displacement of logistics facilities near the urban center occurs in some cities, due to either the combination of the increase in land price and the scarcity of available lands, or public policies. This result underscores the importance of the presence of logistics facilities near the urban center where a large amount of shipment demands exist. Without the logistics facilities nearby, the shipment demands in and around the urban center must be served by the facilities in the suburbs, leading to a drastic increase in freight traffic. On the other hand, an excess concentration of logistics facilities near the urban center would be also detrimental.

The levels of externalities in Scenario V and Scenario VI are not significantly different from those of the Baseline scenario. The differences are about -1% in Scenario V and about +2% in Scenario VI. Despite the significant differences between these two scenarios in terms of the spatial distribution of logistics facilities, the self-adaptation of logistics chains simulated by the LCM resulted in the similar levels of VKT and/or VHT with the Baseline scenario. Also, while the logistics facilities are dispersed under Scenario VI, a number of logistics facilities still choose to locate near the urban center despite the scenario setup that makes the area unattractive. This happens because the benefit of being close to the shipment demands outweigh the negatives, and those facilities play a critical role in the reduction of externalities by serving a large amount of shipment demands in or around the urban center. These results show that the self-adaptations of logistics chains would diminish the effects of the spatial distribution of logistics facilities on externalities. At the same time, for such adaptations to happen, overly strict regulation of logistics facilities, as were seen under the Scenarios III and IV, that allows no logistics facilities in some areas (e.g. urban center) would probably be counterproductive.

Also, while the spatial pattern of Scenario V is similar to that of Scenario II (Figure 5), the latter entails significantly less externalities. In Scenario II, the location of each facility is “customized” to exactly match the shipment demands handled by the facility to minimize the shipment distance. Meanwhile, in Scenario V, logistics chains must adapt to the locations of the logistics facilities that had been determined by the LFLCM that are almost exclusively in the port area by design. While a finely tuned logistics land use, such as that of Scenario II, is extremely difficult to achieve in reality, the gaps in the levels of externalities between Scenario V and Scenario II indicate that creating logistics cluster(s) in an urban area for the purpose of reducing freight-related negative externalities requires sophisticated analysis to get it right.

Furthermore, we evaluated the impacts of local pollutants in relation to the spatial distribution of residential population, for the scenarios of baseline, concentration, and deconcentration (Scenarios I, V, and VI). For this, we calculated the indicator of exposure to pollution, the product of residential population and the emissions of local pollutants for each 1 km by 1 km polygon, and summed for the study area. The results are shown in Table 2. The indicators illustrate rather large adverse effects (increases of over 4% from the Baseline) of concentration (Scenario V) when population exposure is taken into account despite the reductions in the absolute levels of externality indicators shown in Table 1. Contrastingly, deconcentration (Scenario VI) performed considerably better than the Baseline (decreases of over 4.5%) when exposure is considered. Although the implication to the overall level of externality is still unclear, these results indicate that the planning of logistics land use must take into account possible negative impacts on surrounding areas in addition to broader externalities such as carbon emission.

It should be noted that our approach simplifies the complex mechanism of logistics operations. For example, while the floor areas of logistics facilities are considered in the LCM, some facilities handle more shipments than they do in the reality; in such case, they are assumed to operate more efficiently, in terms of throughput - floor space ratio, than the actual situation. However, many constraints, e.g. ability of logistics facilities to handle refrigerated or hazardous goods, which need to be considered in the real world are ignored in the LCM. Also, the assumption of the shortest path-based routing and the fixed network speed might cause the underestimation of the indicators. While we believe these simplifications do not invalidate the findings discussed above, the model assumptions should be taken into account in the interpretation of the estimated figures.

Table 1: Indicators of externalities

		VKT [mil. km]	VHT [thou. hr.]	Fuel [mil. l]	CO_2 [thou. ton]	NOx [ton]	SPM [ton]	CO [ton]	SO_2 [ton]
(Scn. I) Baseline	Mean	26.9	560	6.14	16.3	34.1	0.347	40.9	0.503
	SD	0.05	1.0	0.012	0.03	0.07	0.001	0.09	0.001
(Scn. II) Distance minimization	Mean	23.8	494	5.42	14.4	30.0	0.306	36.0	0.445
	SD	0.01	0.2	0.003	0.01	0.02	0.000	0.03	0.000
	Diff. from Scn. I	-11.6%	-11.7%	-11.7%	-11.7%	-11.8%	-11.8%	-11.9%	-11.7%
(Scn. III) Centralization	Mean	27.8	568	6.38	17.0	35.5	0.358	39.3	0.523
	SD	-	-	-	-	-	-	-	-
	Diff. from Scn. I	+3.6%	+1.3%	+4.0%	+4.1%	+4.2%	+3.1%	-3.8%	+4.0%
(Scn. IV) Prohibition in the urban core	Mean	29.6	613	6.75	17.9	37.4	0.381	45.1	0.554
	SD	0.06	1.0	0.011	0.03	0.06	0.001	0.09	0.001
	Diff. from Scn. I	+10.2%	+9.4%	+9.9%	+9.9%	+9.9%	+9.7%	+10.4%	+9.9%
(Scn. V) Concentration	Mean	26.6	554	6.08	16.2	33.8	0.344	40.4	0.499
	SD	0.05	1.1	0.010	0.03	0.06	0.001	0.12	0.001
	Diff. from Scn. I	-1.1%	-1.1%	-0.9%	-0.8%	-0.7%	-0.8%	-1.2%	-0.9%
(Scn. VI) Deconcentration	Mean	27.4	571	6.25	16.6	34.7	0.353	41.8	0.513
	SD	0.05	0.8	0.009	0.02	0.05	0.001	0.10	0.001
	Diff. from Scn. I	+2.0%	+1.9%	+1.9%	+1.9%	+1.8%	+1.8%	+2.2%	+1.9%

Table 2: Indicators of local pollutants – population overlapping

		NOx [thou. ton-pop.]	SPM [thou. ton-pop.]	CO [thou. ton-pop.]	SO_2 [thou. ton-pop.]
(Scn. I) Baseline	Mean	164	1.73	180	2.42
	SD	0.434	0.004	0.419	0.006
(Scn. V) Concentration	Mean	172	1.81	187	2.53
	SD	0.366	0.004	0.383	0.005
	Diff. from Scn. I	4.8%	4.6%	4.0%	4.2%
(Scn. VI) Deconcentration	Mean	156	1.65	172	2.31
	SD	0.401	0.004	0.423	0.006
	Diff. from Scn. I	-4.8%	-4.8%	-4.5%	-4.7%

6. Conclusion

We evaluated the spatial distribution patterns of logistics facilities at the metropolitan scale using the ULLTRA-SIM, through which the locations of logistics facilities, the logistics chain formulations, and traffic flow were simulated in sequence. Given the dearth of research on the relationship between the spatial distribution of logistic facilities and the negative externalities, this research provides valuable insights on the subject.

Obviously, some of the scenarios, Scenario III for example, are not realistic or feasible in the real world. Our intent in analyzing these admittedly unrealistic scenarios is to clearly demonstrate the potential of logistic land use patterns such as centralization, decentralization, and clustering, for increasing or decreasing externalities when they are taken to extreme levels. Yet, the analysis shows relatively modest effects of the concentration or deconcentration of logistics facilities (with respect to the urban center) on negative externalities even under the extreme conditions assumed for those scenarios. This suggests that using a simple measure, e.g. the distance from the urban center, to evaluate the efficacy of spatial distribution of logistics facility is probably not effective. Giuliano et al. (2016) noted that the association between shipment pattern and location and characteristics of facilities must be considered when analyzing the effect of spatial distribution of warehousing and distribution facilities on truck VKT. The results presented in this paper bear out their claim.

In terms of the strategies to reduce negative externalities, we did not find a "magic bullet" among the scenarios tested. Simply preventing logistic facilities from migrating outward is not likely to generate much benefit in terms of reducing truck travel and various externalities. On the other hand, we found that the prohibition of logistics land use in high demand areas (e.g. urban center) would lead to a significant increase in negative externalities. We presume that a similar situation might occur even without regulation if a severe competition for land in a busy urban core pushes logistics land use out of the area. When the choice of logistics facilities is severely restricted, the negative externalities would increase significantly because some of the shipments become extremely inefficient. Simulations also indicate that creating a large cluster of logistics facilities near the urban center only moderately reduce the overall truck VKT and amount of various pollutant emissions while increasing the risk for population's exposure to local pollutants.

The insights obtained from our analysis are more detailed and in depth compared the existing research such as Wagner (2010), which has a limitation in considering the dynamics of the shipment demand - logistics land use location matching, or Dablanc and Rakotonarivo (2010) that analyzed only the parcel deliveries to the urban core. This study presents a potential framework for an integration of land use and freight transportation planning, a practice advocated by Dablanc and Ross (2012). However, our study has also revealed that the relationship between the degree of deconcentration of logistics facilities and negative externalities is not as straightforward as widely presumed. The discourse on logistics sprawl and its impacts must recognize the complex relationship among the distribution of logistics facilities as well as other types of land use, shipment demands, and various types of negative impacts.

Furthermore, we believe that the rich insights obtained from the analysis outlined in this paper demonstrate the utility of rigorous analytical tools that can capture the relationships among the spatial distributions of shipment demands and logistics facilities, and decisions related to logistics chains. However, there are also many shortcomings that need to be addressed in future research. Although the ULLTRA-SIM is developed using rich data and allows us to examine the spatial distribution of logistics facilities at the level of detail which has not been achieved in the previous studies, the model simplifies extremely complex urban freight system. For instance, we do not address the inter-relations among delivery pattern, inventory management, consolidation and deconsolidation, cooperation and competition among shippers, and the location of a logistics facility. Also, as the ULLTRA-SIM focuses only on logistics facilities and associated shipments, the integration with a general urban and traffic model is required to evaluate the broader impacts of logistics facility locations, such as the impacts on passenger traffic. There is a dire need for analytical tools that can facilitate accurate assessment of alternative policies and approaches to achieve socially desirable logistics land use. We expect the advances in the ICT, Data Science techniques, and the data collection efforts may allow the future research to address a larger part of such complex system.

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Appendix A Variables and estimation results for the logistics facility location choice model (LFLCM)

Table A.1. shows the list of variables used for the LFLCM.

Table A.1: Variables used for LFLCM

Variable	Description
Accessibility	
Average shipment distance	Average network distance in kilometers to the shipment origins and destinations for each facility. This is a facility specific indicator.
ln(average shipment distance)	The log-transformed "average shipment distance".
ln(accessibility to employments)	The log-transformed "accessibility to employments". "Accessibility to employments" at location l is defined as: $\sum_m E_m \exp\left(-\mu \times \log(D_{l,m})\right)$ where: E_m: no. of employments in location m (a 1km-by-1km polygon) $D_{l,m}$: network distance between locations (1km-by-1km polygons) l and m in kilometers μ: impedance factor (=0.5)[a]
ln(distance from nearest expressway interchange)	The log-transformed distance from the nearest expressway interchange in kilometers.
Land Characteristics	
Population density	Population density in thousand per km^2.
Along Ring Road 2 (dummy)	1 if along Ring Road 2; 0 otherwise. This includes the sections completed in 2014 and earlier.
Along Ring Road 3 (dummy)	1 if along Ring Road 3; 0 otherwise. This includes the sections completed in 2014 and earlier.
Port Area (dummy)	1 if in port areas along Tokyo Bay; 0 otherwise.
ln(Average land price)	The log-transformed average land price in million yen per m^2.
Zoning	
Share of residential zone	Share of land within each polygon that is zoned for residential, commercial, etc.
Share of commercial zone	
Share of quasi-industrial zone	
Share of industrial zone	
Share of exclusively industrial zone	
Share of urbanization control zone	
Share of miscellaneous land use	
Share of non-urban planning zone	

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

Table A.2. shows the estimated LFLCM for small, medium, and large logistics facilities.

Table A.2: Estimated LFLCM

Floor Area	Small $<=400$ m^2		Medium 400-3000 m^2		Large > 3000 m^2	
Variables	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
Accessibility						
Average shipment distance	-0.159	-45.09**	-0.164	-54.72**	-0.102	-38.46**
ln(average shipment distance)	-1.197	-21.13**	-1.295	-24.90**	-1.342	-19.19**
ln(accessibility to employments)	0.511	26.39**	0.509	32.61**	0.321	22.30**
ln(distance from nearest expressway interchange)	-0.030	-2.08**	-0.043	-3.55**	-0.017	-1.17
Land Characteristics						
Population density	-0.050	-17.17**	-0.089	-31.86**	-0.135	-35.66**
Along Ring Road 2 (dummy)	-0.257	-3.97**	0.016	0.32	-0.064	-0.87
Along Ring Road 3 (dummy)	0.450	7.75**	0.294	6.04**	0.570	10.70**
Northern exurb (dummy)	1.101	11.90**	1.103	14.96**	0.707	10.74**
Port area (dummy)	0.138	2.06**	0.030	0.46	0.705	10.52**
ln(average land price)	-0.497	-20.15**	-0.567	-26.51**	-0.428	-17.55**
Port area × ln(average land price)	-0.031	-0.81	-0.098	-2.87**	0.166	5.53**
Zoning						
Share of commercial zone	0.231	2.31**	-0.428	-4.23**	1.737	16.13**
Share of quasi-industrial zone	0.686	8.61**	1.460	23.23**	2.954	38.61**
Share of industrial zone	-0.104	-0.73	0.978	10.43**	2.440	22.35**
Share of exclusively industrial zone	-0.017	-0.16	0.172	2.13**	2.043	25.22**
Share of urbanization control zone	-0.238	-3.69**	-0.609	-10.99**	-0.187	-2.52**
Share of miscellaneous land use	0.150	1.46	-0.251	-2.75**	0.018	0.16
Share of non-urban planning zone	0.930	4.68**	-0.411	-1.98**	0.073	0.26
Null log-likelihood		-57,490		-77,794		-54,918
Maximum log-likelihood		-40,080		-53,912		-39,538
Rho-squared		0.303		0.307		0.280
Adjusted Rho-squared		0.303		0.307		0.280

Note: * Significant at 90% confidence level; ** significant at 95% confidence level.

Appendix B Variables and estimation results for the logistics chain model (LCM)

Table B.1. shows the list of variables used for LCM.

Table B.1: Variables used for LCM

Variable	Description	Expected sign of effect
Accessibility		
Ship. dist.	For internal trips, network distance between P, C or A and a logistics facility. For external trips, network distance between the border point that is associated with P or C and a logistics facility.	+/- [a]
ln(ship. dist.)	The log-transformed "ship. dist.".	+/- [a]
ln(acce. est.)	The log-transformed "accessibility to relevant establishments". "Accessibility to relevant establishments" is defined as: $\sum_l E_l \exp(-\mu \times \log(D_l))$ 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)[b]	+
ln(acce. pop.)	The log-transformed "accessibility to residential population". "Accessibility to residential population" is defined as: $\sum_l P_l \exp(-\mu \times \log(D_l))$ 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)[b]	+ (for mixed goods only)
ln(dist. to Exp. IC)	The log-transformed distance from the nearest expressway interchange in kilometers.	-
Facility characteristics		
ln(floor area)	The log-transformed floor area of a facility in m^2.	+
Site characteristics		
Pop. dens.	Population density of a 1km-by-1km polygon where a logistics facility is located in thousand per km^2.	-
ln(land price)	The log-transformed average land price of a 1km-by-1km polygon where a logistics facility is located in million yen per m^2.	-
Dum port	1 if in port areas along Tokyo Bay; 0 otherwise.	+/-
Dum rr2	1 if along Ring Road 2; 0 otherwise. This includes the sections completed in 2014 and earlier.	
Dum rr3	1 if along Ring Road 3; 0 otherwise. This includes the sections completed in 2014 and earlier.	+/-

Note: [a] The combined effect of "ship. dist." and "ln(ship. dist.)" should be negative for the range of possible "ship. dist.". [b] Quoted from a gravity model which is based on the OD and distance matrices developed by TPCTMR in 2003.

Tables B.2, B.3, and B.4 show the estimated LCM. The variables that are not statistically significant at 90% confidence level and/or showing the opposite sign from the expected are not included in the final models, except for the dummy variables that are included regardless of the significance and the sign.

Table B.2: Estimated LCM (P→A and G→C trips, internal)

	P→A trips (internal)						G→C trips (internal)					
Variables	Food	Daily goods	Raw materials	Machinery	Chemical Goods	Mixed Goods	Food	Daily goods	Raw materials	Machinery	Chemical Goods	Mixed Goods
Ship. dist.	-1.81 (-95.0**)	-1.16 (-43.6**)	-0.59 (-15.8**)	-1.70 (-80.4**)	-1.32 (-60.9**)	-1.72 (-38.1**)	-1.02 (-89.6**)	-0.91 (-57.3**)	-1.06 (-57.8**)	-1.44 (-88.5**)	-1.28 (-71.9**)	-2.21 (-77.1**)
ln(ship. dist.)	-0.005 (-6.79**)	-0.016 (-15.6**)	-0.036 (-29.2**)	0.013 (18.3**)	-0.023 (-23.8**)	-0.055 (-17.3**)	-0.030 (-63.3**)	-0.026 (-41.4**)	-0.020 (-29.2**)	-0.005 (-9.19**)	-0.009 (-16.6**)	-0.014 (-9.73**)
ln(acce. est.)									0.23 (2.75**)	0.51 (5.69**)		
ln(acce. pop.)						0.11 (4.35**)						0.08 (4.65**)
ln(dist. to Exp. IC)										-0.06 (-6.45**)	-0.08 (-8.40**)	-0.11 (-8.07**)
ln(floor area)	0.39 (58.7**)	0.26 (35.7**)		0.25 (34.9**)		0.20 (18.2**)	0.22 (75.6**)	0.25 (65.0**)	0.08 (15.7**)	0.28 (55.0**)		0.22 (27.4**)
Pop. dens	-0.02 (-8.29**)	-0.04 (-17.8**)		-0.03 (-13.4**)		-0.09 (-14.2**)			-0.01 (-7.52**)	-0.02 (-9.87**)	-0.01 (-5.20**)	-0.14 (-27.4**)
ln(land price)	-0.43 (-27.4**)		-0.44 (-30.9**)		-0.37 (-25.8**)		-0.31 (-54.5**)		-0.31 (-21.4**)	-0.30 (-19.8**)	-0.46 (-32.6**)	-0.25 (-13.8**)
Dum port	-0.50 (-12.8**)	-0.73 (-19.8**)	0.20 (6.12**)	0.11 (3.36**)	-0.02 (-0.62)	-0.93 (-12.6**)	-0.10 (-7.11**)	-0.63 (-32.7**)	-0.34 (-12.7**)	-0.84 (-28.3**)	-0.33 (-11.2**)	-0.30 (-6.28**)
Dum rr2	-1.50 (-11.8**)	-0.47 (-9.11**)	-0.77 (-8.98**)	0.36 (6.16**)	-0.04 (-0.66)	-0.07 (-0.84)	-0.26 (-9.53**)	-1.09 (-28.1**)	-0.18 (-4.89**)	0.01 (0.17)	0.06 (1.61)	-0.21 (-2.97**)
Dum rr3	-0.06 (-1.66*)	0.62 (15.4**)	-0.80 (-11.1**)	-0.33 (-7.42**)	-0.48 (-9.06**)	-0.59 (-7.27**)	-0.31 (-15.8**)	0.57 (26.9**)	-0.66 (-16.9**)	-0.42 (-14.3**)	-0.22 (-6.30**)	-0.76 (-13.1**)
ρ^2 (adjusted)	0.219	0.097	0.100	0.093	0.167	0.332	0.121	0.094	0.097	0.122	0.108	0.290
No. of P/C	10,026	6,989	5,438	6,550	8,068	3,285	44,408	23,089	14,970	14,412	13,115	5,873
No. of alt.	10,620	11,241	7,775	7,747	7,453	4,887	10,620	11,241	7,775	7,747	7,453	4,887

Note: t values are shown in the parentheses; * significant at 90% confidence level; ** significant at 95% confidence level.

Table B.3: Estimated LCM (G→A trips, internal)

G→A trips (internal)						
Variables	Food	Daily goods	Raw materials	Machinery	Chemical Goods	Mixed Goods
Ship. dist.	-0.67 (-38.9**)	-0.99 (-43.1**)	-1.15 (-34.9**)	-1.16 (-40.5**)	-1.13 (-28.5**)	-1.38 (-44.3**)
ln(ship. dist.)	-0.015 (-29.2**)	-0.002 (-2.52**)	-0.016 (-13.3**)	-0.004 (-4.06**)	-0.014 (-10.0**)	-0.014 (-9.94**)
ln(acce. est)	0.84 (12.6**)	1.47 (18.2**)				
ln(acce. pop)						0.15 (7.13**)
ln(dist. to Exp. IC)			-0.11 (-6.97**)			-0.06 (-4.02**)
ln(floor area)	0.60 (135**)	0.36 (59.3**)	0.15 (17.3**)			0.13 (13.8**)
Pop. dens		-0.02 (-7.24**)	-0.03 (-10.5**)	-0.01 (-4.29**)	-0.02 (-3.42**)	-0.07 (-13.6**)
ln(land price)	-0.43 (-41.8**)	-0.37 (-22.1**)		-0.54 (-28.1**)	-0.45 (-17.0**)	-0.29 (-14.2**)
Dum port	-0.36 (-19.4**)	-0.67 (-20.9**)	-0.15 (-3.07**)	1.00 (25.2**)	0.32 (6.04**)	-0.02 (-0.46)
Dum rr2	-1.48 (-19.5**)	0.53 (18.8**)	-0.82 (-9.62**)	0.72 (10.2**)	-0.38 (-3.62**)	-0.16 (-1.86*)
Dum rr3	1.24 (75.9**)	-0.30 (-6.48**)	0.80 (15.8**)	0.82 (18.7**)	0.38 (5.94**)	-0.24 (-3.22**)
ρ^2 (adjusted)	0.111	0.060	0.105	0.083	0.097	0.134
No. of A	24,959	11,090	4,405	5,222	3,017	3,698
No. of alt.	10,620	11,241	7,775	7,747	7,453	4,887

Note: t values are shown in the parentheses; * significant at 90% confidence level; ** significant at 95% confidence level.

Table B.4: Estimated LCM (P→A and G→C trips, external)

	P→A trips (external)						G→C trips (external)					
Variables	Food	Daily goods	Raw materials	Machinery	Chemical Goods	Mixed Goods	Food	Daily goods	Raw materials	Machinery	Chemical Goods	Mixed Goods
Ship. dist.						-0.53 (-5.57**)	-0.68 (-9.50**)		-0.79 (-14.5**)		-0.31 (-2.96**)	
ln(ship. dist.)	-0.011 (-24.4**)	-0.003 (-5.22**)		-0.003 (-5.93**)	-0.006 (-6.86**)		-0.004 (-4.49**)	-0.006 (-17.8**)		-0.007 (-21.3**)	-0.004 (-2.96**)	-0.004 (-5.29**)
ln(acce. est)		1.72 (20.5**)	0.89 (4.63**)	1.68 (9.54**)	1.12 (5.30**)	2.59 (9.06**)		1.17 (17.2**)	2.91 (16.7**)	0.58 (5.61**)		0.97 (4.94**)
ln(acce. pop)						0.48 (9.00**)						1.70 (24.0**)
ln(dist. to Exp. IC)			-0.20 (-8.68**)		-0.19 (-7.70**)	-0.59 (-20.5**)						-0.62 (-26.9**)
ln(floor area)	0.43 (44.7**)	0.59 (61.7**)	0.36 (26.2**)	0.38 (36.8**)	0.11 (6.91**)	0.45 (20.7**)	0.46 (61.5**)	0.47 (75.5**)	0.08 (8.50**)	0.13 (21.4**)	0.36 (34.8**)	0.53 (32.1**)
Pop. dens			-0.02 (-2.56**)			-0.37 (-9.86**)	-0.04 (-13.0**)					-1.38 (-25.3**)
ln(land price)			-0.21 (-5.37**)	-0.41 (-14.5**)	-0.42 (-10.4**)	-1.65 (-24.4**)	-0.16 (-10.4**)	-0.07 (-4.32**)	-0.46 (-16.5**)	-0.17 (-9.35**)	-0.52 (-26.7**)	-1.12 (-24.2**)
Dum port	0.08 (2.26**)	-1.36 (-29.9**)	-1.24 (-13.4**)	-0.12 (-2.55**)	-0.11 (-1.44)	0.14 (1.29)	0.51 (15.5**)	-1.33 (-40.2**)	0.02 (0.35)	0.17 (5.23**)	-0.05 (-1.01)	-0.74 (-6.98**)
Dum rr2	-1.78 (-8.33**)	-0.47 (-7.67**)	-0.17 (-1.62)	0.47 (6.56**)	0.54 (5.45**)	0.07 (0.26)	-2.14 (-9.30**)	-0.23 (-6.16**)	2.29 (51.6**)	-0.10 (-1.46)	0.31 (3.88**)	2.37 (21.0**)
Dum rr3	-0.05 (-0.85)	-0.30 (-5.03**)	1.00 (17.4**)	-0.04 (-0.73)	0.57 (7.03**)	-1.53 (-10.5**)	-0.06 (-1.38)	-1.16 (-20.6**)	1.01 (18.3**)	1.56 (62.5**)	-0.68 (-8.34**)	-2.30 (-15.8**)
ρ^2 (adjusted)	0.040	0.053	0.046	0.031	0.013	0.176	0.060	0.039	0.072	0.038	0.037	0.191
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.	10,620	11,241	7,775	7,747	7,453	4,887	10,620	11,241	7,775	7,747	7,453	4,887

Note: t values are shown in the parentheses; * significant at 90% confidence level; ** significant at 95% confidence level.

The linear regression models for estimating the numbers of As (for G → A trips) for each size group of logistics facilities that serve the As are shown in Table B.5. An independent variable, the number of medium logistics facilities, was excluded in the model for small facilities because the sign of the coefficient of the variable is negative if the variable is included.

Table B.5: Estimated attraction generation models (for G → A trips)

	Small $\leq 400\ m^2$		Medium 400-3000 m^2		Large > 3000 m^2	
Variables	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
No. of small LFs	1.46	3.58**	1.65	5.14**	3.32	7.27**
No. of Medium LFs			0.96	3.88**	1.46	4.14**
No. of Large LFs	1.94	6.38**	1.64	7.11**	4.10	12.42**
Adjusted R^2		0.44		0.71		0.84

Note: * Significant at 90% confidence level; ** significant at 95% confidence level.