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Title: Spatial Reorganization of Urban Logistics System and Its Impacts: Case of Tokyo

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ABSTRACT

We use the comprehensive freight survey data from 2003 and 2013 to analyze how the restructuring of logistics industry that occurred amid the broad trend of decentralization in the Tokyo Metropolitan Area has affected the efficiency of truck shipments. The analysis reveals that the negative effects of the outward migration of logistics facilities were offset by the increase in average shipment load and efficient spatial distribution of logistics facilities that occurred in parallel with the decentralization. As a result, the truck shipment efficiency improved by 4%.

Key words: Freight, logistics sprawl, decentralization, land use

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1. Introduction

The spatial distribution of logistics facilities (e.g. distribution centers and warehouses) observed in large cities around the world, especially in North American and European cities, is becoming a germane topic of discussion for researchers and practitioners engaged in transport and urban planning. The advances in the Information and Communication Technologies (ICT) and globalization have led to the evolutions in logistics operations and supply chain management practices and also the restructuring of urban freight systems (Hesse and Rodrigue, 2004). While facilities with larger footprints are desired for modern supply chains, appropriate sites are rarely found near the urban centers where many activities are concentrated, traffic is congested, and the land value is prohibitively high. As a result, logistics sprawl, "the movement of logistics facilities away from urban centers" (Dablanc et al., 2014) has occurred in many metropolitan regions. The outward migration of logistics facilities is a concern because it may lead to an increase in vehicle-kilometer-traveled (VKT) and exacerbate negative externalities, such as traffic congestion, carbon emissions, local air pollution, infrastructure damage and traffic accidents.

In recent years, a large number of studies of logistics sprawl have been conducted in various cities around the world. In most studies, the outward migration of logistics facilities was verified. On the other hand, studies that measure traffic impacts of such outward migration have been almost nonexistent due to the fact that such study requires shipment data at a reasonable level of geographic resolution if not at the facility level. One such study is Sakai et al. (2015) that use the Tokyo Metropolitan Freight Survey (TMFS) from 2003 to examine the inefficiencies associated with the outward migration of logistics facilities observed for the Tokyo Metropolitan Area (TMA). Their analysis identifies the outward migration of logistics facilities in the TMA and also finds higher shipment inefficiencies for the logistics facilities that are located far from the urban center. However, the study is limited in that it relies on the data from a single year; especially, the changes in the spatial distribution of shipment demand cannot be measured accurately without the data from more than one time period.

In 2013, the latest urban freight establishment survey (2013 TMFS) was conducted in the TMA with a survey design similar to the 2003 version of the TMFS. In this study, we use both 2003 and 2013 TMFS to overcome the limitations of Sakai et al. (2015) and expand the analysis to reveal how the outward migration of logistics facilities influences truck shipments. We combine the TMFS data 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 we 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 we believe this paper contributes beneficial insights for the research on the spatial distribution of logistics facilities.

The rest of the paper consists of the following contents; in section 2, we introduce the literature on the structural changes that modern logistics practices have gone through in the past few decades, the measurements of the outward migration of logistics facilities, and the impacts of such migration; in section 3, the data and the methodology of the analysis are discussed; in section 4, the results of the analysis are presented and the findings are discussed; finally, section 5 concludes the paper with a summary of the findings and their implications.

2. Literature review

In this section, we first provide a brief overview of the changes in logistics and supply chain industries that took place over the last two to three decades and associated impacts. The discussion is intentionally brief since there are many references on the topic including the ones mentioned here. We then provide a more detailed review of research on the outward migration of logistics facilities, followed by the discussion of the gaps in the existing literature.

2.1 Transformation of logistics operations and its impacts

The evolutions in the logistics operations that took place during the last two to three decades have led to the changes in the location and design of logistics facilities such as distribution centers and warehouses. Hesse and Rodrigue (2004) argue that various components of logistics activities have adapted to the process of globalization and the innovations in the ICT. The globalization, or the rise of global production networks (Coe et al, 2004), entails the fragmentation of spatial locations for production, which requires supply chain management that integrates various logistics components and realizes the complex institutes of production and transport. Such process of integration cannot be achieved without managing information flows by the ICT connecting the different components of supply chain and making them function seamlessly. The transformation of logistics operations and the supply chain managements that are based on the demand-side information, instead of supply-side information, allowed logistics operators to minimize their total operation cost through the decrease in inventory cost. This has led to the need for modern logistics facilities that are designed to handle higher through-put in an efficient manner, instead of storing products as the foremost objective. Such process of logistics evolution is backed by several empirical evidences (e.g. Allen et al., 2012; Hesse and Rodrigue, 2004; McKinnon, 2009). The changes in logistics operations enhance the values of land that have sound transport access and also are relatively inexpensive and expandable, as potential sites for new logistics facilities (Hesse, 2004). Wachs (2013) argues that the evolution in logistics operations also supports the restructuring in urban centers. He argues that the activities in the increasingly dense urban centers are sustained by efficient freight systems, though such relationships are often ignored by the proponents of the new urbanism in the US.

2.2 Outward migration of logistics facilities

Given the global trend of urban growth and the increases in population density and land-price in the urban centers of many cities, it is a plausible hypothesis that the transformation of the industry mentioned earlier has led to the outward migration of logistics facilities. A good number of research in recent years measure the outward migration of logistics facilities, including Paris (Dablanc and Rakotonarivo, 2010; Heitz and Dablanc, 2015), Toronto (Woudsma et al., 2016), Atlanta (Dablanc and Ross, 2012), Los Angeles and Seattle (Dablanc et al., 2014), Tokyo (Sakai et al., 2015) and Zurich (Todesco et al., 2016). Those studies typically compare the change in the distance of logistics facilities from a reference central location (this is, in most studies, the geometric center) against that of business establishments or population. For example, Dablanc and Ross (2012) find that between 1998 and 2008, the average distance of all establishments from the geometric center increased by 1.3 miles (2.1 km) while that of warehousing establishments increased by 2.8 miles (4.5 km) in the Atlanta metropolitan area. They call such phenomenon "relative (logistics) sprawl", which is defined as more pronounced outward migration of logistics facilities than that of the businesses as a whole. Like Atlanta, most of other cities studied, excluding Seattle, have experienced the outward migration of logistics facilities, though the details and the process are not necessarily the same among the cities. Some of the studies also focus on the difference between the distributions of facilities by operator type. For example, Todesco et al. (2016) find the outward migration occurred for the storage and courier services establishments but not for those operated by freight transport and postal services. Heitz and Beziat (2016) compare the distributions of the parcel industry and other logistics activities in the Paris region and find that the former is more centralized. Cidell (2010) targets the fifty largest metropolitan areas in the US and analyzes the locations of warehousing establishments across the country and within the metropolitan areas. She finds that in many cities in the US, the numbers of warehousing establishments grew faster in the suburban counties than their central counterparts both in numbers and percentages and confirms the decentralization in most of the cities examined during 1986 – 2005.

As those studies indicate, the outward migration of logistics facilities is actually widely observed, especially in the North American and European cities. On the other hand, the impacts of such migration, including how it affects the movement of freight and truck travel in urban areas, have not been examined rigorously (Aljohani and Thompson, 2016). Although the evaluation of the systems adapting urban distribution centers, given the pre-determined shipment demands, is one of the major subjects in city logistics research (e.g. Taniguchi et al., 1999; Kia et al., 2003; Crainic et al., 2004; van Duin et al., 2012), those research focus on a subset of urban logistics system, rather than the spatial distribution of numerous logistics facilities of various types. Notable efforts include Wagner (2010)'s traffic impact assessment of logistics-related land use. She uses the data from Hamburg, Germany, to compare the impacts of a large freight village near the urban center with those of several smaller sites for logistics activities that are away. The analysis indicates that the former produces less traffic impacts due to the fact that the increase in the distance from the city center contributes to the additional lorry-kilometer-traveled. On the other hand, Davydenko et al. (2013) use a logistics chain model to evaluate the impacts of logistics sprawl in the Netherlands. They find that centralization (or decentralization) of logistics facilities in the Randstad region has only limited impacts on traffic. However, their model is at the national level and is not necessarily transferable to urban areas. Sakai et al. (2015) use the data of establishments and their shipments from the 2003 TMFS to empirically analyze the impacts of the outward migration of logistics facilities. The study compares the actual shipment distances against those under the optimized condition in which each logistics facility is assumed to be at the location that minimizes the sum of the shipment distances given actual origins and destinations of shipments. They find that the distance from the urban center positively correlates with the gap between the actual and optimum shipment distances.

2.3 Aim of this research

While the impacts associated with the outward migration of logistics facilities have been studied using models (Wagner, 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 relationship between the outward migration of logistics facilities and spatial restructuring of urban areas that occur 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 study 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.

3. Methodology

3.1 Tokyo Metropolitan Freight Survey (TMFS)

As mentioned earlier, we use the data from the 2003 and 2013 TMFS. The TMFSs are establishment surveys conducted by the Transport Planning Commission of the Tokyo Metropolitan Region (TPCTMR). The survey area for the 2003 TMFS is 15,950 km^2, covering the prefectures of Tokyo, Kanagawa, Chiba, Saitama, and the southern part of Ibaraki. The survey area was expanded for the 2013 TMFS by 7,099 km^2 with the inclusion of the southern parts of Gunma, Tochigi and the northern part of Ibaraki. The survey packages were sent to 119,737 and 136,632 establishments in 2003 and 2013, respectively. The surveys targeted manufacturers, wholesalers, retailers, transportation companies, restaurants and service companies which are randomly selected, using the sampling frames defined by Neyman Allocation based on the 2003 Economic Census and the 2013 Establishment and Enterprise Census. The survey form requests the facility information (such as function, employment size, floor area, and the year of establishment) and shipping information (such as origins/destinations and their industry types and functions, commodity types, number of truck trips, and weight) for both inbound and outbound shipments. A total of 29,485 establishments (a response rate of 24.6%) in 2003 and 43,131 establishments (a response rate of 31.6 %) in 2013 returned filled survey forms.

In order to maintain consistency, we only use the data for the area covered by both the 2003 and 2013 TMFSs, where approximately 37 million people reside (2010 Census) and 1.4 million establishments (2012 Economic Census) are located. We use the responses only from logistics facilities for our analysis. Logistics facilities cover distribution centers, truck terminals, warehouses, intermodal facilities and oil terminals. In 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, respectively, are included. For this research, we use the facility location (address level), floor area, and inbound and outbound shipment origins and destinations with the numbers of trucks used for those shipments. In the TMFS data sets, shipment records are aggregated at the municipality level (within the survey area) or at the prefecture level (for the external shipments to/from the outside of the survey area); for example, if a truck travels from a logistics facility to a municipality and makes several stops within the municipality, it is recorded as an outbound shipment by one truck to that municipality, regardless of the number of the delivery stops made within the municipality. On the other hand, it treats a tour of a truck with multiple delivery or pick-up points across two or more municipalities as multiple truck shipments. The study area includes 268 municipalities with the average size of 59.5 km^2.

In all analyses presented in this paper, we use the official expansion factors assigned to each logistics facility. Those expansion factors were calculated based on location, type of industry and employment size to reproduce the whole populations targeted in the surveys. For the comparison of the data from 2003 and 2013, we need to use 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, which was used for sampling design. Expansion factors, however, are derived in the manner that makes it possible to compare these data sets.

3.2 Spatial reorganization of logistics facilities and urban structure

In the first step, we examine the change in the distribution of logistics facilities between 2003 and 2013. Kernel Density

Estimation (KDE) is conducted to compare the distributions of logistics facilities. The KDE has been used in some 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 chosen after testing various bandwidth values for their effectiveness in highlighting the distributional characteristics. Furthermore, we observe the changes in the spatial distribution of logistics facilities as well as some indicators of urban structure, including business establishments, factories, population, shipment origins and destinations (which will be referred to as "shipment demands"), in terms of the distance from the urban center. This is to obtain insights on the interaction between the logistics facilities and urban structure since literature suggests that relative (logistics) sprawl may exacerbate the negative impacts associated with the outward migration of logistics facilities.

We use the establishment count data from the 2001 Establishment and Enterprise Census and 2012 Economic Census in the GIS polygons of 1 km by 1 km that cover the whole study area. We also use population data from the 2000 and 2010 National Census in the same data format. We derive the locations of the factories from both TMFS data sets (2003 and 2013). We also use the TMFSs to obtain the shipment data; the origins of inbound truck trips to, and the destinations of outbound trips from the logistics facilities in the study area are used after the expansion. Here, only the origins and destinations at non-logistics facilities are considered as shipment demands. The detailed shipment record is available for 65.1 % of the logistics facilities included in the 2003 TMFS and 48.8 % of the facilities in the 2013 TMFS. To address the possible sampling bias, we 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, we compare the quintiles of the distances from the urban center. We define the urban center as the point in front of the Tokyo Railway Station that is effectively the center of ring and radial road networks in the TMA, following Sakai et al (2015), and thus, we can use the same reference point for different subjects. To calculate the distance from the urban center, we use the road network distance. Road network distance is preferred over Euclidean distance because the former accounts for the presence of Tokyo Bay.

3.3 Shipping efficiency

We analyze all the truck shipments destined to or originated from the logistics facilities in the study area. As truck trip is used as the unit of shipment in this research, we use the term "shipment" and "truck trip" interchangeably. We use the distances between a facility and the origins/destinations of the associated truck trips for estimating shipment distance, while we also pay attention to the potential bias caused by using shipment records that, unlike vehicle routing data, do not capture touring by the trucks.[1] Shipment distances are calculated for each shipment using the TMA road network, for both internal and external trips. An internal trip is a 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. Although the locations of the origins and destinations outside the study area are available at the prefecture level, shipping efficiency can be evaluated with a reasonable accuracy by calculating the distances to/from the cordon points along the border of the study area that the trucks are likely to use for long-distance trips. Specifically, for each external demand point, a cordon point along the border of the study area is assigned as a substitute for the shipment origin/destination. Thus, for external trips, we take into account only the portion of the shipment distance that is within the study area. Five boarder points, all of which are on expressways, are defined and assigned to external trips considering the potential shipment routes.

The shipping efficiency of the logistics facilities in the TMA is measured in three ways. First, truck-kilometer (km)-traveled (that is the product of the average shipment distance and the number of trucks used) per tons handled are compared between 2003 and 2013. We believe this measure is more appropriate than total truck-km-traveled, which is heavily dependent on the size and the structure of the economy and the level of freight activities. Second, we take a close look at average shipment distance, which is directly connected to the spatial distribution of logistics facilities. The changes in average shipment distances are compared for internal, external and all truck trips.

For the third measure of shipping efficiency, following the approach of Sakai et al. (2015), we calculate the optimum location for each logistics facility, where the sum of the shipment distances (in the study area) for the trips attributed

[1]Later in this manuscript, we discuss the implications of ignoring the effect of truck tours on the total distance traveled.

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 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, we compare the actual average shipment distances against the minimum shipment distances that can be achieved at the optimum locations for 2003 and 2013, respectively. In the analysis of this measure, only logistics facilities that have at least two different origins of inbound and/or destinations of outbound trips are considered.

4. Spatial reorganization between 2003 and 2013

4.1 Tokyo Metropolitan Area

The TMA is the largest metropolitan area in Japan in terms of residential population and the center of politics and business. Furthermore, the TMA is an international gateway where the busiest seaports and airports in the country are located. The urban structure of the TMA is monocentric, having the highest activity density in the Special Wards of Tokyo in the center. The expressway system that consists of ring and radial toll roads has been developed, though still incomplete, with the busiest district in its center. Many expressway sections, especially the ring roads, have remained incomplete for decades (Figure 1); however, several 3rd Ring Road (or Ken-O Expressway) sections, which are roughly 50 km away from the urban center, were recently opened. This makes the corridor along the 3rd Ring Road attractive for industrial development, although the port area, which is the traditional industrial cluster of the TMA, still attracts intensive industrial activities. While the increase in population has been moderate (6.3%) between 2000 and 2010, the improvement in the expressway system in combination with the advances in logistics practices, is a plausible contributor to the changes in the distribution of freight demand and the logistics system in the TMA.

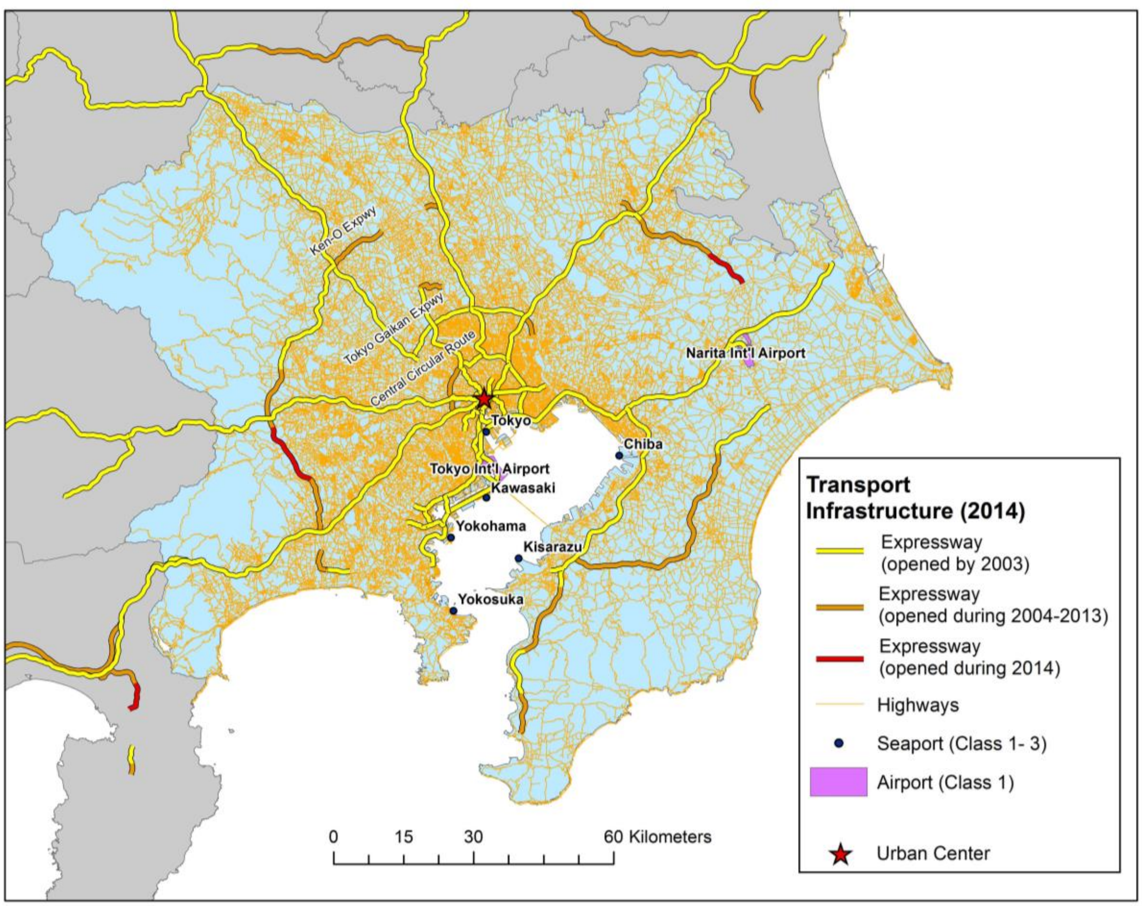
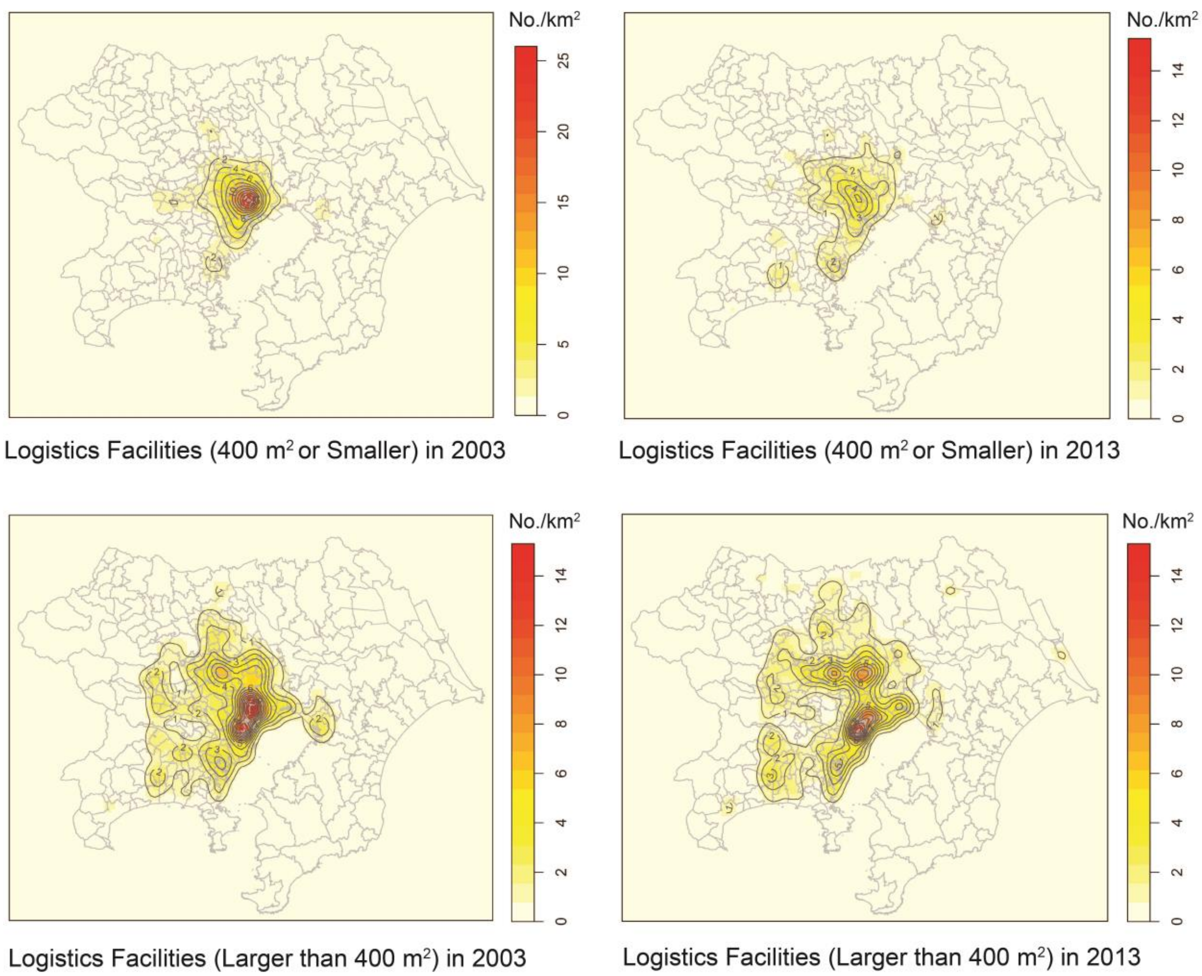


Figure 1: Transport system in the Tokyo Metropolitan Area

4.2 Spatial reorganization

In this section, the spatial distributions of logistics facilities are discussed - first on their own, and then in relation to other indicators of urban structure. Figure 2 compares the results of the KDE for 2003 and 2013 separately for 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 have mostly disappeared by 2013 (upper-right). As for the facilities of 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 logistics facilities during the study period was significant.



Source: TPCTMR, 2003, 2013, calculations by authors.

Figure 2: Kernel density maps for logistics facilities

Table 1 shows that as a whole, smaller facilities were replaced by 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 account 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 are more modest for the area beyond 50 km.

Table 1 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%)

Source: TPCTMR, 2003, 2013, calculations by authors.

The outward migration of logistics facilities did not occur by itself; their customers, i.e. shippers/receivers and shipment demands, also moved outward, showing an interesting spatial restructuring pattern. Table 2 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 business establishments and population changed only slightly during the study period. On the other hand, the outward migration of factories and 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 relative sprawl, following the definition by Dablanc and Ross (2012)). In 2003, 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 logistics facilities in terms of the distance from the urban center became more similar to that of shipment demands. The next question that naturally arises is how such dispersion of logistics facilities affected the shipping efficiency.

Table 2 Quintiles (QUs) of the distance from the urban center for urban structure indicators and logistics facilities

		2003				2013[1)]			
		QU1	QU2	QU3	QU4	QU1	QU2	QU3	QU4
Distance from the Urban Center (km)	Establishments[2)]	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[3)]	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)

Notes: 1) The differences between 2003 and 2013 are shown in the parentheses underneath the 2013 figures. 2) The data for 2001 and 2012 are used. 3) The data for 2000 and 2010 are used. Source: Ministry of Internal Affairs and Communications, 2000, 2001, 2010, 2012; TPCTMR, 2003, 2013, calculations by authors.

4.3 Impacts of reorganization in the logistics system

In this section, we will examine the efficiency of truck shipments. It should be noted that total tons handled by logistics facilities (shown in column a. of Table 3) 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 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-traveled 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-traveled per ton decreased by 12% for the logistics facilities within 50 km from the center. This is 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, average load decreased for the facilities located beyond 50 km, and also the share of 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-traveled per ton increased by 54% for those facilities. Since most logistics facilities are located within 50 km of the urban center, the overall effect is the aforementioned increase in the efficiency by 4%.

Table 3 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

Source: TPCTMR, 2003, 2013, calculations by authors.

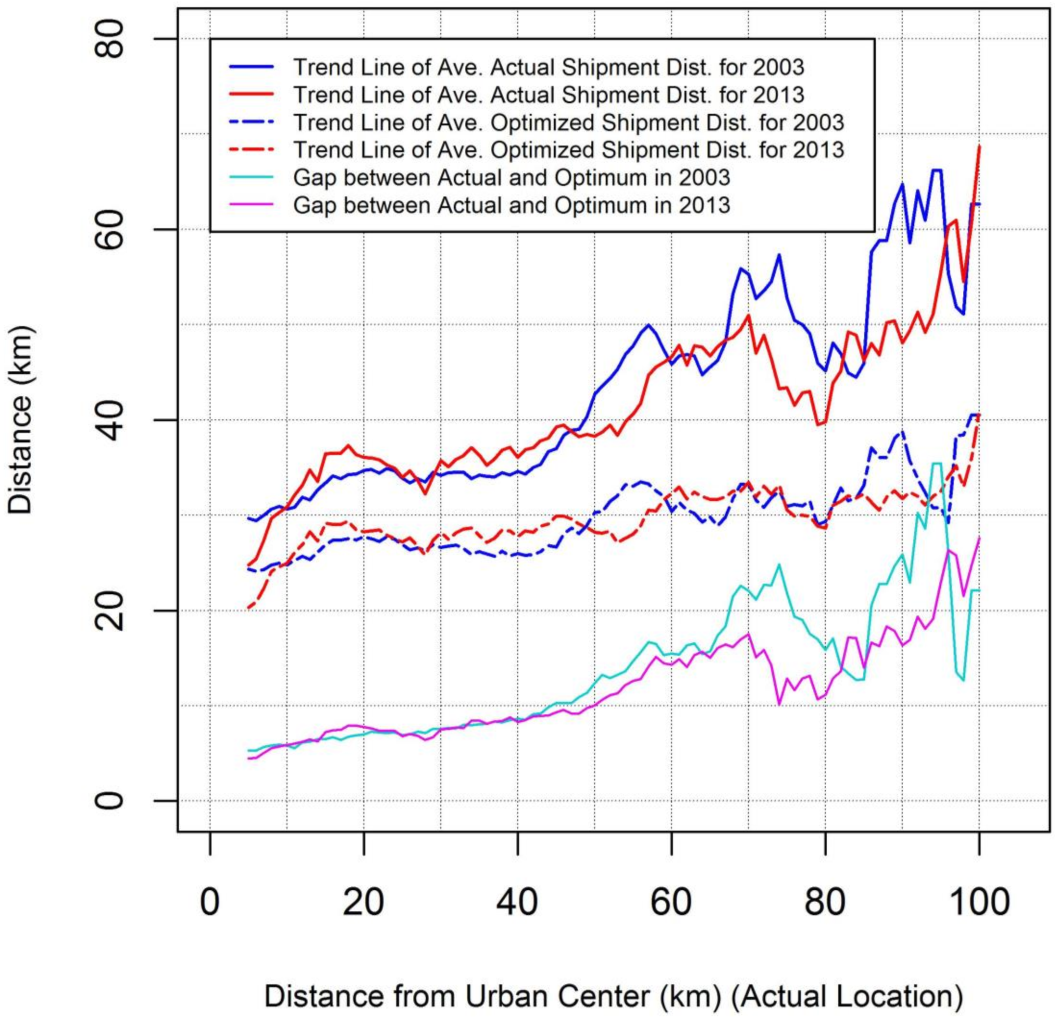
The average shipment distance for the internal trips increased by 6.1%, from 23.3 km in 2003 to 24.8 km in 2013. On the other hand, the change for the external trips is much more moderate, an increase of 1.6% (78.9 km in 2003 and 80.2 km in 2013). It should be noted that the external trips accounted 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 3 depicts another measure of shipment efficiency, based on the optimized distance, with respect to the distance from the urban center. In the charts, 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 ± 5km for each x value. The gaps between the actual and optimized distances, i.e. the levels of inefficiency, are also shown as 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 3 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 demands that are spatially concentrated. As for the facilities between 10 km and 50 km from the urban center, both the optimum and actual shipment distances increased between 2003 and 2013, while the efficiency remained almost unchanged. This indicates that the increase in shipment distance occurred mainly because the shipment demands (the origins of upstream trips to 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 spatial mismatch.

As for the facilities that are more than 50 km from the urban center, both the actual and 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, logistics facilities moved closer to the demands. This is understandable because as the shipment demands, especially those associated with factories, migrated, 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 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 in 2013 ($r = 0.31$) while such correlation does not exist in 2003 ($r = 0.07$). As a result, the average shipment distance remained nearly unchanged between 2003 and 2013, as shown in Table 3.

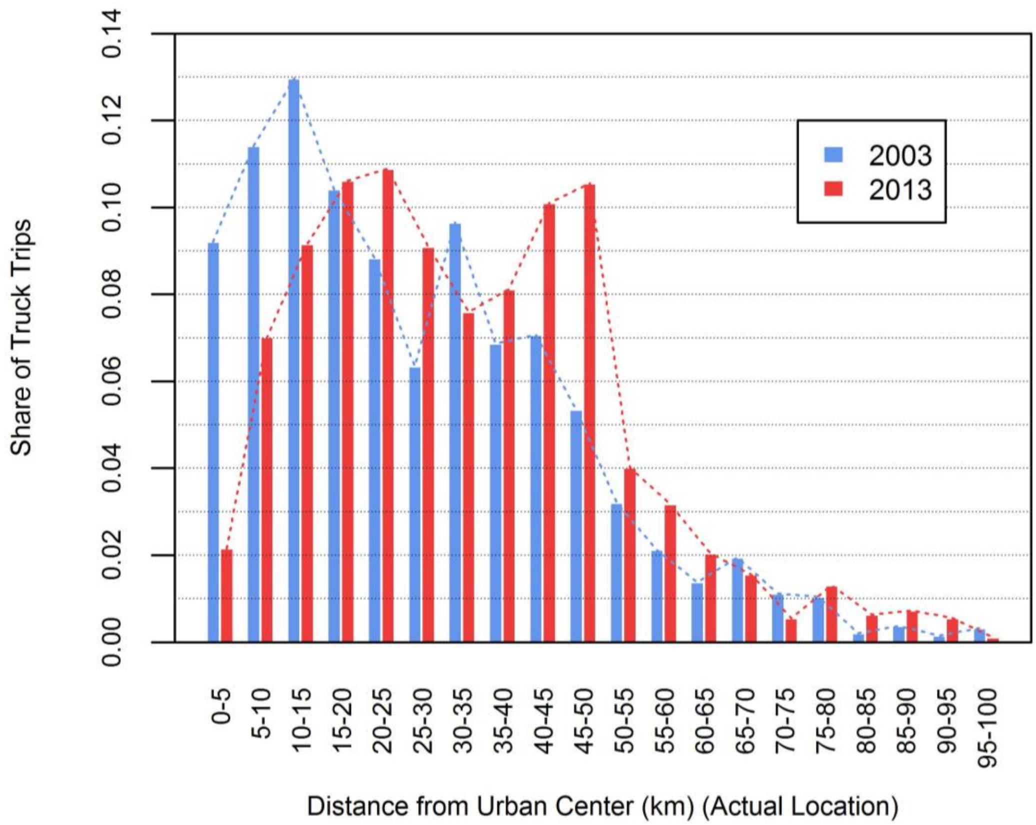
Those findings underline the fact that, despite the considerable outward migration of logistics facilities, the locations of those facilities did not become inefficient in relation to the optimum (i.e. distance minimizing) locations as a whole; such migration occurred following the shipment demands, which were also moving outward. The change in 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 we do not consider the effects of truck tours due to the limitation in the data (see Section 3.1), it is likely that considering the impacts of truck tours would 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 our calculations which use the shipment records. The significant increase in the average load observed for 2013 suggests an increase in multi-stop tour trips. 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. However, due to the limitation in the data, the net effect of these potential biases cannot be determined.



Source: TPCTMR, 2003, 2013, calculations by authors.

Figure 3: Average actual and optimum shipment distance against the distance from the urban center

Figure 4 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.



Source: TPCTMR, 2003, 2013, calculations by authors.

Figure 4: Shipment demand distribution by logistics facility location

5. Conclusion

This study used arguably the most comprehensive freight survey in the world to investigate how the decentralization and the structural change in urban logistics system in the TMA affected the shipment distances and truck traffic. The analysis sheds light on the details, especially the relationship between the locations of logistics facilities, shipment origins and destinations, and shipment distances, that are virtually impossible to discern in other cities due to data limitations. Despite the richness of the data, this research has some limitations. For example, we were not able to analyze the effects of congestion due to the lack of accurate traffic data for the study time periods. This prevented us 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, this research examined the mechanism and the impacts of the outward migration of logistics facilities at the level of detail that has never been achieved. Main findings and policy implications are discussed below.

Our 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, the data indicate that the migration occurred in response, at least partly, to the decentralization of the shipment demand locations[2]. The narrative of the migration of the facilities that we found in the TMA is not surprising considering the

[2] 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 logistics facility location choices

changes in the logistics operations that led to the type of facilities that are desired; smaller logistics facilities in the urban center are replaced by larger facilities in the suburbs. Between 2003 and 2013, the median size of logistics facilities nearly doubled (585 m^2 to 1,077 m^2). Also, the share of the shipments handled by the facilities larger than 3,000 m^2 increased from 34 % to 49 %.

So-called logistics sprawl is considered problematic generally because the logistics facilities in the suburb or exurb tend to be farther away from the origins and destinations of shipments and the analysis of shipment efficiency confirms that such claim is true when the data of each year are examined independently. As such, the outward migration that occurred in the TMA would have been an ominous sign. However, our longitudinal analysis revealed 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 logistics facilities brought them closer to the shipment demands that had already sprawled by 2003. At the same time, the increase in average load per truck, which is a likely consequence of the prevalence of larger logistics facilities[3], 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 we 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 average load, the spatial distribution of logistics facilities in 2013 is almost equality efficient as was in 2003. We believe that this would not have been possible without the spatial reorganization of logistics facilities in the TMA that kept the distances between logistics facilities and demands at a reasonable, if not the optimum, level. This underscores that spatial reorganization, which may involve deployment of larger facilities and/or clustering with other logistics facilities or businesses, rather than dispersion on its own, is important for improving the efficiency of shipments.

Furthermore, our analysis revealed profound differences among various parts of the TMA in how the reorganization of the logistics industry and the outward migration affected 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 shipment distances. On the other hand, truck-km-traveled 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 the decrease in 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.

We hope that this research will contribute to an advancement in the discourse on logistics sprawl by illuminating its complex and nuanced effects. While logistics sprawl is generally regarded as an undesirable phenomenon that escalates the negative externalities associated with urban freight, the analysis presented in this paper demonstrates that the actual impacts, insofar as truck-km-traveled per ton is concerned, are far from predictable. In the TMA, the magnitude of the increase in 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, shipment demands were already decentralized in relation to logistics facilities at the beginning of the study period. As such, the outward migration of logistics facilities simply brought them in line with the shipment demands. Secondly, the outward migration 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.

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[3] 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.

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.

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