Locational dynamics of logistics facilities: Evidence from Tokyo

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ABSTRACT

This study uses data from a large-scale freight survey conducted in the Tokyo Metropolitan Area to jointly analyze the spatial distribution of logistics facilities and their proximities to the locations of shipment origins and destinations. The aim of the study is to examine in detail the argument that logistics sprawls increase truck trip distances, and thus would incur negative impacts to the society. We found that between 1980 and 2003, logistics facilities in the Tokyo Metropolitan Area have migrated outward, albeit in a much smaller scale than the cases documented in some U.S. and European cities. Our analysis of the shipment data confirms that logistics sprawl increases truck travel. Furthermore, we found that, regardless of their age, logistics facilities tend to increase shipping distances as their distances to the urban center increase, due to the spatial mismatch between the locations of the facilities and the shipment origins and destinations. The findings underscore the importance of comprehensive efforts to coordinate land use, not only for logistics facilities but also other businesses that generate freight movements.

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1. Introduction

Logistics-related infrastructure systems in metropolitan areas around the world have gone through significant transformations over the last several decades promoted by the growth of the logistics industry, the evolution of global supply chain management practices, and technological innovations in logistics. In the U.S., the number of establishments and employment in the warehousing and storage sector increased by 111 % and 451%, respectively, between 1998 and 2011 (U.S. Census Bureau, 2014). In England and Wales, warehousing space increased by 22% during the 1998 - 2008 time period (Allen et al., 2012). While flourishing warehousing and logistics industries are often coveted by local governments for their economic development potentials, the concern over the negative impacts caused by freight traffic is increasing. Negative impacts associated with truck traffic, including carbon emissions, energy use, congestion and infrastructure damage, are considered to be especially problematic when the development of logistics facilities occurs in an uncoordinated manner. Logistics sprawl is defined by Dablanc et al. (2014) as “the movement of logistics facilities away from urban centers” (Dablanc et al., 2014, p.105). While outward migrations of logistics facilities reflect rational business decisions by firms in many cases, their impacts on the society are one of the emerging issues of concern for transportation researchers and practitioners alike. While the need for analyzing the impacts of the rapid shifts in logistics distribution using empirical data is recognized (e.g. Cidell, 2010; Hesse and Rodrigue, 2004), the dearth of freight facility and shipping data has prevented researchers to examine in detail some of the key issues concerning the logistics sprawl.

With the leadership of the Transport Planning Commission of the Tokyo Metropolitan Region in Japan, detailed freight surveys with a large sample of business establishments, Tokyo Metropolitan Freight Surveys (TMFS), are carried out in the Tokyo Metropolitan Area (TMA) roughly every 10 years. The data from the 2003 survey, which is the latest available as of July 2014, includes the responses from around 30,000 establishments and covers standard freight activity measures as well as facility and business information. The survey is arguably the most comprehensive of its kind. We derive insights into some key issues concerning logistics sprawl by analyzing the 2003 TMFS data.

Specifically, this paper discusses the changes in the spatial distribution of logistics facilities and their implications on the social impacts of goods distribution in the TMA through two main threads of investigations including, 1) analysis of the spatial distribution of logistics facilities in relation to the population and shipment demands, and 2) comparison of the proximities of the logistics facilities to origins of inbound shipments and destinations of outbound shipments with respect to the location and age of the logistics facilities. The paper tries to answer the questions such as how the spatial distribution of logistics facilities changed over time and whether their locations in relation to the urban center enhance or mitigate social impacts of trucking in urban areas.

This study introduces two proximity measures that can be used with freight survey data. The first measure is the average shipment distances based on the Euclidean distance between the coordinates of the facilities and the origins and destinations. The second measure is the difference between the actual and optimized (or minimized) shipment distances, where the latter is estimated by solving a simple optimization problem to find the median center of shipment origins and destinations. Although travel distance, for which proximity measures represent, does not always correspond to the level of negative social impact, the use of vehicle travel distance as the indicator of social disutility is quite common (Richardson, 2005).

To our knowledge, all existing literature on logistics sprawl examine cities in Europe or the U.S. We believe a study using the data from Tokyo, a megacity in Asia which is considered the largest metropolitan area in the world (United Nations, 2014), will provide a novel reference for understanding logistics sprawl and its implications.

The rest of the paper consists of the following contents; in section 2 the literature concerning spatial distribution of logistics facilities are reviewed and discussed; in section 3, the data and the analysis methodology are presented; in section 4, the analyses of the geography of the logistics facilities through above-mentioned threads of investigations are provided; the final section summarizes the findings and puts forward recommendations for further research.

2. Spatial distribution of logistics facilities: literature review

2.1 Changes in logistics facility requirements

The recent changes in the roles and functions of logistics facilities are well-acknowledged phenomena. The elimination of barriers separating economies, in the forms of deregulation and liberalization, widened the scope of supply chain management, and the evolution in logistics integration transformed the way in which supply chain is actually managed (Hesse and Rodrigue, 2004). Using several different data sets, mainly from the U.K., McKinnon (2009) identifies the factors that influence logistics land requirements as the off-shoring of manufacturing, rebalancing of logistics cost trade-offs and advances of warehouse technology among others. Similarly, Cidell (2011) argues that containerization, the globalization of production, and the prevalence of just-in-time (JIT) production model have enhanced the need for high through-put facilities. In addition, the changes in retail business practices, such as the rise of electronic commerce (Dablanc et al., 2011), have increased the importance of the capacity of handling flows compared to the capacity of storage (Hesse, 2004). The need for centralized logistics facilities, which are desired to be larger and expandable, has emerged with the evolution of logistics practices and supply chain management. Several researches discuss the suburbanization or decentralization of logistics facilities, promoted by the availability of larger lands and cheaper land price in suburban locations and undesirable traffic conditions in core urban areas (Bowen, 2008; McKinnon, 2009; Hesse, 2004; Hesse and Rodrigue, 2004; Mueller and Mueller, 2007).

2.2 Studies of logistics facility distribution

Spatial decentralization of logistics facilities in metropolitan areas, which is often called "logistics sprawl", is the interest of several recent studies. The studies of U.S. cities typically use the Census Bureau's County Business Patterns data. Examples include a work by Dablanc and Ross (2012) for the Atlanta Piedmont Megaregion, Dablanc et al.'s study of Los Angeles and Seattle (2014) and Cidell's study of U.S. metropolitan areas (2010). Dablanc and Ross (2012) show that, between 1998 and 2008, the average distance to the barycenter of warehousing establishments increased by 2.8 miles (4.5 km) while the average for all business establishments increased by only 1.3 miles (2km). They termed this phenomenon "relative logistics sprawl" in which logistics facilities move farther away than the businesses they serve for pick-ups and deliveries. Dablanc and Rakotonarivo (2010) compare locations of large parcel and express transport companies in Paris, France, using databases of establishments and building permits as well as the yellow pages of the French postal companies. They found that the average distance of terminals to their barycenter increased from 6 km in 1974 to 16 km in 2008. Meanwhile, logistics sprawl is not necessarily a consistent phenomenon in all metropolitan areas; in Seattle, the increase of warehousing establishments during 1998 – 2009 is mainly in the Puget Sound region, near the weighted geographic center and, therefore, sprawl has not occurred (Dablanc et al., 2014).

Some studies have examined spatial distribution of logistics facilities at national scale. Cidell (2010) applies indicators such as the number of establishments per population and Gini coefficients of logistics establishment's distribution for measuring the concentration of logistics activities in the U.S., while Rivera et al. (2014) apply Horizontal Cluster Location Quotient and Logistics Establishments Participation index for the same purpose.

While these studies often point out that logistics sprawls are likely to generate negative impacts due to increased shipment and truck travel distances, because of data limitations, they do not analyze in detail actual changes in shipment patterns that may accompany logistics sprawls. As noted above, since logistics sprawls have been partly driven by the changes in supply chain strategies, it is a legitimate possibility that the newer facilities are not used in the same way as older ones. As such, actual impacts of logistics sprawl, at least the ones that are related to truck vehicle kilometers traveled (VKT) or frequency of trips (e.g. congestion, energy use, infrastructure damages, and greenhouse gas emissions) may be greater or less than those implied by the spatial distribution of the facilities.

2.3 Locational decision making of logistics-related entities

The research on location decisions for logistics facilities is relatively scarce in comparison to the studies of general business establishments. Woudsma et al. (2008) analyze the performance of accessibility indicators for estimating the locations of logistics land use developments using spatial-autoregressive modeling techniques. The analysis, conducted using the data from Calgary, Canada, finds that accessibility measure based on travel time is a statistically significant predictor of logistics land use developments. They also find that congestion has even stronger influence on logistics land use. Furthermore, the study identifies 5-10 year lag between accessibility and its influence on land use developments. Van den Heuvel et al. (2013) examine the spatial concentration of logistics establishments during the period 1996-2009 using the data from North Brabant in the Netherlands. Their analysis identifies agglomeration as well as the knowledge of local areas influence the location choices for logistics establishments.

TMFS data have been used to study locational choices. Nguyen and Sano (2010) develop a location choice model (discrete choice model) for logistics firms that considers spatial effects using the 2003 TMFS data. They estimate models for retailers, product wholesalers and other manufacturers applying zonal population, number of zonal employees, land price, number of employees and floor area of a firm as predictors. Hagino and Endo (2007) also develop a location choice model for regional freight facilities and distribution centers based on the multi-nominal logit framework and estimate the location-based potential of future development. In the subsequent study, Hagino et al. (2011), they expand this model to include the location choices for factories and businesses. Using the model, which includes changes in land prices given exogenous population growth, they estimate the trend of decentralization of logistics facilities toward suburban areas up to 2020.

2.4 Contributions of present research

Past studies seem to indicate that in many metropolitan areas in Western Europe and North America, logistics sprawls have occurred during the last several decades. However, many of the studies reviewed in this section rely on data with limited sample size and generalizability. Also, to our knowledge, detailed analysis of the impacts of logistics sprawl has not been carried out. Such analysis requires data that connect changes in facility locations with shifts in shipment patterns. This study aims to fill these gaps by using data from a large-scale freight survey to examine the relationship between the ages of logistics facilities and distribution and shipment patterns, and then analyze the proximity of the distribution patterns to shipment demands in relation to the location and age of the facilities.

3. Methodology

3.1 Data

The 4th TMFS was conducted during January to March, 2003 and targeted 1) all factories and logistics facilities with storage[1] and 2) a random sample of shops, restaurants and business offices in the TMA. The survey package was sent to a total of 119,737 establishments and obtained responses from 29,485 subjects (a response rate of 24.6%). The survey of factories and logistics facilities collected a total of 19,017 responses. Logistics facilities consist of establishments that include distribution centers, truck terminals, warehouses, intermodal facilities and oil terminals. For the analysis described in this paper, only the data from the logistics facilities, a total of 4,109 responses, were used since the focus of the investigation is on the logistics facilities. The survey collected data on standard freight activity measures such as tons shipped, truck trips generated, commodity, origin and destination of shipments. The survey also collected information on industry classification, size, and age of each establishment. The locations of facilities and shipment origins and destinations are geocoded by coordinates.

The TMFS covered many tiny facilities, often nothing more than a small business with a garage space. Since including those small establishments in the analysis often led to severe skews in the results, we used a subset of the data that includes 2,803 logistics facilities that have floor area of at least 400 square meters (m^2). While such facilities represent 63% of the respondents, they cover approximately 90% of the shipments in terms of both shipment weights and vehicle trips associated with logistics facilities. While the threshold of 400 m^2 still seems low considering the sizes of typical logistics facilities in the U.S. and European countries, small to medium-sized logistics facilities are important in the TMA due to the extreme price and the scarcity of land, and the analysis of proximities to shipment origins and destinations in particular must account for the goods movements associated with such facilities that play an important role in the “last mile” part of the supply chain.

Historically, a significant share of industrial facilities in the TMA, especially the large ones, have been located along the coastal line of Tokyo Bay, near three major ports, Tokyo, Yokohama, and Chiba. Combined, those ports handled

[1] Business listings were used to identify the business establishments in the study area and also categorize into factories/logistics facilities and shops, restaurants and business offices.

354 million tons of freight in 2011, making them the seventh largest in the world (American Association of Port Authorities, 2012). Based on the TMFS data, around 30% of logistics facilities with over 400 m^2 of floor area are located within 1.5 km from the coastal line (Table 1). These port-related facilities are located in heavily industrialized areas and are distinct from the inland facilities in terms of function and locational dynamics. Including the port-related facilities often obscure important and more generalizable trends associated with the inland facilities. To deal with such bifurcation of logistics facilities in the TMA, in this paper, some of the analyses only include inland facilities that are located more than 1.5 km from the coastal line.

Table 1: Sample size of the logistics facilities

	No. of data points
Logistics facilities with floor area data[1)]	4,109
400 m^2 or larger	2,803
more than 1.5 km from the coastal line	1,971
less than 1.5 km from the coastal line	832
Smaller than 400 m^2	1,306
more than 1.5 km from the coastal line	1,067
less than 1.5 km from the coastal line	239

Note: 1) Floor area data is missing for 308 responses. Source: TPCTMR, 2003, calculations by authors.

In this study, year of establishment will be used as one of the variables to characterize logistics facilities. It should be noted that the data do not include the facilities that have been closed or converted to other uses since the year of establishment was obtained for the facilities that responded to the survey that was conducted in 2003. All the shipment data reflect their practices as of 2003 (i.e. data on shipments, including origins and destinations, are for 2003 for each facility regardless of the year of establishment).

Table 2 shows the distribution of the year of establishment for the logistics facilities in the data set. While the number of closed or converted establishments is unknown, a significant number of facilities established decades ago still exist in 2003. The data indicate that while the oldest facilities (pre-1950) are quite large, those built during the 1950s and 1960s tend to be small. The average size continued to increase throughout the 1970s, the 1980s, and the 1990s. The shares of the facilities of at least 400 m^2 in floor area are between 44.8% and 69.3% for all the establishment year categories. While excluding the facilities in the coastal area further decreases those shares, it does not change the relative scales of sample sizes from different establishment year categories.

Table 2: Floor area characteristics of logistics facilities by year of establishment

Year of establishment	Total number of facilities	Avg. floor area (m^2)	Facilities 400 m^2 or larger: All (No.)	(%)	More than 1.5 km from the coastal line (No.)	(%)
-1950	140	4,154	92	61.3%	63	42.0%
1950s	217	2,920	104	44.8%	75	32.3%
1960s	460	3,496	265	53.4%	192	38.7%
1970s	749	3,948	511	64.0%	382	47.9%
1980s	909	4,167	648	67.7%	420	43.9%
1990s	1,131	4,269	819	68.5%	592	49.5%
2000-2003	421	3,286	311	69.3%	209	46.5%
N/A	82	2,557	53	37.9%	38	27.1%
All	4,109	3,891	2,803	68.2%	1,971	48.0%

Source: TPCTMR, 2003, calculations by authors.

It should also be noted that not all of the respondents provided shipment data since some facilities do not have regular shipments (and thus had no shipments to report during the survey period) and also the most of the facilities owned by carriers did not provide the details of their shipments in order to protect the interests of their customers. Therefore, we only used the shipment data from the shippers and the receivers, but not the carriers[2]. Since the TMFS collected information on both outbound and inbound shipments from each facility, the survey captured all the shipments that had at least one of the trip ends at a facility belonging to a non-carrier business. In other words, the survey captured all the shipments except for those that originate and also terminate at the facilities belonging to carriers.

Of the 2,803 respondents which are at least 400 m^2 in floor area and the 1,971 respondents which are both at least 400 m^2 in size and farther than 1.5 km from the coastal line, 764 (27.3%) and 631 (32.0%) facilities, respectively, provided shipment data. For the analysis of facility proximities to shipment demands, only the intra-TMA shipments, which are approximately 70% of the total shipment records in the sample, are considered. While the analysis including inter-regional shipments is of a significant research interest, neither the TMFS nor other data sources can provide sufficient geographical detail about the origin or destination points for those shipments to allow for a meaningful analysis to be carried out. The TMFS data provides the origins and destinations of the inter-regional shipments only at the prefectural level, which is too coarse. Other data sources, such as Freight Traffic Census, a survey that is conducted every five years covering entire Japan, does not provide detailed facility locations and only covers outbound shipments. The exclusion of inter-regional shipments prevents the analyses from taking the impact of such shipments into account. However, in our view, due to the high percentage of the intra-TMA shipments in the data set, it is unlikely that an inclusion of inter-regional shipments would drastically change the study findings.

3.2 Analysis of spatial distribution of logistics facilities

In this step, the relative locations of logistics facilities, measured as the distance from the center of the TMA which is defined as the location in front of the Tokyo Railway Station, is analyzed. This location, which will be referred to as "urban center", is the central point of radial and ring roads network in the TMA and is the most expensive land in Japan. The analysis of the distributional trend examines the changes in the average distances from this urban center over time to determine if logistics sprawl has occurred in the TMA. The concept of "relative (logistics) sprawl", introduced by Dablanc and Ross (2012), compares the rate of the outward migration of logistics facilities against the rate for the business establishments as a whole. In the Atlanta Region, for example, logistics facilities sprawled considerably more than businesses as a whole, 4.5km versus 2.1 km. An occurrence of relative logistics sprawl suggests that newer logistics facilities are built farther away from the geographical center of the origins and destinations of the shipments, and thus causing shipment distances to increase. We are not able to conduct the same analysis due to data limitations. Instead, we carried out analyses using two different spatial references that we believe will add to the existing literature. First, we compared spread of logistics facilities against that of the population. Second, we calculated the barycenter of the shipment origins and destinations. Since smaller logistics facilities included in the data set provide service to small stores and even residences, comparison against the population distribution would capture how the spatial distribution of facilities that provide "last mile" services has changed in relation to that of their customers.

The distributions of population are based on the archived data (MIAC, 2014), and thus reflect the actual condition measured at each time point of the analysis, 1980, 1990 and 2005. However, the distribution of logistics facilities and shipment origins and destinations are calculated based on the data collected in 2003 and categorized by the year of establishment of each facility. This requires somewhat nuanced interpretation, as described in Section 4.2, but is effective in detecting an occurrence of logistics sprawl.

3.3 Analysis of proximities to shipment origins and destinations

In past studies (Dablanc and Ross, 2012; Dablanc and Rakotonarivo, 2010), the dispersed distribution (or the sprawl) of logistics facilities is suspected of exacerbating negative impacts in a city by requiring longer trip distance. We calculated two proximity measures to test whether this is also the case in the TMA. For the analysis, the facilities were aggregated into three groups depending on the year of establishment: 1980 or earlier, during the 1981-1990

[2] Shippers and sometimes receivers hire carriers to transport freight. Only instances in which a carrier can be a shipper or a receiver is when it hires another carrier for transporting freight.

period and during the 1991-2003 period. The first proximity measure is the average shipment distances. For each shipment, the Euclidean distance between the coordinates of the facility and the origin (for inbound shipments) or destination (for outbound shipments) was calculated. Then, the average shipment distance was calculated for each facility. Use of Euclidean distances is not ideal as, in some cases, businesses can reduce travel distances by locating closer to expressway interchanges or major arterials that provide less circuitous routes to destinations. While shortest path analysis (based on travel time to reflect real-world situation) would address such issue, it would require detailed information on the prevailing network condition in 2003, which is not available. We have decided not to conduct a shortest path analysis based on distances as it is likely to introduce additional uncertainty in the analysis while it may not bring significant improvements in accuracy. It should be noted that the recent empirical work by Blei et al. (2015) indicates that the ratio between the actual travel distance and the Euclidean distance is relatively consistent across locations and local network figurations in an urban area. Based on these reasons, we believe the approximation using Euclidean distances is the most appropriate approach for this study.

The second proximity measure is the difference between the actual and optimized (or minimized) shipment distances. To obtain the optimized shipping distance, we computed, for each facility, the location that would minimize the shipping distance D_i, given the spatial distribution of origins and destinations associated with the facility. Specifically, the coordinates of the optimum facility location, X_i and Y_i, are determined by minimizing D_i in the following function,

$$D_i = \sum_k v_{ik} \sqrt{(x_{ik} - X_i)^2 + (y_{ik} - Y_i)^2}$$

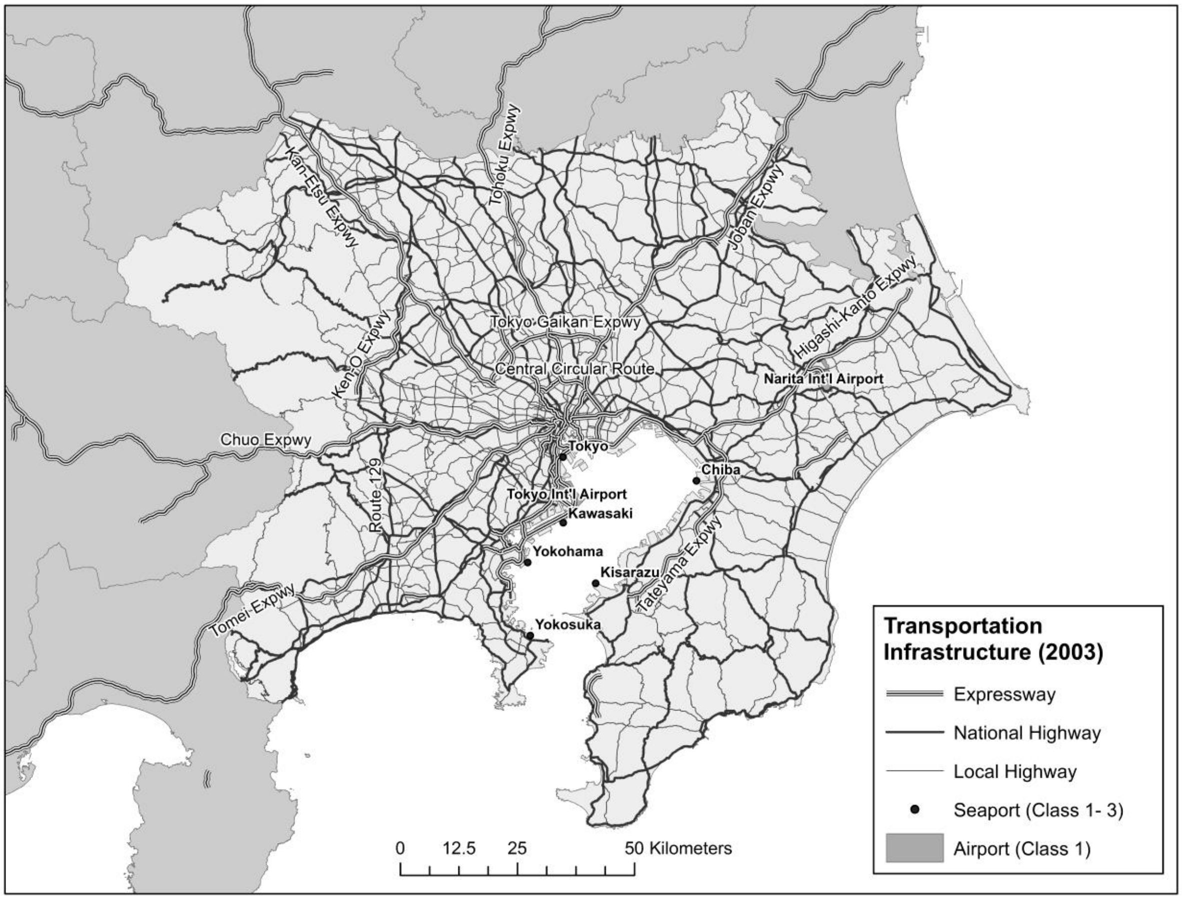
where,
(X_i, Y_i) : the coordinates of the optimum location for facility i
(x_{ik}, y_{ik}) : the coordinates of the shipment k's origin/destination associated with facility i
v_{ik} : the number of vehicles for shipment k of facility i

This definition of the optimal location is the "median center" proposed by Kulin and Kuenne (1962) as the solution to Alfred Weber's classic facility location problem. For this optimization problem, quasi-Newton method in R software environment was applied. It should be noted that this is not necessarily equal to the operator's optimal location which minimizes its total operation costs for the firms. However, if it can be assumed that Euclidean distances between shipment origin and destination serve as reasonably accurate approximations of non-user costs associated with shipments, this measure can be used to evaluate the social impacts of the locations of logistics facilities.

4. The Geography of Logistics Facilities in Tokyo Metropolitan Area

4.1 Tokyo Metropolitan Area

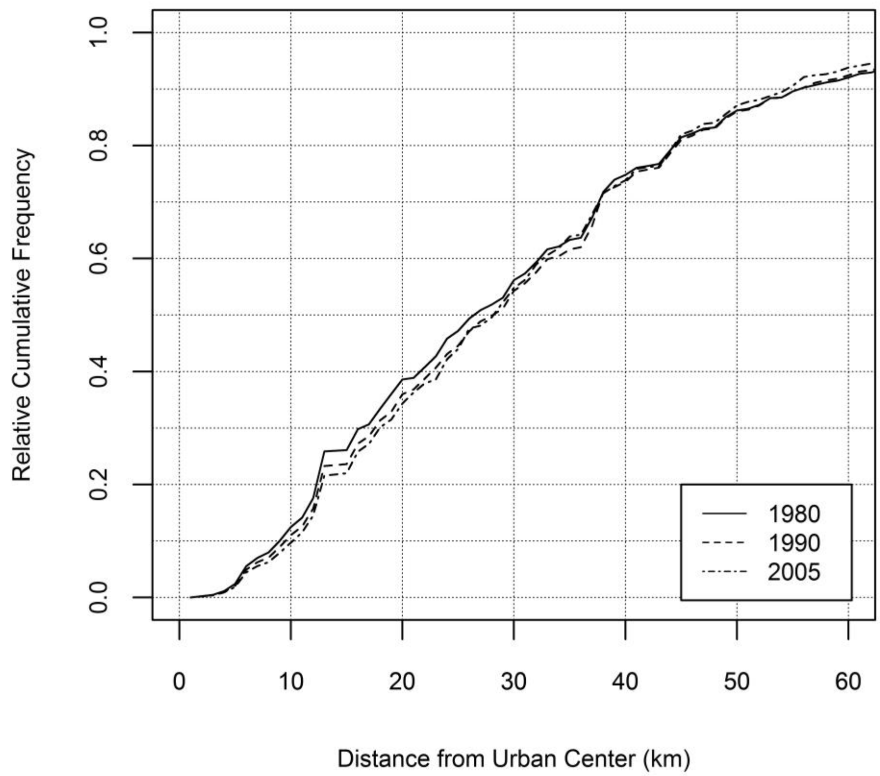
The Tokyo Metropolitan Area (TMA), which is covered by the 2003 TMFS, was home to 36 million people (MIAC, 2005) and 1,493 thousand establishments (MIAC, 2006) at the time of the survey. As shown in Figure 1, two international airports and several large seaports along the Tokyo Bay function as gateways for the area. As in many cities, surface roads in the TMA are congested; however, even compared against other major cities in the world, the level of congestion in Tokyo is extreme. A study by the Ministry of Land, Infrastructure, Transport, and Tourism (2011) found that the accessibility in the TMA, measured as the total land area that can be covered within one hour of travel by auto from the urban center, is less than half of those in Paris, New York, or Berlin while comparable in areal size. While there has been a plan to complete a system of expressways consisting of three ring and nine radial roads since 1963, the construction of the ring roads has stagnated compared to radial roads; by 2003 only the northern and the eastern sections of Central Circular Route (ring road 1), the northern sections of Tokyo Gaikan Expressway (ring road 2) and the north-west sections of Ken-O Expressway (ring road 3) have been completed while the most parts of radial roads have been completed by 1980s. Therefore, national highways, such as Route 129, played a complementary role for missing ring road sections.



Note: National and Local Highway network shows the system circa 1995. Source: MLITT, 1996, 2003, 2008, 2012a, 2012b, visualization by authors.

Figure 1: Geography of the Tokyo Metropolitan Area

After the World War II, the TMA has experienced a massive migration from the rural area. Such population inflows and the deterioration of environment, the shortage of residential units, and land price increase in the central locations caused the rapid suburbanization in the TMA until late 1970s. However, the pace of migration and suburbanization slowed down considerably thereafter (Okamoto, 1997). Cumulative distribution curves of population for 1980 and 2005, shown in Figure 2, confirm that, in terms of population, the TMA did not experience a sprawl unlike many of the large urban areas in other developed countries. As discussed in the following section, the average distance of population from the urban center increased only slightly during the study period.

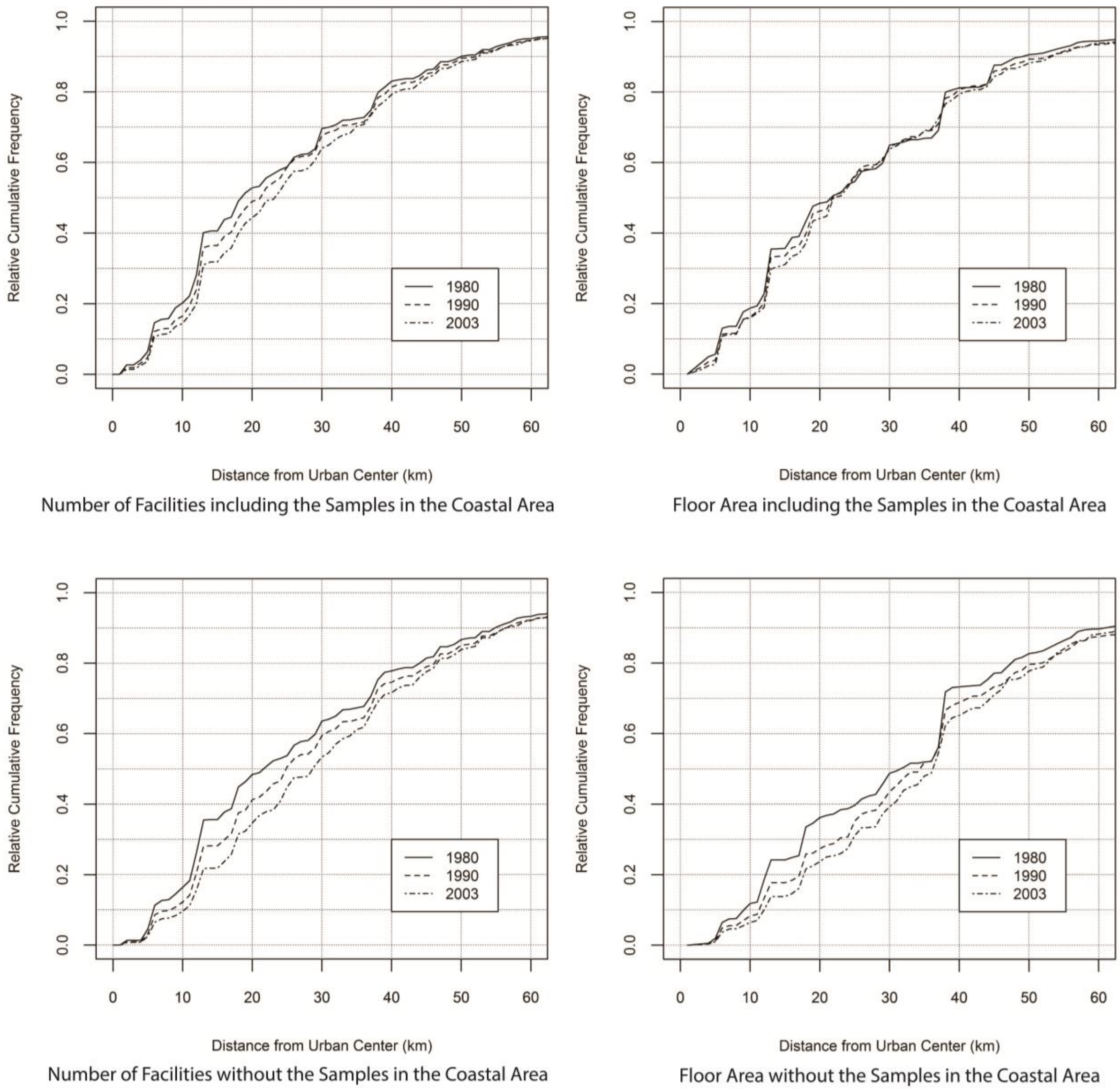


Source: MIAC, 2014, calculations by authors.

Figure 2: Distribution of population in the Tokyo Metropolitan Area

4.2 Spatial distributions of logistics facilities

The spatial distribution of logistics facilities is measured using both the number of facilities and floor area of the facilities. Figure 3 shows that in terms of the number, logistics facilities exhibited a small, but observable outward expansion between 1980 and 2003. The difference between the two cumulative distributions, for 1980 and 2003, reaches the maximum around 15 kilometers from the urban center and thereon continues to decrease until about 50 kilometers away. The cumulative distributions beyond 50 kilometers track closely to one another. In terms of floor areas of the logistics facilities, however, the distributions are nearly identical, except for a small gap that exists between 13 and 22 kilometers from the urban center. Excluding the coastal areas amplifies the gaps in the distributions of both the number and floor areas across time periods. This suggests a sprawling of inland logistics facilities.



Note: Logistics facilities equal to or larger than 400 m^2 only. Source: TPCTMR, 2003, calculations by authors.

Figure 3: Distribution of logistics facilities

Tables 3 and 4 show the average distances from the urban center for population, logistics facilities, and shipment origins and destinations. Our analysis reveals that the average distance of the logistics facilities from the urban center has increased considerably more than that of the population (2.4km versus 0.4km). When only the inland facilities are included, the average distance increased by 4.1 km. Although the concentration of logistics facilities along the coastal area seems to neutralize the sprawl of inland facilities to a degree, it should be noted that the facilities in the coastal areas are not interchangeable with those in the inlands as they tend to serve importing/exporting businesses, heavy industries, and energy sectors that are located along the Tokyo Bay. The pattern of outward migration parallels the trends observed in other studies (Dablanc and Rakotonarivo, 2010; Dablanc and Ross, 2012) that found strong evidences of logistics sprawls. Unlike many other large urban areas in the world, the TMA has not experienced significant outward migration of population since the 1980's. As such, this analysis shows that even without a population sprawl, an outward migration of logistics facility has occurred in the TMA. Our analysis is based on a cross-sectional data and thus the results are not directly comparable with past studies that used longitudinal data (e.g. Dablanc and Ross (2012)). However, our analysis shows that newer facilities are located farther away from the urban center, which is indicative of logistics sprawl[3].

Interestingly, the origins and destinations associated with these logistics facilities in the TMA do not show much variation among the facilities of different ages. This suggests two possibilities. The first interpretation is that the businesses in the TMA, represented by the origins and destinations of shipments, did not migrate outwards between 1980 and 2003. This interpretation is valid only if the older logistics facilities in the sample kept serving the same origins and destinations over the years. In other words, if the logistics facilities that were built before 1980 still serve the same origins and destinations today, the shipment data can be used to measure the migration of businesses in the TMA. The second interpretation is that there has been a migration of businesses in the TMA, but the logistics facilities, regardless of their age, serve similar set of origins and destinations. This requires older facilities to cultivate new customers as businesses migrated. It is likely that the truth is somewhere between these two possibilities. Regardless, both of these possible interpretations point to an occurrence of a relative logistics sprawl in the TMA. In the next section, we will examine the proximities of facilities to shipment demands in more detail using the TMFS data.

Table 3: Distribution of population in the Tokyo Metropolitan Area (1980, 1990 and 2005)

Year	Population (mil.)	Ave. Dist. from the center (km)
1980	30.1	29.8
1990	33.4	30.4
2005	35.7	30.2

Source: MIAC, 2014, calculations by authors.

Table 4: Distribution of logistics facilities and shipments in the Tokyo Metropolitan Area

		Logistics facility		Shipment origin and destination	
	Establishment Year (prior to)	No. of facilities	Ave. Dist. from the center (km)	No. of vehicles	Ave. Dist. from the center (km)
Including coastal area	1980	1,020	24.5	6,663	26.9
	1990	1,700	25.7	9,599	26.3
	2003	2,803	26.9	17,532	26.4
Excluding coastal area	1980	744	27.0	5,319	27.9
	1990	1,186	29.3	7,661	27.1
	2003	1,971	31.1	13,600	27.3

Source: TPCTMR, 2003, calculations by authors.

4.3 Analysis of proximity measures

In this section, the analysis will only include the inland logistics facilities that are located more than 1.5 km from the coastal line. Table 5 compares average shipment distances, calculated based on the Euclidean distances between the recorded origins and destinations of shipments for each facility, for logistics facilities built during different time periods (and were still in existence in 2003). The table shows that the average shipping distance increase for newer facilities. The table also shows that the average shipping distance increases along with the outward migration of newer facilities, suggesting that logistics sprawl played a role in longer shipment distances. However, it should be noted that the rate of migration, as measured by the average distance from the urban center, is the greatest for the facilities built during 1991 – 2003 while the greatest increase in the average shipment distance is observed for those built during 1981-1990.

[3] For this finding to be a "false positive", a disproportionate share of facilities that have closed or converted had to be located far away from the urban center, which we believe is very unlikely.

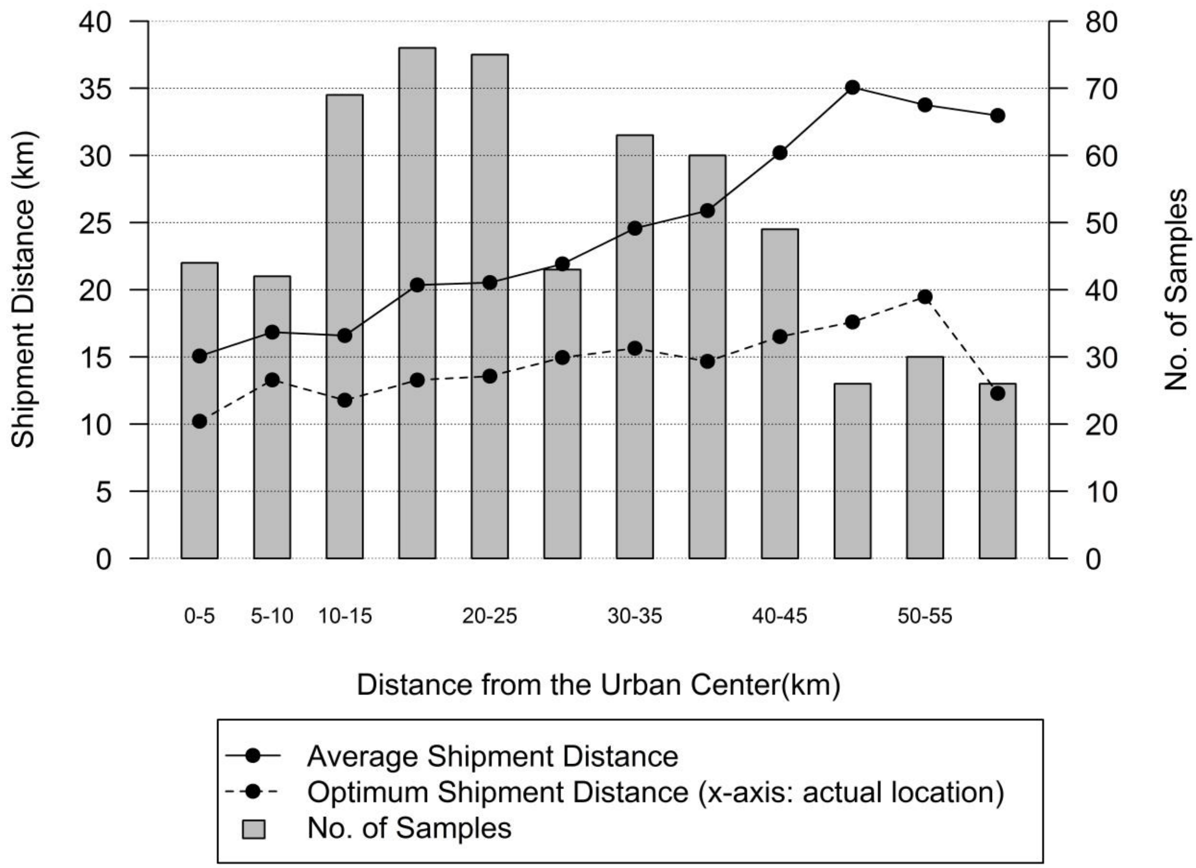
Table 5: Distance from the urban center and shipment distance by year of establishment

Year of establishment	No. of samples	Average distance from the center (km)	Average shipment distance (km)
Pre-1981	258	26.2	19.2
1981-1990	128	28.0	23.3
1991-2003	245	32.6	23.8
All	631	29.0	21.8

Source: TPCTMR, 2003, calculations by authors.

The next step of our investigation compares the proximities of facilities to shipment demands by calculating the difference between the actual shipment distance and the median center of the shipment destinations and origins. As discussed earlier, the median center for each facility is determined by an iterative procedure that found the coordinates that minimize the aggregate shipment distances given the locations of origins and destinations recorded in the survey. Both the actual and optimum shipment distances are calculated as Euclidean distances. The difference between the two would capture the degree of spatial mismatch between the locations of logistics facilities and their customers.

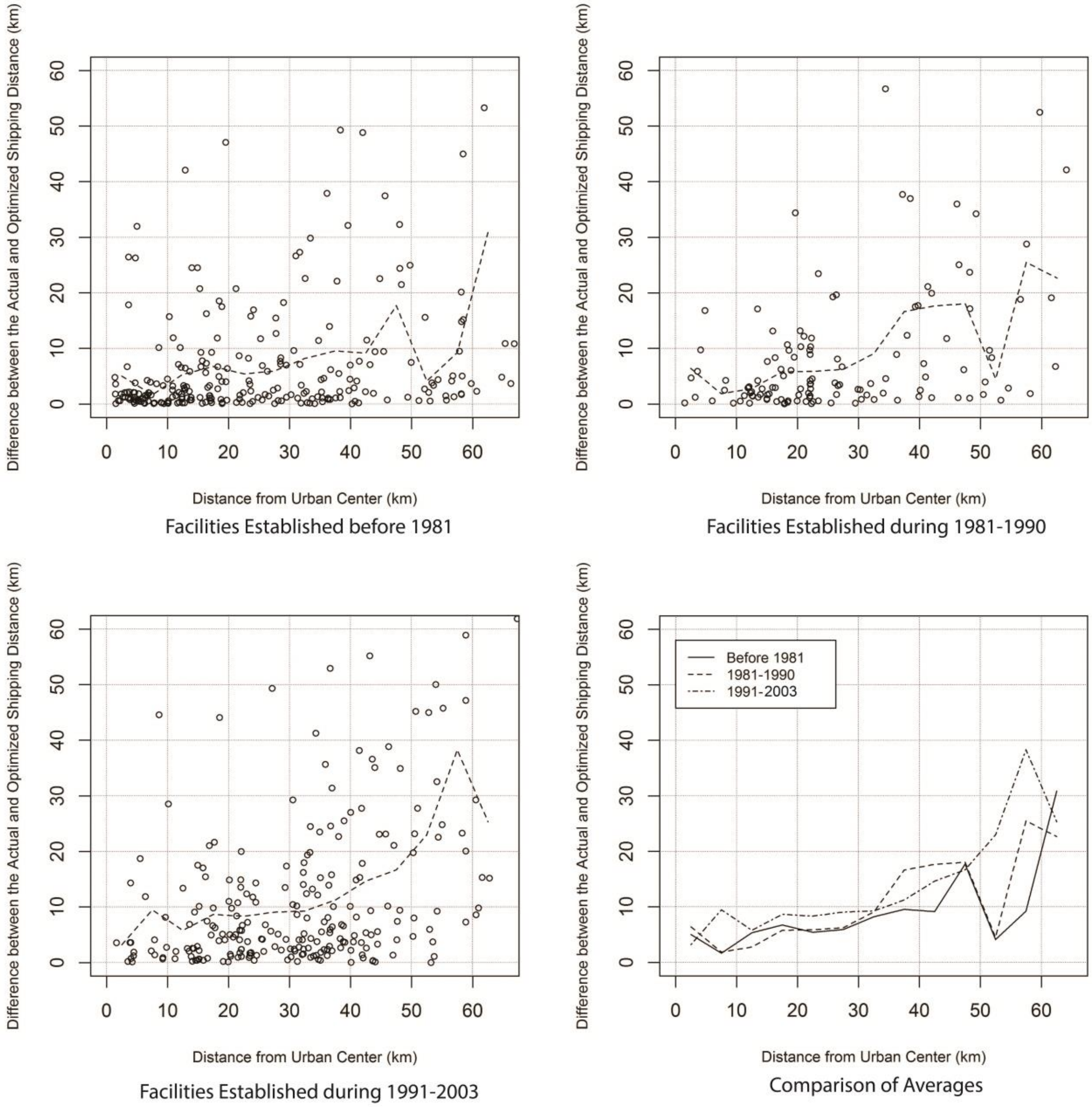
Figure 4 plots the difference in the actual and optimum distances against the distances of the facilities from the urban center, which is aggregated at 5 kilometer increments. The plot shows that the levels of spatial mismatch, represented by the vertical difference between the two lines, increase as the facilities move farther away from the urban center. In the outer suburbs, the actual shipment distance is nearly twice that of the optimum case on average. The reason for the rather rapid increase in spatial mismatch of logistics facilities in outer suburbs is not clear but one key consideration is that in the suburbs, proximity to the expressways and National Highways is of greater importance than distances to shipment origins and destinations for locating logistics facilities for minimizing travel times, and presumably costs.



Source: TPCTMR, 2003, calculations by authors.

Figure 4: Actual and optimum shipment distances

Figure 5 compares the levels of spatial mismatch by the age of facilities. Each plot depicts the differences between the actual and optimum shipping distances in the y-axis and the facilities' distances from the urban center in the x-axis. Each dot represents a facility. Each plot also includes a trend line, depicting the averages for facilities at 5 kilometer increments (of the distance from the urban center). The last plot, in the right bottom, compares the trend lines from the three time periods.



Note: Lines show the averages of the facilities having more than one shipment origins and destinations at 5 km increments. Source: TPCTMR, 2003, calculations by authors.

Figure 5: Difference between the actual and optimized shipping distance

The plots indicate that for all three time periods, the levels of spatial mismatch increase as facilities move away from the urban center. This finding suggests that the location, rather than the age of facility, is the main determinant of spatial mismatch and thus curbing logistics sprawl should be an effective way to reduce truck traffic and various negative impacts associated with it. However, the plots also suggest it will be a challenge to actually implement policies to control the logistics sprawl in an effective manner even if it is politically and administratively possible to do so. This is because the plots show that there are some facilities in the suburbs that are quite close to shipment demands, for example those that are 50-55 km away from the urban center for the first two earlier periods. Moving those facilities closer to the urban center will likely to make them farther from the associated shipping demands. If the locations of shipment origins and destinations shift frequently, it will be quite difficult to determine which facilities would be better matched to the spatial distribution of shipment demands in the long run and thus should be allowed to locate in the suburbs.

5. Conclusion

This paper analyzed the spatial distribution of logistics facilities and examined the argument that logistics sprawl impart negative impacts on the society by increasing truck trip distances. While there are some data limitations, a large-scale freight survey conducted in the Tokyo region enabled us to jointly analyze the logistics facilities' locations with actual shipment records. Past studies of logistics sprawl have focused on the U.S. or European cities, and this, to our knowledge, is the first systematic examination of the issue for a large Asian metropolitan area. As such, the spatial distribution of logistics facilities in the TMA should be a valuable data point to be added to the existing literature. In addition, the methodologies introduced to investigate the spatial distributions and proximities of logistics facilities to shipment demands in this paper should serve as useful references for other researchers.

Between 1980 and 2003, the locational pattern of logistics facilities has changed significantly in the Tokyo region. We found that the logistics facilities in the TMA have migrated outward, albeit at a much smaller scale than the cases described in past studies (Paris (Dablanc and Rakotonarivo, 2010) and Atlanta (Dablanc and Ross, 2012)). It should be noted that the population in the TMA did not migrate outward during the time period, unlike many U.S. and European cities. Due to the lack of historical business location data for the TMA, we were not able to directly verify whether or not the outward migration of the logistics facilities outpaced businesses as a whole. However, there are circumstantial evidences that a relative sprawl, as defined by Dablanc and Ross (2012), occurred in the TMA.

Our analysis of the shipment data validates the thesis put forward by Dablanc and others that logistics sprawl increases truck travel. Furthermore, we found that, regardless of their age, logistics facilities tend to increase spatial mismatch with the locations of shipment origins and destinations as they locate farther away from the urban center. However, it is also important to note that some facilities in the suburbs are located close to the optimum spot. Furthermore, although it is widely assumed that increased shipment distances and truck travel result in negative social impacts, we must keep in mind that when considering costs of time and effects of congestion, whether or not an outward migration of a facility is actually socially detrimental depends on an individual facility and its business operations (e.g. vehicle types used, time of operation, shipment origins and destinations, etc.). In terms of actually developing a policy and a system to control logistics sprawl, further research is needed to determine the factors that can be used to assess which logistics facilities would operate efficiently and which one would not given the dynamic nature of freight movement. This underscores the importance of coordinated land use planning, both for logistics facilities and other businesses, as it would reduce the degree of spatial mismatch and contribute greatly toward the reduction of negative impacts from truck freight movements in urban areas. One promising approach may be market-based tools such as distance-based pricing of trucks as it would provide incentives for the logistics facilities to self-organize their locations efficiently[4]. At the same time, however, policies must be implemented to ensure that there is an adequate supply of land, both in quantity and locations, for logistics facilities to choose from for such program to be effective. For formulating market-based strategies, or any policies to address logistics sprawl for that matter, it is imperative to understand the location choice behavior of logistics entities to avoid unintended effects.

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