The Simulations of the Urban Logistics Land Use and Associated Logistics Chains for Policy Insights

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THESIS

Submitted as partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Urban Planning and Policy
in the Graduate College of the
University of Illinois at Chicago, 2017

Chicago, Illinois

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ACKNOWLEDGEMENTS

I would like to acknowledge that I could not have completed this dissertation research without the thoughtful and kind supports of many people, including faculty members, senior researchers, friends and family.

I am profoundly grateful to my academic advisor and dissertation committee chair, Professor Kazuya Kawamura. I believe my studies at the PhD program were never as meaningful as they actually are without having Kazuya as my advisor. Kazuya is extremely knowledgeable and insightful and his advices and comments always hit the nail on the head. To discuss with Kazuya about research issues is exciting and inspiring. In addition to his intellectual supports, he seriously cared about my future success as a researcher and offered me a lot of opportunities to work with other researchers and to publicize myself.

I appreciate the supports of the dissertation and preliminary committee members. Prof. Mohammadian, Prof. Derrible and Dr. Auld provided me beneficial comments and advices on the model specifications. I really enjoyed the constructive discussions on how to improve the models and expand them for the broader scope. Prof. Tilahun also gave me valuable advices on modeling. Especially, his advices helped me a lot in developing the logistics chain model, one of the main components of the simulation tool developed in this research. Prof. Lowe gave me precious comments for elaborating the policy implications of the research. She helped me to improve the dissertation to be appealing to wider audiences. I also would like to thank Prof. Weber for participating my preliminary examination committee.

Most of my research products at the University of Illinois at Chicago were not achievable without the supports from Japan. Prof. Hyodo, a professor at Tokyo University of Marine Science and Technology, encouraged me to learn the advanced econometrics, which was needed to complete this dissertation, and also supported me on the data collection in Japan. The members of The Institute of Behavioral Sciences, Dr. Hagihara, Dr. Kenmochi, and Mr. Oka, provided me valuable information about the Tokyo Metropolitan Freight Survey and shared the relevant data. Their inputs about urban freight policies in Tokyo were also indispensable for the research design.

I also would like to thank my colleagues at the Urban Transportation Center: Sriraj, Silvia, Edward, Paul, Lise, Robert, Steve, Jody, Vanessa, and Jordan. Thank you for offering me a wonderful working space and sharing the great time with me at the UTC. I could not have enjoyed the PhD life without my dear friends in the transportation research group, Alex, Yaye, Moyin, and Jaeyong. I am really happy that I was able to work with you. I also would like to thank my cohorts at the PhD program, Sarah, Natalia, Johann, Ivis, April, Zafer, Malissa, Megan, Nabil, Jihwan, Leonor, Youngjun, Andrea, Amanda, Charlie, and Junjun; the time we spent together was amazing.

Lastly, I would like to acknowledge that, without the devoted support of my wife, Trang, I was not able to engage myself in the studies at the UIC. She is the best partner of my life and, at the same time, the closest and the strongest supporter for my ambition. I really appreciate that Trang, and our little Tomoharu (6 month old as of April 19, 2017), got through the busy and hard days of the newborn period, allowing me to concentrate on the research works.

This research is financially supported by the Department of Urban Planning and Policy at the University of Illinois at Chicago (UPP Award) and the National Center for Freight and Infrastructure Research and Education (CFIRE). CFIRE is a national university transportation center supported by the US Department of Transportation.

PREFACE

The parts of this dissertation were published in the following research papers:

> **Sakai**, T., Kawamura, K., Hyodo, T. (2017). Logistics Chain Modeling for Urban Freight: Pairing Truck Trip Ends with Logistics Facilities. *Transportation Research Record: Journal of the Transportation Research Board, No. 2609. doi:* 10.3141/2609-07 *(*Forthcoming)
>
> **Sakai**, T., Kawamura, K., Hyodo, T. (2017). Spatial Reorganization of Urban Logistics Systems and Its Impacts: Case of Tokyo. *Journal of Transport Geography*, 60, 110-118.
>
> **Sakai**, T., Kawamura, K., Hyodo, T. (2015). Locational Dynamics and Efficiency of Logistics Facilities: Evidence from Tokyo. *Journal of Transport Geography*, 46, 10-19.

The author, Takanori Sakai, was responsible for all of the writings and analyses in the papers listed above, while the co-authors provided advices on research frameworks and editing the manuscripts.

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LIST OF ABBREVIATIONS

A	Attraction
BPR	Bureau of Public Roads
C	Consumption
G	Generation
ICT	Information and Communication Technology
JIT	Just-In-Time
KDE	Kernel Density Estimation
LCM	Logistics Chain Model
LFLCM	Logistics Facility Location Choice Model
MCE	Multi-Criteria Evaluation
MG	Model Group
MIAC	Ministry of Internal Affairs and Communications
MLITT	Ministry of Land, Infrastructure, Transport and Tourism
MM	Materials Management
OD	Origin Destination
P	Production
P-C flows	Flows between Production and Consumption Locations
PD	Physical Distribution
QIZ	Quasi-Industrial Zone
SCM	Supply Chain Management
SD	Standard Deviation
TFIS	Traffic Flow and Impact Simulator
TKT	Ton-Kilometers Traveled

LIST OF ABBREVIATIONS (Continued)

TMA	Tokyo Metropolitan Area
TMFS	Tokyo Metropolitan Freight Survey
TPCTMR	Transport Commission of the Tokyo Metropolitan Region
TRB	Transportation Research Board of the National Academics
ULLTRA-SIM	Urban Logistics Land-use and Traffic Simulator
VHT	Vehicle-Hours Travelled
VKT	Vehicle-Kilometers Travelled
VMT	Vehicle-Miles Travelled
2PL	Second-Party Logistics
3PL	Third-Party Logistics

SUMMARY

In the past several decades, logistics practices have gone through a significant evolution process along with advances in the Information and Communication Technologies and the globalization of supply chains. Logistics operations have become increasingly reliant on the information flow from the demand-side. Such demand-driven logistics systems need larger logistics facilities that can handle a large amount of goods in an efficient manner, instead of conventional facilities that provide storage as their foremost function. Such change in the functional needs of logistics facilities, together with the lack of adequate sites with enough size in dense urban areas, have led to the outward migration of logistics facilities in many metropolitan areas in the developed countries.

Researchers and practitioners are concerned that such spatial restructuring of logistics facilities would exacerbate the negative externalities associated with urban freight, such as congestions, emissions, noises, vibrations and traffic accidents. However, the impacts of such spatial restructuring, as well as the policies to address it, have rarely been analyzed in the past. The goal of this research is to fill the research gaps through empirical analysis and simulations using large and comprehensive urban freight survey datasets.

Three research questions that are examined in this study are: (I) *Does the outward migration of logistics facilities increase negative externalities associated with urban freight traffic?*; (II) *What is the distribution of logistics facilities that minimizes negative externalities associated with urban freight traffic?*; and (III) *How and to what degree can public policies affect negative externalities associated with urban freight traffic through the spatial distribution of logistics facilities?*. To answer these questions, a series of analyses that consist of four research components were conducted: (1) *the empirical analysis of spatial reorganization of urban systems and its impacts*, (2) *the development of a simulation model for analyzing logistics facility*

distribution and associated urban freight traffic, (3) *the evaluation of various spatial distribution patterns of logistics facilities* and, (4) *the analysis of different policy options and the evaluation of their impacts*. The study area for this research is the Tokyo Metropolitan Area (TMA), and large-scale urban freight surveys, the Tokyo Metropolitan Freight Survey (TMFS) conducted in 2003 and 2013, were used as the main data sources.

The comparison of the 2003 and 2013 TMFS data (Research Component 1) indicates that the logistics facilities in the TMA moved outward by 26% in only 10 years. The analysis shows, however, the outward migration occurred in response, at least partially, to the sprawl of the shipment demand locations that had already occurred by 2003. In the same period, median size of the logistics facilities nearly doubled and the share of the shipments handled by the large facilities (> 3,000 m^2) markedly increased. My analysis indicates that truck trip distance per ton of shipment deceased by 4%, which means the logistics systems in the TMA became more efficient overall, despite the 6.4% increase in average shipment distance. These results indicate that the outward migration of logistics facilities does not necessarily lead to an increase in negative externalities, although I found that the logistics facilities in the exurbs, those sprawled beyond their shipment demand locations, are quite inefficient in terms of truck trip distance per tons handled.

The Urban Logistics Location and Traffic Simulator (ULLTRA-SIM) was developed for evaluating various spatial distributions of logistics facilities as well as the policies aiming to reduce urban freight impacts (Research Component 2). The ULLTRA-SIM consists of three components: (i) the logistics facility location choice model (LFLCM) that simulates the spatial distribution pattern of logistics facilities, (ii) the logistics chain model (LCM) that simulates choices of logistics facilities for routing the shipments and estimates truck trips, and (iii) the traffic flow and impact simulator (TFIS) that assigns truck trips on a road network and estimates the indicators of negative externalities. The LFLCM is a set of spatial discrete choice models. The utilities of alternative locations for each logistics facility are defined by accessibility indicators, site characteristics, and zoning types. The LCM, which also consists of discrete choice models, estimates truck trips by pairing trip ends (shipment demands) with logistics facilities that handles the shipments, given the locations and the characteristics of the logistics facilities and the locations and the quantities of the trip ends. The utilities of alterative logistics facilities for each trip end depend on accessibility indicators, facility and site characteristics. Lastly, the TFIS conducts shortest-path assignment and estimates the externality indicators (vehicle-kilometers travelled (VKT), vehicle-hours travelled (VHT), fuel consumption, the emissions of CO_2, NOx, SPM, CO, and SO_2) based on the energy consumption and emission factors.

The simulations of various spatial distribution patterns (Research Component 3) show that the effects of concentration and deconcentration of logistics facilities (with respect to the urban center) on the negative externalities are small, while the prohibition of logistics land use in high-demand areas would lead to a significant increase in negative externalities. Meanwhile, negative externalities can be reduced by approximately 12% if the logistics facilities are located in the most efficient manner. The most efficient distribution of logistics facilities, in terms of VKT, involves concentration of large facilities in the urban center and relatively dispersed distribution of small facilities.

Three groups of policies were considered for the simulations: zoning, clustering, and distance-based pricing (Research Component 4). The policies were designed to guide the logistics facilities that were established recently (during 2003-2013) to reduce negative externalities. However, none of the tested policies, including those considered extreme, produces massive effects on the externalities through changes in the locations of logistics facilities. By far the greatest reduction in negative externalities is observed for the distance-based pricing. The distance-based pricing, simulated as an increase in transportation cost by 50%, leads to a significant reduction in negative externalities, by about 7% – 8%, due to the self-organization of logistics chains that significantly improve efficiency.

This research unveiled the relationship among urban structure, shipment demand locations, spatial distribution of logistics facilities, and traffic impacts. Also, I was able to estimate the levels of reductions in externality that are achievable through the restructuring of the spatial distribution of logistics facilities as well as various policy measures. The assertion that outward migration of logistics facilities increases negative externalities is not always true and ignores the complex interactions among various components in an urban freight system.

Shortage of logistics facilities near the urban center and/or development of logistics facilities in the exurb are likely to increase freight traffic and, therefore, negative externalities. However, outward migration of logistics facilities might make them closer to the shipment demands under certain conditions. Furthermore, the outward migration allows logistics facilities to become larger, which, in turn, facilitates an increase in average load per truck and more efficient operations.

The results of the simulations indicate that small facilities that mainly serve shipment demands within a small area in the vicinity should be allowed to be close to their demands. On the other hand, large facilities that are likely to serve wide areas can minimize the total shipment distances by locating near the urban center. Considering the scarcity of available sites near the urban center, it is a prudent policy to reserve some spaces with adequate size for logistics facilities in or near the urban center.

As for the impacts of public polices, achieving a meanignful reduction in negative externalities through public policy interventions is difficult especially when the policies do not affect the mechanism of logistics chain formulations directly. The findings from the simulations indicate that using land use regulations such as zoning to direct the locations of logistics facilities is unlikely to produce much impacts. For reducing negative externalities at the metropolitan scale, focus should be on streamlining logistics chains to reduce or eliminate extremely inefficient shipments, and, at the same time, ensuring that existing policies or market conditions do not hamper such streamlining to take place. However, crafting actual policy to facilitate such streamlining is difficult because of the heterogeneity of the urban freight system. It requires understanding the needs and intentions of carriers, shippers, and operators at the microscopic level and fine-tuning the policies for individual market, commodity, and area. Considering the dificutly of collecting such intricate information, makerket-based policies that are designed to encourage logistics operators to improve the efficiency of their operations, and thus reducing externalities, should be considered.

1 INTRODUCTION

Parts of this chapter were previously published as Sakai, T., Kawamura, K., Hyodo, T. (2015). Locational Dynamics and Efficiency of Logistics Facilities: Evidence from Tokyo. Journal of Transport Geography, 46, 10-19.

1.1 Trend in Freight Flow and Supply Chain

Over the last several decades, freight transportation has experienced various structural changes amid enormous growth. Typically, freight traffic increases as the economy grows; increases in the production and consumption lead to approximately proportional increase in freight traffic[1] (McKinnon & Woodburn, 1996; Rodrigue, 2006). In addition, the removal of the barriers for international trade and the improvements in the transportation, Information and Communication Technology (ICT) have promoted globalization through the formulation of global production networks (Coe et al., 2004). The manufacturing industry in the developing world has grown rapidly and enhanced the significance of the international freight flow. Based on the available statistics, the worldwide maritime trade volume increased from 4,140 to 9,932 in million metric tons during the period 1990-2013 (Statista, 2015a). Improvements in the transportation infrastructures such as highways, railways, seaports, airports, canals, inland depots and intermodal facilities as well as the invention and the standardization of containers lowered transportation costs significantly (Rodrigue and Notteboom, 2009) and facilitated the formulation of global production networks. Containerization of freight has progressed significantly since the

[1] Though it is true from a macroscopic point of view, the changes in supply chain management have changed the structures on how the growth in production and consumption affects the freight traffic growth. McKinnon & Woodburn (1996) argue that four types of logistics factors, (i) "structure of the logistical system", (ii) "pattern of sourcing and distribution", (iii) "scheduling of product flow", and (iv) "management of transport resources", changes the manufacture's demand for road freight transportation in U.K. Based on questionnaire survey data, they concluded that, especially, (iii) has a significant impact on the increase in freight traffic volume.

1980s; the total international seaborne trade carried by container ships that was 102 million tons in 1980 reached 1,445 million tons by 2013 (Statista, 2015b). The increasing volume of international freight flows drives the competition among the port cities that aim to stimulate local economic growth through related industries that include not only transportation and warehousing but also wholesale trade, retail trade and manufacturing.

The rise of global production networks has led to more complex supply chains than ever before and promoted the competition over supply chain management (SCM) for streamlining firm's supply chains to minimize the costs and satisfy the demands from their customers at the same time. The rises of the companies that are proficient in SCM (e.g. Walmart, Toyota and Cisco), the second-party logistics (2PL) (i.e. shippers) and the third-party logistics (3PL) providers occurred along with the evolution of logistics practices. The 3PL firms provide logistics services for part or all of the customers' supply chain to "minimize a firm's transaction costs", "maximize a firm's ability to access a rage of resources", and "maximize a firm's ability to leverage relationships" (Zacharia et al., 2011, p.41), and it has become increasingly common for businesses to outsource logistics tasks to such 3PL firms. The operations of the logistics service providers and the companies that are advanced in their SCM require high through-put facilities for taking advantage of the scale economy and achieving speedy freight operations. In fact, the emergence of those facilities in the U.S. have been reported in many studies (Cidell, 2010; Bowen, 2008; Rivera et al, 2014). Such rearrangement and the increasing freight flows have promoted the growth in the warehousing and storage sector. For example, in the U.S., the number of establishments and employment in the warehousing and storage sector increased between 1998 and 2011 by 111 % and 451%, respectively (U.S. Census Bureau, 2014).

1.2 <u>Urban freight</u>

Urban freight is traffic flow within the boundary of a city/metropolitan area. Urban freight is generated by supply chains, and the substantial part of it is ultimately derived from the activities that take place in cities. Behrends et al. (2008) suggest a useful classification of the types of transportation to be included in urban freight, which is developed based upon the definition of urban freight presented by Dablanc[2];

> "provision of industry with raw materials and semi-manufactured articles, provision of the wholesale trade with consumer goods, provision of shops with consumer goods, inbound and outbound consumer goods produced in the area, home deliveries made by professional delivery operators, and transit transport of goods", while excludes "shopping trips made by households, building (including services) and demolition traffic, and waste (reverse logistics)" (Behrends et al. 2008, p.701).

Generally speaking, shipments within the boundaries of cities/metropolitan areas are the costliest parts of a supply chain. The rapid increase in the urban population around the world (e.g. 103%, 50%, and 101% increases in the U.S., EU, and Japan respectably, during the period 1960-2013 (World Bank, 2015)) has resulted in the increases in urban freight flow across many parts of the world. Compared to regional freight, urban freight tends to impose a significant level of negative externality on the society, especially on urban residents. Truck trips in urban areas exacerbate traffic congestions, generate noises and vibrations, contribute to air pollution and increase the risk of traffic accidents. For example, freight traffic generally accounts for between 15% and 30% of the total vehicle-distance in a city (Dablanc, 2007; Schoemaker et al, 2006) and generates between 16% and 50% of urban vehicle emissions (Dablanc, 2007). Although such negative impacts are also generated by the regional truck trips, the significance is higher in urban areas.

[2] "Urban freight is defined as 'the transport of goods carried out by or for professionals in an urban environment'. This definition does not include shopping trips made by households with their automobiles, but it does include home deliveries made for them by professional delivery operators (or by employees of shops where clients have gone shopping but have not carried their own bags). This definition also includes freight traffic which crosses the urban territory without bringing goods into the city (freight in transit). It also includes van traffic, which accounts for about half of the deliveries made in a city." (Dablanc (2008) quoted by Behrends et al. (2008))

The significance of freight traffic's negative impacts on a city/metropolitan area varies by the type of urban freight flow. Although it depends on the configuration of the transportation network, through traffic is likely to keep away from the congested highways and busy urban centers, and thus likely to cause less negative impacts.[3] On the other hand, so-called "last mile" shipments receive more attention because they are often destined to high-density areas. While a high volume of last-mile shipments is problematic in terms of negative externality, the transportation cost for such shipments is also a concern as the congestion and the unpredictability of traffic conditions in the urban area can impose extra costs to the carriers, shippers, and receivers. The operations of the last-mile deliveries are connected to the locations and operations of the distribution centers, and also other logistics facilities (such as warehouses and truck terminals). In the field of urban logistics, the operations of the last-mile deliveries and the distribution centers receive significant research interests (e.g. location of distribution facility, truck routing problem, load factor and consolidation, time-window for delivery, and road space for loading and unloading).

The changes in the SCM that were mentioned earlier have influenced the urban logistics land use and operations. The needs associated with the modern supply chain operations have affected the geography of logistics facilities and have caused a new set of issues such as "logistics sprawl".

1.3 Evolutions in Logistics Practices

The modern practice of logistics has its roots in military logistics; its primary tasks were "procurement, maintenance, and transportation of military facilities, material, and personnel" (Ballou, 2007). The concept has gradually permeated into non-military industries after the World

[3] Of course, this is not always the case; especially, cities without ring roads or bypasses would struggle with the through traffic.

War II, and the practices have become more advanced in the pursuit of efficiency and the minimization of logistics cost. In addition, the rise of global production networks has broadened the scope of logistics and the advances in ICT have enabled the thorough management and utilization of information along supply chain.

There are two main functions of logistics: materials management (MM) - the activities related to the manufacturing of commodities, and physical distribution (PD) - the activities involved in the movement of goods. The main feature of the logistics evolution is the integration of these logistics functions, which were traditionally separated under the framework of divided objectives and responsibilities. The modern concept of logistics incorporates PD into the production activities. According to Hesse and Rodrigue (2004), the integration of two major functions of logistics blurs the concept of freight traffic as the derived demand, which suggests the foremost function of freight traffic is to connect the production and consumption locations.

Along with the horizontal integration of the functions, such as MM and PD, the streamlining of the commodity flow (or vertical integration) has also progressed. Traditionally, the commodities at different stages (i.e. raw material, inter-mediate products, and finished products) were managed independently by different players, and the commodity flow was largely driven by the suppliers. This system was called “push-logistics” since the producers largely drove the movement of commodities (according to the demand forecast), and goods were “pushed” downstream. However, the enhanced information flows achieved by the advances in ICT enabled the management of material flows based on demand-side information. This has led to the emergence of pull-logistics[4]. Such demand-responsive system allows logistics players to reduce the logistics cost mainly through the reductions in the cycle time requirements and the inventory cost (Rodrigue et al., 2006). In the European counties, the share of logistics cost has decreased from

[4] Lean management is a typical example of such logistics operation.

12.1% to 6.1% of sales in the period between 1987 and 2003 (Schoemaker et al., 2006).

Typically, these changes in logistics operations result in more frequent truck operations with lower load factors. The increase in the number of freight vehicle trips in recent years is partially attributable to the change in the logistics structure (Benjelloun and Crainic, 2009). Also, the current logistics systems require larger logistics facilities with high through-put capacities for catering to just-in-time (JIT) (Cidell, 2011) and integrated logistics operations ("receiving, storage, pick operations, value added activities, shipping, return processing and information management" (Strauss-Wieder, 2001 quoted by Hesse, 2004)). The prevalent use of distribution centers, instead of warehouses, in and outside of metropolitan areas is due to the increasing needs for handling the high throughput of commodities in a short time. The growth of E-commerce and the need for express and expedited deliveries also accelerate such trend of logistics transformation (Dablanc et al. 2011; Morganti et al. 2014).

Wachs (2013) argues that the current inland ports, or enormous logistics centers, are more efficient than the traditional terminals that are located near wharves and railroad yards. He insists that the advances in the handling and information technologies applied in those facilities achieve high productivity in logistics and contribute to the re-concentration of population and businesses in the urban centers in the American cities:

> "the growth of megacities depends upon reliable delivery of greater quantities of freight to consumers than ever before just as it does also upon personal mobility within metropolitan centers. Transportation-related land use – railroad yards and logistics hubs – while increasingly efficient thanks to advances in transport and telecommunication technology, are still increasing in scale and today are more likely to be located in the suburbs or the "exurbs" far from the city centers."
> (Wachs, 2013, p.1165)

Wachs theorizes that the logistics innovations responded to the needs of the urban centers as they grew larger and increased in density. Based on his theory, the expansions and the decentralizations of logistics facilities are the result of the transformation of the city-freight transportation relationship.

1.4 Public Planning Scope for Urban Freight/Logistics

There is an increased awareness and concern about the growth in freight traffic and the changes in the spatial distribution of logistics facilities in urban planning. As discussed earlier, the geography of logistics facilities is now an important subject of planning since it relates to the economic standing of a metropolitan area as a part of the global production networks, as well as the vitality of high-density urban centers, urban transportation performance, urban environmental sustainability, and the qualities of life in local communities.

Dablanc and Ross (2012) conducted interviews in Metro Atlanta with planning managers of three counties that have different policies for logistics developments. Fulton Country has traditionally focused on logistics industry and still considers it as a key sector for economic growth. Gwinnett County, on the other hand, applies the strategy of promoting mixed-use developments (offices and other high-rise buildings) instead of the logistics industry that the county attracted in the past. In Henry Country, logistics activities have started to flourish only recently and the county considers the logistics sector as an essential part of its development strategy. Their interviews identified the lack of regional coordination and the conflicts within and between the governments in the metropolitan area. Though the Atlanta Regional Commission identifies the need for a better coordination to deal with logistics issues, the local counties have their own policies, and therefore, the development of logistics facilities remains a local matter.

Cidell (2011) points out that the perspectives of the municipal governments in the suburban area of the Chicago Metropolitan Area are framed by their own administrative boundaries and that the place-based perspectives of the municipal governments narrow their approaches:

> "the tools which planners have to work with and which they use to shape economic development and land uses are based on the notion of discrete territories" (Cidell, 2011, p.842).

Based on the interviews with the local municipalities in Will County, Cidell argues that the limited perspectives expressed by the municipal planners have "a significant impact in shaping both the suburban landscape and freight distribution" (Cidell, 2011, p.839).

The gist of Cidell's argument corresponds to the findings of Dablanc and Ross (2012). In both Atlanta and Chicago regions, logistics facilities are often perceived by the municipalities as just a source of jobs and tax revenues for which the local counties and municipalities compete. The decline in the manufacturing jobs and the increasing prominence of the logistics industry has only strengthened such view. The conflicts among the local policies often result in a piece-meal planning approach (Dablanc and Ross, 2012) and the lack of coordination entails inefficient freight transportation system (Dablanc and Ross, 2012; Cidell, 2010). Similar situations have been observed in European cities as well (Lindholm and Behrends, 2012; Hesse, 2004).

The mismatch between the planning of logistics facilities and the parochial attitudes of the local governments is a common and substantial issue. If a regional framework to manage the distribution of logistics facilities based on the regional perspective is non-existent while the local governments exercise their autonomies on land use (which is true in most of U.S. metropolitan areas), the situation often results in various issues as seen in Atlanta and Chicago. The mismatch is harmful not only for land use but also for infrastructure development. Cidell describes the situation in the suburb of the Chicago Metropolitan Area as:

> "the infrastructure and facilities that constitute the physical embodiment of transportation and communication networks are being built in individual municipalities operating under their own goals and constraints" (Cidell, 2011, p. 833).

However, the shipment areas covered by the distribution centers tend to extend far beyond individual municipality boundaries, often encompassing a metropolitan or even larger area. As such, the regional coordination of logistics land use and transportation system is essential for socially efficient (or sustainable) urban freight transportation system; as Dablanc and Ross suggest:

> "the public and private sectors both need to optimize warehouse locations and distribution networks and improve transportation system performance" (Dablanc

and Ross, 2012, p.441).

Another challenging issue for urban freight transportation planning is the mismatch in the planning time horizons between the government and the private-sector including the logistics sector. As the logistics practices evolved over the years, the adaptability of supply chain has become essential for the businesses to stay competitive. Meanwhile, typical transportation and land use planning is carried out with 10, 20 or 30 year time horizons. Hall and Hesse (2012) argue that:

> "physical planning, concerned with the supply of land use and infrastructure, tends to be structurally disadvantaged in the attempt to steer or to integrate the spatio-temporal dynamics of logistics and freight distribution operations." (Hall and Hesse, 2012, p.14)

Hesse (2010) aptly mentions that "the location bundling or clustering of economic activity seems to be limited if based on the volatile flow of materials" (Hesse, 2010, p.89). Facing such dynamic and unpredictable nature of logistics activities, local planners often realize that they do not possess sufficient knowledge and tools even though they understand the importance of freight transportation and logistics (Lindholm and Behrends, 2012).

Castells describes the contradiction between flows and the place-based institutions:

> "… there is increasing contradiction between the actual spatial unit and the institutions of political representation and metropolitan management" (Castells, 2002, p.552).

Also, he emphasizes the vulnerability of cities in face of the fickle and ever-evolving nature of flows:

> "… this urban roller coaster at different periods, across areas of the world, illustrates both the dependence and vulnerability of any local, including major cities, to changing global flows." (Castells, 2011, p.381)

While his notion of flows is abstract, implying mainly information and material flows, Castells' argument of the contradiction that exists between emerging spatial unit and the local institutions precisely fits with the above-mentioned issues of logistics activities and freight transportation/logistics planning.

However, while the control of logistics activities is challenging, the local governments still have a control over their jurisdictions and it is very important to achieve an effective transportation system. Planners are in need of reframing the scope of planning and overcoming the above-mentioned mismatches.

1.5 The Aim of the Research

Freight flow is the consequence and the representation of the economic and social activities in the society. As described in this chapter, the pattern of freight flows has transformed in the last several decades due to the formulation of global production networks, the innovation in ICTs, the evolution of logistics practices, and the improvements in transportation systems. Such broad transformation of freight flow also led to the restructuring of urban freight systems, including the spatial distribution of logistics facilities.

Urban freight flow is the costliest and arguably socially and environmentally the most impactful component of any supply chain, causing negative externalities to the residents and the environment, through congestions, emissions, noises, vibrations, and traffic accidents. Moreover, the rapid growth in the populations and the ever-increasing congestions in the urban areas around the world heighten the urgency to address the negative externalities that urban freight entails. The need for achieving more efficient and socially and environmentally acceptable urban freight system is growing.

The spatial distribution of the logistics facilities, as origins and destinations of truck trips, is one of the factors that determine the level of urban freight traffic. Although in the past, planners typically employed a parochial and limited scope for managing urban freight, the need for addressing the logistics land use is increasingly acknowledged. For example, FHWA Freight and Land Use Handbook (Federal Highway Administration, 2012) lists the freight and land use integration strategies for mitigating traffic impacts with example practices. However, those strategies are mostly anecdotal and their effectiveness is unclear. This is partly because the existing research that quantitatively evaluate the impacts of land use policies on urban freight are limited in both the number and the depth. The scarcity of the data and the complexity and heterogeneity of urban freight are obstacles for conducting rigorous evaluation of the effectiveness of logistics land use policies.

To develop and implement the policies to reduce the negative externalities associated with urban freight, we must understand both how the different policy approaches affect the locations of the logistics facilities and how they influence the urban freight traffic. Fortunately, there has been an increase in the efforts to collect better freight data, and combined with the advancement in modelling techniques, the stage is set for conducing the research to address the knowledge gap. The present research aims to provide the insights for developing policies that address logistics land use and the associated urban freight traffic to minimize the negative externalities that accompanies urban freight. This research addresses the relationships among policy, the spatial distribution of logistics facilities, and negative externalities taking two major approaches: (1) the study of the dynamics of logistics facility distributions and shipment efficiency using the date set from two time points and (2) the simulation of the policies and the scenarios regarding the spatial distribution of logistics facilities using an integrated model for urban logistics land use and truck traffic.

2 LITERATURE REVIEW

Parts of this chapter were previously published as Sakai, T., Kawamura, K., Hyodo, T. (2015). Locational Dynamics and Efficiency of Logistics Facilities: Evidence from Tokyo. *Journal of Transport Geography*, 46, 10-19, Sakai, T., Kawamura, K., Hyodo, T. (2017). Spatial Reorganization of Urban Logistics Systems and Its Impacts: Case of Tokyo. *Journal of Transport Geography*, 60, 110-118., and Sakai, T., Kawamura, K., Hyodo, T. (2017). Logistics Chain Modeling for Urban Freight: Pairing Truck Trip Ends with Logistics Facilities. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2609. doi: 10.3141/2609-07.

This chapter reviews the literature relevant to the present research. As this research tries to address various aspects of the urban logistics land use and associated shipments based on both empirical and simulation studies, the review correspondingly covers a wide range of subjects. Firstly, the studies that focus on the spatial distribution of logistics facilities are reviewed. This research topic is a relatively new[5] and the papers addressing it were mostly published in the last 10 years. Secondly, the studies of location choice analysis are reviewed, covering those focusing on logistics facilities and those involving the microsimulations of business locations. Thirdly, the existing freight models are reviewed. The discussion covers both the overview of the exiting freight models and the models considering the transshipment locations. Fourthly, although they are limited in number, the studies that evaluate logistics facility distribution are reviewed. Lastly, the indicators used or proposed for evaluating urban freight policies in the existing literature are summarized.

[5] On the other hand, a similar but different research subject, the optimization of distribution center locations, is major in operations research and has been studied for more than 20 years.

2.1 Spatial Distribution of Logistics Facilities

The recent changes in supply chains, urban freight flows, and the evolutions in logistics practices, which are discussed in the Chapter 1, have led to the wide-spread restructuring of the spatial distribution of logistics facilities in many cities/metropolitan areas around the world. Because of the factors such as "economies of scale, newfound flexibilities afforded by contemporary communication technologies, cheap land, cheap labor, and access to both urban and nonurban transportation networks" (Hesse, 2002), newly developed urban distribution centers are often located in the suburbs, away from the congested and expensive urban centers. Dablanc and Rakotonarivo (2010) define this widely recognized phenomenon as Logistics Sprawl, "the historical trend towards spatial de-concentration of logistics terminals in metropolitan areas". They argue that such new distribution of logistics facilities would increase negative externalities.

The literature argues that, for the modern logistics system, the proximity to the origins and destinations of the shipments is less important than before, because operational capacity became relatively more important against travel time and distance from facility operator's perspective. Studying the rapid growth of logistics industry in the Inland Empire region of California, De Lara (2012) found that "retailers needed large parcels of relatively cheap land in order to build the mega-warehouses required by their high velocity supply chain models" (De Lara, 2012, p.81). Hall et al. (2006) argue that the dramatic fall of transportation costs in the last half of the 20th century, as well as the growing emphasis on the scale, contributed to the suburbanization of logistics facilities.

Many recent studies on the spatial distribution of logistics facilities confirmed the outward migration of logistics facilities in the North American and European cities (Bowen, 2008; Cidell, 2010; Dablanc and Rakotonarivo, 2010; Dablanc and Ross, 2012; Dablanc et al., 2014; Hesse, 2004; Woudsma et al., 2015). To examine the changes in the locations of warehouses in Atlanta between 1998 and 2008, Dablanc and Ross (2012) applied centrographic analysis using the data from the

US Census Bureau County Business Patterns Survey. Their analysis shows that in the Atlanta Metropolitan Area, the number of warehousing establishments increased by 203.8% between 1998 and 2008 and the average distance to the barycenter for all warehousing establishments increased by 2.8 miles (4.5 km), from 17.8 to 20.6 miles (28.6 to 33.1 km). On the other hand, the average distance to the barycenter for all business establishments increased only by 1.3 miles (2.1 km) during the same period. The similar approach was applied to Paris, France (Dablanc and Rakotonarivo, 2010), Los Angeles, and Seattle (Dablanc et al., 2014), and Toronto, Canada (Woudsma et al., 2015). In the case of Paris, the average distance to the barycenter for all cross-dock terminals increased from 6 km in 1974 to 16 km in 2008. The authors estimated that this increase of 10 km from the barycenter contributes to the generation of 14,700 additional tons of CO_2 each year in the Paris region. The analysis in Los Angeles indicates that the average distance from the barycenter for all warehousing establishments increased from 25.91 to 31.96 miles (41.70 to 51.43 km) between 1998 and 2009. For the same period, however, Seattle did not experience such decentralization possibly because of the existence of the significant clustering of warehouses in the Kent/Renton area, near the geographic center of the area. In the Greater Golden Horseshoe region, including the Greater Toronto Area, Canada, the average distance of warehouses to the barycenter increased from 29.6 km to 39.1 km in the period 2002-2012, while that of all businesses increased only by 3.6 km. For analyzing the suburbanization of warehousing and distribution activities in the major metropolitan areas in the U.S., Cidell (2010) used the data from the US County Business Patterns Survey and captured “the move towards inland distribution centers and the suburbanization of freight activity” (Cidell, 2010, p.370) although she also found exceptions. Sakai et al. (2015) analyzed the change in the distribution of the logistics facilities in the Tokyo Metropolitan Area for the period 1980 – 2003 and found the long-term trend of outward migration of logistics facilities. They also found a positive correlation between the outbound shipment efficiency and the logistics facility’s distance from the urban center. Cidell’s study of

Chicago found that “shippers and distributers are taking advantage of agricultural land on the fringe of the metropolitan area to build distribution centers and intermodal yards on a scale not previously seen” (Cidell, 2010, p.833). As these studies indicate, although the circumstances and characteristics of outward migration of logistics facilities are not exactly the same among different cities, such migration is widely observed.

Dablanc and Ross (2012) emphasize the environmental impacts of logistics sprawl as the main concern:

> “logistics sprawl contributes significantly to the unsustainable nature of large metropolitan areas by generating congestion, CO_2 emissions and local atmospheric pollution. These impacts are the result of additional vehicle-miles travelled (VMT) generated by the changing location of freight terminals and the increase in distances travelled by trucks and vans to deliver commodities to urban areas where jobs and households remain concentrated.” (Dablanc and Ross, 2012, p.434)

However, the outward migration of logistics facilities does not necessary lead to an increase in vehicle-miles travelled (VMT) and vehicle-kilometers travelled (VKT); such outward migration could also occur as the result of location choices of private logistics players pursuing their shipment efficiency as argued by Sakai et al. (2015). Meanwhile, an increase in truck traffic in highly dense urban areas could be more problematic than in suburban areas. Thus, a detailed investigation is required for accurately evaluating the impacts of outward migration of logistics facilities (or logistics sprawl).

While the impacts of traffic congestion and CO_2 emissions at the metropolitan scale are very important issues, the local impacts of logistics sprawl are not negligible. Uncoordinated developments of logistics facilities lead to local traffic congestions and bottlenecks, deterioration of local roads, and other unfavorable economic and environmental impacts for the local communities. Cidell (2011) describes how the development of a logistics facility could go against the planning goals of local municipalities:

> “such facilities are often built wherever land is available, meaning that they are often erected in a piecemeal fashion that does not take into account the planning

goals of local municipalities.” (Cidell, 2011, p.836)

2.2 Location Choice Studies, Models, and Microsimulations

The process and the mechanism of location choice for residential units and commercial and industrial establishments (or the locations of residents, employments and firms) have been an interest in various academic disciplines including spatial economics, operations research, and transportation studies. The theory of location, started from Von Thunen’s rural/agricultural land use model in 1826, has advanced through notable works including Alfred Weber’s theory of the location of manufacturing industry (1909), William Alonso’s bid rent function for land use (1964) and more realistic and complex models (Beyers and Fowler, 2012).

In general, location models can be categorized into three types according to their purposes. One of the purposes is to describe the holistic structures of cities, concerning aggregate land demand and supply; another is to find the optimum location or land allocation that maximizes a pre-defined utility function of a decision maker under given conditions; the third purpose is to investigate and describe the influencing factors (or often causal relationships) for the location decisions. Transportation studies generally focuses on the models in the third category for evaluating the influence of accessibility on location choice and/or forecasting the future location choices of population, employments or establishments (commercial or industrial). Together with the classic regression models, discrete choice models (McFadden, 1978) are widely used for such purposes. In the discrete choice models, which are based on the random utility theory, the probabilities of the different possible outcomes (e.g. alternative sites) are estimated, taking the variations in the tastes of individuals into account. The regression and discrete choice models for location choice require actual location data and, in some cases, specially designed surveys, to find the relationship between dependent and independent variables. Each of the following sections summarizes the studies of logistics facility location choice, and microsimulation models focusing on establishment locations.

Studies of location choice for logistics facilities

The past studies of location decisions for logistics facilities are very limited. The scarcity of logistics facility data seemingly accounts for it. Typically, the land use - transportation models categorize business establishments by industry type, not facility type, (e.g. Waddell and Ulfarsson, 2003) since the business records often do not have accurate facility type information. Some of the existing studies focus on modelling the location choices of logistics facilities using discrete choice model framework, while other studies focus on analyzing the factors influencing location choice.

The only studies that focus on the model development for the location choice of logistics facility are those using the 4th (2003) Tokyo Metropolitan Freight Survey (TMFS). Cao and Sano (2010) developed the discrete choice models for logistics firms that consider the spatial correlation in the error term and the correlations among the firms in the deterministic terms using the 2003 TMFS data. The models are estimated for retailers, product wholesalers and other manufacturers, using zonal population, zonal employments, land price, employment size and floor area of a firm, as predictors; those variables are statistically significant in at least one of the estimated models.

Hagino and Endo (2007) also developed the location choice models for the regional freight facilities and the distribution centers based on the multi-nominal logit framework using the 2003 TMFS data and estimated the potentials for future development for each of the analysis zones in their model. The explanatory variables include population density, labor accessibility, accessibility to manufacturing establishments, accessibility to transportation hubs, distance to the closest highway ramp, land price, and land use regulations and others. In the subsequent study, Hagino et al. (2011) expanded this model to include land price changes and the location choices of factories and businesses in addition to the logistics facilities. Using the model, they estimated the trend of the decentralization of logistics facilities toward the suburban areas of Tokyo during the period 2000 – 2020.

Unlike the studies mentioned above, the foremost objective of the following three studies is to evaluate the factors that potentially influence the logistics facility locations. Woudasma et al. (2008) analyzed the performance of accessibility indicators for estimating the locations of logistics land use developments using spatial-autoregressive modelling techniques. The analysis, conducted using the data from Calgary, Canada, found that the accessibility measure based on travel time is a statistically significant predictor of logistics land use developments. They also found that congestion has even stronger influence on logistics land use. Furthermore, the study identified 5-10 year lag between accessibility and its influence on land use developments.

Van den Heuvel et al. (2013) examined the spatial concentration of the logistics establishments in North Brabant, Netherlands, using the database covering the period 1996 – 2009. They used the binomial distribution test to examine the preference for two types of locations: the areas where logistics employments concentrate, and the other areas. They found that the establishments that were located in the study area in the past are more likely to choose the existing clusters of logistics activities for their relocation than the new establishments searching the locations for their operation.

Verhetsel et al. (2015) used the data from the stated preference survey conducted in Flanders, Belgium, to analyze the location choice by logistics companies. They asked the companies to compare virtual alternatives with different values of attributes including land rent, port accessibility, road accessibility, rail accessibility, inland navigation accessibility (the distance to the nearest inland waterway port), and business park (whether the site is in business park or not). They found that, among the factors considered, land rent is the most important in the location decisions by the logistics companies, followed by the accessibility to the port.

Establishment-based micro-simulation models

Microsimulation is one of the computerized analytical approaches, which addresses the behaviors of individual units, such as people or firms, and the interactions among them. The approach allows an analyst to evaluate the process of decision-makings and interactions and the outcomes of the process with aggregate-measures. In microsimulation, by introducing stochastic parameters, it is possible to replicate the heterogeneous behaviors of various individuals. Due to its stochastic nature, it is also possible to evaluate the level of variation and uncertainty in the outcomes after repeating the simulation multiple times.

Microsimulation is a popular approach for land use/transportation analysis. In the land use analysis, microsimulation models typically simulate the behaviors of individual businesses and are used for evaluating the policy impacts (e.g. taxation, zoning and transportation improvement) on the land use. The simulation of the process over time is useful as it allows the evaluation of time-effect (or speed of change). Furthermore, the assessment of the variation in the outcomes across the repeated simulations is beneficial to understand the relative impacts of policy factors against random factors.

Usually, location choice models are incorporated into a land use simulation model as one of the modules (other typical modules are population growth, business growth, business entry, business closure, etc.). To the best of my knowledge, Hagino et al. (2011) is the only existing location choice model for the logistics facilities with the micro-simulation framework. On the other hand, many models for the spatial allocation of employment or firms were developed in the past several decades (see Moeckel (2013) for the short history of employment location simulation). In recent years, the urban simulation models that had previously depended on zonally aggregated data have improved considerably by the advent of the discrete choice models and the use of disaggregated data. The employment location model or the firm location choice model included in the recent urban simulation models take the characteristics of individual locations such as land price, land use regulations, distance to transportation hubs, distance to existing industries and the characteristics of individual establishments such as number of employments, industry type and facility type, into account.

The California urban futures (CFU-2) model (Landis and Zhang, 1998) is believed to be the first explicit attempt to incorporate an employment location model using the discrete choice analysis (multinomial logit framework) (Moeckel, 2013). The CFU-2 model applies a grid cell of one-hectare as the unit of analysis. Unlike the later models, the land use is determined based only on the land characteristics without the information concerning actual agents such as individuals and firms.

SIMFIRMS (Van Wissen, 2000) is the first micro-simulation computer program for firm demography. The concept of "firm demography" (or "economic demography" or "firmography") was created by adapting the concept of population demography for analyzing the population of firms. Just as the notion of demography encompasses the events in a human life, such as birth, growth and death, firm demography covers the dynamics of population of firms associated with the events such as firm formulation, growth, closure, split and relocation (Dijk and Pellenbarg, 2000). The aim of the SIMFIRMS is to model the behavior of firms for evaluating policy impacts on the demography of the firm. Using the data from the Netherlands for the period 1991 – 1998, SIMFIRMS models births, closures, growth and relocation of firms. The relocation of the firms is represented by a joint decision model: the binary logit model for the decision of moving or not moving, and the multinomial logit model for the choice of region. While the approach of SIMFIRMS is relatively crude as it uses only a limited set of variables including age, business type, size and the choices of locations (40 regions in Netherland), the work of van Wissen is considered a "milestone" for business simulation (Moeckel, 2013).

Khan et al. (2002) tested the microsimulation framework to model the business establishments and their locations in a virtual urban space. They developed a nested logit model for the decisions to move, stay or leave as well as the choice of location. The utility function includes the size of the market, the prices of commodities and the ease of transporting the commodities in addition to the rent for floor space. In the simulation, the utility of each location reflects, among other characteristics, the rent that changes depending on vacancy.

Maoh and Kanaroglou (2009), as a module of a firm demographic microsimulation model, developed a location choice model of business establishments with fewer than 200 employees for Hamilton, Canada for the periods 1996 – 1997 and 2001 – 2002. Similar to SIMFIRMS, the model includes the modules for the growth, decline, failure and migration of existing establishments. The location choice model is a multinomial logit model that includes several location-specific factors and industry categories in addition to a dummy variable for newly established facilities.

De Bok (2009) developed the Spatial Firm-demographic Micro-simulation (SFM) model for South Holland in the Netherlands using extensive longitudinal firm data for 1990–2004. The model is estimated for the period 1990 – 1996 and validated for the period 1996 – 2004. Like other simulators, the SFM incorporates the firm demographic components (firm migration, growth, formulation and dissolution). The firm migration is captured with a joint model (for decisions on migration and a new location) for each industry sector (including logistics industry). The variables used in the location choice model include the distance from the original location, accessibility attributes, agglomeration attributes, and centrality parameter.

A microsimulation model of establishments, capturing growth, closure and relocation of firms, was also developed as a part of the ILUMASS system (integrated land-use modelling and transportation system simulation) for Dortmund in Germany (Moeckel, 2009). Moeckel conducted a simulation for the period 2000 – 2030 and evaluated five scenarios covering land use, transportation, and fiscal policies. The scenarios include “compact city”, “decentralized concentration”, “everything goes (no land development restrictions)”, “regional cooperation” and “subsidy”. Moeckel evaluated the impacts of economic cycles on the distribution of employment (or firms). Very interestingly, he found that economic cycles contribute to the urban sprawl of employment. This corresponds to Sakai et al. (2016b) that found that the outward migration of logistics facilities in the Tokyo Metropolitan Area (TMA) was accelerated by the asset price bubble of 1986-1991 and the subsequent collapse. Moeckel emphasizes that this effect is not observable if employment, instead of firms, were the unit of the simulation.

The recent establishment-based models (Maoh and Kanaroglou (2009), de Bok (2009) and Moeckel (2009)) emphasize the capability to simulate the firm's behavior, including location choice, in the manner that is more realistic than the employment-based models. For example, Urban Sim, one of most recent urban models, applies employment as the analysis unit (Waddell and Ulfarsson, 2003). As Moeckel indicates, in reality, "location decisions are taken by firms rather than by employees" (Moeckel, 2009, p.902). The recent development also indicates that the establishment-based simulators have advantages in taking space availability and economic cycles into account.

These micro-simulations of firm demography are valuable references for the analysis of the distribution of logistics facilities. Impacts of logistics related policies, such as development control that permits facility development only if specific conditions are satisfied[6], cannot properly be simulated with an aggregated level analysis.

2.3 Freight Models

2.3.1 Overview

This section provides a brief overview of the existing freight models. I do not intend to provide a comprehensive review of freight models in the manners of Chow et al. (2010), Transportation Research Board of the National Academics (TRB) (2008) and TRB (2012)). Instead,

[6] For example, in Japan, the development permissions in some designated area require the improvements of shipping efficiency and the proximity to highway ramp.

the general features of freight models with the emphases on the issues that are relevant to the present research are discussed.

Freight modelling is one of the major research subjects in transportation studies. Literally, hundreds of freight models have been proposed in the past. However, due to the scarcity of the data and the complexity of the stakeholder behaviors, substantive progresses in freight modelling have been more difficult to come by than for the passenger travel modelling; there is a huge gap between the needs and the available data and analytical methods (TRB, 2008; Holguin-Veras et al., 2011).

Commodity-based vs. vehicle-based

The existing freight models can be broadly categorized into two groups: commodity-based and vehicle-based approach (Giuliano et al, 2010; TRB, 2012). The vehicle-based approach can be further categorized into two sub-groups, which are trip-based and tour-based[7]. The difference in the base analysis unit (i.e. commodity versus vehicle) is mainly attributable to the data availability and the goals of the analysis.

Commodity-based models generally start with the prediction of commodity demand (demand flows or generations) using the economic data such as make/use table, input-output matrix demographics, and/or land use data. Estimated commodity flows are converted into vehicle trips using pre-determined rates and/or statistical models (e.g. regression models). The advantage of this approach is that it is possible to associate socio-economic data with freight traffic demand (Giuliano et al, 2010). On the other hand, this approach entails the overly simplified assumptions on very complex factors behind commodity and truck trip demand generations. As such, commodity-based models often cannot produce sufficiently accurate estimates. Especially the

[7] Ruan et al. (2012) proposed the third subgroup, vehicle-based approach, which is tour-chain-based.

commodity flow-to-vehicle flow conversion models tend to have low explanatory powers (Holguin-Veras et al., 2011).

On the other hand, vehicle-based models, which start with the estimation of vehicle trip demand, do not rely on the unreliable estimation of commodity demand and the commodity-to-vehicle conversion, and, therefore, are considered to have higher potential for accurate estimations of vehicle traffic. However, some researchers argue that commodity-based approach is “more realistic and robust” because vehicle trips can capture the demand-supply relationship (Giuliano et al, 2010; Wisetjindawat et al., 2006). According to TRB (2012), vehicle-based models are more common; among 69 papers reviewed, 47% apply vehicle-based approaches while 38% use commodity-based models. The rest, 15%, use the combination of the two, in which trips within the analysis area are estimated using vehicle based approaches. As for metropolitan-scale models, 70% use vehicle-based approach.

For both commodity-based and vehicle-based approaches, TRB (2012) proposes developing the generation models by industrial sector, then using the share of industrial sectors within each land use type as weights for predicting trip generation; such segmentation works for handling heterogeneity and mitigating errors.

Model components and model classes

TRB (2008) identifies six typical components of freight models: (i) “direct factoring”, (ii) “trip generation”, (iii) “trip distribution”, (iv) “mode split”, (v) “traffic assignment” and (vi) “economic/land-use modelling”. It also identifies five model classes that include (a) “direct facility flow factoring method”, (b) “O-D factoring method”, (c) “truck model”, (d) “four-step commodity model”, and (e) “economic activity model”. Model classes differ from one another in terms of the components, but the latter models are relatively more comprehensive and therefore can address more policy and analytical needs.

Chow et al. (2010) added two advanced model classes: (f) "logistics models" and (g) "vehicle touring models". These models take into account logistics elements that classic freight models do not consider, such as distribution channel selection and vehicle touring. For logistics activities, shipment/vehicle demand is usually treated in a disaggregated form. Logistics models are commodity-based while vehicle touring models are vehicle-based.

As the state-of-the-art examples of the applications of logistics models in urban areas, Chow et al. list *Goodtrip model* (Boerkamps et al., 2000) and *Urban freight micro-simulation* (Wisetjindawat and Sano, 2003). On the other hand, Chow et al. introduce *spatial-time multinomial probit model* (Garrido and Mahmassani, 2000) and *truck tour-based microsimulation model* (Hunt and Stefan, 2007) as vehicle touring models. While these advanced models require detailed information that are often not available, they can be used to analyze the logistics policy impacts on traffic, such as the regulations concerning load factor and vehicle size, time-restrictions, use of inter-mediate facilities, etc. While various types of freight models are proposed, there is no consensus on which one is the best model specification (TRB, 2012); eventually, it depends on the available data and the purpose of the analysis.

2.3.2 Consideration of Transshipments in the Existing Models

As discussed in Chow et al. (2010) and De Jong et al. (2013), an increasing number of freight models are taking logistics elements into consideration. Those models vary in the level of data aggregation, scale (urban, regional, national, international), the unit of analysis (commodity-based, vehicle-based or mixed), and the supply chain and logistics elements that are considered. There are significant differences in the approaches to incorporate the elements such as the decisions on trading, transportation channels, shipment size and delivery/pick-up frequency, vehicle touring, and/or delivery/pick-up time window in the models. However, the models that consider the use of logistics facility for transshipments are still limited. Huber et al. (2015), 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.

Only a small number of works have been carried out to integrate the decisions regarding the use of logistics facilities in freight models, especially at the urban scale. Even when transshipment locations are considered, most existing models treat the decisions related to logistics chains in the manner analogous to route choice and apply the cost minimization approach. 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 (Chow et al., 2010; Boerkamps and Van Binsbergen, 1999). In the agent-based models, such as InterLog (Liedtke, 2009) and Wisetjindawat et al. (2006), the use of logistics facilities is not explicitly considered.

There are few different approaches for explicitly modelling 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) (Huber et al., 2015; De Jong et al., 2007; Tavasszy et al., 1998; Jin et al., 2005).

The recent extension of the SMILE model details a methodology of transport chain generation (Davydenko and Tavasszy, 2013). Using the transportation survey data for the heavy goods vehicle[8] operators in the 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 estimate the intermediate trips associated with transshipments based on the P-C flows. In their model, the multinomial logit model is used for the choice between direct and indirect shipments, taking the logistics cost (transportation and stock-related costs) into account in the

[8] Heavy goods vehicles are trucks with gross combination mass over 3.5 tons.

utility function. In the case of indirect shipments, this choice also involves the selection of a location (zone) for transshipment. Interestingly, Davydenko et al. (2013) used the same models to evaluate the impacts of the centralization and decentralization of transshipment locations as well as the increase in transportation cost. Since this is directly relevant to the present research, the work by Davydenko et al. (2013) is discussed in detail in Section 2.4.

The similar structure is also in the models developed by the Los Angeles County Metropolitan Transportation Authority and the Chicago Metropolitan Agency for Planning (Fischer et al., 2005; Cambridge Systematics, 2011). Though covering only the food retailing companies in Germany, Friedrich (2010) developed 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.

2.4 Evaluation of Logistics Facility Distribution

The literature that quantifies the association between the spatial distribution of logistics facilities and the scale of negative externalities is limited. Wagner (2010) conducted a scenario analysis, comparing two different spatial patterns of logistics-related land use through traffic analysis using the origin-destination matrices in Humburg, Germany. Her analysis indicates that the scenario with a concentration of logistics land use near the urban center causes less externalities (due to shorter vehicle travel distances) than that with dispersed logistics-related land use.

Wygonik and Goodchild (2016) focused on the last-mile travel and analyze, using linear regression, the combined effects of different delivery service schemes and urban form (e.g. road density, distances from warehouse to store, store service area, etc.) on externalities that are measured in terms of VMT, CO_2, NO_X, and PM10. They identified strong effects of road density and the distance to warehouse on the externalities.

Davydenko et al. (2013) used a national scale logistics chain model, i.e. SMILE (Tavasszy et al.,1998), to measure the changes in ton-kilometers traveled (TKT) and VKT associated with the centralization and decentralization of transshipment points in the Randstad region in the Netherlands. The results indicate that the effects of the changes in transshipment locations are limited as far as the scenarios examined by the authors are concerned. While this research is a pioneering and interesting effort using a logistics chain model to measure the effects of the spatial pattern of logistics facilities, the geographical scale of the study, which covers the entire nation, and the spatial unit of analysis, region, do not allow the generalization of the findings to urban areas.

The evaluation of logistics facility operation is one of the major research topics in Operations Research (e.g. Taniguchi et al., 1999; Crainic et al., 2004; Crainic et al., 2009); however, while the approach using optimization would be useful to evaluate a small number of facilities for which the associated shipment demands are given, it is not suited for analyzing the collective performance of the thousands or tens of thousands of logistics facilities in a metropolitan area.

Sakai et al. (2015) used the data from the 2003 TMFS to analyze the relationship between the distance from the urban center and the 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. The cross-sectional study shows that logistics facilities become less efficient as the distance from the urban center increases.

2.5 Indicators to Evaluate Urban Freight Policies

Sustainability indicators such as economic, social, and environmental objectives are often used for evaluating urban freight and logistics policies (Patier and Browne, 2010; Anderson et al., 2005; Russo and Comi, 2012). At the detailed level, because there are diverse sets of policy measures for urban freight and logistics involving different actors, a number of evaluation indicators are proposed depending on the objective of the analysis.

Measurability is one of the important issues in policy evaluation. Especially, social impacts caused by urban freight transportation such as effects on equality/inequality or community cohesion/dispersion, are often difficult to measure. Some impacts are difficult to measure because they have various potential causes and thus the contribution of a specific policy measure or a type of activity cannot be isolated. In some cases, there is no proper indicator that can be measured with a reasonable amount of efforts. In other cases, the evaluation is challenging because it requires normative judgements. For comparing various policy measures, use of single criterion, i.e. money, is often preferred although it may not be applicable for evaluating non-quantifiable and/or non-comparable aspects of an impact (Taniguchi, 2012). As an alternative to such single-criteria evaluation, the multi-criteria evaluation (MCE), using measurable indicators without translating them to monetary value, is beneficial in many cases and commonly used for policy evaluation. The MCE highlights both advantages and disadvantages of policy, avoiding oversimplification of policy impacts.

Table I summarizes the indicators used or proposed in the past studies for evaluating public policy measures in urban freight and logistics through the MCE framework. Russo and Comi (2012) applied the three sustainable objective categories (economic, social and environmental) and identified the types of impact associated with different policy measures. Anderson et al. (2005) developed a list of indicators for evaluating four policy measures applied in the U.K.: “low emission zones, congestion charging, vehicle weight restrictions and vehicle access time restrictions”. Browne et al. (2007) developed an evaluation framework for Urban Consolidation Centres based on the literature review and the interviews with various relevant parties including logistics operators, receivers and shippers, and governments and policy makers. Kapros et al. (2005) proposed an integrated methodological process and indicators for evaluating freight villages and applied them to a new freight village project in northern Greece. Van Duin et al. (2012) developed a multi-agent model to evaluate the use of urban distribution centers and apply three types of indicators for evaluating various scenarios. While they did not carry out actual evaluation, Dasburg and Schoemaker (2008) present indicators to be considered in their attempts to evaluate various city logistic measures in European countries.

TABLE I

INDICATORS FOR EVALUATING URBAN FREIGHT AND LOGISTICS POLICY MEASURES

Russo and Comi, 2012	Anderson et al, 2005	Browne et al., 2007
Economic • Traffic congestion • Trip length • Delivery time • Infrastructure cost Social • Reduction of interferences among segment of urban mobility • Reduction of operating vehicles • Reduction of road accidents • Livability of city Environmental • Reduction of pollutants • Reduction of noise • Habitat loss	Operational • Time taken • Speed • Distance travelled • Vehicle fill • Proportion of on- and off-street deliveries Environmental • CO, CO_2, NOx and PM10 emissions Financial • Cost of making deliveries and collections to the distribution company	Logistics and supply chain changes • (Efficiency, on time delivery, etc.) Social/environmental • Fossil fuel consumption • Emissions • Congestion Goods vehicle activity • Vehicle kms • Vehicle trips • Vehicle load factor Loading/unloading activity • Space utilization • Time
Kapros et al., 2005	Van Duin et al., 2012	Dasburg and Schoemaker, 2006
Private financing • Financial IRR National economy • Economic IRR (vehicle operating costs) Local economy • Increase of employment Environmental • Noise • Air pollution • Landscape Land use reorganization Complementarity with other policy plans	• NOx emission • Km count • Financial impacts	Internal • Management costs • Operation fixed costs • Operation variable costs • Revenues • Transport times • Accidents External • Air pollution • Noise • Social life • Economic scene • Financing conditions

In many studies, the indicators for operational efficiency (or benefit) are selected (Anderson, 2005; Browne et al. 2007; Dasburg and Schoemaker, 2006). They could be regarded as analogous to the indicators for user benefits (time saving and travel cost saving) in passenger transportation. Indicators of operational efficiency are generally associated with the direct benefits to logistics operators, senders and receivers that are generated through lower cost and fare and/or the improved convenience in shipping or receiving. Also, financial viability is considered in some papers (Anderson et al, 2005; Kapros et al. 2005; Van Duin et al., 2012, Dasburg and Schoemaker, 2006). Use of the indicators for operational efficiency and financial viability reflects the consideration of the views of logistics businesses; the perspectives of logistics businesses are important in studies of freight due to the fact that successful measures must take into account market behavior and provide appropriate incentive or penalty to change firms' behaviors.

The complex interactions among the factors that are represented by the indicators defy a neat and straightforward categorization under economic, social, and environmental objectives. For example, congestion can be considered in the context of economic, social or environmental objectives as its impacts are diverse. Richardson (2005) categorizes freight factors according to whether they are affected by market forces or by governmental policies. Then, he connected indicators representing the factors to sustainability measures. The conceptual structure presented by Richardson indicates that the upper level factors, such as truck VMT and land use pattern, are important, because they affect multiple measures such as safety, fuel consumption, congestion, and environment.

3 RESEARCH PROBLEM

3.1 Research Needs

As discussed in the previous chapters, the spatial distributions of logistics facilities, along with logistics practices, have gone through profound changes over the last two to three decades. As literature argues, the spatial distribution of logistics facilities is guided by various forces. The changes in the functional requirements of logistics facilities to enable high-throughput and/or just-in-time operations have led to the development of larger facilities. Due to the growing need for larger facilities together with other factors such as the scarcity of available space and the high land prices in and around the traditional urban centers, there has been a prevailing trend of logistics facilities moving outward to the suburbs and even to the exurbs that can be accessed by the highway systems. This has been validated by the recent studies that have identified the outward migration of logistics facilities in many cities around the world.

While many researchers and practitioners suspect that the outward migration of logistics facilities leads to an increase in vehicle travel distance and greater negative externalities, there have been very little empirical evidence on the actual impacts of such spatial transformation. Though the lack of data is clearly the main culprit, the argument about "logistics sprawl" is often based on the assumption that the outward migration of logistics facilities that is faster than that of other economics activities entails an increase in vehicle trip distance. However, the shipment demand locations are dispersed throughout the metropolitan areas, and the outward migration of logistics facilities may actually bring them closer to those demand locations. Furthermore, while the shipments connecting logistics facilities and the end receivers, such as shops, restaurants, offices and households, which is so called "last mile delivery", account for a large share, other types of shipments, such as factory-to-warehouse and warehouse-to-distribution center shipments, also contribute to urban freight traffic, although the extent of their impacts varies from city to city. In fact, like urban sprawl, the impacts caused by the outward migration of logistics facilities is not as obvious as it may seem.

Despite the growing interest, existing research on logistics sprawl do not provide sufficient knowledge to guide the development of effective policies to minimize the negative impacts of truck travel in a given urban area. It is not well understood how the spatial distribution of the logistics facilities affects truck travel and associated impacts at the metropolitan level. Furthermore, there is a dearth of knowledge on how the public policies affect logistics facility locations.

There are many reasons for the abovementioned gaps in the current knowledge and understanding, but the literature consistently point to the lack of appropriate analytical tools as one of the main causes. The policies that are developed to manage the locations of logistics facilities may not achieve the intended effects on negative externalities if the policies are not developed based on the proper understanding of the dynamics and the mechanism of urban logistics systems. In particular, the existing freight models cannot address the interaction between the spatial distribution of logistics facilities and truck trips because their structures do not adequately differentiate the decisions on the use of logistics facilities from the siting of the facilities. 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.

3.2 Research Questions

To address the research needs mentioned above, this study intends to address the following three questions:

Research Question I:

Does the outward migration of logistics facilities increase the negative externalities *associated with urban freight traffic?*

Research Question II:

What is the distribution of logistics facilities that minimizes negative externalities associated with urban freight traffic?

Research Question III:

How and to what degree can public policies affect the negative externalities associated with urban freight traffic through the spatial distribution of logistics facilities?

To investigate these research questions, I propose the analytical framework that consists of the four components that are explained in Chapter 4.

4 RESEARCH FRAMEWORK

4.1 Research Components

I designed the four components to address the research questions (Figure 1). These are:

Component 1: Analyze the spatial reorganization of the urban systems and its impacts in the Tokyo Metropolitan Area (TMA) by comparing the data for two time points, 2003 and 2013. (Chapter 5)

Component 2: Develop a simulation model for analyzing logistics facility distribution and associated urban freight traffic (named Urban Logistics Land-use and Traffic Simulator (ULLTRA-SIM)) for policy simulations. (Chapter 6)

Component 3: Evaluate various spatial distribution patterns of logistics facilities using the ULTTRA-SIM. (Chapter 7)

Component 4: Conduct policy analysis with different policy options (zoning, clustering, and distance-based pricing) and evaluate the impacts. (Chapter 8)

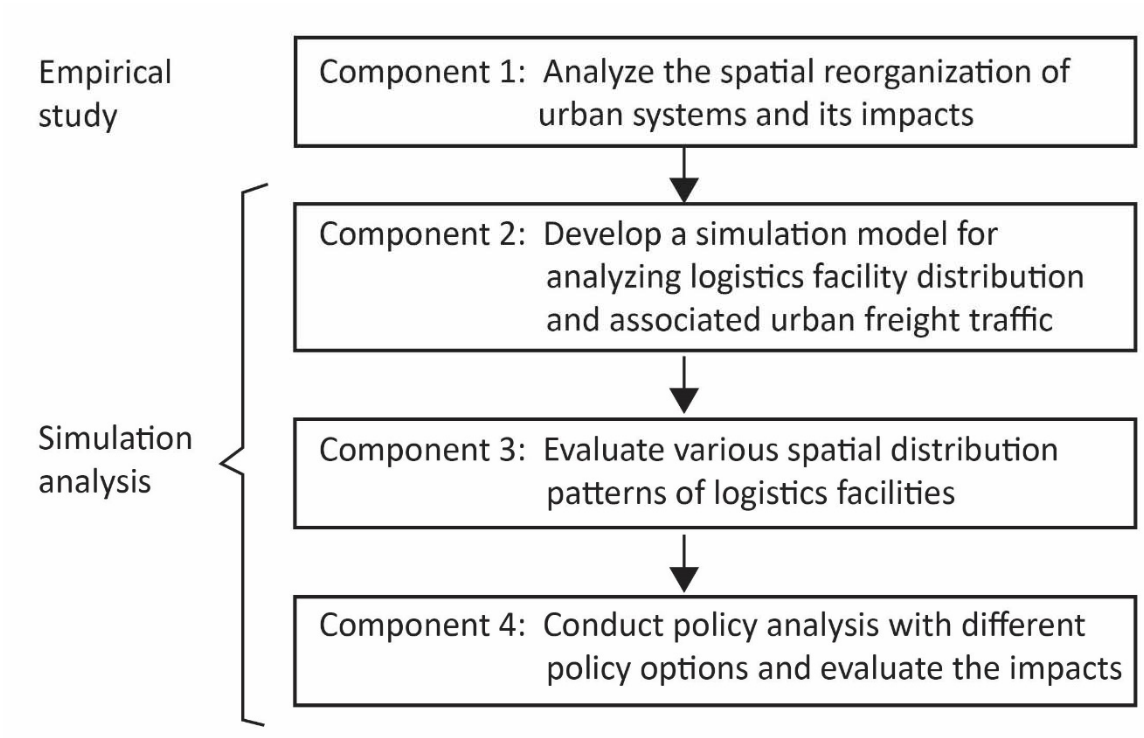


Figure 1: Roadmap

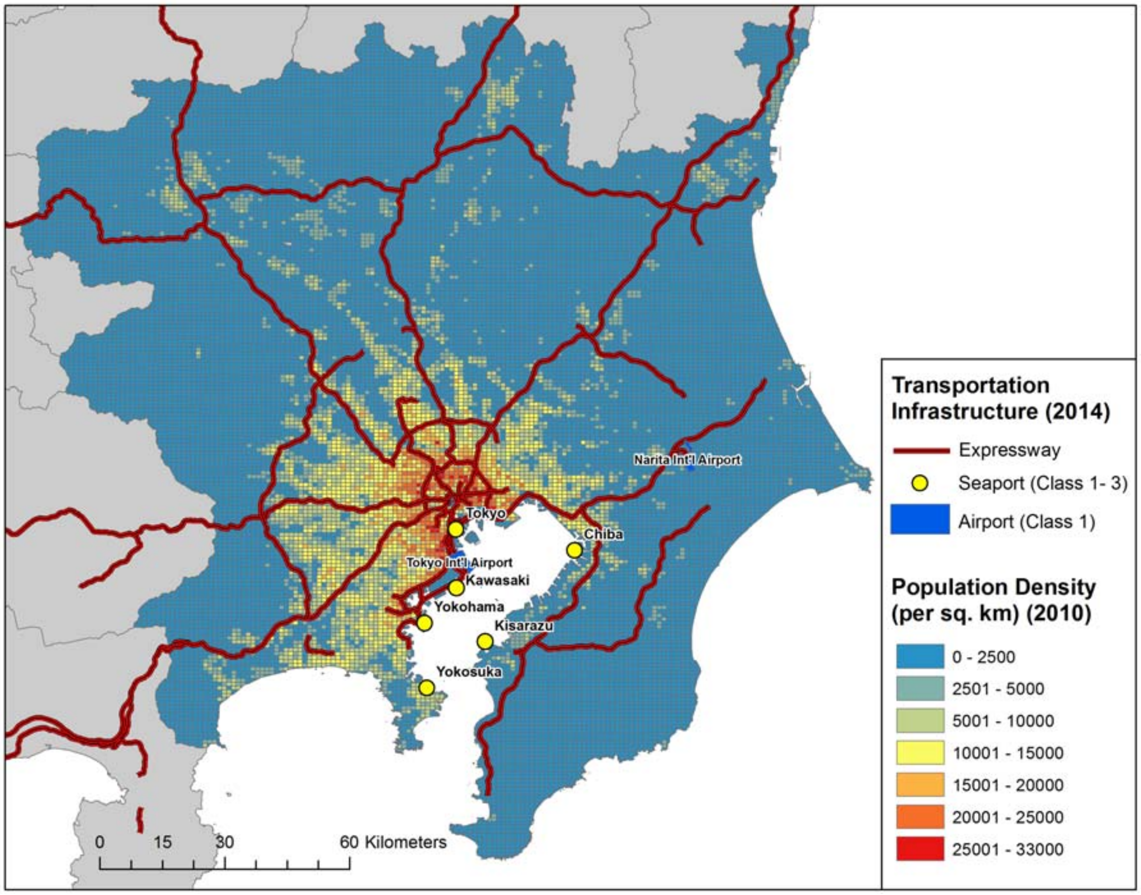
4.2 Study Area

This research uses the data set for the TMA, Japan. The comprehensive urban freight survey data are available for the TMA for two time points (2003 and 2013), as well as the data on road network, demography, business, land use, zoning, and land prices. The urban freight surveys in the TMA are, to the best of my knowledge, the largest urban freight surveys in the world and cover both facility and shipment data. The availability of the data allows this research to conduct in-depth analysis and to minimize the need for setting various assumptions.

In Japan, the public sector has a relatively centralized and strong administration system regarding the urban and transportation policies. For example, the national government applies rigorous land use regulations based on a national law (City Planning Act, 2014), and the prefectural governments, instead of the municipality governments (cities, towns, villages and special wards), have the authority for zoning and development control. With the existence of such centralized administration systems, some of the alternative policies tested in this study are considered more plausible propositions than in other metropolitan areas where the authority is decentralized. The evaluations of the policies for the TMA should provide useful insights even for metropolitan areas that face more difficulties in metropolitan-level policy coordination by elucidating the benefits of coordinated policy efforts.

The TMA, the largest metropolitan area in the world (United Nations, 2014), is the center of economic activities in Japan and a major international gateway; several large seaports and two major international airports are located in the area. The massive traffic demand that exceeds the road capacity, regularly causing serious congestion, is a challenging issue in the TMA, like other large metropolitan areas in the world. Although an expressway network plan that designates three ring roads and nine radial roads was published back in 1963, the ring road system is still incomplete. The constructions of the large portions of ring roads were delayed due to the opposition by the local residents who were concerned about the deterioration of local environment. In some cases, right-of-way acquisitions have been difficult and slow. Only recently, the construction of the ring roads has picked up the pace and the openings or the anticipated completions of the sections of Ring Road 3 (the outer ring road) have started to influence the land use in the surrounding areas.

I call the center of the expressway system (and the TMA), the "urban center". The population is most concentrated around the urban center and the density decreases as the distance from the urban center increases (see Figure 2). The most of the high-density area (≥ 5,000 /km^2) is within 40 km from the urban center. The study area also covers the sections along the ease-west expressway that runs about 80 km north of the urban center (the Kita-Kanto Expressway) along which there are small population clusters.



Source: Ministry of Internal Affairs and Communications (MIAC), 2010; Ministry of Land, Infrastructure, Transport and Tourism (MLITT), 2008, 2014a, 2014b, 2014c, visualization by the author

Figure 2: Major transportation infrastructure and population density in the TMA

4.3 Data Source

This section provides general information regarding the data set used in this research. Although each component of this research requires a different set of data, the Tokyo Metropolitan Freight Surveys (TMFS), socioeconomic data, and the road network data are the critical elements. This section provides an overview for each of the three data elements. More specific information for the data used in each component is provided in the subsequent chapters.

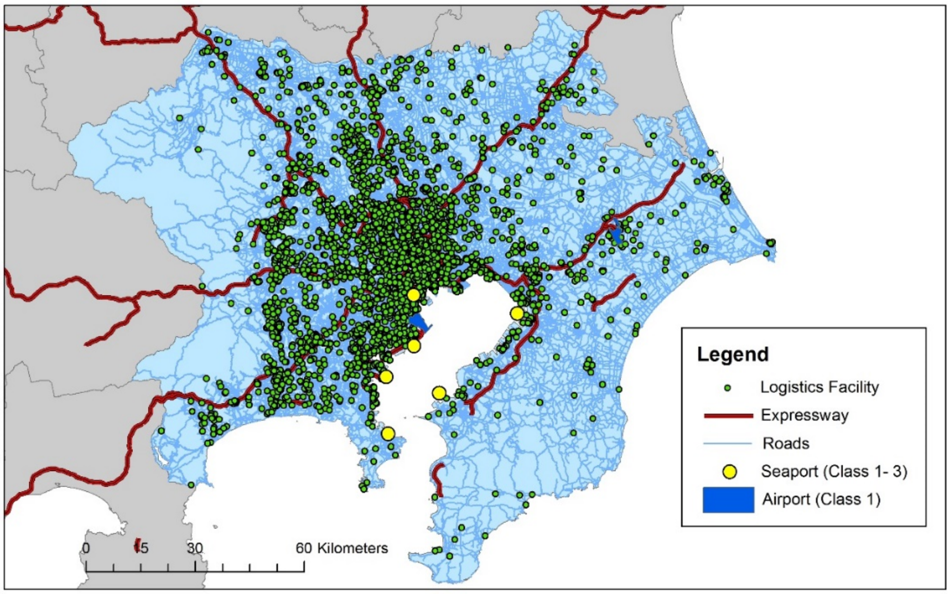
Tokyo Metropolitan Freight Survey

In this research, I define the area that is covered by the 2013 Tokyo Metropolitan Freight Survey (TMFS), 23 thousand km^2, as the main study area. The study area is home to 42 million people (2010 National Census (MIAC, 2010)) and 1.6 million establishments (28 % of the whole country, based on 2012 Economic Census (MIAC, 2012)). The TMFS is an establishment survey conducted roughly every 10 years by the Transport Commission of the Tokyo Metropolitan Region (TPCTMR). The two most recent TMFS were conducted in 2003 (4th survey) and 2013 (5th survey). Both TMFS employed random sampling, targeting almost all groups of establishments that engage in logistics activities, including manufacturers, wholesalers, retailers, restaurants and transportation service providers.

The survey area was expanded from the 2003 TMFS to the 2013 TMFS (see Figures 3 and 4). The survey area of the 2003 TMFS, totaling 16 thousand km^2, included Tokyo, Kanagawa, Chiba, Saitama, and a part of the Ibaraki prefecture. The 2013 TMFS, encompassing 23 thousand km^2, expanded the coverage to include the parts of Gunma, Tochigi, and additional parts of Ibaraki.

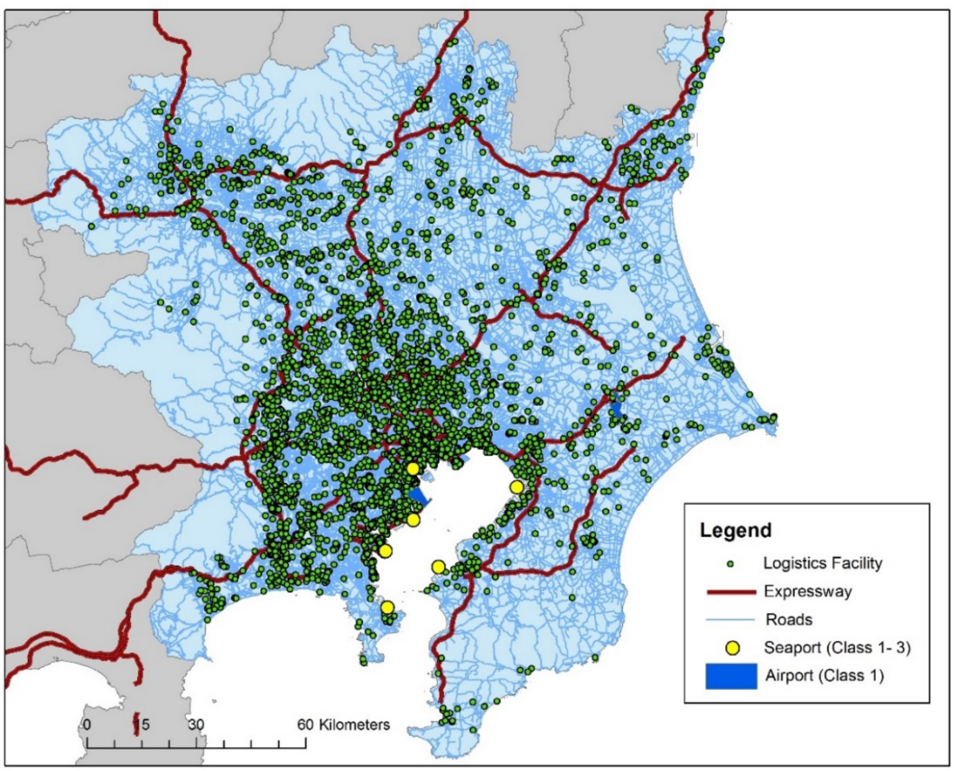
For the 2003 TMFS, the survey packages were sent to 119,737 establishments, of which 29,485 responded (a response rate of 24.6 %). The 2013 TMFS sent the survey packages to 136,632 establishments, and 43,141 of those establishments responded (a response rate of 31.6 %). In this research, the responses from logistics facilities that include distribution centers, truck terminals, warehouses, intermodal facilities and oil terminals, are mainly used; 4,109 and 4,580 responses are from logistics facilities in 2003 and 2013, respectively.

The TMFS data collected information such as location, function, industry classification, floor area, and the age of establishment, as well as the shipment information, including the number of trucks used, tons shipped, commodity type, the origins/destinations for inbound and outbound shipments. Both TMFS have official expansion factors calculated based on location, type of industry and employment size to reproduce the population of the targeted establishments.



Source: MLITT (2014a, 2014c); visualization by the author.

Figure 3: Logistics facility included in the 4th TMFS



Source: MLITT (2014a, 2014c); visualization by the author.

Figure 4: Logistics facility included in the 5th TMFS

Mesh (1 km-by-1 km polygons) data

The mesh data for the area of the 2013 TMFS were prepared by the TPCTMR (unpublished). The data set provides the following variables for each 1 km-by-1km polygon:

- Population density (night-time population based on the 2010 national census)
- Accessibility to employments (calculated based on the 2009 economic census using distance-based impedance)
- Distance from the nearest expressway interchange (based on the 2013 road network)
- Average land price (based on the 2013 official land price)
- Shares by zoning type (based on the 2011 urban planning map)
- Developable land (based on the 2011 geographical survey)

I added the following variables to the mesh data:

- Port Area along Tokyo Bay (a dummy variable based on the 2008 port GIS data from MLITT (2008), Japan).
- Areas along the Ring Road 2/Ring Road 3 (a dummy variable, based on the 2014 expressway time-series GIS data from MLITT(2014c), Japan).
- Accessibility to establishments (calculated based on the 2012 economic census (MIAC, 2012) using distance-based impedance)

Road Network data

I use the 2013 road network data of the TMA that consists of 271,218 links (unpublished). The data include average speed for each link calculated based on the Bureau of Public Roads (BPR) function using the 2010 traffic census data. I use this network data for calculating the distances of truck trips and for traffic assignment.

4.4 Terminology for the Subject of Analysis

This research analyzes a complex system that consists of urban freight, land use, and truck traffic. For describing the analyses in the research and discussing the results, I need to use various terms that are not necessary understood or used in a consistent manner even by freight transportation researchers. This section provides the definitions for the terms that are used in this manuscript. It should be noted that very few, if any, studies have analyzed urban freight at the level of detail as this research has. As such, some of these terminologies and the concepts associated with them are novel and are in themselves important contributions of this research.

Logistics facility

A "logistics facility" is an establishment that is either a distribution center, a truck terminal, a warehouse, an intermodal facility, or an oil terminal.

Logistics chain

A "logistics chain" is the movement of a commodity (or a bundle of commodities) from a production site to a consumption site. Each logistics chain consists of one or more shipments or truck trips. Some logistics chains include one or more transshipment points that is often a logistics facility.

Shipment/Truck trip

A "shipment" is a movement of a commodity (or a bundle of commodities) from one point to another without a transshipment in between. This research uses truck trip as the unit of shipment in this research, and therefore, I use the term "shipment" and "truck trip" interchangeably.

Shipment demand location/Demand location

"Shipment demand location" or just "demand location" is the location that is the origin of an inbound truck trip to a logistics facility or the destination of an outbound truck trip from a logistics facility. Factories and retail stores are the examples of demand locations. Also, a logistics facility can be a demand location when it becomes the origin or the destination of a trip between two logistics facilities.

Internal trip/External trip

An "internal trip" is a truck trip for which both the origin and the destination are within the study area. An "external trip" has either the origin or the destination out of the study area.

Shipment distance

Unless otherwise stated, "shipment distance" means the distance from a logistics facility to a shipment demand location, if the shipment is an internal trip. In case of an external trip, "shipment distance" includes only the portion of the trip within the study area, which is calculated as follows. For calculating the shipment distance for an external trip, I assign a cordon point along the border of the study area to each external demand location; such cordon point is on the path the truck is likely to take for the trip. Then, the distance between the cordon point, instead of the actual external demand location, and the logistics facility is calculated. In total, five boarder points, all of which are on expressways, are defined and assigned to external trips considering the potential trip routes.

Furthermore, I define the following terms for the components of a logistics chain:

Trip end

A trip end is either the origin or the destination of a truck trip. In other words, a trip always has two trip ends.

Production/Consumption

The beginning and the end of the entire logistics chain are defined as "production" (or P) and "consumption" (or C), respectively. Furthermore, I call an external trip end "production" (or P) if it is the origin of the inbound trip, and "consumption" (or C) if it is the destination of the outbound trip, regardless of whether those trip ends are the actual beginning/end of the logistics chain. Therefore, for external trips, this definition does not distinguish between the transshipment points outside of the study area and the actual origins and destinations of logistics chains.

Generation/Attraction

The trip ends at the logistics facilities 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 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 5 depicts these definitions.

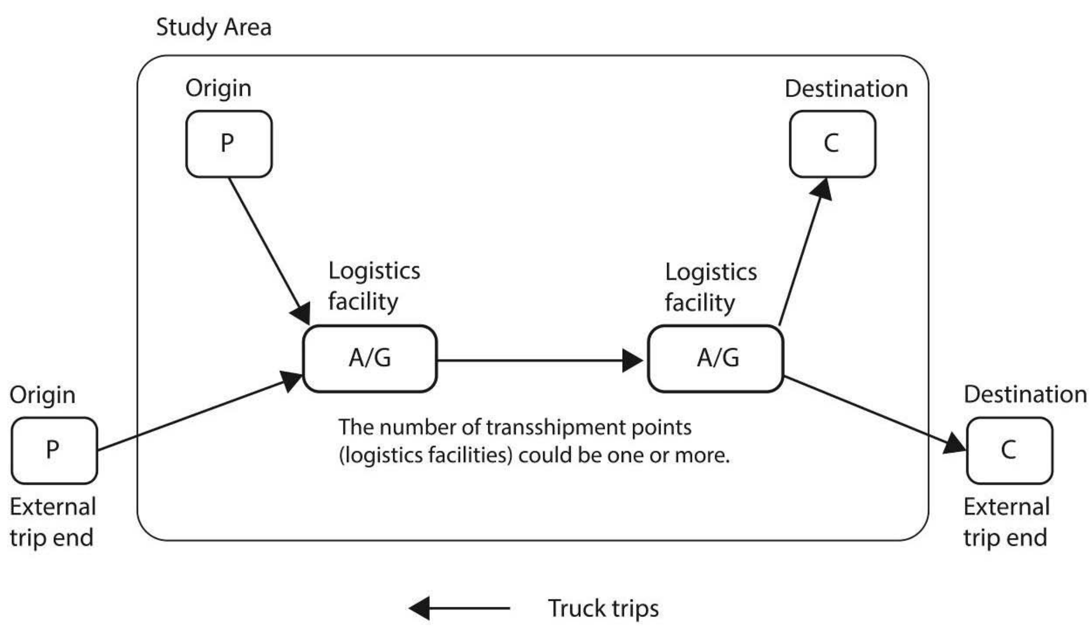


Figure 5: Trip ends and truck trips of indirect shipments

5 SPATIAL REORGANIZATION OF URBAN LOGISTICS SYSTEM AND ITS IMPACTS

Parts of this chapter were previously published as Sakai, T., Kawamura, K., Hyodo, T. (2017). Spatial Reorganization of Urban Logistics Systems and Its Impacts: Case of Tokyo. *Journal of Transport Geography*, 60, 110-118.

5.1 Scope

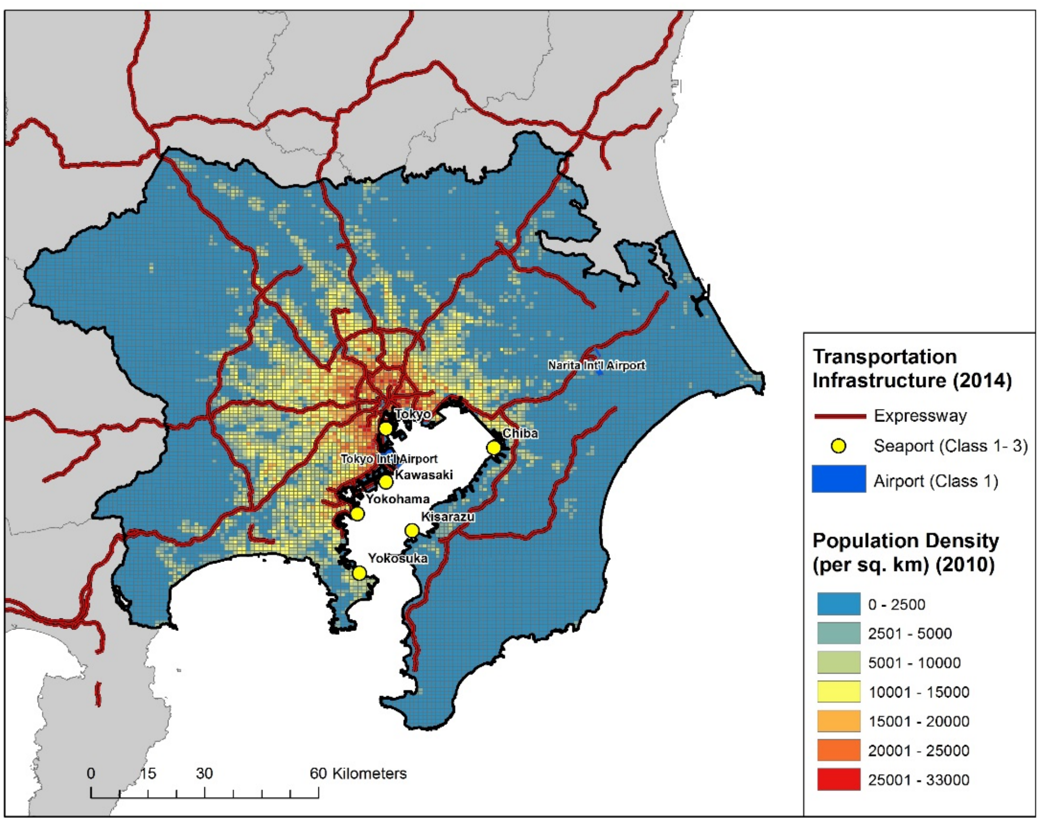
While the impacts associated with the outward migration of logistics facilities have been studied using models (Wager, 2010; Davydenko et al., 2013) and the actual shipment data (Sakai et al. 2015), they are cross-sectional studies. Longitudinal analysis is essential for understanding the dynamic relationship between the outward migration of logistics facilities and spatial restructuring of urban areas that occurred over years or even decades.

As noted in Sakai et al. (2015), the outward migration of logistics facilities in itself may not necessarily be a problem if it is occurring as an efficient response to the broader restructuring of the shipment origins and destinations. As such, it is critical to understand how the outward migration of logistics facilities occurs and under what conditions it can lead to an increase in truck travel distances to ascertain if government intervention is needed, and if so how it may look like. This research component strives to address these gaps by longitudinally analyzing the outward migration of logistics facilities and interpreting it against the backdrop of broader changes in the urban structure that are captured in the movements of business establishments and people.

I combine the TMFS data from 2003 and 2013 with other socio-economic data to analyze the changes in urban structure, including the distributions of shipment demand locations, and urban freight system in the TMA. As far as I know, this is the first detailed diagnosis of the dynamics of the migration of logistics facilities and its impacts on truck shipments based on the comprehensive freight survey data from two different years, and I believe the study contributes beneficial insights for the research on the spatial distribution of logistics facilities.

5.2 Data for Logistics Facilities

In order to maintain consistency, I only use the data for the area covered by both the 2003 and 2013 TMFS, where approximately 37 million people reside (2010 Census (MIAC, 2010)) and 1.4 million establishments (2012 Economic Census (MIAC, 2012)) are located (Figure 6). In the 2003 and 2013 data sets, 4,109 and 3,630 logistics facilities, which represent 18.1 % and 21.0 % of all logistics facilities in the area are included, respectively. For the study in this chapter, I use the facility location (address level), floor area, shipment demand locations, and the numbers of trucks used for each shipment. The study area includes 268 municipalities with the average size of 59.5 km^2.



Source: MIAC, 2010; MLITT, 2008, 2014a, 2014b, 2014c, visualization by the author

Figure 6: Study area (Chapter 5)

For all analyses in this chapter, I use the official expansion factors assigned to each logistics facility. Comparing the data from 2003 and 2013 requires the use of these expansion factors to account for the changes in the sampling frame between 2003 and 2013 that is attributable to the modification in the data format of the public business record used for sampling design. Expansion factors, however, are derived in the manner that makes it possible to compare these data sets.

5.3 Methodology

Spatial reorganization of logistics facilities and urban structure

In the first step, I examine the changes in the distribution of the logistics facilities between 2003 and 2013. I conduct the Kernel Density Estimation (KDE) to compare the distributions of the logistics facilities. The KDE has been used in the past research on the spatial distribution of logistics facilities (Heitz and Dablanc, 2015; Sakai, et al., 2016b). For the kernel function, the Gaussian distribution with the bandwidth of 3 km is selected after testing various bandwidth values for their effectiveness in highlighting the distributional characteristics.

In the next step, I compare the changes in the spatial distributions of logistics facilities with the indicators of urban structure, including business establishments, factories, population, and shipment demands, in terms of the distance from the urban center. The purpose of this step is to obtain the insights on the interaction between the logistics facilities and the urban structure (i.e. distributions of businesses and population) since literature suggests that relative (logistics) sprawl may exacerbate the negative impacts associated with the outward migration of logistics facilities.

For computing the urban structure indicators, I use the establishment count data from the 2001 Establishment and Enterprise Census (MIAC, 2001) and the 2012 Economic Census (MIAC, 2012) in the GIS polygons of 1km-by-1km that cover the whole study area. I also use the population data from the 2000 and 2010 National Census in the same data format.

I derive the locations of the factories from both TMFS data sets (2003 and 2013).

Furthermore, I use the TMFSs to obtain the shipment demand locations; the origins of the inbound truck trips to, and the destinations of the outbound trips from the logistics facilities in the study area are used after the expansion. Here, only the shipment demand locations at the non-logistics facilities are considered.

The detailed shipment records are available for 65.1 % and 48.8% of the logistics facilities included in the 2003 TMFS and the 2013 TMFS, respectively. To address the possible sampling bias, I compute another set of expansion factors for shipment, based on facility floor size (3 groups) and the distance from the urban center (4 groups) for each year. To compare the distributions of those indicators and logistics facilities, I compare the quintiles of the distances from the urban center. To calculate the distance from the urban center, I use the road network distance.

Shipping efficiency

I analyze all the truck trips destined to or originate from the logistics facilities in the study area. Shipment distances are calculated for each trip using the TMA road network, for both internal and external trips. The shipping efficiency of the logistics facilities in the TMA is measured in three ways. First, truck-kilometer (km)-traveled (the product of the average shipment distance and the number of shipments) per tons of freight handled are compared between 2003 and 2013. I believe this measure is more appropriate than total truck-km-traveled, because the size and the structure of the economy and the level of freight activities changed considerably between 2003 and 2013. The second measure of efficiency is the average shipment distance. The average shipment distances for 2003 and 2013 are compared for internal, external and all truck trips.

For the third measure of shipping efficiency, following the approach of Sakai et al. (2015), I first calculate the optimum location for each logistics facility, where the sum of the shipment distances (in the study area) for the trips attributed to that facility is minimized. It should be noted that such optimum point is not necessarily the best location from the perspective of an operator who wants to minimize the total cost including the non-transport costs such as the capital cost, but is a proxy of the socially desirable point to minimize social externalities associated with truck-km-traveled. Then, I compare the actual average shipment distances against the minimum shipment distances that can be achieved at the optimum locations for 2003 and 2013. For this third measure, only the logistics facilities that have at least two different origins of inbound and/or destinations of outbound trips are considered.

5.4 Result

Spatial reorganization between 2003 and 2013

In this section, the spatial distributions of the logistics facilities are discussed - first on their own, and then in relation to other indicators of urban structure. Figure 7 compares the results of the KDE for 2003 and 2013 separately for the small logistics facilities (400 m^2 or less in floor area) and the rest. The distribution of the logistics facilities in 2003 is characterized by the very high concentration of small (400 m^2 or less) logistics facilities around the urban center (see the upper-left map). However, these small facilities mostly disappeared by 2013 (upper-right). As for the facilities larger than 400 m^2, the intense concentration in and near the urban center that existed in 2003 became dispersed by 2013, although the port area maintained a high level of concentration. While the figures depict a diffusion of the monocentric structure of the logistics facility distribution during the 10 years, only a very limited generation of new clusters of logistics facilities can be seen. Between 2003 and 2013, the average distance from the urban center increased by 26% (from 25.7 km to 32.3 km) for all logistics facilities: 38% (from 22.1 km to 30.5 km) for those of 400 m^2 or smaller, and 17% (from 28.3 km to 33.1 km) for those larger than 400m^2. As these statistics indicate, the progress of the outward migration of the logistics facilities during the study period was significant.

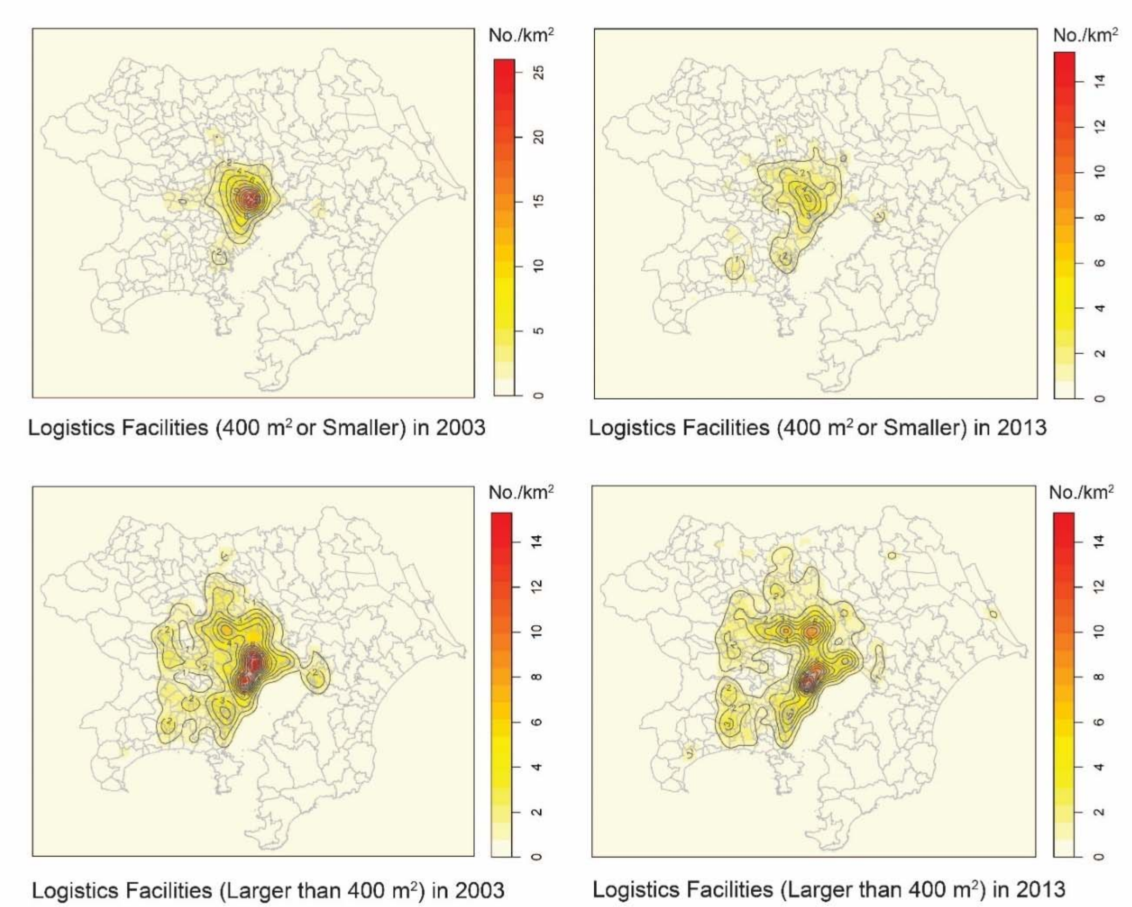


Figure 7: Kernel density maps for logistics facilities

Table II shows that as a whole, the smaller facilities were replaced by a fewer number of larger facilities, resulting in a reduction of the total number of logistics facilities by almost 24% during the study period. While the facilities that are 400 m^2 or smaller in floor area accounted for about 43% of the total in 2003, the share dropped to 29 % in 2013. On the other hand, the share of the facilities that are larger than 3,000 m^2 increased by 12.1%. It is important to note that these changes occurred mostly within 50 km from the urban center, which roughly matches the part of the TMA inside of the 3rd Ring Road. The logistics facilities that are larger than 3,000 m^2 increased from 3,306 to 4,146 in the area, while the number of small facilities (400 m^2 or smaller) declined by more than 50%. On the other hand, the changes were more modest for the area beyond 50 km.

TABLE II

LOGISTICS FACILITIES (LFS) BY SIZE

	Ave. floor area (m^2)	Median floor area (m^2)	No. of logistics facilities (share of total)			
			Floor area ≤ 400 m^2	400 - 3000 m^2	3000 m^2 <	Total
All LFs in the study area						
2003	2,552	585	9,672 (42.6%)	8,992 (39.6%)	4,044 (17.8%)	22,708 (100%)
2013	4,808	1,077	5,083 (29.4%)	7,027 (40.7%)	5,161 (29.9%)	17,271 (100%)
LFs within 50 km from the urban center						
2003	2,400	530	8,840 (43.9%)	8,013 (39.7%)	3,306 (16.4%)	20,159 (100%)
2013	4,917	1,029	4,263 (29.9%)	5,833 (41.0%)	4,146 (29.1%)	14,242 (100%)
LFs farther than 50 km from the urban center						
2003	3,755	1,000	831 (32.6%)	979 (38.4%)	738 (29.0%)	2,549 (100%)
2013	4,297	1,250	821 (27.1%)	1,193 (39.4%)	1,015 (33.5%)	3,030 (100%)

The outward migration of logistics facilities did not occur by itself; their customers, i.e. the shippers/receivers and the shipment demands, also moved outward, showing an interesting spatial restructuring pattern. Table III shows the quintiles of the distance from the urban center for establishments (all industries/facilities), population, factories, shipment demands for internal trips (measured in truck trips), and logistics facilities. The distributions of the business establishments and population changed only slightly during the study period. On the other hand, the outward migration of the factories and the shipment demands was more prominent; 2nd and 3rd quintiles increased by 3.7 km and 4.8 km for factories and by 5.3 km and 4.5 km for shipment demands. This indicates that, among various types of establishments, factories have an outsized influence on the distribution of shipment demands.

On the other hand, the outbound migration of logistics facilities outpaced those of factories and shipment demands (which is an evidence of a relative sprawl, following the definition by Dablanc and Ross (2012)). In 2003, the logistics facilities were located much closer to the urban center as a whole, compared with the urban structure indicators considered; however, by 2013, the distribution of the logistics facilities in terms of the distance from the urban center became more similar to that of the shipment demands. The next question that naturally arises is how such dispersion of logistics facilities affected the shipping efficiency.

TABLE III

QUINTILES (QUS) OF THE DISTANCE FROM URBAN CENTER FOR URBAN STRUCTURE INDICATORS AND LOGISTICS FACILITIES

		2003				2013[a]			
		QU1	QU2	QU3	QU4	QU1	QU2	QU3	QU4
Distance from the Urban Center (km)	Establishments[b]	9.0	18.4	32.1	48.2	9.7 (+0.7)	19.3 (+0.9)	32.7 (+0.6)	48.0 (-0.2)
	Population[c]	15.4	25.6	36.4	49.2	15.1 (-0.3)	24.9 (-0.7)	35.6 (-0.8)	48.2 (-1.0)
	Factories	12.0	20.4	35.4	50.6	14.6 (+2.6)	24.1 (+3.7)	40.2 (+4.8)	54.5 (+3.9)
	Shipment demands	10.9	20.5	33.9	49.7	14.2 (+3.3)	25.8 (+5.3)	38.4 (+4.5)	51.7 (+2.0)
	Logistics facilities	8.2	15.4	27.2	41.5	13.4 (+5.2)	23.2 (+7.8)	35.2 (+8.0)	48.2 (+6.7)

[a] The differences between 2003 and 2013 are shown in the parentheses underneath the 2013 figures.

[b] The data for 2001 and 2012 are used.

[c] The data for 2000 and 2010 are used.

Source: MIAC, 2000, 2001, 2010, 2012; calculations by the author.

Impacts of Reorganization in the Logistics System

In this section, I examine the efficiency of the truck shipments. It should be noted that the total tons handled by the logistics facilities (shown in column a. of Table IV) decreased by 15% between 2003 and 2013. The reason for the decrease is not clear but the decline in the manufacturing industry in the TMA probably played a role. This, combined with the considerable increase in the average load per shipment (column d), resulted in the decreases of 24% and 19% in total truck trips (column c) and total truck-km (column f), respectively. The overall efficiency, measured in truck-km-travelled per ton (column g), improved by 4% despite the 6% increase in average trip distance (column e), again due to the increase in average load.

Dividing the data at the 50 km mark from the urban center reveals that the improvement in efficiency did not occur evenly. Truck-km-travelled per ton decreased by 12% for the logistics facilities within 50 km from the center. This was accomplished by a large (20%) increase in average load that offsets the 6% increase in the average trip distance, mirroring the overall trends. It is likely that the substantial increase in the number of large facilities within 50 km from the urban center played a role in the increased average load. In contrast, the average load decreased for the facilities located beyond 50 km, and also the share of the trips between logistics facilities (which can be inferred from the changes in the figures in column a and b for the respective years) increased. As a result, the truck-km-travelled per ton increased by 54% for those facilities. Since most logistics facilities are located within 50 km of the urban center, the overall effect was the aforementioned increase in the efficiency by 4%.

TABLE IV

SUMMARY OF FREIGHT TRAFFIC HANDLED BY LOGISTICS FACILITIES (LFS)

	a. Tons handled by LFs (excluding trips between LFs) (mil.)	b. Tons handled by LFs (including trips between LFs) (mil.)	c. Total truck trips (thou.)	d. (b/c) Average load (ton/truck trip)	e. Average shipment distance (km)	f. (c×e) Total truck-km-traveled (mil.)	g. (f/a) Truck-km-traveled per tons handled by LFs
All LFs in the study area							
2003	1.16	1.85	680	2.72	34.9	23.7	20.5
2013	0.99	1.61	520	3.10	37.1	19.3	19.6
2013/2003	0.85	0.87	0.76	1.14	1.06	0.81	0.96
LFs within 50 km from the urban center							
2003	0.97	1.56	597	2.62	33.1	19.7	20.4
2013	0.87	1.39	442	3.14	35.1	15.5	17.8
2013/2003	0.90	0.89	0.74	1.20	1.06	0.79	0.88
LFs farther than 50 km from the urban center							
2003	0.19	0.28	83	3.39	48.0	4.0	21.0
2013	0.12	0.23	78	2.90	48.6	3.8	32.3
2013/2003	0.62	0.80	0.94	0.85	1.01	0.95	1.54

The average shipment distance for the internal trips increased by 6.1%, from 23.3 km in 2003 to 24.8 km in 2013. On the other hand, the change for the external trips was much more moderate, an increase of 1.6% (78.9 km in 2003 and 80.2 km in 2013). It should be noted that the external trips accounted for about the same share, 22%, of all the trips for both 2003 and 2013. Overall, the trucks traveled 6.4% longer on average within the TMA in 2013, compared with 2003, which is moderate relative to the outward migration of logistics facilities by 26% and the shipment demand by 11% during the same time period.

Figure 8 depicts another measure of shipment efficiency, based on the optimized distance, with respect to the distance from the urban center. In the chart, the x-axis is the distance from the urban center, based on the actual logistics facility locations. The trend lines show the moving average shipment distances of the facilities within ± 5 km for each x value. The gaps between the actual and optimized distances, i.e. the levels of inefficiency, are also shown by the bottom two lines in the figure. The figure clearly shows that the levels of inefficiencies increase with the distance from the urban center. Although there are exceptions, the logistics facilities that are farther from the urban center are likely to be less efficient, which corresponds to the finding of Sakai et al. (2015).

Figure 8 also shows that, for the facilities within 10 km from the urban center, the average actual distance and optimized distance are considerably shorter and the efficiency is slightly better in 2013 than 2003. This suggests that although many of the logistics facilities left the urban center, the remaining facilities operated very efficiently by serving the demands that are spatially concentrated. As for the facilities between 10 km and 50 km from the urban center, both the optimum and the actual shipment distances increased between 2003 and 2013, while the efficiency remained almost unchanged. This indicates that the increase in shipment distances occurred mainly because the shipment demands (the origins of upstream trips to the logistics facilities and the destinations of downstream trips from those logistics facilities) became farther apart from one another, not because the outward migration of logistics facilities created a spatial mismatch.

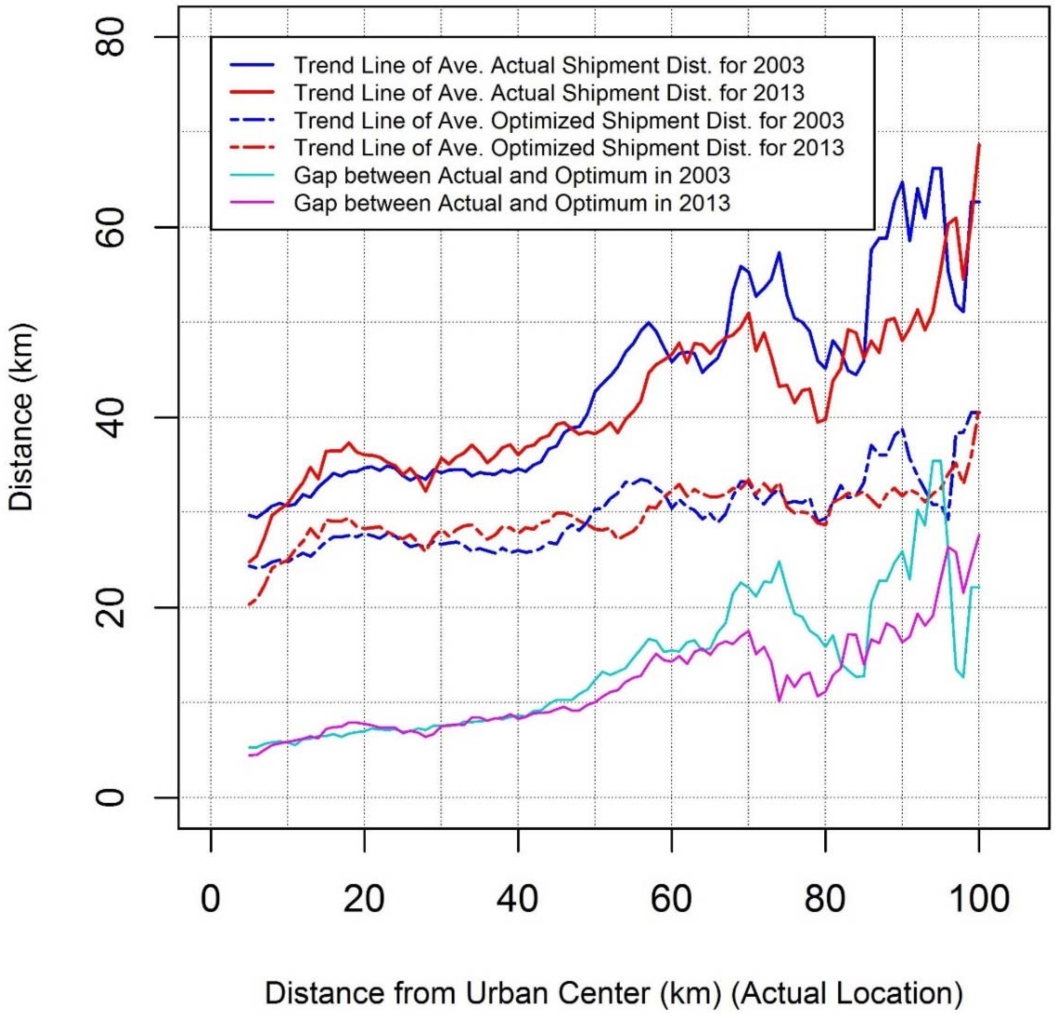


Figure 8: Average actual and optimum shipment distance against the distance from the urban center

As for the facilities that are more than 50 km from the urban center, both the actual and the optimum shipment distances decreased, indicating that the distribution of the demands (origins and destinations) became more efficient (possibly through clustering), and at the same time, the logistics facilities moved closer to the demands. This is understandable because as the shipment demands, especially those associated with the factories, migrated, the logistics facilities also moved outward, which brought the demands and the facilities closer. Interestingly, the facilities with longer average shipment distances generate considerably more trips in 2013 relative to 2003. For facilities that are more than 50 km from the urban center, the ones with the average shipment distances greater than 60 km generated 29.6 truck trips per day in 2003 and 65.0 truck trips per day in 2013; there is a positive correlation between the average shipment distance and truck trips for 2013 ($r = 0.31$) while such correlation does not exist for 2003 ($r = 0.07$). As a result, the average shipment distance remained nearly unchanged between 2003 and 2013, as shown in Table IV.

Those findings underline the fact that, despite the considerable outward migration of the logistics facilities, the locations of those facilities did not become inefficient in relation to the optimum (i.e. distance minimizing) locations as a whole; such migration occurred following the shipment demands, which were also moving outward. The change in the shipment distances can be attributed mainly to the spatial dispersion of the locations of demands, not the logistics facilities, as well as the increasing use of the high throughput facilities that handle the demands that are widely dispersed. Though I do not consider the effects of truck tours due to the limitation in the data, considering the impacts of truck tours might have led to greater improvements in the shipment efficiency. This is because an increase in the share of deliveries/pick-ups that are done as a part of multi-stop tours would reduce the truck VKT, but this effect is not reflected in my calculations which use the shipment records. However, the effect of truck tours can also lead to an underestimation of truck VKT if a truck visits a single municipality and makes multiple stops within it because the TMFS records them as one shipment. The significant increase in the average load observed for 2013 might be due to an increase in such multi-stop tour trips. As such, the net effect of these potential biases cannot be determined.

Figure 9 depicts the distribution of the share of the total truck trips associated with logistics facilities at 5 km increments of the distance (of the logistics facilities) from the urban center. The figure shows that the share of the truck trips to/from the facilities within 10 km from the urban center decreased considerably, while the contributions of those at around 20 km and 45-50 km increased drastically; these locations are in the vicinity of the 2nd Ring Road and the 3rd Ring Road.

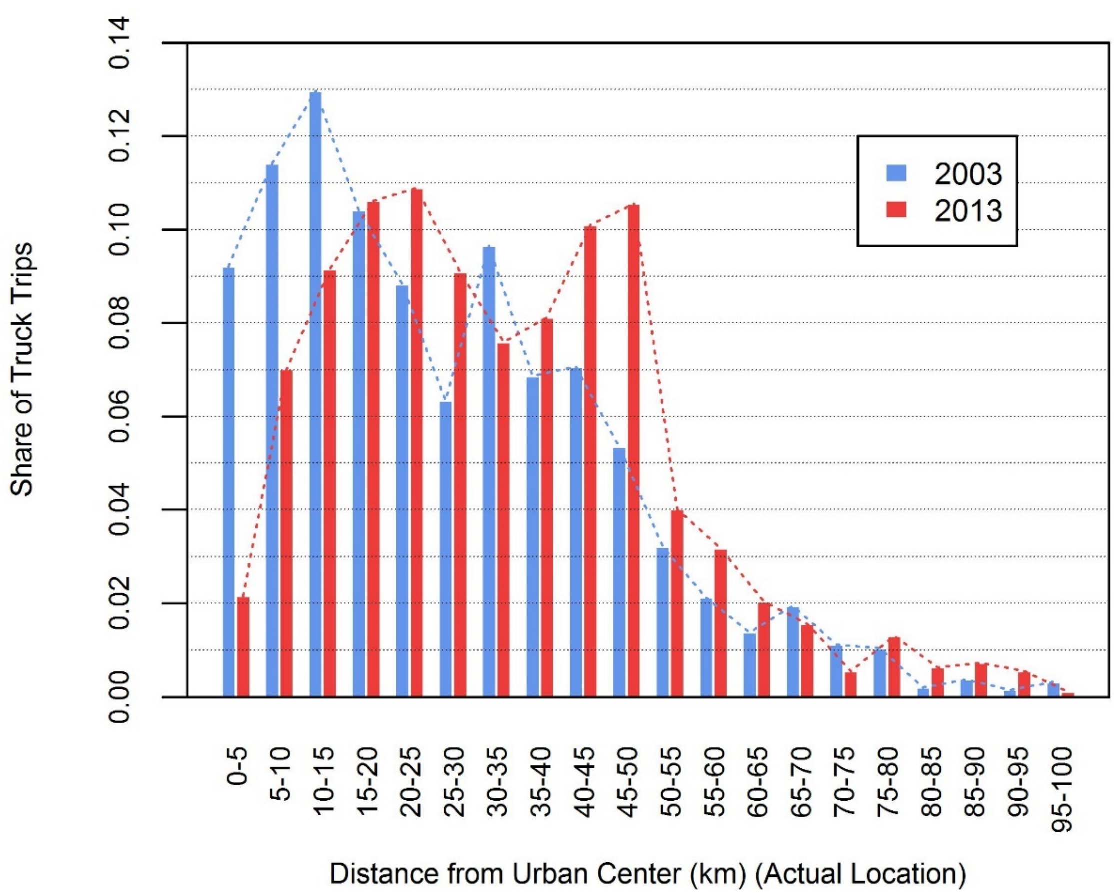


Figure 9: Shipment demand distribution by logistics facility location

5.5 Summary

I investigated how the decentralization and the structural changes in the urban logistics system in the TMA affected the shipment distances and truck traffic. The analysis shed light on the details, especially the relationship between the locations of logistics facilities, shipment demand locations, and shipment distances, at the level that has not been done in the past due to data limitations. Despite the richness of the data, this study has some limitations. For example, I was not able to analyze the effects of congestion due to the lack of accurate traffic data for the study time periods. This prevented me from accurately evaluating the extent to which the outward migration of logistics facilities contributes to the migration of local congestion and vice versa. The lack of the vehicle routing data that can capture the effects of truck tours is another shortcoming. In spite of these limitations, the analysis has revealed key insights into the mechanism and the impacts of the outward migration of logistics facilities. Main findings and policy implications are discussed below.

- The analysis confirms the occurrence of the outward migration of logistics facilities in the TMA during the study period. The speed of the migration is astonishing; logistics facilities moved outward by 26% in only 10 years. However, data indicates that the migration occurred in response, at least partly, to the decentralization of the shipment demand locations[9]. The narrative of the migration of the facilities that I found in the TMA is not surprising considering the changes in the logistics operations that led to the type of facilities that are desired; the smaller logistics facilities in the urban center are replaced by the larger facilities in the suburbs. Between 2003 and 2013, the median size of the logistics facilities nearly doubled

[9] The statistical analysis of the 2013 TMFS data, reported in Sakai et al. (2016a), revealed a strong effect of distance to the shipment demands on the logistics facility location choices

($585\ m^2$ to $1{,}077\ m^2$). Also, the share of the shipments handled by the facilities lager than $3{,}000\ m^2$ increased from 34% to 49%.

- The longitudinal analysis in this chapter reveals rather surprising results that underscore the beneficial aspects of the outward migration of logistics facilities that are often overlooked. As a whole, the outward migration of logistics facilities in the TMA has had only a modest effect on shipment distances. The 6.4% increase in the average shipment distance can be mainly attributed to the broad trend of decentralization that caused shipment demands, including the factories, to spread apart. It can even be argued that the outward migration of the logistics facilities brought them closer to the shipment demands that had already sprawled by 2003. At the same time, the increase in the average load per truck, which is a likely consequence of the prevalence of the larger logistics facilities[10], led to an overall improvement in the shipment efficiency. The truck trip distance (of the shipments to/from logistics facilities) per ton of shipment, which I consider to be an effective metric of inefficiency that takes into account the changes in overall freight activities, actually decreased by 4%. Such improvement in efficiency was achieved by the increase in average load that outweighed the slightly longer average truck travel distance in 2013.
- It should be noted that even without the effect of the greater average load, the spatial distribution of the logistics facilities in 2013 is almost equality efficient as was in 2003. This would not have been possible without the spatial reorganization of the logistics facilities in the TMA that kept the distances between the logistics

[10] It should be noted that the presumed causal relationship between the spatial reorganization of logistics facilities and the observed increase in average load is only anecdotal at this point.

facilities and the demands at a reasonable, if not the optimum, level. This underscores that spatial reorganization, which may involve the deployment of larger facilities and/or clustering with other logistics facilities or businesses, is important for improving the efficiency of shipments.

- The analysis reveals profound differences among various parts of the TMA in how the reorganization of the logistics industry and the outward migration affected the shipments and their efficiencies. In the area around the urban center, the facilities that remained, although small in number, operated very efficiently by serving the demands nearby, resulting in a noticeable decrease in the shipment distances. On the other hand, the truck-km-travelled per ton increased by a whopping 54% for the facilities in the outlying areas (more than 50 km from the urban center). This was caused by a decrease in the average load (for reasons unknown), and the increased share of the shipments between logistics facilities. Fortunately, this was countered by a significant increase in the average load for the facilities located between 10 km and 50 km from the urban center, which account for 70% of the total in number as of 2013.

While logistics sprawl is generally regarded as an undesirable phenomenon that escalates the negative externalities associated with urban freight, the analysis in this chapter demonstrates that the actual impacts, insofar as the truck-km-travelled per ton is concerned, are far from predictable. In the TMA, the magnitude of the increase in the average load more than compensated for the increase in shipment distances. However, there were underlying factors that contributed to such outcome.

- Firstly, the outward migration of logistics facilities resulted in only a slight increase in the average shipment distance. This is because in the TMA, the shipment demands were already decentralized in relation to the logistics facilities at the beginning of the study period (i.e. 2003). As such, the outward migration of the logistics facilities simply brought them in line with the shipment demands.

- Secondly, the outmigration created clusters of logistics facilities along the industrial corridors, which resulted in a significant number of short shipments.
- Thirdly, some logistics facilities remained near the urban center, covering the shipments to the urban core area efficiently. If those shipments had to be made by the suburban or exurban facilities, it would have affected the shipment efficiency negatively.
- Fourthly, the average load increased significantly when the facilities became larger.

These insights are to be used to guide the analysis using model simulations that are discussed in the subsequent chapters. However, it is important to note that these factors are not always possible. For example, in urban areas that already have a high load factor and/or large vehicles are used, such a large increase in average load cannot be expected. Also, if the outward migration moves the logistics facilities to the outlying areas beyond the shipment demands, it is likely that the average shipment distance would increase significantly. On the other hand, the policies that enable or encourage those factors to happen, e.g. development of freight villages in accessible locations not far from the shipment demands, preserving industrial land uses in or near the urban core, or incentivizing high load factor, should be examined as possible strategies to reduce truck travel.

6 MODEL FRAMEWORK: ULLTRA-SIM

Parts of this chapter were previously published as Sakai, T., Kawamura, K., Hyodo, T. (2017). Logistics Chain Modeling for Urban Freight: Pairing Truck Trip Ends with Logistics Facilities. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2609. doi: 10.3141/2609-07.

6.1 Scope

The objective of the model development is to obtain the policy analysis tool for measuring the level of negative externalities under several spatial distribution patterns of logistics facilities, both actual and hypothesized, and for evaluating the impacts of public policies that are designed to affect the logistics facility locations and the freight shipments (e.g. zoning, clustering, and distance-based pricing.). The existing land use and transportation simulators that consider goods movements, as well as dedicated urban freight models, treat logistics facilities (or logistics land use) in the same way as other facility types (i.e. as trip generators) and, thus, do not adequately address the unique features of logistics facilities as the transshipment points in urban logistics chains. To overcome the limitation of the exiting simulators/models, I propose a new model, named the Urban Logistics Location and Traffic Simulator (ULLTRA-SIM), that successively simulates logistics facility locations, logistics chain formations, and truck trip flow. The ULLTRA-SIM targets logistics facilities and associated indirect shipments; the direct shipments from productions to consumptions are not covered in the framework. I estimate the ULLTRA-SIM using the 2013 TMFS data.

The novelty of the ULLTRA-SIM is highlighted by the distinction of two types of decisions relevant to the logistics chain formulation in an 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 necessary to capture the actual routing of shipments between the production and consumption locations. Such model design allows me to analyze the impacts of policies and/or the changes in the land characteristics through the distribution pattern of logistics facilities, urban logistics chains, and truck traffic.

6.2 Structure of the ULLTRA-SIM

The ULLTRA-SIM consists of three main components:

- The logistics facility location choice model (LFLCM) that estimates the spatial distribution pattern of logistics facilities.
- The logistics chain model (LCM) that simulates the use of the logistics facilities for handling the shipment demand and estimates truck trips.
- The traffic flow and impact simulator (TFIS) that aggregates the estimated shipment demands, assigns truck trips on the road network and, then, estimates the indicators of externalities.

I name the entire simulator that consists of LFLCM, LCM and TFIS as ULLTRA-SIM. Figure 10 shows the flow of the ULLTRA-SIM. Although the model structure can be more complex than what is adapted in this research, the increase in complexity makes it more difficult to use the model in the simulations for the scenarios designed for policy insights. I focused on developing models that are sensitive to inputs (i.e. scenarios) and also economical to run, rather than achieving the complexity and sophistication to the extent the available data allows. The next section describes the model structure for each component.

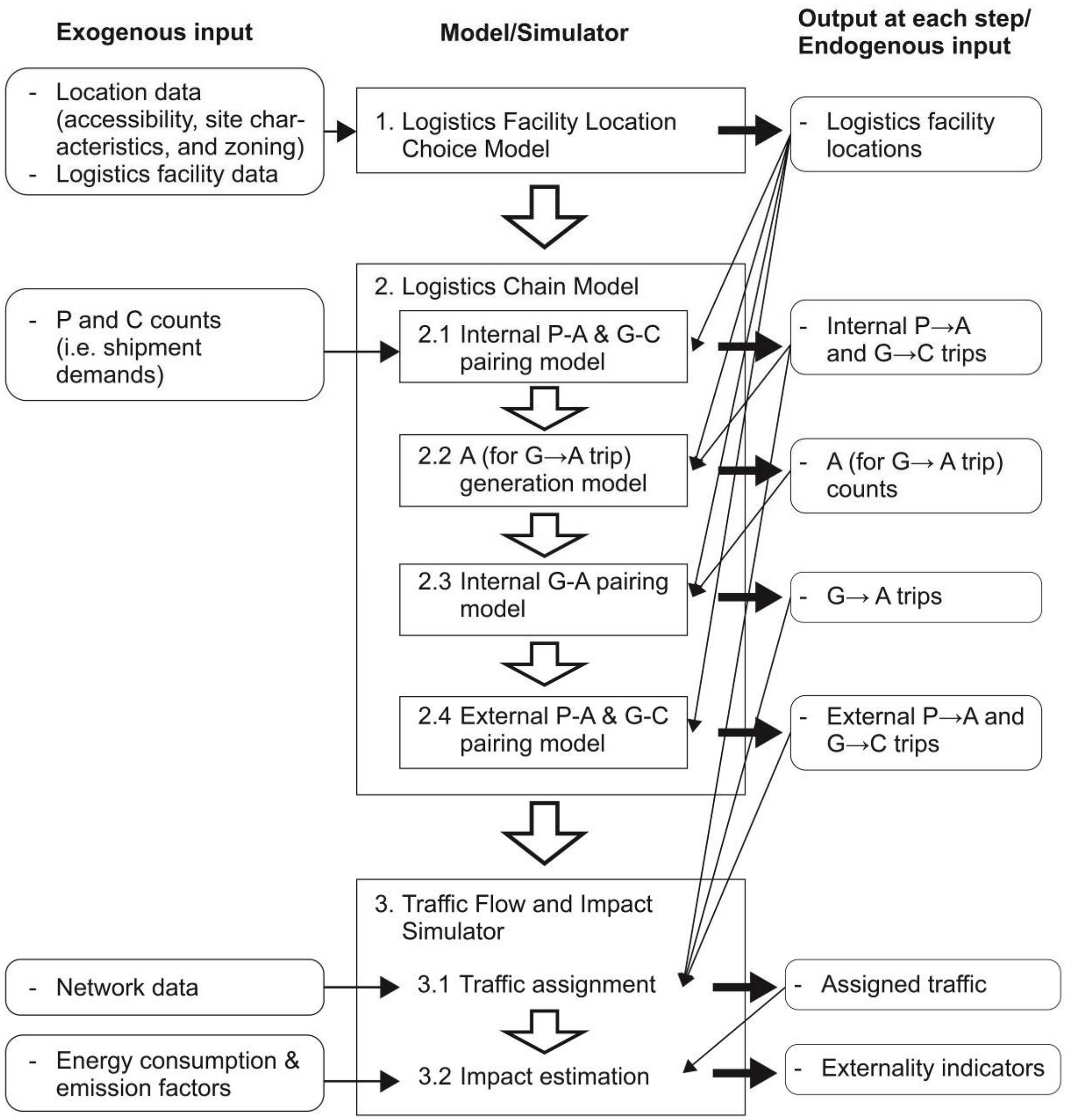


Figure 10: Flow of ULLTRA-SIM

6.2.1 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 the location alternatives for the logistics facilities are 1km-by-1km polygons. Within the study area (see Section 4.2), 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 a is defined as:

$$U_{f^a,l} = \boldsymbol{\beta}_a^{ACCESS\_LFLCM}\mathbf{ACCESS}_{f^a,l} + \boldsymbol{\beta}_a^{SITE\_LFLCM}\mathbf{SITE}_l + \boldsymbol{\beta}_a^{ZONE\_LFLCM}\mathbf{ZONE}_l + \varepsilon_{f^a,l} \quad (6.1)$$

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 location l is:

$$P_{f^a,l} = \frac{\exp(V_{f^a,l} + lnA_l)}{\sum_l \exp(V_{f^a,l} + lnA_l)} \quad (6.2)$$

where:

$V_{f^a,l}$: the deterministic component of $U_{f^a,l}$

A_l: the size of the developable area at location l

In location choice models, spatial correlation may exist in the deterministic and/or unobserved components of the utility function, and therefore, model specifications considering spatial correlations (i.e. spatial error models and spatial lag models) may be more appropriate to obtain unbiased estimates of the parameters. However, high computational cost of such models for both estimation and simulation made them infeasible for this study.[11] Similarly, Waddell et al. (2007) applied the standard multinomial logit specification for location choice models in their urban simulation model (UrbanSim) due to its computational efficiency.

6.2.2 Logistics chain model (LCM)

The function of the LCM is to estimate the probability of each logistics facility being used for routing a shipment. For the LCM, I define four types of trip ends, Production (P), Consumption (C), Attraction (A) and Generation (G), as discussed in Section 4.4. P is the origin of an inbound trip to a logistics facility, which is at a non-logistics facility in the study area, or is 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; A is the destination, a logistics facility, of an inbound trip; and G is the origin, a logistics facility, of an outbound trip. The LCM estimates P→A, G→C and G→A trips, given the locations and the characteristics of the logistics facilities and the locations and the quantities of trip ends at the non-logistics facilities within the study area and at all facilities outside of the study

[11] The model specifications considering the spatial correlations using the 2013 TMFS data are discussed in detail by Hyodo et al. (2016).

area (i.e. Ps and Cs).

I develop the multinomial logit models for each of the five model groups (MG) (see Figure 11). 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, As and Gs, in the study area. 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 (pairing P with A), and MG5 is for the outbound external trips (pairing C with G). The models in the MG4 and MG5 would capture the selection of the logistics facilities for inter-regional shipments. The spatial unit of trip ends are municipalities; the study area consists of 315 municipalities.

It is important to note that in the LCM, the P-C pairs (the pairs between the beginning and the end of logistics chains) are not fixed; The LCM directly estimates individual segments within a logistics chain (truck trips) by connecting trip ends (Ps, As, Gs, and Cs). This approach implies that the pairing between P and C could change as the locations of logistics facilities shift and also from simulation run to simulation run. Such model specification allows the estimation of the trips that compose logistics chains without requiring the data for the entire logistics chains, which are extremely difficult to collect, although it also has a disadvantage; the model cannot capture the relationship between the trips in the upper and down-streams of a supply chain.

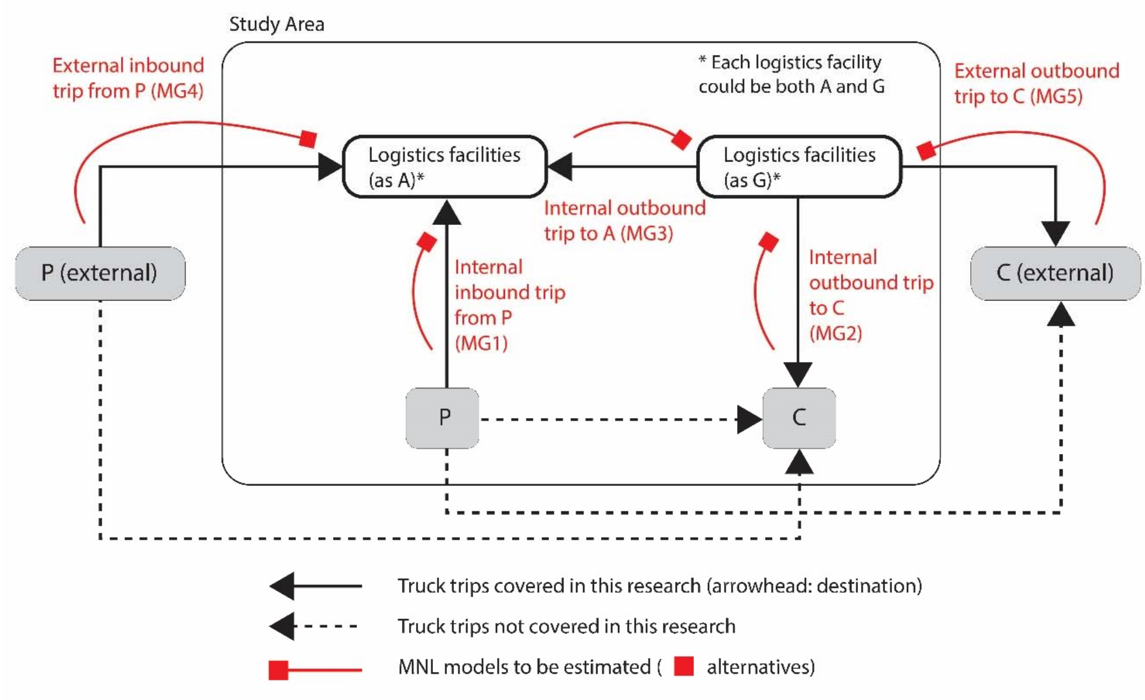


Figure 11: Target truck trips of five model groups

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

$$U_{t^{ec,g},f^g} = \boldsymbol{\beta}_{ec,g}^{ACESS\_LCM} \mathbf{ACCESS}_{t^{ec,g},f^g} + \boldsymbol{\beta}_{ec,g}^{FACILITY\_LCM} \mathbf{FACILITY}_{f^g} + \boldsymbol{\beta}_{ec,g}^{SITE\_LCM} \mathbf{SITE}_{f^g} + \varepsilon_{t^{ec,g},f^g} \quad (6.3)$$

where:

$\mathbf{ACCESS}_{t^{ec,g},f^g}$: a vector of the accessibility indicators between a trip end of trip end 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), $t^{ec,g}$, and a logistics facility f^g or at f^g.

$\mathbf{FACILITY}_{f^g}$: a vector of the facility characteristics of logistics facility f^g

$\mathbf{SITE}_{f^g}$: a vector of the site characteristics at location of logistics facility f^g

$\varepsilon_{t^{ec,g},f^g}$: a randomly distributed unobserved component

$\boldsymbol{\beta}_{ec,g}^{ACESS\_LCM}$, $\boldsymbol{\beta}_{ec,g}^{SITE\_LCM}$, $\boldsymbol{\beta}_{ec,g}^{FACILITY\_LCM}$: 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:

$$P_{t^{ec,g},f^g} = \frac{\exp(V_{t^{ec,g},f^g})}{\sum_{f^g} \exp(V_{t^{ec,g},f^g})} \quad (6.4)$$

For running the above pairing model for the G→A trips (MG3), 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. The number of As (for G→A trips) to be served by the logistics facilities of size a' in a municipality m is estimated using the following linear regression model:

$$N_{A^{\mathrm{G}\rightarrow\mathrm{A}},a',m} = \beta_{a'}^{a=1} N_{f^{a=1},m} + \beta_{a'}^{a=2} N_{f^{a=2},m} + \beta_{a'}^{a=3} N_{f^{a=3},m} \qquad (6.5)$$

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 $N_{A^{\mathrm{G}\rightarrow\mathrm{A}},a',m}$ 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 10) at municipality m.

6.2.3 Traffic flow and impact simulator (TFIS)

This simulator consists of two components: traffic assignment and impact estimation. The shipment data 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 Volume Census. For analyzing the changes in the traffic congestion in detail, it is desirable to use capacity-constrained traffic assignment methods, such as user-equilibrium assignment and incremental assignment; however, the passenger traffic OD data is not available and, in addition, they require the estimation of the freight traffic associated with direct shipments. Nonetheless, the use of the average travel times with the shortest-path assignment can reflect the actual traffic condition into the estimation of negative externalities to some extent.

The estimated truck assignment data are used to evaluate the externalities associated with the logistics chains that go through logistics facilities in terms of vehicle-kilometers travelled (VKT), vehicle-hours travelled (VHT), fuel consumption, and the emissions of CO_2, NO_X, SPM, CO, and SO_2. The energy consumption and emission factors are obtained from the report of a governmental research institute (National Institute for Land and Infrastructure Management, 2010); those factors are summarized in Table V.

TABLE V

FUEL CONSUMPTION AND EMISSION FACTORS

	Small Vehicle (Load Capacity < 2 ton)						Other Vehicle (Load Capacity ≥ 2 ton)					
	Fuel	CO_2	NO_X	SPM	CO	SO_2	Fuel	CO_2	NO_X	SPM	CO	SO_2
VKH	(l/km)	(g/km)	(g/km)	(g/km)	(g/km)	(g/km)	(l/km)	(g/km)	(g/km)	(g/km)	(g/km)	(g/km)
5	0.292	739	0.350	0.0206	8.438	0.0240	0.633	1702	5.241	0.0629	2.860	0.0517
10	0.226	572	0.287	0.0144	6.817	0.0186	0.531	1421	4.264	0.0473	2.176	0.0434
15	0.170	431	0.235	0.0094	5.423	0.0141	0.429	1140	3.287	0.0316	1.488	0.0351
20	0.153	385	0.220	0.0087	4.867	0.0126	0.396	1053	2.924	0.0266	1.326	0.0323
25	0.139	350	0.189	0.0079	4.032	0.0115	0.360	964	2.534	0.0240	1.255	0.0295
30	0.128	323	0.167	0.0072	3.085	0.0106	0.331	888	2.214	0.0215	1.184	0.0271
35	0.120	302	0.149	0.0065	2.204	0.0100	0.307	823	1.954	0.0192	1.101	0.0251
40	0.113	282	0.137	0.0060	1.475	0.0094	0.289	770	1.740	0.0172	1.018	0.0234
45	0.108	273	0.128	0.0055	0.947	0.0091	0.272	726	1.575	0.0156	0.947	0.0220
50	0.105	264	0.121	0.0053	0.649	0.0088	0.260	693	1.468	0.0142	0.888	0.0210
55	0.103	258	0.119	0.0051	0.601	0.0086	0.248	669	1.385	0.0132	0.841	0.0203
60	0.102	255	0.118	0.0051	0.815	0.0085	0.248	656	1.362	0.0125	0.793	0.0199
65	0.102	255	0.122	0.0053	1.298	0.0085	0.236	652	1.373	0.0121	0.758	0.0198
70	0.103	258	0.128	0.0056	2.059	0.0086	0.248	658	1.433	0.0121	0.746	0.0200
75	0.106	263	0.137	0.0062	3.101	0.0088	0.248	673	1.539	0.0124	0.734	0.0205
80	0.110	271	0.148	0.0068	4.426	0.0091	0.260	698	1.681	0.0131	0.746	0.0214
85	0.114	282	0.162	0.0076	6.040	0.0094	0.272	733	1.859	0.0142	0.758	0.0225
90	0.121	295	0.178	0.0086	7.941	0.0099	0.284	778	2.084	0.0156	0.793	0.0239
95	0.127	310	0.198	0.0098	10.133	0.0104	0.307	833	2.356	0.0173	0.829	0.0256
100	0.136	328	0.220	0.0111	12.616	0.0110	0.331	893	2.664	0.0194	0.888	0.0276
105	0.146	349	0.245	0.0126	15.394	0.0117	0.355	971	3.019	0.0219	0.959	0.0299
110	0.156	372	0.272	0.0143	18.466	0.0124	0.390	1053	3.410	0.0247	1.042	0.0325

Source: Calculated by the author based on National Institute for Land and Infrastructure Management, 2010.

6.3 Model Estimation

6.3.1 Logistics facility location choice model (LFLCM)

Data

For conducting the simulations detailed in Chapters 7 and 8, two types of models are estimated: one using only the facilities that were established in 2003 or later, and the other using all logistics facilities captured in the 2013 TMFS. The former uses 1,016 logistics facility records (4,201 samples after expansion) and the latter uses 4,580 logistics facility records (19,423 samples after expansion). The breakdown of the samples used for the LFLCM is shown in TABLE VI.

For modeling the location choices of the logistics facilities, I use the 17,961 1km-by-1km polygons that cover the developable land in the survey area of the 2013 TMFS (Figure 12). Each polygon has the data of various variables. This data were originally generated based on the geographical statistics obtained from the archive of the national government. The summary of the variables is provided in Table VII.

The variables that represent accessibility, land characteristics and zoning regulations are used in the model estimations. As for zoning variables, the residential zone is set as the base (anchor) category; therefore, the estimated coefficient for each zoning variable is expressed in relation to the residential zone.

TABLE VI

LOGISTICS FACILITIES USED FOR LOGISTICS FACILITY LOCATION CHOICE MODEL

	(i) 2003 or after		(ii) All years	
	Original record	Expanded record	Original record	Expanded record
Small ($\leq$ 400 m^2)	263	1,350	1,164	5,862
Medium (400-3000 m^2)	373	1,608	1,744	7,926
Large (> 3000 m^2)	380	1,243	1,672	5,635
Total	1,016	4,201	4,580	19,423

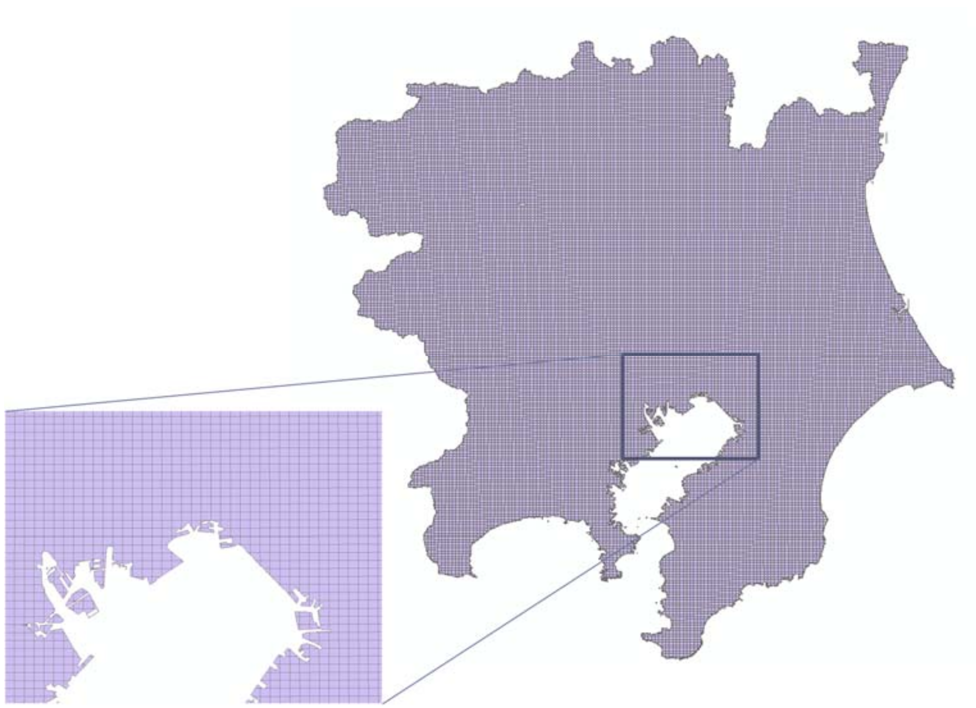


Figure 12: Alternative locations (1km-by-1km polygons)

TABLE VII

VARIABLES USED FOR LOGISTICS FACILITY LOCATION CHOICE MODEL

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: $\sum_m E_m \exp(-\mu \times \log(D_{l,m}))$ 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] Taken from a gravity model which is based on the OD and distance matrices developed by TPCTMR in 2003.

Estimated models

For the estimation of the location choice models, I tested various combinations of the variables (including the ones that are not shown in Table VII) and floor area categories. Some variables that are generally considered important for the location choice of logistics facilities, such as "average shipment time" and "the accessibility to population" were not included in the final models, as those variables were strongly correlated with other variables that showed stronger effects. Specifically, "average shipment distance" has a stronger (and more significant) effect than "average shipment time", probably because the travel time data that are available for the analysis are estimated and do not necessarily represent the actual travel time in reality. Also, "the accessibility to population" is not a significant factor when other accessibility and land characteristics variables are included in the models. Though not all the models are discussed here, two findings are worth mentioning.

- First, grouping of the logistics facilities based on floor area makes non-trivial difference in the coefficients estimated. On the other hand, the differences among different facility types (i.e. warehouses, distribution centers and consignors' facilities) are more modest. The differences are observed for almost all the parameter estimates and some are fairly large. This indicates that there is a considerable variation in the location choice behaviors among small, medium and large logistics facilities.[12]
- Second, the addition of the variables for shipment distance improves the adjusted rho-squared of the estimated models considerably. I decided to include the average

[12] There are some differences in the location choice preferences also by type of commodities that are mainly handled by the facility. However, grouping the logistics facilities based on the combination of size and commodity type handled leads to small sample sizes for each group and, also, making the model more complex than what is needed for answering the research questions. The detailed analysis of the locational characteristics of logistics facilities by type of the commodities handed are provided in Sakai et al. (2017).

shipment distance as both non-transformed and log-transformed values in the final models. While such treatment makes the interpretation of the estimated coefficients complex, the models achieve higher adjusted rho-squared than those using only one of the two. Such treatment makes the models sensitive to the distance-based pricing policies discussed in Chapter 8. It should be noted that the average shipment distance, $D_{f^a,l}$, which is calculated based on the shipment data for each facility, is the only facility-specific variable in the model. Other variables that are polygon specific have less effects on the adjusted rho-squared. This underscores the difficulty of formulating an effective approach for managing logistics facility development. The locations of shipping demands associated with each logistics facility are unique and difficult to generalize. Consequently, the optimum location for each facility that minimizes the shipment distance is also unique. This implies, for example, enforcing logistics facilities to be located in a specific location without carefully analyzing the locations of shipment origins and destinations could increase total shipping distance.

The models for the logistics facilities established in 2003 or after are shown in TABLE XIII and those for all logistics facilities are shown in TABLE IX. Three final models, one for each facility size category, are estimated for each model set. In the models, I used all the variables listed in TABLE VII except for the share of residential zone and added one interaction term for port area and land price. I also tested the models that only include the variables that are statistically significant, but the changes in the estimated coefficients were minor.

First, I will discuss the estimated coefficients for the models for the logistics facilities established in 2003 or later. Analyzing the recently established logistics facilities is insightful for investigating the factors that affect the choices for locating the facilities, as the time period for the data for the independent variables is close to the establishment years of those facilities.

The variables, "average shipment distance" and "ln(average shipment distance)", indicate that small and medium-size facilities (≤ 3000m^2) tend to be located closer to the shipment demand locations than large facilities.[13] On the other hand, "ln(distance from nearest expressway interchange)" has a stronger effect on medium and large facilities (> 400 m^2) than smaller facilities. This can be explained by the fact that medium and large facilities tend to serve dispersed shipment demand locations, and as a result, having a good access to the trunk road network is the best strategy for maintaining a high level of service coverage throughout the region. The slightly higher effect of "ln (accessibility to employments)" for medium-size (400-3,000 m^2) facilities than the others indicates that those facilities are located close to the potential demands generated by the economic activities in general. On the other hand, large facilities (> 3000 m^2) may face more limitations on site availability than small and medium facilities. Consequently, it is difficult for them to select the locations that reduce their shipment distances or the distance to employments.

[13] When "ln(average shipment distance)" is not included in the models, the coefficients for "Average shipment distance" are -0.243 (t-value: -40.3), -0.232 (t-value: -43.8) and -0.135 (t-value: -37.3), for small, medium, and large facilities, respectively.

TABLE VIII

ESTIMATED LOGISTICS FACILITY LOCATION CHOICE MODELS (ESTABLISHED IN 2003 OR AFTER)

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	-0.165	-20.94**	-0.174	-23.96**	-0.114	-19.69**
ln(average shipment distance)	-1.425	-13.45**	-1.470	-10.91**	-0.749	-4.57**
ln(accessibility to employments)	0.427	10.70**	0.542	15.23**	0.409	12.64**
ln(distance from nearest expressway interchange)	-0.055	-1.89*	-0.119	-4.62**	-0.114	-3.91**
Land Characteristics						
Population density	-0.046	-7.98**	-0.120	-17.39**	-0.169	-16.44**
Along Ring Road 2 (dummy)	-0.017	-0.12	0.078	0.78	-0.042	-0.28
Along Ring Road 3 (dummy)	1.152	10.52**	0.228	2.13**	0.701	7.11**
Northern exurb (dummy)	1.082	5.30**	1.224	7.37**	1.113	7.83**
Port area (dummy)	0.488	4.20**	-0.362	-2.12**	-0.111	-0.65
ln(average land price)	-0.387	-7.39**	-0.414	-8.68**	-0.343	-6.68**
Port area × ln(average land price)	0.123	1.66*	-0.126	-1.41	-0.069	-0.95
Zoning						
Share of commercial zone	0.527	2.56**	-2.320	-8.06**	0.786	2.75**
Share of quasi-industrial zone	0.978	5.97**	1.439	10.03**	2.897	15.36**
Share of industrial zone	0.249	0.84	0.692	3.28**	2.977	12.80**
Share of exclusively industrial zone	0.356	1.57	0.072	0.39	2.547	13.56**
Share of urbanization control zone	-0.108	-0.76	-0.477	-3.93**	0.705	4.12**
Share of miscellaneous land use	0.972	4.87**	-0.191	-0.85	0.955	3.98**
Share of non-urban planning zone	-0.793	-0.61	0.465	0.82	-2.163	-1.09
Null log-likelihood		-13,150		-15,784		-12,129
Maximum log-likelihood		-8,731		-10,864		-8,775
Rho-squared		0.336		0.312		0.277
Adjusted Rho-squared		0.335		0.311		0.275

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

As for the land characteristics, "population density" is more influential for medium and large facilities than for small facilities, which may be due to the fact that it is more difficult for a larger facility to locate in the high density areas due to the oppositions (either actual or potential) from the residents and the lack of appropriate plots. "Along Ring Road 2", a dummy variable that identifies the areas around the traditional industrial corridor, has no statistically significant effects on logistics facility locations. On the other hand, "along Ring Road 3" that identifies the areas along a newly developed industrial corridor, has strong effects on both small and large facilities but only weak effect on medium-size facilities. The reason for this is uncertain, but perhaps, the availability of large plots near the Ring Road 3 is a strong attraction for larger facilities, while small facilities congregate near those large anchor facilities. "Northern exurb" has strong effects on all logistics facility sizes; such effects are probably due to the good accessibility to the external regions and the availability of adequate sites. Interestingly, "port area" has a strong positive effect only on small facilities. This traditional industrial cluster probably has no space for new medium and large scale logistics facilities (on the other hand, the model for all years (TABLE IX) indicates that the port area has a strong positive effect on large facilities). The effects of "ln(average land price)" are statistically significant for all logistics facility sizes.

Finally, as for the zoning variables, only the "quasi-industrial zone" among the three industrial zoning classes is significant for small and medium size facilities. For large facilities, all three industrial zoning classes are significant. In the study area (the survey area of the 2013 TMFS), the total land area that is designated either as industrial zones or exclusively industrial zones is much less than that of quasi-industrial zones. While many of the small and medium facilities are allowed to locate in quasi-industrial or commercial zones, for some large facilities, industrial or exclusively industrial zones are the only options. The model results are reasonable in that small and medium facilities tend to value the factors that give them a competitive advantage. Meanwhile, large facilities tend to value the variables that are associated with the availability of sites. It should be noted however that the results do not prove that competitive advantages are not important for large facilities. Rather, a more natural interpretation is that large facilities face more constraints in site selection and thus the effects of competitive advantages tend to be less transparent in their location choices.

The models for all logistics facilities have similar characteristics with those for the facilities that are established in 2003 or after. But, there are also some differences. For example, the effects of "ln(distance from nearest expressway interchange)" are weaker for the former, as the old facilities were not necessarily developed near the sites along the expressways that did not exist at the time. Furthermore, the effect of "port area" is strongly positive for all large logistics facilities while such effect is not statistically significant if only the large logistics facilities developed in and after 2003 are considered.

TABLE IX

ESTIMATED LOGISTICS FACILITY LOCATION CHOICE MODELS (ALL YEARS)

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

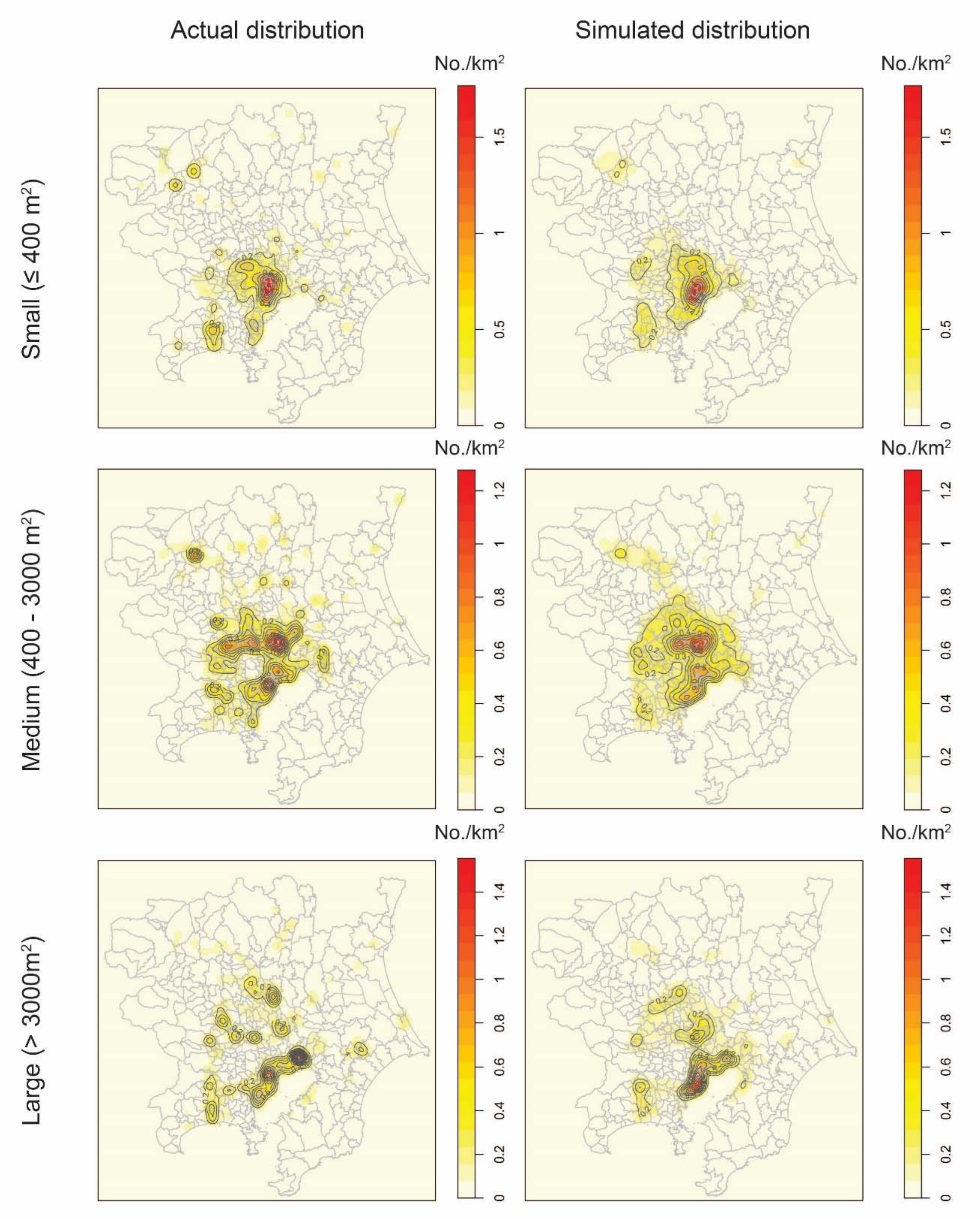
Note: * Significant at 90% confidence level; ** significant at 95% confidence level.

Reproducibility of the models

The simulations were conducted using the estimated models to assess the reproducibility of the observed data. The actual and the simulated distributions of logistics facilities are compared in Figure 13 and Figure 14, for those established in 2003 and after and in all years, respectively. The overall patterns of the actual and simulated distributions are similar for all six comparisons, but there are some differences.

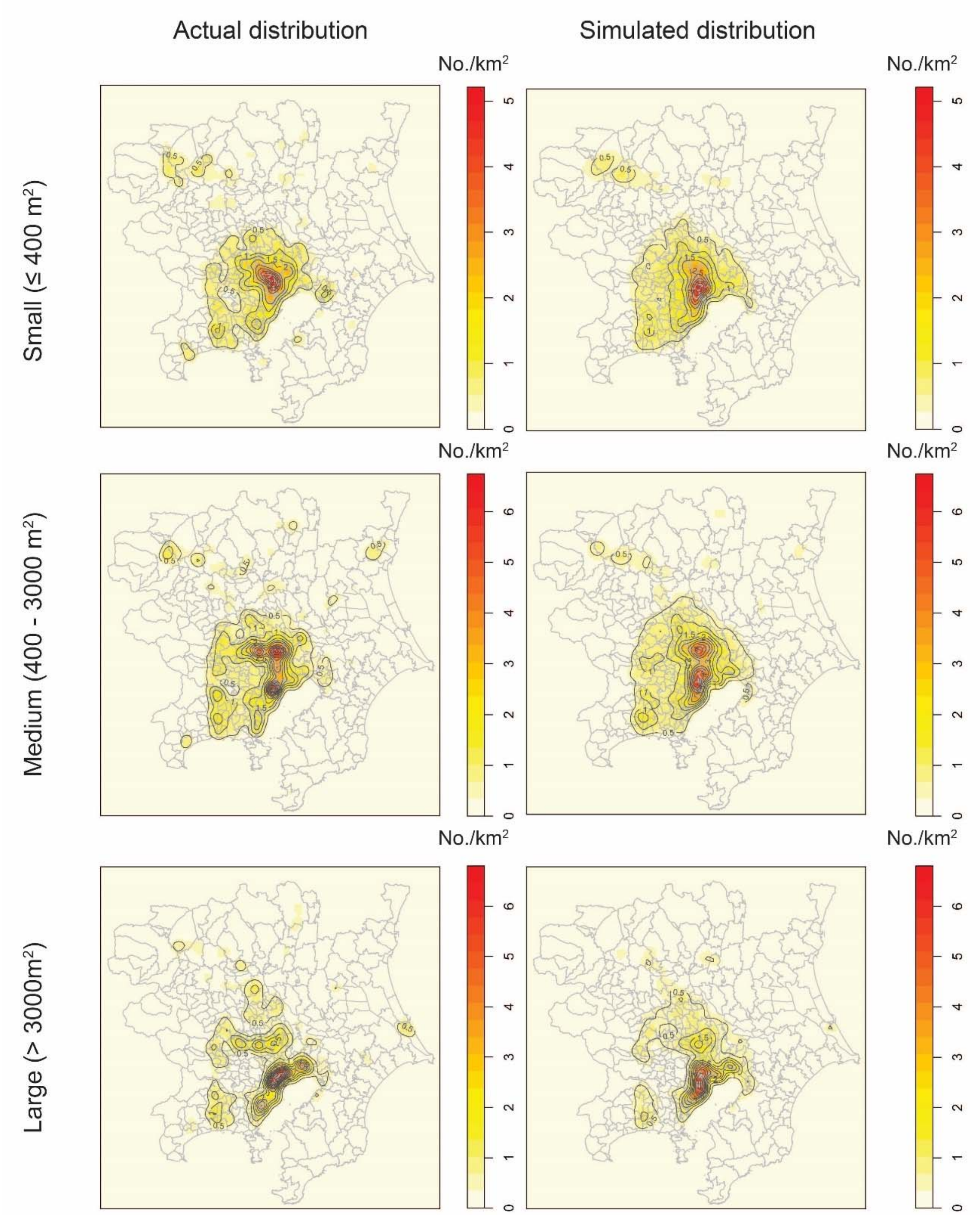
Actual distribution patterns tend to shows more small clusters with relatively high concentrations compared with the simulated ones, especially for the facilities established in 2003 or after. This is because the actual distributions were drawn using the expanded samples; the expanded samples are assumed to be at the exactly same locations with the original (unexpanded) samples and, therefore, small clusters are more likely to be generated around the samples with high expansion factors.

Another difference between the actual and simulated distributions is that the latter tend to have less clusters in the exurbs. The reason for this is unknown but I found that the models without “average shipment distance” (but with “ln(average shipment distance)” in the models) tend to generate the distributions with more clusters in the exurbs like the actual distribution, although the fits (i.e. rho-squared) of those models are generally poor. The combination of “average shipment distance” and “ln(average shipment distance)” may enhance the capturing of the facilities near the urban center at the expanse of the ones in the exurbs.



Note: The Gaussian distribution with the bandwidth of 3 km is used for the kernel function.

Figure 13: Comparison between actual and simulated distributions of logistics facilities established in 2003 or after



Note: The Gaussian distribution with the bandwidth of 3 km is used for the kernel function.

Figure 14: Comparison between actual and simulated distributions of logistics facilities (all years)

6.3.2 Logistics chain model (LCM)

Data

For the LCM, I use the data for the logistics facilities that reported facility and shipment information in the 2013 TMFS. After the expansion, the data set includes 40,356 internal trips going from origins to logistics facilities, 115,867 internal trips going from logistics facilities to destinations, 52,391 internal truck trips between logistics facilities, and 16,835 inbound and 36,453 outbound external truck trips.

The independent variables considered in the models are summarized in TABLE X. As is the case with the LFLCM, I use the data of various variables, which are organized in 1km-by-1km polygons covering the TMA, in addition to the 2013 TMFS. For “Acce. est.”, the types of establishments to be included in the calculation of accessibility are defined for each commodity group, considering the potential associations between the industries (TABLE XI). Both non-transformed and log-transformed shipment distances, “ship. dist” and “ln(ship. dist.), are considered in the models. Other variables, excluding “pop. dens.” and dummy variables, are log-transformed as it improves the fits of the models. In the final models, the variables that are not statistically significant at the 90% confidence level or show the opposite sign from the expected are excluded. However, “dum port”, “dum rr2”, and “dum rr3” are always included in the models regardless of the sign and the significance.

TABLE X

VARIABLES USED FOR LOGISTICS CHAIN MODEL

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.	+/-

[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.

TABLE XI

ESTABLISHMENT INDUSTRY TYPES CONSIDERED FOR ACCESSIBILITY INDICATOR

Commodity type	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.)

TABLE XI

ESTABLISHMENT INDUSTRY TYPES CONSIDERED FOR ACCESSIBILITY INDICATOR (CONTINUES)

Commodity type	Potential attraction establishments	Potential generation establishments
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

Estimated models

Using the maximum-likelihood estimation, a total of 30 models were estimated (six commodity groups for each of the five model groups). It should be noted that, while various implications are obtainable from these estimated models, the characteristics of the estimated models or coefficients cannot be summarized in a simple manner. Therefore, I focus on the performance of the models and the observed characteristics that are most insightful.

First, the estimated models for MG1 and MG2 are shown in TABLE XII. The Rho-squared values range from 0.093 to 0.332. While the rho-squared values are fairly typical for this type of model, they are noticeably higher for the mixed-goods (0.332 and 0.290), 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." and/or "ln(ship. dist.) are very strong factors, indicating that logistics facilities that are closer to the demand locations are highly attractive for routing the shipments. In fact, without the "ship. dist" and "ln(ship. dist), 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, indicating the importance of facility size, although 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). This indicates that the logistics facilities in the 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. Also, the shipments to the customers tend to be under a greater level of delivery time window constraints, and the congestion associated with density may also be a factor. Furthermore, the statistically significant effect of “land price” indicates that facility costs are important to the facility choice for deliveries to the destination.

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

TABLE XII

ESTIMATED LOGISTICS CHAIN MODELS (P→A AND G→C TRIPS, INTERNAL)

	MG1: P→A trips (internal)						MG2: G→C trips (internal)					
	Food	Daily goods	Raw materials	Machinery	Chemical Goods	Mixed Goods	Food	Daily goods	Raw materials	Machinery	Chemical Goods	Mixed Goods
Ship. dist.	-1.81	-1.16	-0.59	-1.70	-1.32	-1.72	-1.02	-0.91	-1.06	-1.44	-1.28	-2.21
	(-95.0**)	(-43.6**)	(-15.8**)	(-80.4**)	(-60.9**)	(-38.1**)	(-89.6**)	(-57.3**)	(-57.8**)	(-88.5**)	(-71.9**)	(-77.1**)
ln(ship. dist.)	-0.005	-0.016	-0.036	0.013	-0.023	-0.055	-0.030	-0.026	-0.020	-0.005	-0.009	-0.014
	(-6.79**)	(-15.6**)	(-29.2**)	(18.3**)	(-23.8**)	(-17.3**)	(-63.3**)	(-41.4**)	(-29.2**)	(-9.19**)	(-16.6**)	(-9.73**)
ln(acce. est.)									0.23	0.51		
									(2.75**)	(5.69**)		
ln(acce. pop.)						0.11						0.08
						(4.35**)						(4.65**)
ln(dist. to Exp. IC)										-0.06	-0.08	-0.11
										(-6.45**)	(-8.40**)	(-8.07**)
ln(floor area)	0.39	0.26		0.25		0.20	0.22	0.25	0.08	0.28		0.22
	(58.7**)	(35.7**)		(34.9**)		(18.2**)	(75.6**)	(65.0**)	(15.7**)	(55.0**)		(27.4**)
Pop. dens	-0.02	-0.04		-0.03		-0.09			-0.01	-0.02	-0.01	-0.14
	(-8.29**)	(-17.8**)		(-13.4**)		(-14.2**)			(-7.52**)	(-9.87**)	(-5.20**)	(-27.4**)
ln(land price)	-0.43		-0.44		-0.37		-0.31		-0.31	-0.30	-0.46	-0.25
	(-27.4**)		(-30.9**)		(-25.8**)		(-54.5**)		(-21.4**)	(-19.8**)	(-32.6**)	(-13.8**)
Dum port	-0.50	-0.73	0.20	0.11	-0.02	-0.93	-0.10	-0.63	-0.34	-0.84	-0.33	-0.30
	(-12.8**)	(-19.8**)	(6.12**)	(3.36**)	(-0.62)	(-12.6**)	(-7.11**)	(-32.7**)	(-12.7**)	(-28.3**)	(-11.2**)	(-6.28**)
Dum rr2	-1.50	-0.47	-0.77	0.36	-0.04	-0.07	-0.26	-1.09	-0.18	0.01	0.06	-0.21
	(-11.8**)	(-9.11**)	(-8.98**)	(6.16**)	(-0.66)	(-0.84)	(-9.53**)	(-28.1**)	(-4.89**)	(0.17)	(1.61)	(-2.97**)
Dum rr3	-0.06	0.62	-0.80	-0.33	-0.48	-0.59	-0.31	0.57	-0.66	-0.42	-0.22	-0.76
	(-1.66*)	(15.4**)	(-11.1**)	(-7.42**)	(-9.06**)	(-7.27**)	(-15.8**)	(26.9**)	(-16.9**)	(-14.3**)	(-6.30**)	(-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.

The estimated models for the trips between two logistics facilities (MG3) are shown in TABLE XIII. The rho-squared is the lowest for the model of daily goods (0.060) and the highest for mixed goods (0.134). 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."/"ln(ship. dist)" are again observed in this model for all commodity types. On the other hand, the effect of "ln(floor area)" is quite strong for food, but not observed for machinery and chemical goods.

The locations of "hub" logistics facilities that deliver goods to other facilities, differs by commodity type. The facilities along the Ring Road 3 are popular for food and raw materials while those in the Ring Road 2 are preferred for daily goods. The hub logistics facilities in the port, along Ring Road 2 and 3 are relatively more used for machinery than those in the other locations, and those in port area are most preferred. Though the effects are not very strong, the facilities in the port areas and also along Ring Road 3 are preferred for chemical goods, but the ones along Ring Road 2 are not. Unlike the other commodity types, the port areas or the areas along Ring Road 2 and 3 do not positively affect the choice of a hub facility for routing mixed goods.

TABLE XIII

ESTIMATED LOGISTICS CHAIN MODELS (G→A TRIPS, INTERNAL)

MG3: G→A trips (internal)						
	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 XIV shows the estimated models for the external trips. The rho-squared are relatively modest compared against other models. It is especially notable that the coefficients for the "ship. dist." and "ln(ship. dist.)", which, for these model groups, are based on the distance between the logistics facility and the assigned border points, are considerably lower in magnitudes than those for the same variables for the models discussed earlier. The low rho-squared values indicate that the powers of the models to explain the selection of the transshipment points for external trips are relatively weak. Meanwhile, the effects of facility size ("ln(floor area")), land price, and the accessibility 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. For mixed goods, most of the independent variables are significant with expected signs, and many of them show stronger effects than for the other commodity groups.

TABLE XIV

ESTIMATED LOGISTICS CHAIN MODELS (P→A AND G→C TRIPS, EXTERNAL)

	MG4: P→A trips (external)						MG5: G→C trips (external)					
	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.

Reproducibility of the models

Using the Monte Carlo method, I 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 that were 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 likelihood functions.

For each of the 30 models, the probabilities of the match between the trip ends and the available logistics facilities are calculated using the estimated parameters. Then, the selection of the logistics facility for each shipment is simulated using the calculated probabilities. In essence, each P, C or A is paired with a logistics facility where the shipment goes through a transshipment.

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 figures derived from the survey data. For the internal trips, the number of truck trips between individual ODs (a total of 99,225 (315 × 315) pairs) are also compared. As the indicator of the prediction performance, R-squared that is defined by the following function is calculated:

$$R^2 = 1 - \frac{\sum_k (y_k - \widehat{y_k})^2}{\sum_k (y_k - \bar{y})^2} \qquad (6.6)$$

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 15. The reproducibility of the models are generally acceptable, especially for MG1 and MG2 (upper-left and upper-right) with the R^2 of 0.547 and 0.597, 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 (0.467) 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 0.607 (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 (0.607) is considerably higher than that for the outbound shipments (0.454), which indicates the selection of transshipment locations for the inbound movements from the external areas has a systematic pattern that can be captured by our model than the outbound movements.

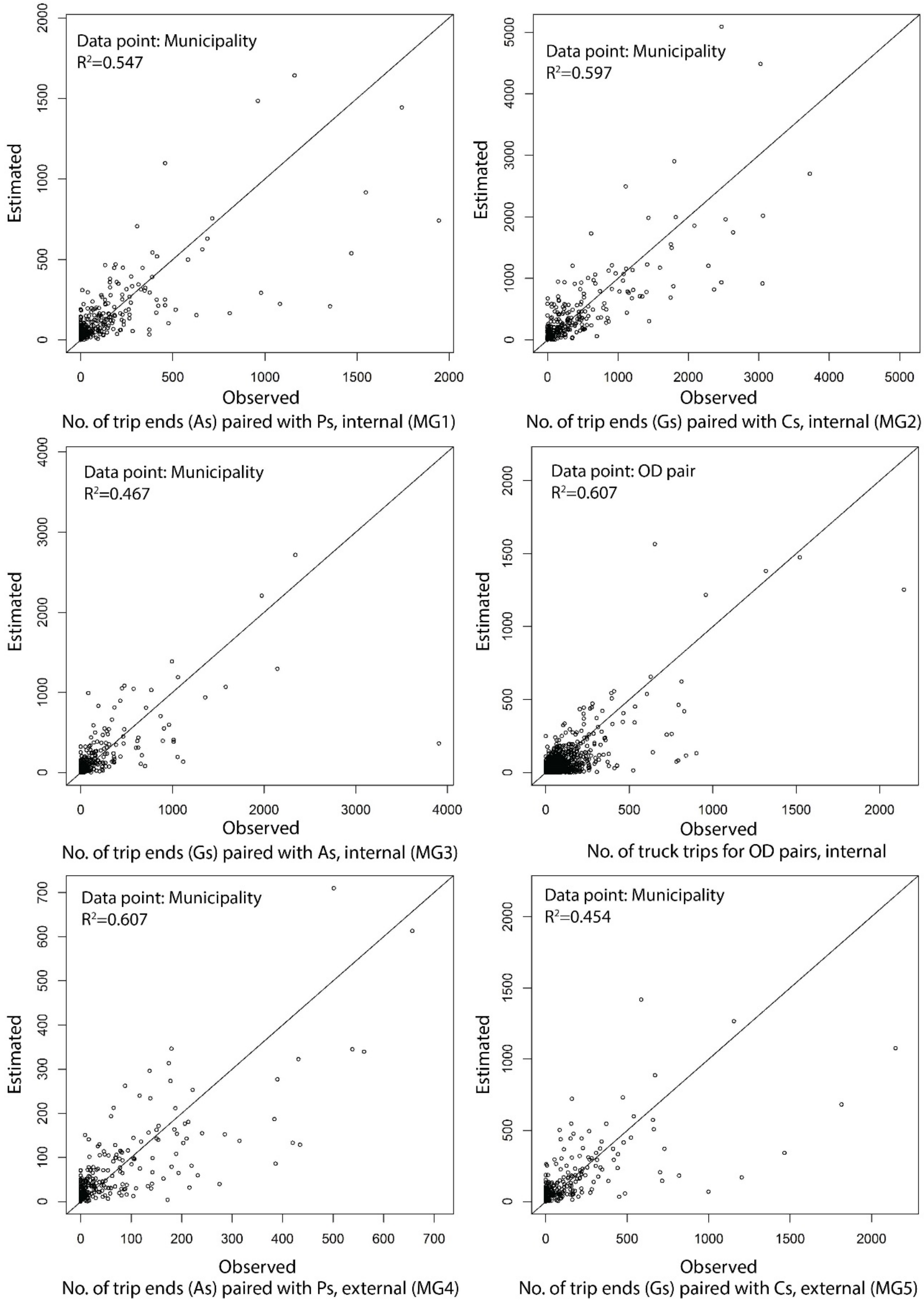


Figure 15: Reproducibility for number of trip ends and truck trips

7 SIMULATIONS FOR SPATIAL DISTRIBUTION PATTERNS

7.1 Scope

The analysis discussed in Chapter 5 provided some useful insights into the spatial distribution of logistics facilities in relation to the shipment demands and transportation systems. While the analysis revealed that outward migration of logistics facilities is not always detrimental in terms of reducing negative externality, it did not provide the broad and coherent principles that can guide long-term land use planning to reduce truck travel and maximize shipment efficiency. In other words, Chapter 5 helped me understand "what happened" but not "what should be done". To this end, using the ULLTRA-SIM discussed in Chapter 6 as well as the 2013 TMFS data, this chapter carries out a series of simulations to derive high-level insights into how the logistics facilities should be distributed in a metropolitan area to reduce negative impacts of truck traffic.

Unlike the evaluations of logistics facilities assuming the optimized shipping behavior, which is common in the field of operations research (OR), the simulations in this chapter take into account the inherent randomness in the logistics facility location choices and urban logistics chain formulations. In reality, a logistics facility does not necessarily serve the nearest (or least cost) shipment demand. The match-up between a logistics facility and a shipment demand depends on the unique context such as the relation between the facility owner and the shipper, available capacity, and the fit with the downstream and upstream operations within the logistics chain. Therefore, for comprehensively evaluating the spatial pattern of thousands of logistics facilities with different characteristics, the models that assume complete rationality of operators (such as operation research models) are not appropriate. To the extent of my knowledge, the only existing attempt to evaluate the impacts of logistics facility locations using random utility modelling framework is Davydenko et al. (2013), though their model is a national scale model as discussed in Section 2.4.

The work presented in this chapter is the first attempt to evaluate the spatial distribution pattern of logistics facilities in a comprehensive manner using the urban and transportation simulation model applying the random utility framework. I believe that, in the situation that socially desirable design of freight transportation system is far from being elucidated, the present study provides useful information for the policy makers and planners.

7.2 Approach

The estimated models (LFLCM and LCM) described in Section 6.3 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. Also, the shipment demands, i.e. the locations and quantities of Ps and Cs, their commodity types, and the sizes of vehicles to handle them, are taken from the 2013 TMFS. It is important to note that the analysis only considers the shipments that involve at least one transshipment at a logistics facility, and all the results need to be interpreted as such. According to the 2013 TMFS, 55% of the total shipments are direct shipments (i.e. the shipment between non-logistics facilities).

A total of 19,423 logistics facilities (small (≤ 400 m^2): 5,862, medium (400 – 3000 m^2): 7,926, large (> 3000 m^2): 5,635) and the associated shipment demands at non-logistics facility locations (439,786 trips) are considered in the simulations. The detail of the shipment demands locations is shown in TABLE XV.

For the simulations, the following two assumptions are made for demand locations:

- Each demand (trip end, P or C) has a specified size of vehicle in addition to the commodity type information. This implies that the size of vehicle depends on the locational characteristics of the demand (e.g. residential neighborhood) and the demand itself (e.g. size, package, commodity type, etc.). As for Attractions (A), the vehicle size is not considered in the LCM but considered in the TFIS using the constant shares between two vehicle sizes: small (load capacity ≤ 2 ton, 43.6%) and large (load capacity > 2 ton, 56.4%). This is necessary to calculate the emissions associated with truck trips.

- The size of the logistics facility (i.e. small, medium, or large) that serves a specific demand (trip end, P or C) is fixed. This means, for example, a large facility cannot replace a small facility for serving the demand (trip end) for which small facilities are assigned. As a result, the shipment demands handled by each facility size group remain same with the survey data.

Figure 16 shows the distribution of the trip ends (Ps and Cs) in the TMA used for the simulation. Despite the strong monocentric structure of population and establishments, the shipment demands are not simply concentrated in the area around the urban center and the ports (the east side of Tokyo Bay). Although the urban center and the port areas 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 in general (as discussed in the Chapter 5).

TABLE XV

BREAKDOWN OF DEMANDS (TRUCK TRIPS) BY TRIP END TYPE, VEHICLE SIZE, AND FACILITY SIZE

Trip End Type	Vehicle Size (Load Capacity)	Size of the logistics facility that serves Small	Medium	Large	All
Production (internal)	≤ 2 tons	4,169	8,378	7,721	20,268
	> 2 tons	18,590	26,207	36,357	81,154
Consumption (internal)	≤ 2 tons	27,424	32,287	19,964	79,675
	> 2 tons	26,874	46,844	85,459	159,177
Production (external)	≤ 2 tons	1,444	3,880	5,923	11,247
	> 2 tons	3,611	9,705	14,812	28,128
Consumption (external)	≤ 2 tons	2,517	5,862	8,798	17,177
	> 2 tons	6,295	14,660	22,005	42,960
	All	90,924	147,823	201,039	439,786

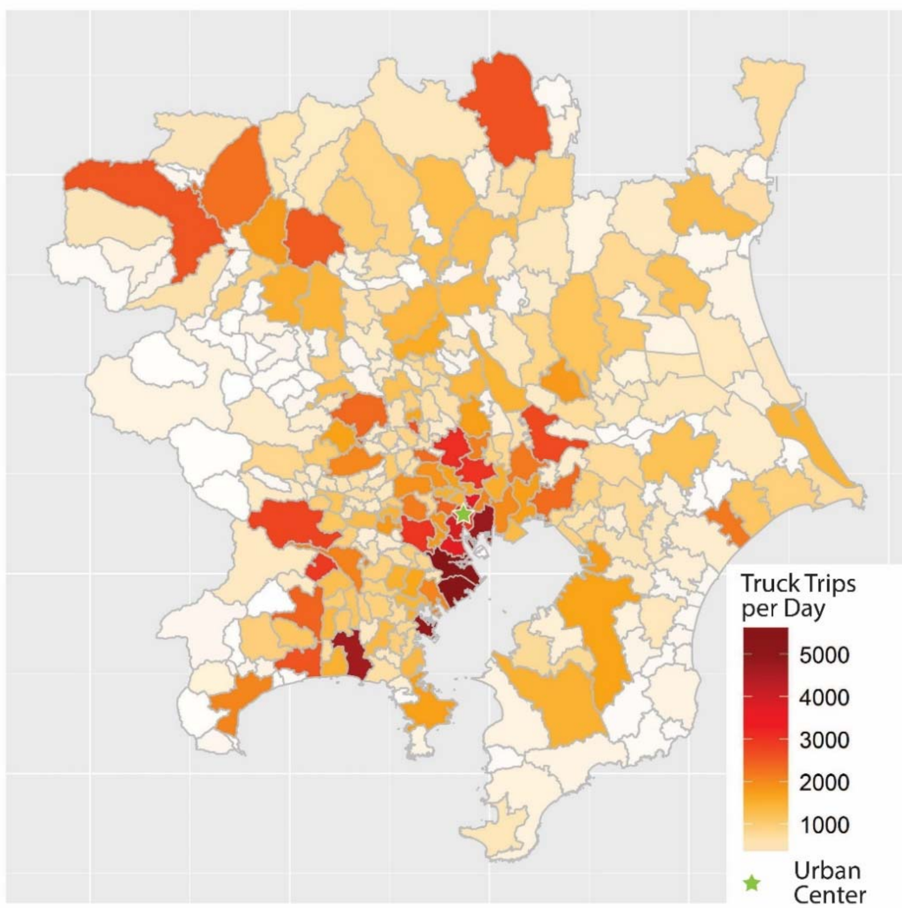


Figure 16: Distribution of productions and consumptions

I simulate several different spatial distributions (i.e. scenarios) of logistics facilities by manipulating the LFLCM model parameters and/or estimated probabilities. In the LFLCM, "average shipment distance" is included as independent variables in two ways: with and without log-transformation. At this stage, 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 a logistics facility changes its location, then, the logistics chains should be restructured based on its new location. The simulation is repeated 20 times for each scenario to check the effects of random components in the LFLCM and the LCM (i.e. standard deviations (SD) of the results).

7.3 Spatial Structure Scenarios

The simulation process starts from generating the spatial distribution of logistics facilities. Before choosing the scenarios discussed in this Chapter, I ran tens of scenarios and checked the sensitivity of the simulation model. This exercise was very useful for understanding the behavior of the model, especially the interactions among the components. The six scenarios presented below were selected as they are the most illustrative of the relation between the spatial distribution of logistics facilities and externalities. While the simulation was run 20 times for each scenario, the spatial distributions of the logistics facilities for a particular scenario did not differ much, meaning that the effects of unobserved random factors that are not considered in the LFLCM are limited. The description of each scenario is provided below and the examples of the spatial distributions for the scenarios are shown in Figure 17.

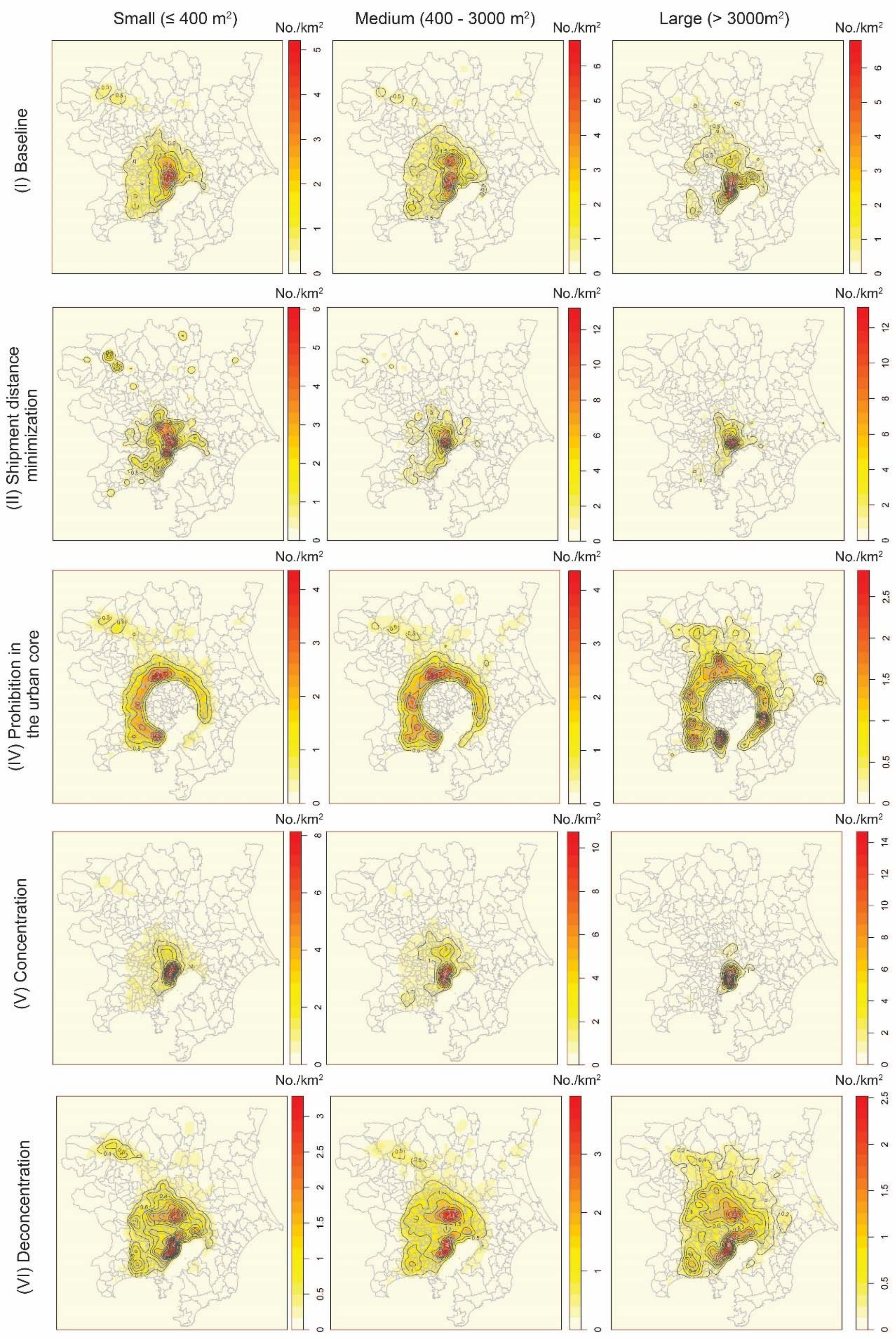


Figure 17: Spatial distribution of logistics facilities

First, I compare the “baseline” and “shipment distance minimization” scenarios. The results of the simulations of the two scenarios provide the maximum level of reduction in the externalities achievable through the spatial distribution of the logistics facilities. Then, four additional scenarios, each representing a specific concept for the spatial distribution of the logistics facilities, are simulated.

(I) Baseline: This scenario provides the spatial distribution of logistics facilities observed in the 2013 TMFS (Figure 16) replicated, as best as can be, by the ULLTRA-SIM. No manipulation of model parameters or the estimated probabilities is performed in the LFLCM for the purpose of achieving a specific distribution. The means (and the 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: Under this scenario, 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.

Following two scenarios are simulated to check the level of externalities in the extreme cases that strictly control the logistics facility locations.

(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.

(IV) Prohibition on logistics facility development in the urban core: In this scenario, no logistics facilities are allowed within 30 km from the urban center. 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.

Lastly, I test two additional scenarios that are more moderate than the previous two scenarios. They will provide the insights on the impacts of deconcentration and concentration.

(V) Concentration: The choice probabilities of the LFLCM are manipulated to create a highly concentrated distribution of logistics facilities in the port areas around the Port of Tokyo, which are close to the urban center. The probabilities of the locations in those port areas are quintupled. The means (and the standard deviations (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: In this scenario, the logistics facilities are forced to deconcentrate relative to the actual situation in the TMA. Three changes are imposed in the LFLCM model parameters and the estimated probabilities: (1) the effect of industrial zone is removed; (2) the coefficients for the population density for the LFLCMs for small and medium facilities are adjusted to be the same as the value for large facilities; and (3) the choice probabilities for the locations that are in the highest 0.5 % of employment accessibility are changed to zero. Firstly, removing the effect of industrial zone, that is mostly concentrated in the port areas, leads to 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 that are concentrated near the urban center. Thirdly, the prohibition of choosing the highest employment accessibility locations lessen the attractiveness of the urban center for placing logistics facilities, which would be very high without the intervention.

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.

7.4 Results of the Simulations

The LCM and TFIS were run for the generated distribution patterns and the indicators of externalities are estimated as shown in Table XVI. This section summarizes the results of the simulations.

The Scenario II archives a significant mitigation of negative externalities compared with the Baseline. The simulation result indicates that when the logistics facilities are positioned at the locations that minimize the aggregate shipment distances, various measures of externalities are reduced by approximately 12% compared with the Baseline scenario. The spatial distribution of the Scenario II indicates that, for large facilities, the locations that minimize the shipment distance are concentrated in the urban center (as they serve relatively large areas and the urban center is highly accessible to the demands), while small facilities are dispersed (as their service areas are small).

The two extreme scenarios, the scenarios III and IV, indicate both the perfect concentration of logistics facilities at the urban center and the restriction on the logistics facilities near the urban center accompany the higher level of externalities than the baseline (excluding CO under the 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. The measures of externalities are much higher under the Scenario IV; traffic and emissions are about 10 % more than those of the baseline. The displacement of the logistics facilities near the urban center occurs in some cities, due to either the combination of the increase of land price and the scarcity of available lands, or public policies. This result, on the other hand, underscores the importance of the presence of logistics facilities near the urban center although an excess concentration there would be detrimental.

The levels of externalities in Scenario V and Scenario VI are not significantly different from those of the Scenario I (Baseline). The differences are about -1 % for Scenario V and about +2 % for Scenario VI. Despite the significant differences between these two scenarios in terms of the spatial distribution of logistics facilities, the logistics chains are adapting in the manner that maintains the similar levels of VKT and/or VHT with the baseline. While the logistics facilities are dispersed under Scenario VI, a number of logistics facilities choose to locate near the urban center, serving a large amount of shipment demands. That means, under Scenario VI, some logistics facilities must achieve higher throughput per floor area than the actual situation so that all the shipments are delivered. The result indicates that the process of logistics chain formulations would alleviate the effects of the spatial patterns on the externalities. If a policy allows no logistics facilities in some area where the demand exists, such adaption of logistics chains to buffer the impacts would disappear as seen in Scenario IV.

Also, while the spatial pattern of Scenario V is similar to that of Scenario II, the latter entails much less externalities. The large gaps in the levels of externalities between Scenario V and Scenario II underlines the potential of a finely tuned policy for logistics land use. Specifically, the Smart City approach should be pursued in the area of logistics land use; with such approach, the logistics facility operation would be guided by pricing and/or incentive policies tuned based on the shipment demand information. Simply promoting the concentration or deconcentration may not lead to the mitigation of externalities to a significant extent.

It should be noted that the applied approach simplifies the complex mechanism of logistics operation. For example, while the floor areas of logistics facilities are considered in the LCM, some facilities handle more shipments than they do in 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, that need to be considered in the real world are ignored in the LCM. While I 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 XVI

INDICATORS OF EXTERNALITIES (PER DAY; SPATIAL STRUCTURE)

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

7.5 Summary

In this chapter, I evaluated the spatial distribution patterns of logistics facilities at the metropolitan scale using the ULLTRA-SIM. This chapter provides valuable insights on the effect of the spatial distribution of logistics facilities on the externalities. The key findings and insights are as follows.

- The analysis shows relatively small effects of the concentration and deconcentration of logistics facilities on negative externalities. This suggests that using a simple measure, e.g. distance from the urban center, to evaluate the efficiency of spatial distribution of logistics facility is not effective. Simply preventing logistic facilities from migrating outward is not likely to generate much benefit in terms of reducing truck travel and various externalities.
- The prohibition of logistics land use in high demand area would lead to the significant increase in negative externalities. I 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, then, the negative externalities would be enhanced.
- The analysis highlights the potential advantage of "smart" policy approach that takes the shipment demand information into account for logistics land use management, compared with traditional approaches that simply designates the areas dedicated to logistics activities or that restricts the development in so-called "greenbelt" or a busy urban district.

8 POLICY SIMULATION

8.1 Scope

Chapter 7 discussed the relationship between the spatial distribution of logistics facilities and the level of the externality indicators. The analysis assumed that the spatial distribution of the logistics facilities can be shaped to perfectly reflect the concept under each scenario. The analysis provided valuable insights into how to distribute logistics facilities to reduce externalities. However, it is not a simple or easy task to actually achieve such distribution using policy tools. Taking the study discussed in Chapter 7 forward, in this chapter, I conduct another series of simulations to evaluate the effectiveness of several policy measures on the spatial distribution of logistics facilities and the externalities. The policy measures considered in this chapter include land use regulations (zoning), the promotion of clustering (such as freight village), and the distance-based pricing. The analysis using the ULLTRA-SIM enables the assessment of the degree of changes in the spatial distribution of logistics facilities and the decrease/increase in the negative externalities that are brought on by different policy measures.

8.2 Approach

Like Chapter 7, the estimated models shown in Section 6.3 are used. While the analysis described in Chapter 7 included all existing logistics facilities regardless of the year of establishment, in this analysis, only those established in 2003 or after are considered in the location choice (LFLCM). The facilities established earlier than 2003 are assumed to be in the actual locations that are obtained from the 2013 TMFS, although they are considered in the logistics chain formation (LCM). This approach analyzes the policies and their effects based on retrospective "what if" simulations. The simulations assume that each policy was implemented in the year of 2003 and continued until 2013. The results are then compared against the do-nothing case (i.e. baseline) for the year 2013.

Except for the above-mentioned focus on the logistics facilities that are established in 2003 or later, the same data set, the assumptions, and the simulation approach discussed in Chapter 7 are used. The logistics facility information (floor area, commodity handled, and the associated demand locations) and the shipment demand data (types of trip ends, their locations, commodity types, and handling vehicle sizes) are taken from the 2013 TMFS. Again, the analysis considers only the shipments that involve at least one transshipment at a logistics facility.

8.3 Policy Scenarios

As mentioned earlier, three groups of policies are considered. Here I call the baseline scenario as “Scenario A”, for which no policy inputs are considered. The results of the simulations for this scenario are nearly identical with those of the baseline scenario (Scenario I) in Chapter 7. The minor variations from Scenario I are due to the stochasticity of the simulation as well as the use of different location choice models (i.e. LFLCM). Alternative scenarios are explained below. The policies selected in this chapter are intentionally extreme, and therefore, not necessarily realistic. This is because the goal of the analysis is to highlight the sensitivity of the negative externalities to the policies for obtaining the insights on the general policy direction that should be followed, rather than finding the detailed policy designs for actual implementation. In addition, analyzing extreme policy options will demonstrate the limits of those policies’ effects on the negative externalities.

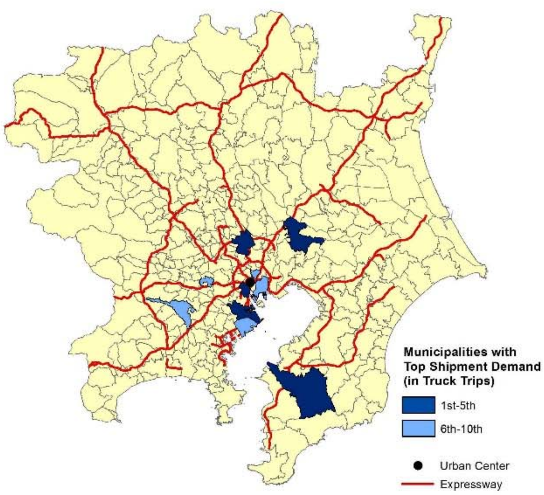
Zoning policy

The estimated LFLCM for the facilities established in 2003 or after (TABLE VIII) indicates that “quasi-industrial zone” (QIZ) is the only zoning category that is statistically significant for all facility size groups; QIZ is, in fact, the most common zoning category for logistics facility locations. This observation led to the development of policies that alter the locations and also the total area designated as QIZ. The scenarios represent zoning strategies that make it easier for logistics facilities to locate closer to their shipment locations by converting residential zones, where logistics facilities are prohibited, into QIZs. The descriptions of the scenarios are as follows;

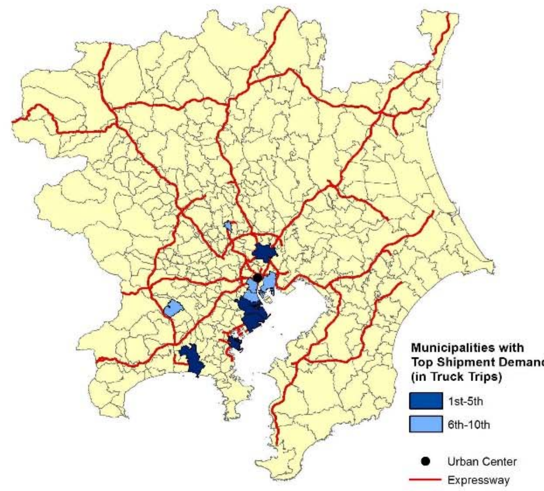
Scenario B (expansion of QIZs at top 5 municipalities): For the municipalities that are in the top five in the sum of shipment locations (in truck trips), all the residential zones are converted to QIZ. This was done separately for each logistics facility size group (small (≤ 400 m^2), medium (400 – 3000 m^2) or large (> 3000 m^2). The zoning conversions applied are different across the facility size group because the distributions of demand locations differ based on facility size group.

Scenario C (expansion of QIZs at top 10 municipalities): This scenario is the same as Scenario B except that in this scenario, top ten municipalities, instead of five, are targeted for conversion, entailing even larger increase in QIZs.

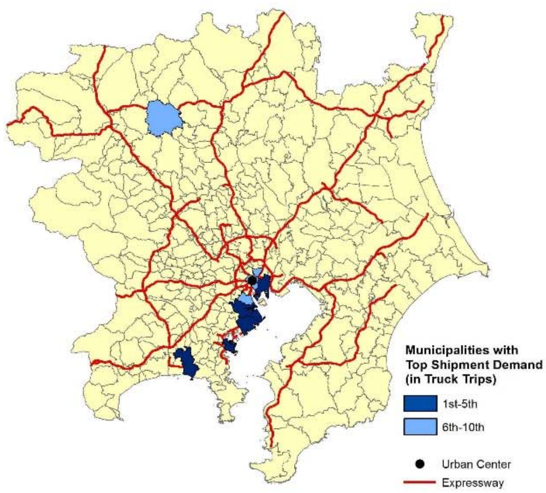
The locations of top shipment demand municipalities are shown in Figure 18 and the changes in the total area of QIZ are shown in TABLE XVll.



Small logistics facilities



Medium logistics facilities



Large logistics facilities

Figure 18: Municipalities with top shipment demand volumes by logistics facility size

TABLE XVII

CHANGES IN THE AREA OF QUASI-INDUSTRIAL ZONES UNDER ZONING POLICY SCENARIOS

	Area of quasi-industrial zone (QIZ) (km^2)		
Logistics facility size group	Baseline	Scn. B: Increase in QIZ in top 5 municipalities	Scn. C: Increase in QIZ in top 10 municipalities
Small (≤ 400 m^2)	413.6	526.8 (+ 27.4%)	599.1 (+ 35.2%)
Medium (400 – 3000 m^2)	413.6	507.3 (+ 22.7%)	553.4 (+ 27.6%)
Large (> 3000 m^2)	413.6	485.4 (+17.4%)	522.8 (+ 22.5%)

Note: The differences with the baseline are shown in the parentheses.

Clustering policy

The next two scenarios reflect more typical industrial corridor development strategies that strive to concentrate logistics facilities in specified areas that typically offer good transportation access and are buffered from residential developments. The following two scenarios are designed to further encourage the logistics facilities to locate in the areas that have been the historical home (the port areas) or are the newly developed industrial corridor (Ring Road 3). For the simulation of these scenarios, the choice probabilities (or the share) for the siting of logistics facilities are increased for those areas.

Scenario D (clustering in port area): The probabilities for the port areas (the West part of Tokyo Bay only) are tripled. (See Figure 19 for the area.)

Scenario E (clustering along RR3): The probabilities for the areas along the Southwest section of Ring Road 3 are tripled. (See Figure 19 for the area.)

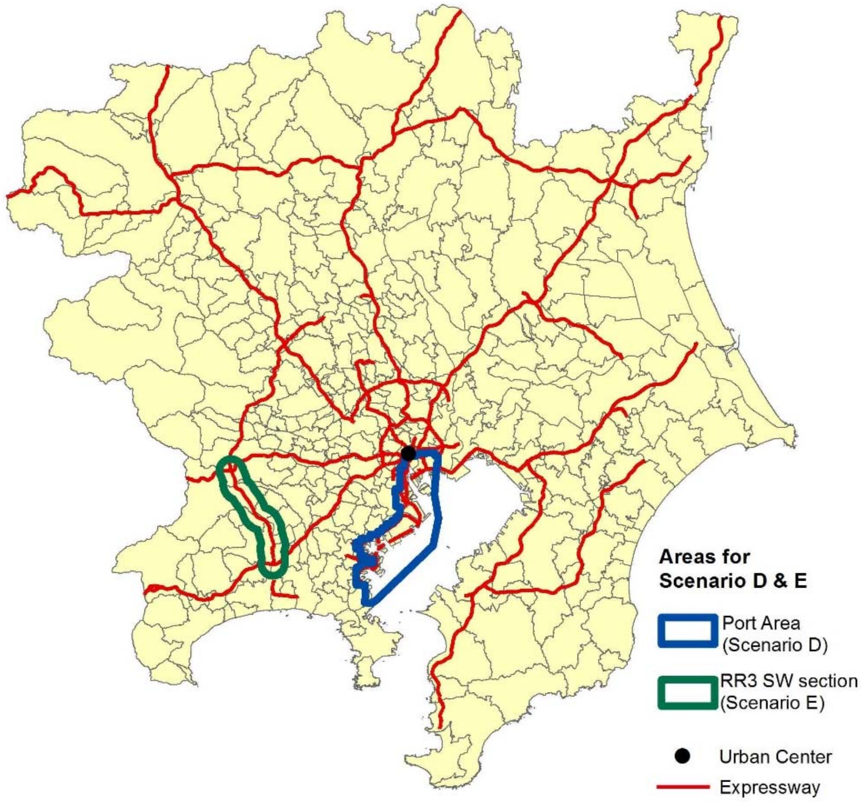


Figure 19: Areas for clustering policy scenarios

Distance-based pricing policy

Scenarios F and G examine the effects of distance-based pricing. There are two reasons that this line of policy would be effective: 1) the effects of shipment distance on location choice and logistics chain formulation are strong, even dominant in some cases, and 2) higher shipment costs would automatically encourage the decisions that reduce shipment distances rather than engaging in a complex land use control that directly dictates their locations.

The distance-based pricing policy is simulated by adjusting the shipment distances used by the ULLTRA-SIM. For example, the effect of increasing the transportation cost by 30% is replicated by inflating all shipment distances used in the simulation by 30%. The level of the distance-based pricing is, thus, defined as the percentage increase relative to the baseline.[14]

To distinguish the effects of the distance-based pricing on logistics facility locations and the logistics chain formulations, two types of simulations are implemented: firstly, the effect of pricing is considered only for the location choice (i.e. LFLCM) but not in the logistics chain formulation (i.e. LCM); secondly, the effect of pricing is taken into account in both LFLCM and LCM. It is important to note that in the LFLCM, only the facilities established in 2003 or later (22 % of the total) are considered, while in the LCM, all the facilities and the shipments associated with them are included in the simulation. The distance-based pricing scenarios are defined as follows.

Scenario F (increase in transportation cost by 30%): Transportation costs are set higher than the actual transportation costs by 30 %. In the Scenario F-1, the change in the transportation costs is applied only for the simulation by the LFLCM. In the Scenario F-2, the change is applied for the simulations by both the LFLCM and LCM.

Scenario G (increase in transportation cost by 50%): A larger increase, 50% higher than the

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[14] The increase in all network distances by a percentage does make little or no effect on the relative utility of an alternative (i.e. a location or a logistics facility) through the log-transformed variables of distance, simply due to the model structure and, therefore, such effect is not considered.

actual, in transportation costs is assumed. In the Scenario G-1, the increase in cost is considered only on the simulation by the LFLCM. In the Scenario G-2, the increase is applied for the simulations by both LFLCM and LCM.

8.4 Results of the Simulations

The changes in the distance from the urban center of the facilities established in 2003 or after as well as all facilities under the scenarios are shown in TABLE XVIII. The estimated externality indicators are shown in TABLE XIX.

First of all, the magnitudes of the policy effects on the externalities are small compared with the scale of the overall externalities, except for F-2 and G-2 in which the substantial increase in the transportation cost directly affects the logistics chain formulations. This is because, as discussed in Chapter 7, the change in the spatial distribution of logistics facilities affects externalities through the logistics chain formulations, which buffers the effect of the spatial distribution on traffic to some extent.

The results of the two zoning policy scenarios, Scenario B and C, indicate that the effectiveness of zoning policies on the spatial structure of logistics facilities and the externalities associated with indirect shipments are limited, at least in the TMA. Even though the tested policies are rather extreme, the changes in the distance from the urban center are less than 1 % for the facilities established in 2003 or after. The improvements on the externality indicators are in the range of 0% to 0.07% for Scenario B and 0.13% to 0.17% for Scenario C.

The result of Scenario D, the clustering in the port area, corresponds to that of the Scenario V in Chapter 7; a stronger concentration of logistics facilities around the port area (near the urban center) is desirable, if the land is available. The policy leads to 0.14% – 0.20% decrease in negative externalities.

On the other hand, the clustering in the suburbs, Scenario E that assume a cluster along the

Southwest section of the Ring Road 3, indicates that such clustering encourages the decentralization of the logistics facilities, which results in slight increases in the level of negative externalities. Under the Scenario E, the changes in the externalities are in the range of 0% to +0.06%.

The results for Scenario F-1 and Scenario G-1 underline the relatively strong effects of the distance-based pricing on the distances from the urban center for the logistics facilities established in 2003 or after, especially for the large logistics facilities (-5.22% under the Scenario F and -7.13% under the Scenario G). As for the efficiency of the logistics facility locations, the negative externality indicators are reduced by 0.13% - 0.27% and 0.20% - 0.33% under Scenario F-1 and Scenario G-1, respectively.

The results also suggest that the increase in transportation cost would lead to a significant decrease in the externalities when the effects on the logistics chain formation are taken into account. Scenario F-2 (30% increase in transportation cost) and G-2 (50% increase in transportation cost) lead to decreases in the externality indicators by about 4.5% and 7.5%, respectively. As mentioned in Chapter 6, the pairing between P and C (that is not handled explicitly) could change under the framework of the LCM. The higher transportation cost leads to the shorter distances between Ps and Cs, as a whole. In the short-term, however, a P for a specific C may not be able to be replaced with another P as flexibly as the model assumes. In such case, the results of those two scenarios (F-2 and G-2), which entail the dramatic reorganization of P-C flows, might be over-estimated to some extent. The results, however, suggest the more promising effects of streamlining the logistics chains, than the policies to change the spatial structure of logistics facilities in the TMA.

TABLE XVIII

CHANGES IN THE DISTANCE FROM THE URBAN CENTER

	Established in 2003 or after						All		
	Distance from the urban center (km) Mean			Standard deviation			Distance from the urban center (km) Mean		
	Small (≤ 400 m^2)	Medium (400-3000 m^2)	Large (3000 m^2 <)	Small (≤ 400 m^2)	Medium (400-3000 m^2)	Large (3000 m^2 <)	Small (≤ 400 m^2)	Medium (400-3000 m^2)	Large (3000 m^2 <)
Scn. A: Base line	35.64	36.73	38.66	0.24	0.26	0.41	39.52	39.90	39.22
Scn. B: Expansion of QIZs at top 5 municipalities	35.59 (-0.13%)	36.66 (-0.20%)	38.37 (-0.75%)	0.29	0.24	0.33	39.51 (-0.03%)	39.89 (-0.04%)	39.16 (-0.16%)
Scn. C: Expansion of QIZs at top 10 municipalities	35.57 (-0.21%)	36.44 (-0.80%)	38.32 (-0.88%)	0.24	0.29	0.45	39.50 (-0.04%)	39.84 (-0.15%)	39.15 (-0.19%)
Scn. D: Clustering in port area	34.87 (-2.17%)	35.97 (-2.07%)	36.24 (-6.25%)	0.19	0.25	0.49	39.34 (-0.45%)	39.75 (-0.39%)	38.69 (-1.36%)
Scn. E: Clustering along RR3	35.86 (+0.63%)	37.17 (+1.20%)	39.24 (+1.51%)	0.32	0.21	0.53	39.57 (0.13%)	39.99 (0.22%)	39.35 (0.33%)
Scn. F: Increase in transportation cost by 30%	35.04 (-1.68%)	35.79 (-2.58%)	36.64 (-5.22%)	0.17	0.26	0.36	39.38 (-0.35%)	39.71 (-0.48%)	38.78 (-1.13%)
Scn. G: Increase in transportation cost by 50%	34.97 (-1.88%)	35.35 (-3.77%)	35.90 (-7.13%)	0.18	0.24	0.37	39.37 (-0.39%)	39.62 (-0.70%)	38.61 (-1.55%)

TABLE XIX

INDICATORS OF EXTERNALITIES (PER DAY; POLICY SCENARIOS)

		VKT [mil. km]	VHT [thou. hr]	Fuel [mil. l]	CO_2 [thou. ton]	NOx [ton]	SPM [ton]	CO [ton]	SO_2 [ton]
Scn. A: Baseline	Mean	27.1	563.0	6.19	16.4	34.4	0.350	41.4	0.508
	SD	0.025	0.55	0.0061	0.016	0.037	0.00034	0.038	0.00050
Scn. B:	Mean	27.1	562.6	6.19	16.4	34.4	0.350	41.4	0.508
Expansion of QIZs at top 5	SD	0.022	0.37	0.0052	0.014	0.032	0.00027	0.035	0.00043
municipalities	Diff. from (Baseline)	-0.04%	-0.07%	-0.04%	-0.04%	-0.04%	-0.04%	0.00%	-0.04%
Scn. C.	Mean	27.1	562.1	6.19	16.4	34.3	0.349	41.4	0.507
Expansion of QIZs at top 10	SD	0.024	0.56	0.0060	0.016	0.037	0.00034	0.045	0.00049
municipalities	Diff. from (Baseline)	-0.14%	-0.17%	-0.14%	-0.14%	-0.13%	-0.14%	-0.13%	-0.14%
Scn. D:	Mean	27.1	562.2	6.18	16.4	34.3	0.349	41.4	0.507
Clustering in port area	SD	0.024	0.43	0.0051	0.014	0.031	0.00028	0.059	0.00042
	Diff. from (Baseline)	-0.20%	-0.15%	-0.16%	-0.16%	-0.14%	-0.14%	-0.18%	-0.16%
Scn. E:	Mean	27.1	563.1	6.20	16.5	34.4	0.350	41.4	0.508
Clustering along RR3	SD	0.023	0.40	0.0052	0.014	0.030	0.00028	0.055	0.00043
	Diff. from (Baseline)	0.04%	0.01%	0.05%	0.05%	0.06%	0.04%	0.00%	0.05%
Scn. F-1	Mean	27.1	562.1	6.18	16.4	34.3	0.349	41.3	0.507
Increase in transportation cost by 30%	SD	0.028	0.53	0.0066	0.018	0.040	0.00038	0.060	0.00054
(effective only on LFLCM)	Diff. from (Baseline)	-0.17%	-0.16%	-0.15%	-0.15%	-0.13%	-0.15%	-0.27%	-0.15%
Scn. F-2	Mean	25.8	538.3	5.90	15.7	32.8	0.334	39.4	0.484
Increase in transportation cost by 30%	SD	0.024	0.45	0.0058	0.016	0.036	0.00033	0.042	0.00048
	Diff. from (Baseline)	-4.98%	-4.39%	-4.69%	-4.68%	-4.51%	-4.56%	-4.98%	-4.69%
Scn. G-1	Mean	27.1	561.9	6.18	16.4	34.3	0.349	41.3	0.507
Increase in transportation cost by 50%	SD	0.025	0.49	0.0063	0.017	0.039	0.00034	0.037	0.00052
(effective only on LFLCM)	Diff. from (Baseline)	-0.23%	-0.20%	-0.22%	-0.22%	-0.22%	-0.23%	-0.33%	-0.22%
Scn. G-2	Mean	25.0	523.6	5.74	15.2	31.9	0.325	38.2	0.471
Increase in transportation cost by 50%	SD	0.024	0.52	0.0055	0.015	0.032	0.00031	0.043	0.00045
	Diff. from (Baseline)	-7.84%	-7.00%	-7.39%	-7.38%	-7.11%	-7.20%	-7.81%	-7.39%

8.5 Summary

In this chapter, I evaluated the impacts of various policy measures including zoning, the clustering of logistics facilities, and the distance-based pricing on logistics land use and negative externalities associated with indirect shipments. The main findings and insights are summarized below.

- None of the policies tested, including ones that can be considered extreme, produces massive effects in externalities through the changes in the locations of the logistics facilities. The significant increase in the concentration of the newly established logistics facilities in the port areas (i.e. tripling the probability for locating logistics facilities in the designated port area in the West side of the Tokyo Bay) reduces the average distance from the urban center for all logistics facilities by 0.69%, but decreases the VKT and VHT only by 0.20% and 0.15%, respectively. The increase in transportation cost by 50% reduces the average distance from the urban center for all logistics facilities by 0.85%, but decreases the VKT and VHT only by 0.23% and 0.20%, respectively, when only the effects of the location changes (but not the effects on the logistics chains) are considered.
- The effects of the distance-based pricing on externalities through the logistics chain formulations are likely to be much larger than that through the restructuring of the logistics facility locations by the tested policies. The strong effect of the distance-based pricing through the logistics chain is not only due to the modelling framework that allows the flexible pairing between P and C but also because the pricing on the shipments directly affects all the logistics chains, while the policy guiding the logistics facility locations affects only the facilities recently (2003 or after) established.

The results of the simulations seemingly imply what is naturally expected; the benefits of the policy measures for logistics facility locations would be small, especially when the capacity constraints of the existing logistics facilities (e.g. lack of facilities in appropriate locations), which hamper the intended efficiency improvement of the logistics chains, do not exist. Policies aiming to reduce the externalities associated with urban truck trips should focus on the streamlining of the logistics chains for efficient operations. At the same time, the logistics facility distribution should be guided so that the availability of the logistics facilities does not constrain such streamlining. Land use regulations that aim to guide the locations of logistics facilities are likely to be detrimental in terms of the efforts to reduce the externalities associated with urban trucking. The distance-based pricing strategies, on the other hand, encourage both the logistics facilities and logistics chains to self-organize in an efficient manner that reduces externalities. Of course, the cost to the shippers and carriers (and ultimately the consumers) would present a major hurdle for the pricing strategies.

9 SUMMARY OF CONTRIBUTIONS AND FUTURE WORK

9.1 Responses to the Research Questions

This research unveiled the details of the complex relationships among urban structure, shipment demand locations, the spatial distribution of logistics facilities, and traffic impacts that the existing literature do not address. The research also estimated the levels of reductions in externality that are achievable through the restructuring of the spatial distribution of the logistics facilities as well as various policy measures. Furthermore, the simulation framework developed for the indirect shipments addresses the missing components of urban freight model in the existing literature. As a whole, this research covers a wide range of subjects relevant to the discourse on the role of planning in urban freight, especially those associated with the spatial distribution of logistics facilities, an active research agenda in the transportation field.

In Chapter 3, a set of research questions were presented. The findings presented in each chapter (Chapter 5 through Chapter 8) are summarized below as responses to each of the research questions.

Research Question I: Does the outward migration of logistics facilities increase the negative externalities associated with urban freight traffic?

The relationship between the outward migration of logistics facilities and the level of negative externalities is complex. The assertion that the outward migration increases the negative externalities is not always true and ignores the complex interactions among various components in an urban freight system.

As discussed in Chapter 5, while the TMA has experienced a significant outward migration of logistics facilities during the period 2003-2013, the increase in the average shipment distance was minor and the efficiency in terms of km per tons actually improved by 4%. There are various potential reasons for this but the following are the most important:

- The outward migration of logistics facilities in the TMA occurred in the way that moved them closer to the shipment demands that had went through a major outward migration of their own prior to 2003.
- Despite the significant outward migration, a number of logistics facilities still remain near the urban center and serve the shipment demand locations in the proximity very efficiently.
- The outward migration occurred mainly within 50 km from the urban center, which led to the emergence of several concentrations of logistics facilities along the Ring Road 2 and Ring Road 3. On the other hand, the development of the logistics facility in the exurb (or more than 50 km away from the urban center) was limited.
- The increase in the size of the logistics facilities likely led to the higher load per truck, which played a considerable role in the improvement in the shipment efficiency.

The analysis of efficiency shows that the logistics facilities in the exurbs (more than 50 km away from the urban center) are very inefficient in terms of truck-km-traveled per tons handled, meaning that the logistics sprawl that goes beyond the extent of urban sprawl would lead to a significant increase in negative externalities. In addition, the simulation analysis in Chapter 7 indicates that, if the choices of logistics facilities are severely limited in the places close to the areas with major shipment demands (either at the urban center or suburb), then, the negative externalities increase.

In summary, two patterns of logistics facility distribution, absence near the urban center and outward migration to the exurbs, would create more traffic (i.e. VKT and VHT) than before, and, as a result, significantly increase negative externalities. The former can be explained by the fact that the demands in the urban center are very difficult to serve efficiently from the facilities elsewhere. The latter is due to the tendency of the facilities in the exurbs to serve the demands that are located very far, sometimes in the opposite part of the TMA. On the other hand, though the positive correlation between the size of logistics facilities and the average load per truck is still hypothetical at this stage, it is possible that the outward migration of the logistics facilities led to an increase in facility size (due to the availability of large sites in less dense areas) and the larger load per truck.

Research Question II: What is the distribution of logistics facilities that minimizes negative externalities associated with urban freight traffic?

In Chapter 7, the simulation of Scenario II, “Shipment distance minimization”, indicates that a well-designed distribution of logistics facility can achieve roughly 12% lower level of negative externalities compared to the actual logistics facility distribution. Together with the outputs of other scenarios, I can conclude that the excessive concentration or deconcentration of logistics facilities is not recommended as a measure to reduce the levels of negative externalities. The results of the simulations indicate that the facilities that mainly serve the shipment demands within a small area should be located close to those demands, while the facilities that serve a large area can minimize the shipment distances by locating near the urban center. As a result, the desirable locations for the small logistics facilities are dispersed, while the larger facilities are concentrated around the urban center in the ideal distribution (See Figure 17: Scenario II – Shipment distance minimization). This is, however, under the assumption that the availability of sites is not a concern. Considering the limitation in available sites near the urban center, it is important to secure reasonable amount of spaces with adequate size for logistics facilities. In case of the TMA, the port area, specifically the west side of the Tokyo Bay that has historically been the industrial zones in the proximity of the urban center, plays a key role for maintaining the efficiency of the urban logistics system. Moreover, to limit the externalities caused by the urban freight traffic, the development of large logistics facilities in the exurbs should be controlled unless the delivery/pickup operations (i.e. vehicle tours) are designed to reduce the total truck travel distance.

Research Question III: How and to what degree can public policies affect the negative externalities associated with urban freight traffic through the spatial distribution of logistics facilities?

While the analyses in Chapter 7 indicate that the spatial distribution of logistics facilities affects the level of negative externalities, the simulations presented in Chapter 8 show that reducing negative externalities through public policy interventions are quite difficult especially when the policies do not affect the mechanism of logistics chain formulations directly. A significant rezoning of residential land use to quasi-industrial land use (QIZ) (i.e. Scenario C) only reduces the externalities by about 0.15%. Furthermore, the higher concentration of logistics facilities in the port area (i.e. Scenario D) reduces externalities by only 0.14% – 0.20%.

In comparison, the strategy that directly penalizes the longer trips works better. An increase in transportation cost by 50% leads to the more efficient logistics facility distributions with about 0.20% – 0.33% reduction in negative externalities. Moreover, when the effects on logistics chain formulations are taken into consideration, about 7% – 8% reduction in negative externalities was possible. The results suggest that, for reducing the negative externalities at the metropolitan scale, the policies should focus on motivating the streamlining of logistics chains (i.e. developing the P-C flow and selecting the logistics facility for transhipment to reduce truck travel distance) and, at the same time, ensuring that the existing urban logistics facility system does not hamper such streamlining to take place. It suggests that, for the policy development, it is crucial to grasp the needs and intentions of the operators for improving their shipment efficiency. Pricing that is designed to encourage the logistics operators to reorganize their operations for reducing externalities would be one of the promising approaches.

9.2 Limitations and Future Development

While, I believe, this research significantly progressed the previous discussions on the spatial distribution of logistics facilities and its implications, the research also has limitations. Although the ULLTRA-SIM is a data intensive model that allows me to examine the spatial distribution of logistics facilities at the level of detail that has not been achieved in the previous studies, the model simplifies the extensively complex urban freight system; some level of simplicity in model specifications is required to reduce the computation cost. On the other hand, as the analyses outlined in this research show, details matter. There is a dire need for the advanced analytical tools that can facilitate accurate assessment of alternative policies and approaches to achieve socially desirable logistics systems. Specifically, the following points regarding to the ULLTRA-SIM should be addressed in the future research:

- The sizes of the logistics facilities are fixed in the LFLCM, although, in reality, there should be cases that the location and facility size are determined simultaneously. Also, in the LCM, the unit of shipment demands are truck trip, which makes it impossible to analyze the shipment size (load per truck). These arrangements were needed to maintain the reasonable level of simplicity for estimating the models and applying them for simulations. On the other hand, the ULLTRA-SIM cannot replicate the trade-off between facility size and location that the planning for logistics facility development may face, and also cannot address the relationship among the logistics facility size, load per truck, and truck trips. As the analysis in Chapter 5 revealed, the outward migration of logistics facilities might lead to the increase in logistics facility size and load size, which in turn contribute to the reduction in truck trips. This mechanism for efficiency improvement is worth being studied in the future, and, if possible, should be incorporated in the simulation model.

- The LCM is the shipment-based model and does not consider vehicle routing that serves demand locations at more than one municipality. The estimated traffic might be overestimated or underestimated, depending on actual tour characteristics. In case the vehicle routing decision interacts with the locations of logistics facilities, the consideration of such routing becomes even more important for the analysis of the spatial distribution of logistics facilities.
- The LCM estimates shipments without explicitly estimating the P-C flows in advance. Such model specification is considered appropriate as the P-C flow data, which are extremely difficult to obtain from a survey, are not available. As a result, the effect of the selection of logistics facility for routing goods and that of the P-C restructuring cannot be isolated. On the other hand, the P-C restructuring is a long-term decision, while the facility selection is a short-term one. To isolate those two effects, the P-C flow data, if not the assumptions on the P-C flow development are introduced, are required.
- This research found that distance-based pricing is one of the effectual strategies to reduce the impacts of urban truck trips. The ULLTRA-SIM needs further modifications to evaluate more complex pricing mechanism, such as zone-based pricing, distance-based pricing with varying marginal prices, and tiered pricing by vehicle type (or load factor). Although, in this research, the ULLTRA-SIM was designed mainly for evaluating the policies focusing on logistics land use, there are other potential strategies that hold promise for reducing the negative externalities that urban freight generates, such as collaboration among different operators by sharing facilities and/or delivering goods jointly. More complex model specification is required for expanding the use of the ULLTRA-SIM.
- The LCM uses the municipalities as the base spatial unit. The estimated traffic

assignment by the TFIS is not fine enough to describe the truck traffic on local roads within each municipality. To address the negative externalities of freight vehicles that are operated within the high residential and/or business density districts, which is often the interest of city logistics research, a micro-level analysis, which is not covered in this research, is required.

- Ultimately, the ULLTRA-SIM is desirable to be redesigned to be a component of an urban model that considers population, jobs, and passenger and freight traffic (both direct and indirect shipments) for evaluating urban freight impacts and urban freight policies that aim to reduce such impacts under a comprehensive framework.

9.3 Concluding Remark

Urban freight researchers and urban planners are increasingly concerned about the outward migrations of logistics facilities that have occurred in many cities around the world because they may contribute to increases in the negative externalities that urban freight traffic generates. However, the needs for the studies that reliably measure the impacts of the outward migration of logistics facilities and explore policy directions that policy makers should follow have not been met sufficiently due to the limitation in the available urban freight data and the lack of policy evaluation tools. The motivation of the present research is to fill such research gap.

This research points out the peril of taking a simplistic view on the relationship between the outward migration of logistics facilities (or “logistics sprawl”) and the negative externalities. The findings summarize in this chapter highlight heterogenous, adaptive, and complex nature of urban freight system. Until we develop more comprehensive and deeper understanding of urban freight systems, it may be futile or even counterproductive to design and implement land use policies that aim to reduce negative impacts of urban freight. The analyses results indicate that policies that focus on the locations of logistics facilities without considering logistics chain formulations are likely to be ineffective. On the other hand, market-based approach that focuses on logistics chain formulations, rather than the rigid land use regulations, seems to be more promising. When considering policies to curb negative externalities, it is important to remember that in most cases, reducing truck travel is desired by the businesses because trucks are expensive to operate, especially in urban areas. For example, both the logistics facility location choice (LFLCM) and logistics chain formulation (LCM) models show that distance to the shipment demands is by far the most influential factor on those decisions. This study affirms that efficient operation of logistics systems can be (and ought to be) the mutual goal of both the private and the public sectors. As a specific policy direction, this points to the market-based approach that utilizes the self-organization mechanism of the logistics system, as a more promising option than prescriptive policies because it is extremely difficult for public agencies to comprehend the complex logistics operations by private operators.

While the analysis uses the data from the TMA, I believe the discussions in this research provide various insightful information for developing policies that address logistics land use and associated logistics chains in cities around the world. The analyses in this thesis, which shed lights on many details, would not have been possible without the large and comprehensive data set provided by the TMFS. While more studies on this research agenda are needed for the TMA and other cities, such efforts are still severely constrained by the data availability. Even the TMFS data has limitations such as the lack of the P-C flow information and the seasonal fluctuation in shipments. While the large scale urban freight survey is still uncommon as such survey is highly costly, the advances in the ICT and the innovative data collection methods may allow the future research to further address the complex urban freight system, building upon the contributions by this research.

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APPENDIX DATA PREPARATION

A.1 Purpose of the Appendix A

To conduct the comprehensive evaluation of the impacts of the spatial distribution patterns of logistics facilities (Chapter 7) and the public policies (Chapter 8) in the TMA, it is necessary to use the data set that represents all logistics facilities and truck trips (or shipment demands) that are targeted. The use of expansion factors is not avoidable as the 2013 TMFS is a sampling survey. Another issue to tackle for the comprehensive evaluation is the filling of the missing data. Especially, as 47.3% of outbound shipment records and 56.8 % of inbound shipment records are missing in the 2013 TMFS logistics facility data (sample size: 4,580), the estimation of shipment relevant information that makes up the missing records is crucial to simulate all targeted shipments/truck trips in the TMA.

The process of filling the shipment relevant information for logistics facilities and the development of shipment demand location data (Ps and Cs) are discussed in the following sections.

A.2 Logistics Facility Data

A.2.1 Filling missing floor area

Some logistics facility records (12.3%) of the 2013 TMFS are missing floor area, which is required to categorise the logistics facilities by size. The missing floor areas are filled by expectation maximization (EM) imputation. The following variables are used:

- Employment size (3.1 % are missing)
- Land price
- Port area or not
- Along Ring Road 3 or not
- Population density at the facility location

- Share of quasi-industrial zone at the facility location
- Share of industrial zone at the facility location
- Share of exclusively industrial zone at the facility location
- Establishment year (before Y1983 or later)

A.2.2 Filling missing trip data

Number of outbound and inbound trips

Among the 4,580 logistics facility records, 47.3% of them have no outbound shipment records and 56.8% of them have no inbound shipment records. For filling the four missing variables, specifically, the number of outbound trips (internal), the number of outbound trips (external), the number of inbound trips (internal), and the number of inbound trips (external), the EM imputation is conducted with the following variables:

- The number of outbound trucks (29.2% are missing)
- The number of inbound trucks (35.1 % are missing)
- Floor area
- Employment size
- Port area or not
- Along Ring Road 3 or not
- Population density at the facility location
- Share of quasi-industrial zone at the facility location
- Share of industrial zone at the facility location
- Share of exclusively industrial zone at the facility location

Number of outbound and inbound trips by commodity type

After the missing numbers of the outbound and inbound trips are filled, each of (1) outbound trips (internal), (2) outbound trips (external), (3) inbound trips (internal), and (4) inbound trips (external) are broken down into 12 categories defined by commodity type (6 types) and by non-LF shipment/LF shipments.

I use K-nearest neighbor (K-NN) algorithm based on the locations of logistics facilities. The averages of the nearest five logistics facilities for internal shipments and the nearest ten logistics facilities for external shipments were used to calculate the shares of trips for 12 categories for each of (1) outbound trips (internal), (2) outbound trips (external), (3) inbound trips (internal), and (4) inbound trips (external). The four categories of trips are then broken down into 36 trip categories (the external trips are not divided by non-LF shipment/LF shipment).

A.4 Shipment Demand Location Data

A.4.1 Vehicle size

The data of the numbers of outbound and inbound trucks (not trips) of the 2013 TMFS has their breakdowns based on vehicle size. The shares of vehicle sizes for each of outbound trucks and inbound trucks for each logistics facility are calculated and, then, those shares are associated with the shipment records for each logistics facility. Then, the shares of vehicle sizes at each shipment demand location (315 municipalities) for each trip end type (P or C), for each commodity type (6 types), and for each size group of logistics facility associated with the shipment demand (three logistics facility size groups), are computed.

As for the vehicle size shares for LF-shipment (i.e. trip end, As) and the external Ps and Cs, the overall rates are calculated and then applied at the stage of calculating the level of negative externalities using TFIS. 43.6 % of all LF-shipments (i.e. G → A) are by the vehicles that load capacity is less than 2 tons and the remaining 56.4 % are by the vehicles with the larger capacity. As for the external trips, 28.6 % are by the vehicles that load capacity is less than 2 tons and the remaining 56.4 % are by the vehicles with the larger capacity.

A.4.2 Shipment demand location (trip ends Ps and As, internal and external)

The flow of the development of the shipment demand location data is shown in Figure 20. The records of non-LF shipments were used to obtain the population Ps and As (both internal and external). Vehicle size shares mentioned above are used to break down the Ps and As by vehicle size. In addition, for making up the missing shipment records, the volumes of Ps and As was adjusted using the control total values obtained from the logistics facility data with filled missing trip information (Section 9.2.2.).

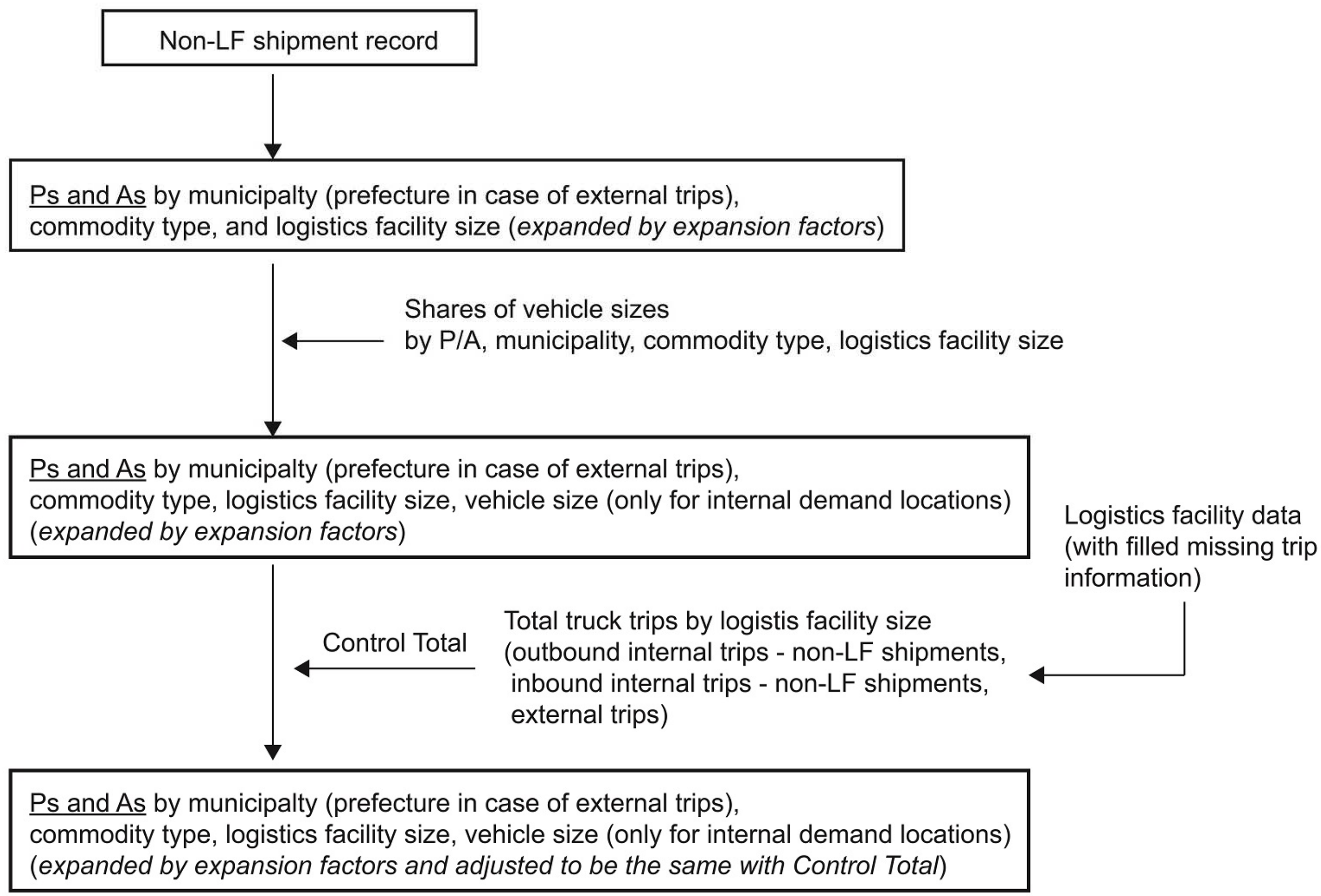

Figure 20: Comparison between actual and simulated distributions of logistics facilities established in 2003 or after

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PEER-REVIEWED PUBLICATIONS

1) **Takanori Sakai**, Kazuya Kawamura, Tetsuro Hyodo. (2017). Logistics Chain Modeling for Urban Freight: Pairing Truck Trip Ends with Logistics Facilities. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2609. doi: 10.3141/2609-07 (Forthcoming)

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3) **Takanori Sakai**, Kazuya Kawamura, Tetsuro Hyodo. (2016). Logistics Facility Distribution in Tokyo Metropolitan Area: Experiences and Policy Lessons. *Transportation Research Procedia*, Vol. 12, pp. 263–277.

4) Tetsuro Hyodo, **Takanori Sakai**, Kazuya Kawamura. (2015). Analysis of Logistics Facility Location Choice in the Tokyo Metropolitan Area using Discrete Choice Models with Spatial

Correlation. *Journal of the Japan Society of Civil Engineers*, Division D, Vol. 71, No. 4, pp. 156-167.

5) **Takanori Sakai**, Kazuya Kawamura, Tetsuro Hyodo. (2015). Locational Dynamics and Efficiency of Logistics Facilities: Evidence from Tokyo. *Journal of Transport Geography*, Volume 46, pp. 10-19.

6) **Takanori Sakai**, Tetsuo Yai. (2009). The Study for Securing Rationality in Plan-Decision Making. *Journal of the Japan Society of Civil Engineers*, Division D, Vol. 65, No. 2, pp. 111-128.

7) Chunyan Shan, Tetsuo Yai, **Takanori Sakai**. (2007). Citizens' Evaluation of Road Planning Process: Case Study of Yokohama North-West Corridor. *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 7, pp. 283-298.

CONFERENCE PROCEEDINGS

1) **Takanori Sakai**, Kazuya Kawamura, Tetsuro Hyodo. (2017). Logistics Chain Modeling for Urban Freight: Pairing Truck Trip Ends with Logistics Facilities. *In the Proceedings of the 96th Annual Meeting of the Transportation Research Board*. Washington D.C. (Received 2017 Best Paper Award in TRB Urban Freight Transportation Committee)

2) **Takanori Sakai**, Kazuya Kawamura, Tetsuro Hyodo. (2016). Location Choice Models of Urban Logistics Facilities and the Impact of Zoning on their Spatial Distribution and Efficiency. *In the Proceedings of the 95th Annual Meeting of the Transportation Research Board*. Washington D.C.

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2) **Takanori Sakai**, Kazuya Kawamura, Tetsuro Hyodo. "Landuse regulations for logistics: policy evaluation with location choice models for the Tokyo Metropolitan Area", the 14th World Conference on Transport Research, Shanghai, China, July 10-15, 2016.

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The author, Takanori Sakai, was responsible for all of the writings and the analyses in the papers listed below, while the co-authors provided advices on the research frameworks and on editing the manuscripts.

> *Sakai, T., Kawamura, K., Hyodo, T. (2017). Logistics Chain Modeling for Urban Freight: Pairing Truck Trip Ends with Logistics Facilities. Transportation Research Record: Journal of the Transportation Research Board, No. 2609. doi: 10.3141/2609-07*
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