Spatial Dynamics of the Logistics Industry and Implications for Freight Flows

June 2016

A Research Report from the National Center for Sustainable Transportation

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Disclaimer

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Spatial Dynamics of the Logistics Industry and Implications for Freight Flows

ABSTRACT

This project examines changes in the spatial pattern of warehousing and distribution (W&D) activities. W&D activities are decentralizing in response to rising land values and scale economies. Ultimately, we seek to understand whether these spatial shifts result in more truck VMT, or whether the efficiencies gained by larger scale operations allow offsetting savings, such as enabling the use of larger trucks or achieving higher average load factors. Understanding how these shifts are affecting truck VMT is essential for developing effective policies for managing truck VMT and their associated emissions. However, there is no good source for tract or zone level truck flow data, or for intra-metropolitan truck origin-destination data. As a first step, we focus on accessibility. From the literature on passenger travel, we know that travel distance is related to accessibility. Thus, changes in accessibility to goods markets should be a proxy for goods travel distance, all else equal.

We examine changes in the spatial pattern of warehousing and distribution activities for the four largest California metropolitan areas: Los Angeles, San Francisco, Sacramento, and San Diego, using ZIP Code Business Patterns data for 2003 and 2013. We develop measures of decentralization and concentration. Our results are mixed. When using establishment counts, only Los Angeles shows a consistent pattern of decentralization. There is more evidence of decentralization when using employment counts, which is consistent with larger scale facilities being built at the periphery. Spatial patterns for the largest metro areas are quite different from those of the smaller metro areas. We surmise that higher development density and associated land prices push W&D activity to more distant areas. In contrast, W&D location in San Diego and Sacramento is relatively closer to employment, population, and the CBD. If all truck traffic were local, our results suggest possible increases in truck VMT, particularly for the largest metro areas. However, more than half of all commodity flows is non-local. The decentralization we observe is likely related to domestic and international trade, for which access to local markets is less important. More research is necessary to determine whether decentralization is a consistent trend in large metro areas, and, if so, whether impacts on truck VMT within metro areas is positive or negative.

1 INTRODUCTION

The purpose of this research is to examine changes in the spatial pattern of warehousing and distribution (W&D). It is argued that W&D activities are decentralizing (moving away from the central core) in response to rising land values and scale economies. Ultimately, we seek to understand whether these spatial shifts result in more truck VMT, or whether the efficiencies gained by larger scale operations allow offsetting savings, such as enabling the use of larger trucks or achieving higher average load factors. Understanding how these shifts are affecting truck VMT is essential for developing effective policies for managing truck VMT and their associated emissions. However, there is no good source for tract or zone level truck flow data, or for intra-metropolitan truck origin-destination data. We therefore focus on changes in the spatial distribution of W&D activities and use measures of relative location to infer potential truck VMT impacts.

One of the most notable recent trends in metropolitan areas is the rapid growth in warehousing and distribution activity. In the US, the number of warehousing establishments increased 15%, and warehousing employment increased 33% between 2003 and 2013.[1] In contrast, total establishments and employment increased by 3% and 4% respectively. Explanations for this growth include continued globalization, changes in consumer demand, advances in information, communication, and transportation technology, just-in-time production, and restructuring of the logistics industry (Hesse & Rodrigue, 2004; Cidell, 2011).

It is argued that logistics restructuring has prompted decentralization of logistics facilities. In seeking more efficient and larger-scale operation, warehousing and distribution (W&D) activities are moving to the urban periphery, trading off higher transport costs and diminished access to the local market and labor force for lower land costs. Decentralization may contribute to reducing freight total shipping cost, whereas increased distance from urban centers may result in increased freight vehicle miles traveled (VMT) and associated externalities, such as congestion, increased fuel consumption, noise, GHG and criteria emissions, accidents, and infrastructure damage (Anderson, Allen, & Browne, 2005). Given scale economies and input costs, decentralization may be a rational business decision. While the logistics business benefits from cost savings, however, any additional external costs are incurred by society at large. (Rodrigue, Slack, & Comtois, 2001).

An understanding of W&D distribution and decentralization trends is a first step in determining the extent to which decentralization may be a problem worthy of policy intervention. However, there is no good source for tract or zone-level truck flow data, or for intra-metropolitan truck origin-destination data. It is therefore not possible to directly test whether W&D location changes result in more truck VMT. Moreover, it is not clear that decentralization necessarily leads to more truck travel. If freight consumers have also decentralized, or if larger scale operations lead to more efficient routing, W&D decentralization may have little effect.

[1] In North American Industry Classification System (NAICS) 493 Warehousing and Storage.

An ideal methodology for this research would be to compare truck VMT with respect to the distribution of W&Ds over time. It would require full information about the type, size and location of W&Ds and the commodity/truck flows in and out of the facility (e.g. type and value of commodity, truck size, load factors, delivery frequency, origin and destination and routing schemes of the supply chain, etc.) for at least two time periods. Such information is not available in the U.S. A second-best option might be to conduct a simulation study. Simulations require some of the same data, or they must be based on numerous assumptions. Given that we do not yet have extensive evidence of decentralization, or the data to inform development of a robust model, we start with the more basic question of spatial change.

As a first approximation of impacts on freight flows, we use the concept of accessibility. The literature on passenger travel has documented that travel distance is related to accessibility. Thus, changes in accessibility to goods markets should be a proxy for goods travel distance, all else equal. This report examines recent trends in W&D location and decentralization in four metropolitan areas in California. We develop multiple measures of spatial location in order to capture both absolute and relative changes in accessibility over time. We use measures of centrality and concentration and consider the distributions of population, employment and freight infrastructure.

The remainder of this report is organized as follows. Section 2 provides a brief review of the literature. Our research approach is presented in Section 3, and data is described in Section 4. Section 5 presents results, and the report closes with some conclusions and suggestions for future research.

2 LITERATURE REVIEW

As production and distribution systems have reorganized, so has their spatial structure. The reorganization of production and distribution systems has been well documented, but their spatial reorganization has not (Hesse & Rodrigue, 2004). Restructuring has been attributed to: 1) globalized market-and customer-driven goods production systems; 2) integrated management of information; 3) e-commerce, consumerism and consumer preference changes; 4) an increasing share of high value/low weight goods; and 5) increased competition due to 1970s and 1980s deregulation and liberalization in the US, and integration of European markets in the 1990s (Hesse & Rodrigue, 2004; Castells, 1996; Knowles & Hall, 1998; Dablanc, Diziain & Levifve, 2011).

2. 1 Restructuring and Decentralization

Restructuring has resulted in geographically fragmented supply chains, which imply geographically separated locations of suppliers, producers, distributors and consumers (Rodrigue, 2008). The concurrent spatial reorganization is attributable to pressure for economies of scale in goods production and distribution systems. Decreased freight transport costs due to transport technology advancement and transportation infrastructure improvements, have eased spatial reorganization processes (Hall, Hesse & Rodrigue, 2006). Containerization and inter-modalism significantly expanded freight transport capacity (Cidell, 2011). These factors have facilitated the emergence of a logistics industry that puts emphasis on reliability and high throughput of goods transportation (Hesse & Rodrigue, 2004). High throughput movement, rather than storage, has become the main goal of logistics, and demand for a centralized goods distribution system (e.g. logistics consolidation) increased significantly (Cidell, 2011; Rodrigue, 2008).

This systematic reorganization of logistics has generated a spatial reorganization of facility locations, termed the “new distribution economy” (Hesse & Rodrigue, 2004, p. 178) and the “new spatial logic” (Hesse, 2007, p. 8). This globalized system, which may span several continents, requires efficient goods distribution chains that have become more and more sensitive to the spatial configuration of logistics facilities rather than the direct transportation costs itself (Movahedi, Lavassani & Kumar, 2009). Location decisions are based on securing proper access to metropolitan, regional, international and intercontinental economies (Bowen, 2008).

Metropolitan population is the main driver for location of goods distribution activities in the conventional model (McKinnon, 1983). The new logistics system selects physical locations based on real estate costs (Hesse, 2006), access to highways and rail facilities (Rodrigue, 2006), access to low-skilled and low-wage labor, and reasonable business costs (Cidell, 2011). In particular, the rebalance of tradeoffs between transport and inventory costs plays significant role (McKinnon, 2009). Also, optimal scale becomes a major factor in location choice (Dablanc & Ross, 2012). Given the emphasis on scale and velocity, we would expect spatial shifts away from the urban core.

The logistics industry responded to high throughput pressure by immediate expansion of freight capacity at freight hubs (e.g. hinterland of seaports or cargo service airports), but this approach soon reached the limit due to development density, land constraints and arterial congestion (Hesse & Rodrigue, 2004). In search of alternative locations, increased distance from the urban core offered cheap land, larger parcels, access to congestion-free transportation infrastructure, and a supporting environment for logistics operations. In addition, global supply chains change the location calculus; access to major links in the national or international network that connect local and global became more important (Hesse, 2002). This new location logic applies to major industry segments: warehousing, trucking, freight forwarding, and air cargo service providers (Hesse & Rodrigue, 2004). The result is logistics decentralization and clustering of freight facilities in large metropolitan areas (Dablanc & Ross, 2012).

2. 2 Empirical Evidence

Empirical studies of W&D location are limited. Two aspects of spatial structure changes have been of particular interest: (1) movement of facilities from the urban core to peripheral places (decentralization) and (2) clustering of logistics functions (concentration).

An expansion of warehousing activities and associated W&D decentralization have been documented in three major North American metropolitan areas – Los Angeles, Atlanta, and Toronto, during the 2000s (Dablanc & Ross, 2012; Dablanc, Ogilvie & Goodchild, 2014; Woudsma, et al. 2016). These studies use centrography point pattern analysis, which calculates the average distance of each W&D from the geographic centroid of all W&Ds. The geographic spread of W&Ds is measured over time and compared to that of all businesses, as generators or attractors of freight shipment. In all cases, W&Ds decentralized more than all businesses. Suburbanization of W&D activities were observed in metro areas in UK (14 metro areas), France (Paris) and Japan (Tokyo) as well (Allen, Browne & Cherrett, 2012; Dablanc & Rakotonarivo, 2010; Sakai et al, 2015). In contrast, W&D concentration is observed for Seattle, again using the same centrography measure (Dablanc, Ogilvie & Goodchild, 2014). The authors surmise that W&D decentralization may occur only in very large metropolitan areas, in which the functions of major trade nodes and major consumer markets coexist.

The logistics industry, which requires a specific land use and transportation infrastructure, tends to cluster around certain locations. Rivera, et al. (2014), using county-level datasets in the U.S., identified 61 major logistics clusters of which location has been stable between 1998-2008.

The authors documented a greater increase in logistics establishments and employment inside the clusters than outside and argued that such businesses take advantage of agglomeration benefits in terms of sharing transportation infrastructure. Cidell (2010) used Gini coefficients and observed decentralization in US metropolitan areas (CBSA, Core-based Statistical Areas) 1986-2009. However, the data were county level, too large a geographic unit to measure Gini coefficient properly, because many CBSAs consist of a small number of counties. Van den Heuvel et al. (2013, 1), also using the Gini coefficient, but at the establishment level, observed increased spatial concentration in a province of the Netherlands 1996-2009. Thus, the empirical evidence on W&D decentralization is mixed. One factor for concentration is municipal policies that either 'actively stimulate' or discourage logistics activities (Van den Heuvel, et al, 2013, 2). The preference for transportation accessibility – road, rail, air, and water – also has been documented (Van den Heuvel, et al., 2014).

3 RESEARCH APPROACH

Accessibility is "*the potential of opportunities for interaction*" (Hansen, 1959, pp. 73). Accessibility quantifies the extent to which the interaction between two locations is likely to occur. It considers how many activities, or opportunities, are spatially distributed around a point and how two locations interact with each other. Accessibility correlates directly with the intensity of activities and inversely with intervening factors, such as distance, travel time, and cost (Isard, 1956). The concept of accessibility was developed for passenger transport. Assuming rational, utility maximizing behavior, individuals economize on travel, and hence are less likely to choose more distant destinations, all else equal. Freight shipments work differently: each supply chain (e.g. product) optimizes within the chain. For example, in the case of direct product distribution to retailers, each producer (Coke, Pepsi) optimizes its own deliveries. Similarly, large retailers (Target, WalMart) utilize firm specific distribution systems. Thus using a traditional accessibility measure that includes a distance weight is not appropriate at an aggregate level. A comparable example for passenger travel would be an aggregate measure of hospital access that did not take into account medical insurance constraints.

A second consideration is the market itself. The above discussion implies an intra-metropolitan market, but supply chains are global. As noted in Section 2, logistics location choice is driven by access to major links to national and global markets, land availability, and access to highways. From a national market perspective, decentralized locations may increase access to customers. Again, a conventional measure of accessibility would not capture these regional or national market considerations. We therefore take a more basic and simpler approach, and address the question of whether there is any change in the spatial distribution of warehousing and distribution.

Anas, Arnott, and Small (1998) conceptualize urban spatial structure in two dimensions: centrality and concentration. Centrality is the degree to which activities are located around a single center. With regard to centrality, urban structure may be centralized (activities located close to the center) or decentralized (activities located further from the center, but still spatially oriented to the center). Concentration is the degree to which activities are located within close proximity to one another, and ranges from clustered to dispersed. Concentration can take many forms; there may be one or a few clusters, or many clusters. The share of activity that is clustered may also vary. The extreme case of dispersion would be a uniform distribution across space.

We use these concepts of spatial organization to characterize W&D locations and measure changes over time. We use both absolute and relative measures of centrality and concentration. Absolute measures provide information on changes in W&D spatial patterns. Relative measures provide information on where goods may be coming from or going to, and hence some indication of how these changes may affect transport to and from markets. We generate four categories of measures, as shown in TABLE 1.

There are many possible ways to generate these measures. For example, we could measure centrality by the average distance of all W&Ds to the city center, or to the geographic centroid of all W&Ds, as in the Dablanc and co-author studies. We could also argue that for W&Ds the "center" might be the primary trade node (port or airport or export node). We therefore generate several different measures, and compare results. TABLE 1 also lists our selected measures.

TABLE 1 Four Categories of Spatial Structure Measures

Spatial structure	Absolute	Relative
Measure of centrality	***Measure 1*. Decentralization** ***1.1 Average distance to CBD*** ***1.2 Average distance to freight nodes*** ***1.3 Average distance to W&D geographic center***	***Measure 2*. Relative decentralization** ***2. 1 Average distance to all establishments*** ***2. 2 Average distance to all employment2. 3 Average distance to all population***
Measure of concentration	***Measure 3*. Concentration** ***3. 1 Gini coefficient for W&Ds***	***Measure 4*. Relative concentration** *4. 1* ***W&D concentration by density quartiles*** ***4. 2 Gini coefficient ratio, W&Ds and all employment***

Furthermore, we use measures based on both establishments and employment of W&Ds for two reasons. First, location choices of firms underlies changes in spatial distribution, hence the establishment is an appropriate unit of analysis. Second, a measure of business size is also appropriate, because the research goal is to understand the effect of W&D location changes. The effect size is assumed to be a function of establishment size. Due to the large differences in establishment size across industries, employment is typically used to measure industry activity. The square footage of W&D facilities might be the most accurate proxy, but data on facility size is not available. In this case, employment is a second-best proxy. Most W&D decentralization studies use establishment as the unit of analysis. Adding employment-based measures may provide more insights on changes in W&D spatial patterns.

3. 1 Measure 1 Decentralization

3. 1. 1 Measures 1-1 and 1-2

Measures 1-1 and 1-2 focus on two different segments of urban goods movement (see FIGURE 1). Measure 1-1 applies to Segment 1, the flows between the CBD and W&Ds, and Measure 1-2 applies to Segment 2, flows between freight nodes and W&Ds. We use the CBD as a proxy for the local market. We define the CBD as the census tract with the highest employment density. Freight nodes include major seaports, airport, and intermodal facilities. These nodes are the metro area's major import/export nodes; locations closer to these nodes would reduce travel to W&Ds. Given the configuration in FIGURE 1, and assuming all goods flow between the CBD and import/export nodes, any location of W&D between the CBD and the nodes would lead to the same total travel. The logic of location may favor freight nodes or CBD depending upon the particular type of goods and market served by any given W&D. In addition, the spatial arrangement of CBD and freight nodes varies across metro areas. For example, the major intermodal connections in Chicago are very near the CBD. When freight nodes are near the CBD, land scarcity and price will push W&D activity to less preferred locations (Hesse and Rodrigue, 2004).

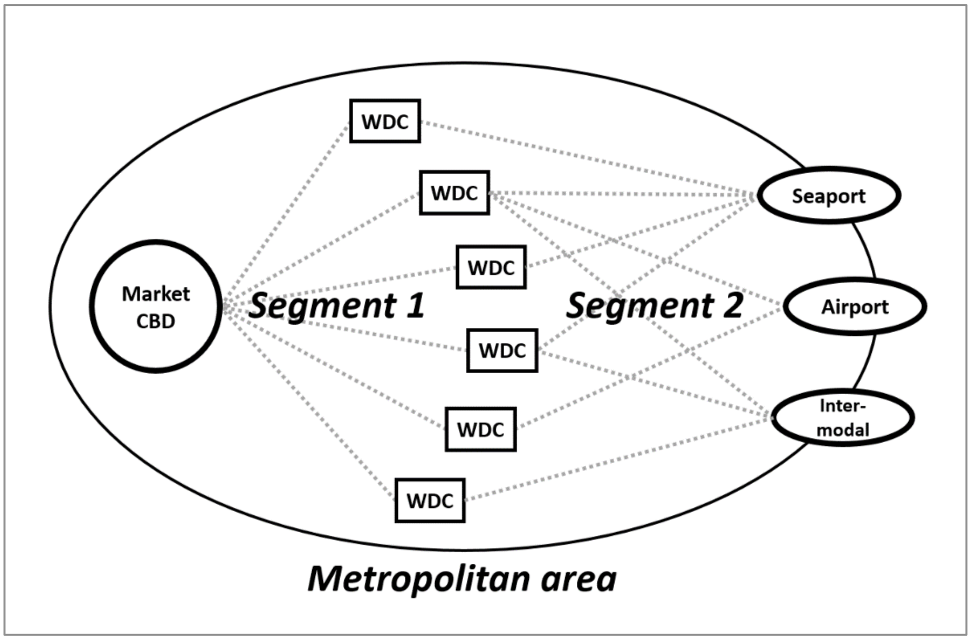

FIGURE 1 Illustration of measures 1-1 and 1-2.

Measures 1-1 and 1-2 are calculated as follows:

$$Average\ distance\ to\ CBD = \frac{\sum_{j=1}^{N} D_j * E_j}{E} \quad (1)$$

Where,
D_j = distance to CBD or freight node from each W&D (j) (n; j = 1, 2,…, N)
E_i = the number of W&D establishments or employment in ZIP Code (j)
E = sum of E_i

Distances are calculated as straight line distances between ZIP Code centroids, as our data is available only at ZIP Code level. See section 4 below.

3. 1. 2 Measure 1-3

Measure 1-3 replicates Dablanc and Ross (2012), and is illustrated in FIGURE 2. Average distance to the geographic center (barycenter) of W&Ds is:

$$Average\ distance\ to\ the\ barycenter = \frac{\sum_{j=1}^{N} D_j * E_j}{E} \qquad (2)$$

Where,
D_j = distance to the barycenter from each W&D (j) (n; j = 1, 2,…, N)
E_i = the number of W&D establishments or employment in ZIP Code (j)
E = sum of E

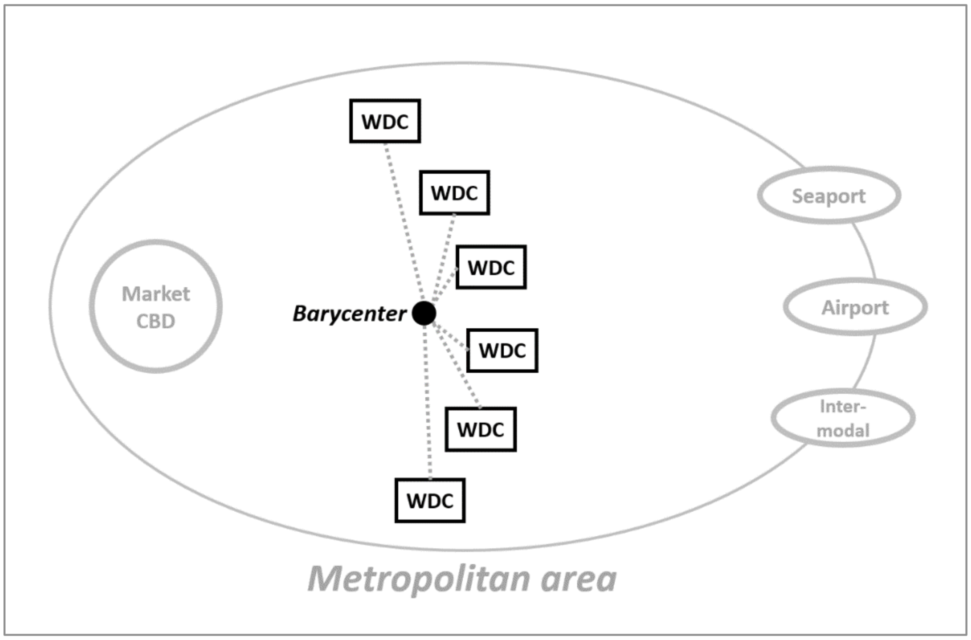

FIGURE 2 Illustration of measure 1-3.

3. 2 Measure 2 Relative Decentralization

Measure 2 quantifies the degree to which W&Ds are decentralized with respect to the distribution of all establishments, all employment and all population. Business establishments are a proxy for economic activity, and hence for goods supply and demand. Employment is also a proxy for general economic activity. Both measures include local as well as import/export activities (e.g. population serving retail, services, as well as manufacturing or trade). Population is a proxy for consumer demand (e.g. the conventional model for W&D location). Population data are available in two census years, 2000 and 2010. W&Ds in 2003 are compared to 2000 population, and W&Ds in 2013 are compared to 2010 population. Decentralized W&Ds relative to employment or population distribution implies increased freight VMT in the traditional model of an economically self-contained metro area, all else equal. Measure 2 is:

$$Average\ distance\ to\ market\ proxies = \frac{\sum_{j=1}^{N} [\frac{\sum_i^n (D_{ij} \times X_i)}{X}] * E_j}{E} \qquad (3)$$

Where,
D_{ij} = distance to ZIP Code (i) from each W&D (j) or distance to census tract (i) from each W&D (j) (i = 1, 2, . . . , n; j = 1, 2,…, N)
X_i = total establishments or employment in ZIP Code (i), or total population in Census Tract (i)
X = sum of X_i
E_i = the number of W&D establishments or employment in ZIP Code (j)
E = sum of E_i

3. 3 Measure 3 Concentration – Gini Coefficient

The Gini coefficient quantifies the degree to which W&Ds are concentrated in relatively few locations, which in our case are ZIP Code centroids. It is possible that W&Ds will cluster around freight nodes for access, or will cluster in response to zoning or other land use regulation. Clustering may provide agglomeration benefits in the form of access to labor or shared infrastructure. The potential effect of concentration on VMT is uncertain, and would depend on location relative to markets. If freight demand is relatively dispersed, a high Gini coefficient would imply more freight travel, all else equal.

The Gini Coefficient measures the proportional distribution of W&Ds relative to the proportion of spatial units in which they reside. A graph of uniform distribution of W&Ds across all spatial units would yield a line with slope = 1. See Figure 3. The Lorenz Curve plots the actual distribution, with observations ordered from the lowest number of W&Ds per spatial unit to the highest. Each point on the curve gives the share of W&Ds for the share of spatial units. The difference between the straight line of uniform distribution and the actual distribution measures the degree of concentration. The more concentration, the more the Lorenz Curve deviates from the straight line. The difference between the Lorenz Curve and uniform distribution is Area A in Figure 3. The remaining area (Area B) may be considered the difference between the actual distribution and total concentration (all activity in one location). The Gini Coefficient measures the proportion of Area A relative to the entire area under the uniform distribution line. It is calculated as:

$$Gini\ coefficient = \frac{Area\ A}{Area\ A + Area\ B} \quad (4)$$

It ranges in value from zero (uniform distribution) to one (maximum concentration).[2]

The Gini coefficient is a measure of concentration, but has no spatial meaning, because the measure is based on the rank ordered cumulative distribution of activities in spatial units, not on their spatial adjacency.

[2] The definition of GINI Index, World Bank, Development Research Group. (http://data.worldbank.org/indicator/SI.POV.GINI)

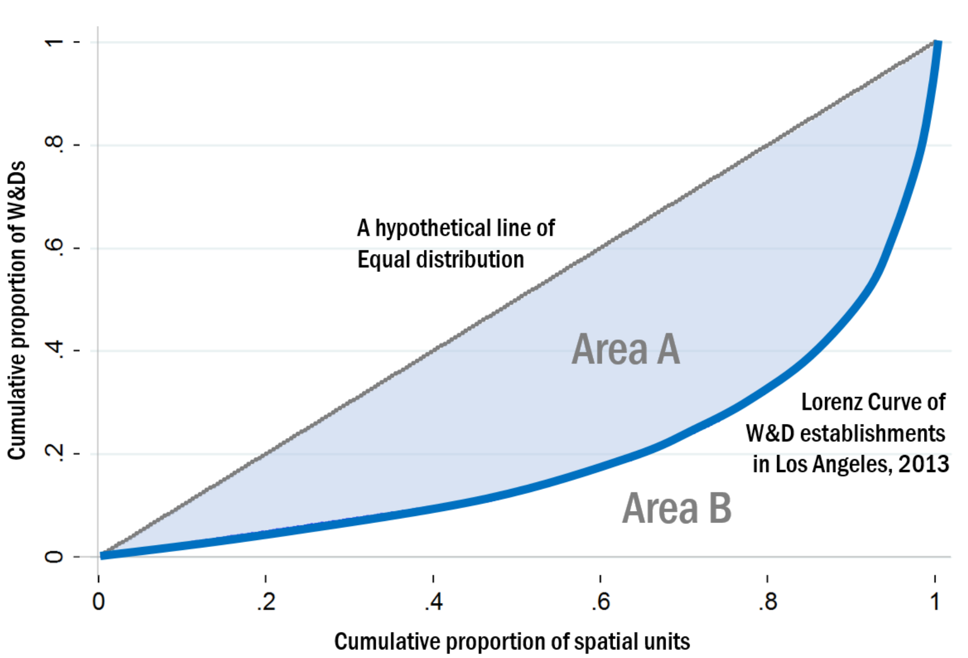

FIGURE 3 Gini coefficient and Lorenz curve, Los Angeles, 2013

3. 4 Measure 4 Relative Concentration

Measure 4 quantifies the degree to which W&Ds are concentrated relative to the concentration of all employment. Total employment is used as a proxy for direct and second-order demand for goods movement.

3. 4. 1 Measure 4-1 Relative Gini coefficient

Measure 4-1 is calculated as the difference between the Gini coefficient of total employment and the Gini coefficient of W&D employment. If Measure 4 exceeds zero, W&D industry is more concentrated than all employment. Measure 4 is calculated as:

$$Relative\ Concentration = Gini_{WD\ i} - Gini_{Emp\ i} \quad (5)$$

Where,
$Gini_{WD\ i}$ = Gini Coefficient of employment in W&D industry in metro (i)
$Gini_{Emp\ i}$ = Gini Coefficient of total employment in the entire industry in metro (i)

3. 4. 2 Measure 4-2 W&Ds in employment density quartiles

Measure 4-2 quantifies the proportion of W&Ds that are located in employment density quartiles. Employment density quartiles are based on total employment density. W&D location with respect to employment density reflects trade-offs between land costs, transport costs, and securing access to market or to labor. W&Ds in the fourth quartile (highest employment density) might benefit most from direct access to markets, whereas W&Ds in the first quartile might benefit most from low land rent.

4 DATA

Our main data source is the annual ZIP Code business patterns (ZBP) datasets for 2003-2013. ZBP is a subset of County Business Pattern (CBP) data. ZBP data includes the number of establishments, employment, first quarter payroll, and annual payroll for all establishments at the 6-digit industry code level. The Business Register is the source of employer and establishment data in CBP, which maintains records of each known establishment with paid employees located in the U. S., Puerto Rico and Island Areas. An "establishment" is defined as "a single physical location at which business is conducted or services or industrial operations are performed." [3] Every business with an EIN (Employer Identification Number) with at least one employee is included in CBP. The spatial unit of ZBP is United States Parcel Service (USPS) ZIP Codes, which are derived primarily from the physical addresses of businesses.

There are some significant limitations to the ZBP data. First, ZIP Codes are relatively large spatial units, and we have no information on the location of establishments or employment within the ZIP Code. We must assume a distribution or use centroids. We examined the centroid locations for Los Angeles and compared to population and employment from other data sources. The centroids generally represent the locations with the highest concentration of establishments, and we therefore choose to use centroids as the basis of our measures. Second, a ZIP Code is an aggregation of physical addresses, rather than a geographically delimited area. Thus, ZIP Code maps are estimates of boundaries. Third, ZIP Codes are not consistent with political boundaries. Fourth, like census tracts, ZIP Code size is correlated with development density.

Finally, some data are suppressed for confidentiality. Employment counts are available only at County- or State-level. ZBP – ZIP Code level – provides the number of establishments by nine establishment size classes. [4] To identify employment counts, we used quadratic programming to find an establishment-size vector that minimizes the difference between the county-level employment count and the ZIP Code-level sum of the number of establishments in each size class multiplied by the size vector. The size vector is estimated for each year. We considered other data sources, including proprietary establishment level data. ZBP is more consistent and reliable across years and locations, and is available for the entire US. We therefore chose ZBP.

To identify W&Ds, we use establishments within NAICS 493, warehousing and storage, which is part of the two digit 48-49 transportation and warehousing sector. NAICS 493 includes facilities that store goods, and/or provide logistics services.

We use the four largest metropolitan areas in California – Los Angeles CSA (Combined Statistical Area), San Francisco CSA, Sacramento CSA, and San Diego MSA (Metropolitan Statistical Area),

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[3] CBP, Census Bureau (http://www. census. gov/econ/cbp/)

[4] Nine establishment size classes: (1) 1-4, (2) 5-9, (3) 10-19, (4) 20-49, (5) 50-99, (6) 100-249, (7) 250-499, (8) 500-999, (9) 1000 or more employees

as our case study areas. [5] [6] They vary in size, industry mix and role in the global economy. The extent to which each metropolitan area participates in freight activities varies widely. Los Angeles CSA (LA) is the largest metro area in California, and has almost half of the population and employment of the State. It is a major international trade node. It has the largest container seaport complex in the U. S., which handles 37% of all containerized trade (USDOT, 2013), and it has the seventh largest air cargo volumes in the US (FAA, 2014). San Francisco CSA (SF) is the second largest in terms of population and employment size, and has a different industry composition. It is well known as the largest high-tech center in the US. San Diego MSA (SD) shares national borders with Mexico, and is second only to Texas in trans-border trade. Sacramento CSA (SC) has the lowest population and employment, and is not a major national or international trade node. Population and employment for the two study periods are given in TABLE 2.

TABLE 2 Population and Employment of Case Study Metro Areas

	Population		Employment	
	2000	2010	2003	2013
Los Angeles	16,372,961	17,876,480	6,389,509	6,502,535
San Francisco	5,973,606	6,372,054	2,518,953	2,505,343
Sacramento	2,028,039	2,414,783	754,214	728,041
San Diego	2,813,833	3,095,313	1,152,761	1,196,292

Population and employment density varies across the four metro areas (TABLE 3). Los Angeles, despite being the largest, is not the metro area with the highest population density. San Francisco and San Diego show denser dwelling patterns in both population and employment measures than the other two. Sacramento is the smallest and least dense metro area. Physical geography might be most attributable to the particular pattern. San Francisco and San Diego have several physical constraints for dispersion (water, hilly terrain, and the border). Los Angeles and Sacramento, on the other hand, have plentiful land availability. In addition, CSA boundaries are established on the basis of counties. The Los Angeles region has vast areas of forest and desert that are not available for development.

TABLE 3 Population and Employment Density of Case Study Metro Areas

	Area (square mile)	Population density (People/sq-mile)		Employment density (Jobs/sq-mile)	
		2000	2010	2003	2013
Los Angeles	33,955	482	526	188	192
San Francisco	8,849	675	720	285	283
Sacramento	7,287	278	331	104	100
San Diego	4,207	669	736	274	284

[5] The 2014 Census definition of CSA includes Stockton County in San Francisco CSA and excludes the Nevada portion from Sacramento CSA.

[6] We did extensive data cleaning to eliminate any problems with the ZBP data. In that process we found big year by year changes in Santa Clara county that could not be verified from other data sources. We therefore omitted Santa Clara County from the San Francisco CSA.

In order to generate our spatial measures, additional data were drawn from the US census, World Port Index, FAA (Federal Aviation Administration, ACAIS 2013 data), and Intermodal Association of North America.

5 RESULTS

We present results in three parts. First, we describe changes in W&D activity and its spatial distribution. Second, we present results for our spatial location measures. Third, we provide a summary.

5. 1 Changes in Warehousing and Distribution

TABLE 4 provides an overview of trends in the number of W&D establishments and employment for each case study area. We use both establishments and employment of W&Ds. TABLE 4 shows entirely different growth patterns for the four metropolitan areas. In terms of the number of establishments, growth ranges from 2% (San Diego) to 79% (Sacramento). In terms of employment, growth ranges from 4% (San Diego) to 52% (Sacramento). There is no consistent relationship between establishment and employment growth. In Los Angeles and San Diego, employment growth was greater than establishment growth (on average, greater number of employees per establishment; see TABLE 5), in San Francisco growth percentages are about the same, and in Sacramento establishment growth is greater (on average, smaller number of employees per establishment). It is possible that these differences are due to the type of W&Ds that were added over the period. Larger warehouses are consistent with increased import/export trade. Up to the Great Recession of 2008, the ports of Los Angeles and Long Beach experienced rapid growth, and NAFTA has facilitated cross-border trade with Mexico.

TABLE 4 Descriptive Statistics of W&D and total employment

Year	Los Angeles CSA		San Francisco CSA		Sacramento CSA		San Diego MSA	
	W&Ds	W&D Emp.	W&Ds	W&D Emp.	W&Ds	W&D Emp.	W&Ds	W&D Emp.
2003	775	34,333	257	9,603	80	3,699	84	1,650
2013	1001	49,266	311	11,476	143	5,641	86	1,720
%Δ	29%	43%	21%	20%	79%	52%	2%	4%

TABLE 5 W&D Employment per establishment ratio

Year	Los Angeles CSA	San Francisco CSA	Sacramento CSA	San Diego MSA
2003	44.3	37.4	46.2	19.6
2013	49.2	36.9	39.4	20.0
%Δ	11%	-1%	-15%	2%

In FIGUREs 4 through 11, we present the changes in spatial distribution of warehousing establishments by ZIP Code between 2003 and 2013: (1) in establishment counts comparison, and (2) in gain or loss of establishments. The size of the bubbles corresponds to the number of W&D establishments by ZIP Code as presented in the legend. Note that the map and the legend are scaled to each metro area. For example, the largest bubble for Los Angeles corresponds to 32 or more, while the largest bubble for Sacramento corresponds to 5 or more. The comparative size difference of bubbles between the two-year periods provides information about the locations where the W&D industry expanded or shrunk. The second map for each metro area presents a simplified schematic of the gain (red), no change (grey), or loss (blue) of warehousing establishments by ZIP Code. Each map consists of ZIP Code centroids that contain at least one W&D establishment in either of the two periods. Other ZIP Code centroids are not shown. We do not present the spatial distribution of W&D employment because of the similarity in the distributions.

The Los Angeles maps (FIGURE 4 and FIGURE 5) show that there are many W&Ds in the core of the region, and along major highway corridors to the east. Although the number of establishments grew in many places (for example around the ports), new growth is particularly evident to the east around San Bernardino and Moreno Valley. The overall growth in W&Ds is evident in FIGURE 4, with gains in far more ZIP Codes than losses.

San Francisco (FIGURE 6 and FIGURE 7) has a different spatial pattern, with many W&Ds clustered around the Bay, and many others located many miles away to the east (Tracy, Stockton) and north (Santa Rosa). The emergence of new clusters to the north around Vallejo is also evident. There is no apparent pattern to the gains and losses.

In Sacramento (FIGURE 8 and FIGURE 9), W&Ds are clustered around the CBD, and along the major highway corridors to the south and to the northeast. The number of W&Ds greatly increased, but the spatial pattern remains approximately the same: most of the expansion has taken place within a 10-30 mile distance range from the CBD.

In San Diego (FIGURE 10 and FIGURE 11), W&Ds are mainly distributed along the coast, to the south and north of the CBD. San Diego is the one metro area that did not have a large increase in the number of W&Ds over the period, and it can be seen that the distribution shifted. New warehousing emerged to the north (again along a major highway), while clusters in the south declined. These maps show that the spatial organization of W&Ds varies greatly across the four metro areas.

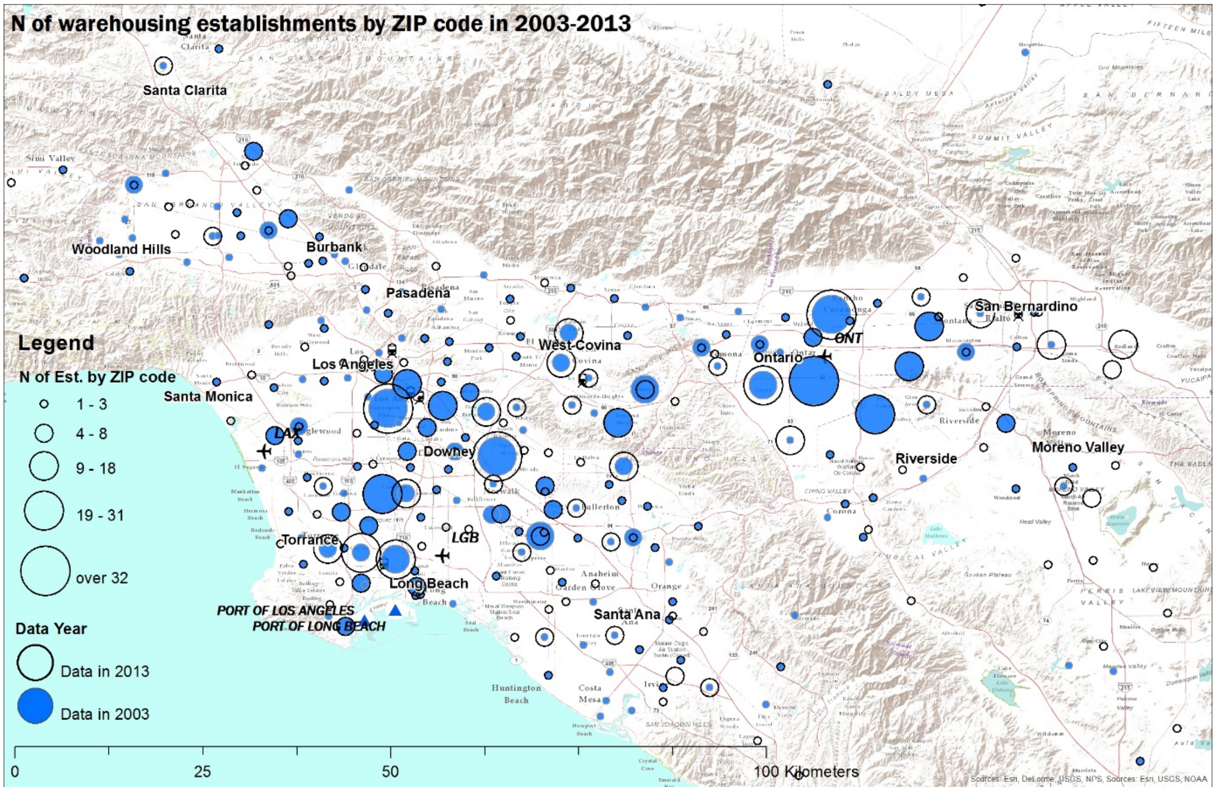

FIGURE 4 W&D establishments by ZIP Code in 2003-2013 in Los Angeles CSA

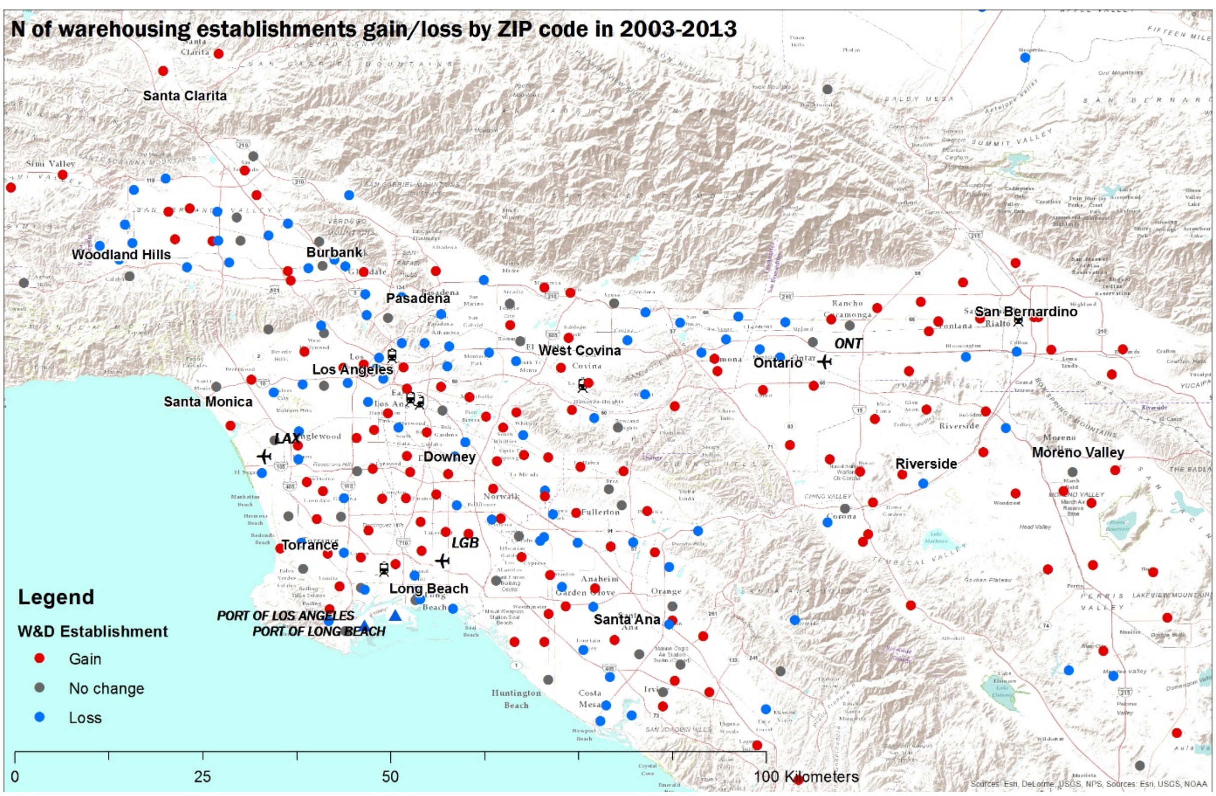

FIGURE 5 W&D establishments gain and loss by ZIP Code in 2003-2013 in Los Angeles CSA

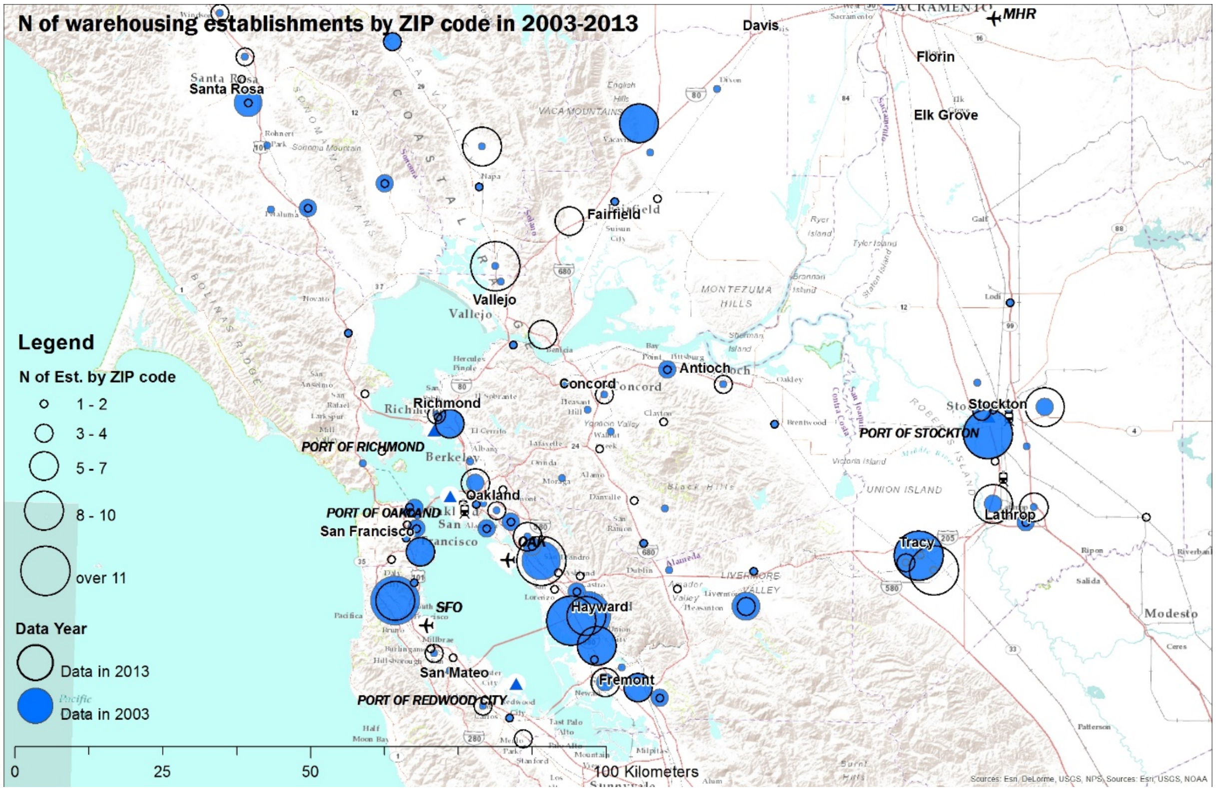

FIGURE 6 W&D establishments by ZIP Code in 2003-2013 in San Francisco CSA

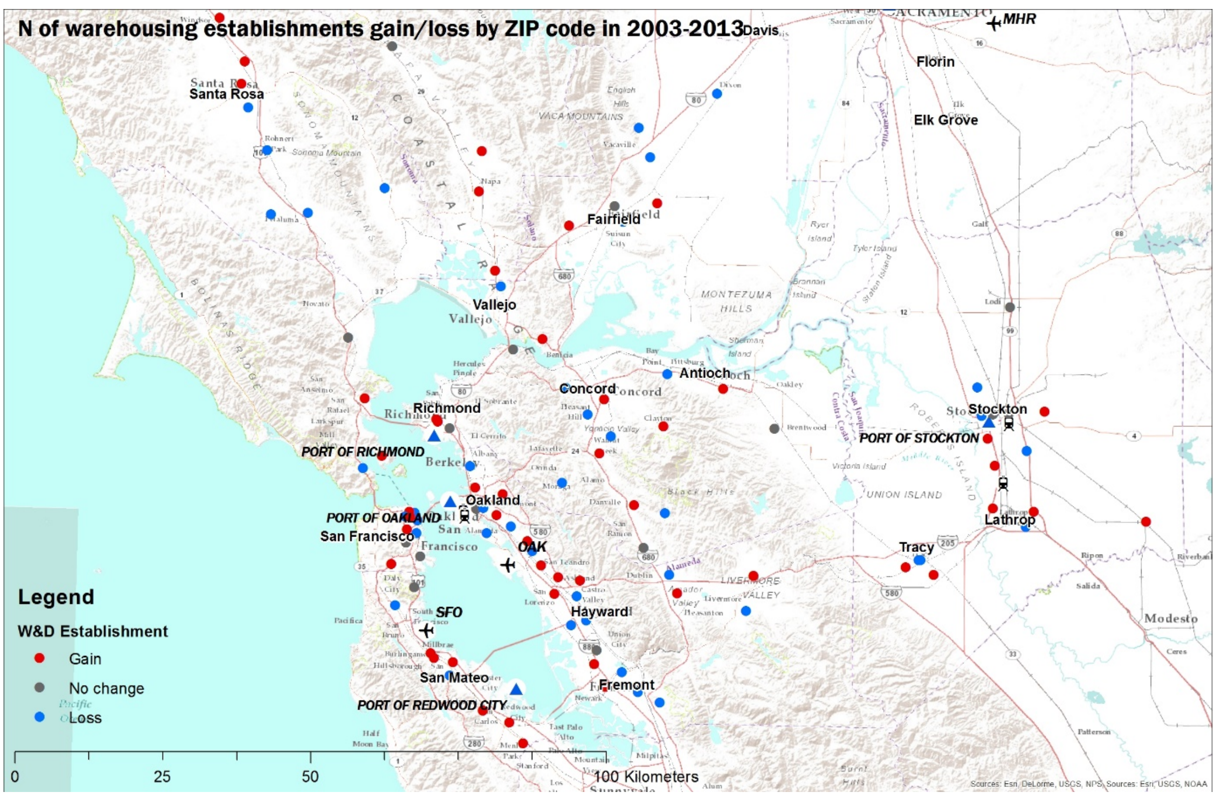

FIGURE 7 W&D establishments gain and loss by ZIP Code in 2003-2013 in San Francisco CSA

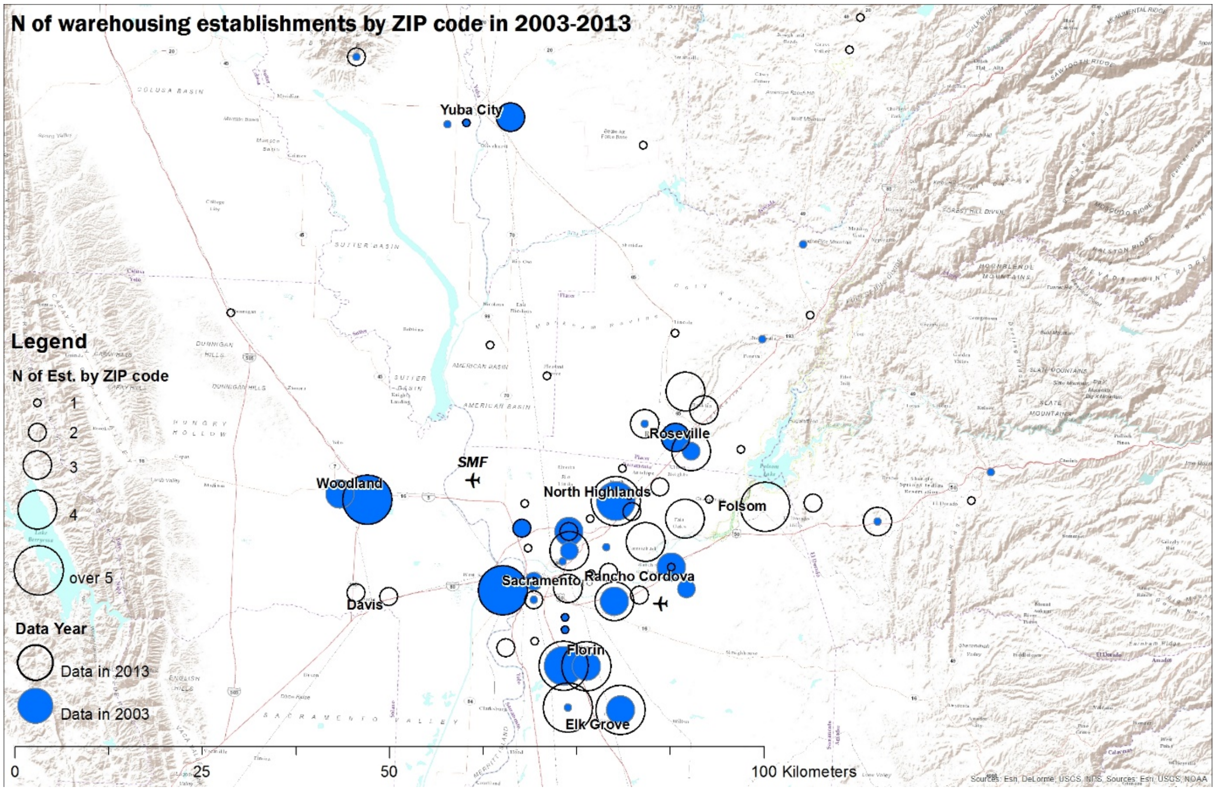

FIGURE 8 W&D establishments by ZIP Code in 2003-2013 in Sacramento CSA

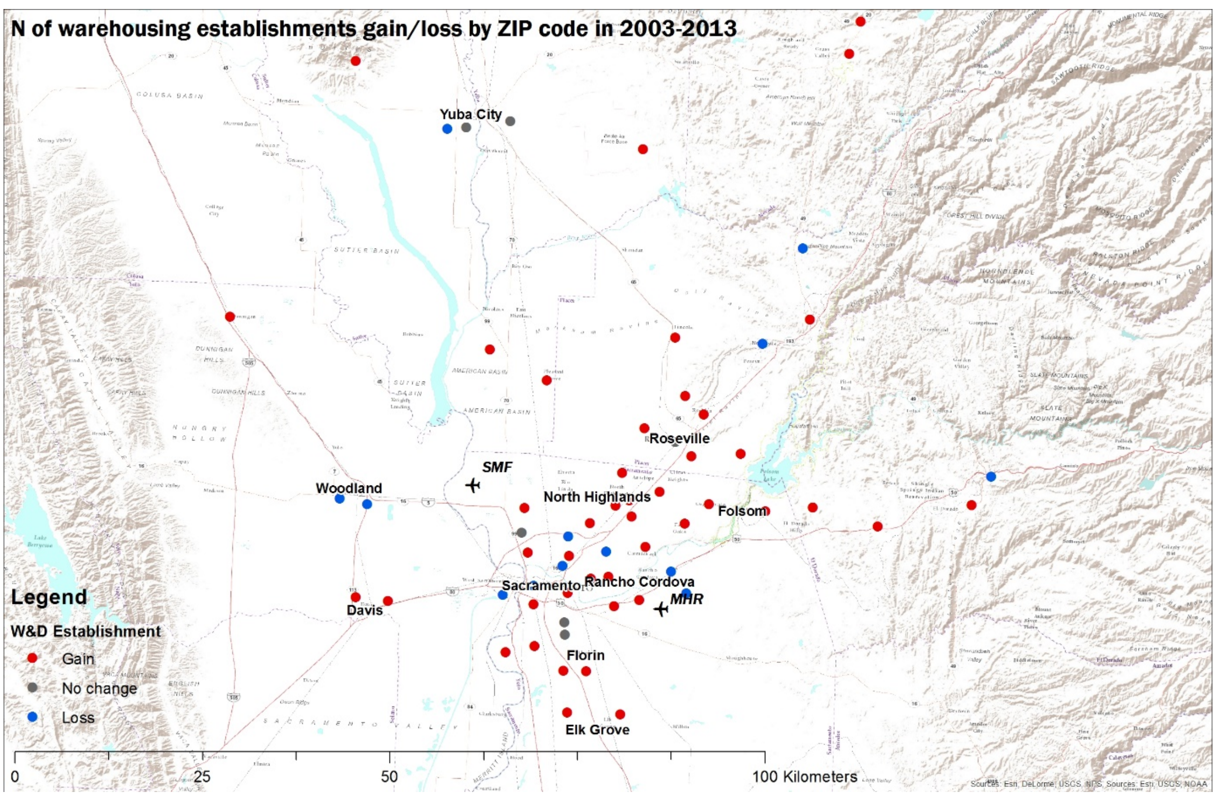

FIGURE 9 W&D establishments gain and loss by ZIP Code in 2003-2013 in Sacramento CSA

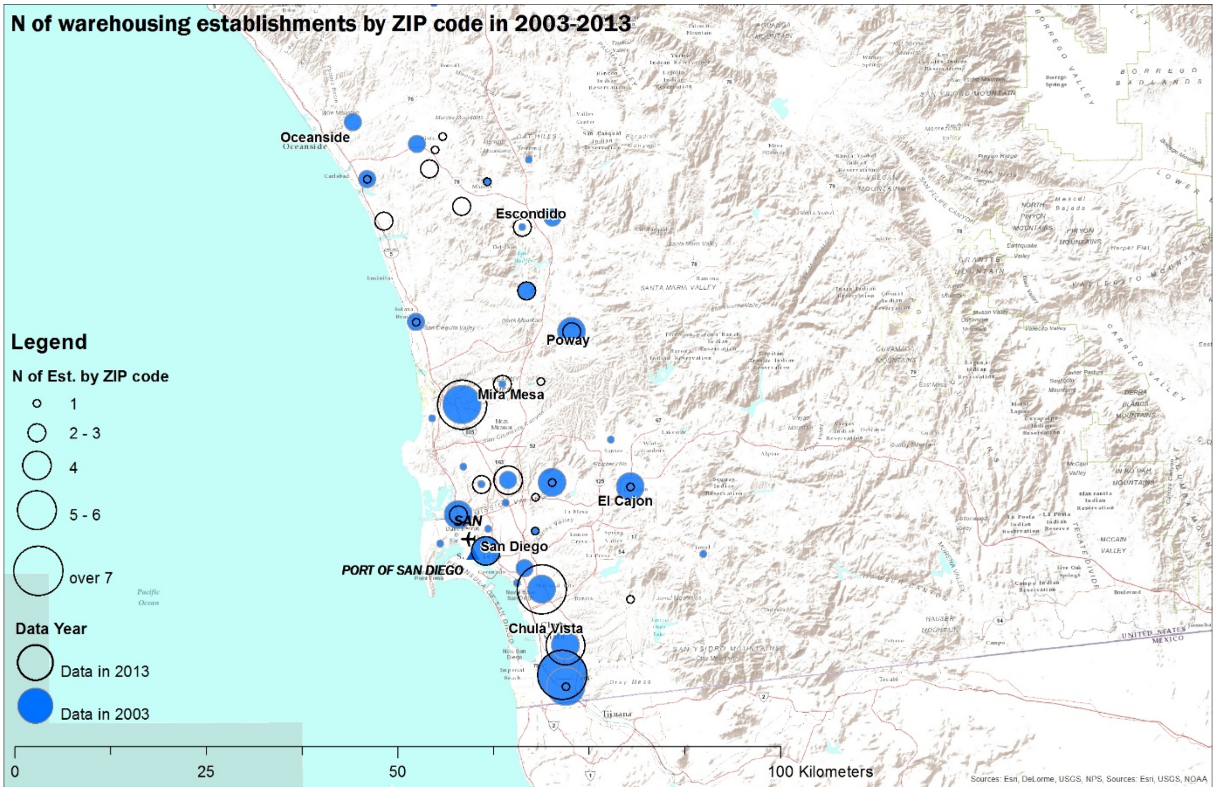

FIGURE 10 W&D establishments by ZIP Code in 2003-2013 in San Diego MSA

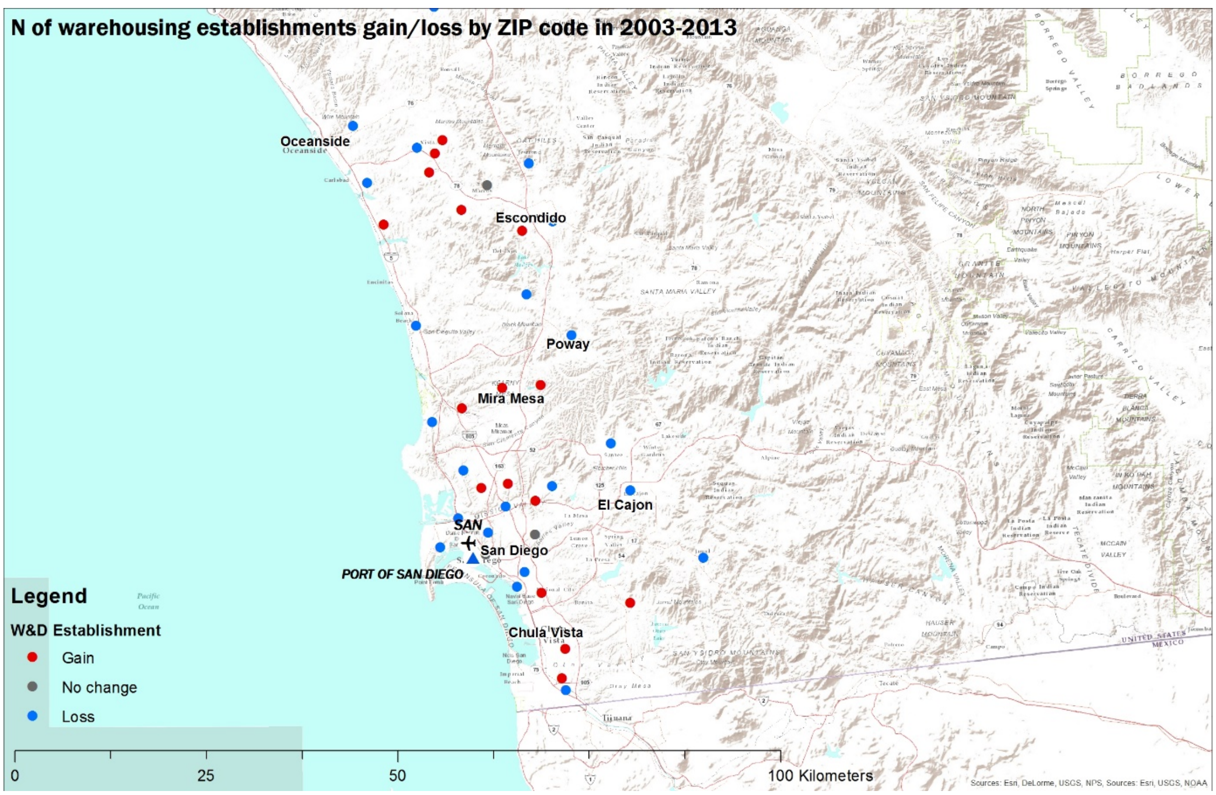

FIGURE 11 W&D establishments gain and loss by ZIP Code in 2003-2013 in San Diego MSA

5. 2 Decentralization and Concentration

In this section, we present the result of the four groups of spatial measures of W&D distribution and its change. In order to determine whether the differences in measures are statistically significant, we conduct several statistical tests. For Measures 1-1, 1-2, 1-3, 2-1 and 2-2, we conduct Welch's t-tests (unpaired, unequal-variance t-tests) between 2003 and 2013. The condition of sample independence is met with an assumption that active W&Ds in 2013 are independent enough from active W&Ds in 2003. We assume this 10-year gap is long enough to capture the logistics industry restructuring process. For Measure 3-1, we use the jackknife standard error to determine whether estimated Gini coefficients between 2003 and 2013 are significantly different. In the following TABLEs, we highlight statistically significant differences with a two-tail 95 percent confidence level ($t > 1.96$). We did not conduct statistical tests for Measure 3-2 and 4-1, but we still highlight if the difference was larger than 5%.

5. 2. 1 Measure 1 Decentralization

TABLEs 6, 7 and 8 give the percent change in each decentralization measure over the ten-year period 2003-2013. We also show the average distance for each year. Starting with Measure 1-1 (TABLE 6), only in Los Angeles do we see a significant change in average distance of establishments to the CBD (3. 5 miles). When measured in terms of employment, all changes are significant and positive. This is consistent with the construction of new, larger W&D facilities at the periphery, as would be expected. The change for Los Angeles is large, nearly 11 miles. TABLE 6 also shows that the average distance from the CBD is longest for San Francisco, notably shorter for Los Angeles, and shortest for Sacramento and San Diego (refer to maps in previous section). This rank order is observed across all three TABLEs. We surmise that the geography of San Francisco imposes more constraints on W&D location relative to the other metro areas. The shorter average distances for Sacramento and San Diego are consistent with their smaller population size, and likely greater availability of land closer to the CBD than in the much larger CSAs.

TABLE 6 Decentralization measure 1-1: Average distance from CBD

Metro areas		Los Angeles	San Francisco	Sacramento	San Diego
Measure 1-1 Average distance from CBD Between 2003-2013	W&Ds	14.2%	3.8%	4.6%	-4.6%
	2003-2013 (mile)	25.1 – 28.6	33.8 – 35.1	14.3 – 15.0	13.5 – 12.8
	W&D Employment	43.0%	8.3%	4.6%	21.0%
	2003-2013 (mile)	25.3 – 36.1	41.4 – 44.8	13.2 – 13.8	8.6 – 10.4

With regard to distance to major freight nodes (TABLE 7), again Los Angeles is the only metro area where all changes are significant and positive; W&D has decentralized both from the CBD and from major freight nodes. Employment again shows more decentralization than establishments. W&D employment in all metro areas shifted away from airports and seaports (there is no major seaport in the Sacramento CSA). The changes in the average are large for Los Angeles, around 7 to 9 miles. This could be a response to limited land availability around these facilities.

TABLE 7 Decentralization measure 1-2: Average distance to freight nodes

Metro areas		Los Angeles	San Francisco	Sacramento	San Diego
Measure 1-2 Average distance to freight nodes – Airport Between 2003-2013	W&Ds	7.1%	4.1%	-0.4%	-3.4%
	2003-2013 (mile)	27.4 – 29.3	34.8 – 36.3	17.1 – 17.0	13.7 – 13.3
	W&D Employment	25.6%	11.1%	6.8%	22.9%
	2003-2013 (mile)	26.5 – 33.3	37.7 – 41.9	15.5 – 16.6	8.9 – 10.9
Measure 1-2 Average distance to freight nodes – Intermodal Between 2003-2013	W&Ds	7.8%	-1.2%	-	-
	2003-2013 (mile)	26.3 – 28.4	39.3 – 38.9		
	W&D Employment	27.0%	0.4%	-	-
	2003-2013 (mile)	25.5 – 32.4	35.6 – 35.7		
Measure 1-2 Average distance to freight nodes – Seaport Between 2003-2013	W&Ds	10.5%	3.2%	-	-4.6%
	2003-2013 (mile)	28.1 – 31.0	32.0 – 33.0		13.9 – 13.3
	W&D Employment	34.5%	8.4%	-	20.3%
	2003-2013 (mile)	28.4 – 38.2	38.7 – 41.9		9.0 – 10.9

Using average distance of all W&Ds from their geographic center (TABLE 8) gives the same result as measure 1-1. Only Los Angeles shows significant dispersion of establishments from one another, while we observe significant dispersion of employment in all cases. Los Angeles results are explained by the growth of large new W&D facilities in the San Bernardino and Moreno Valley areas, about 70 miles southeast of central Los Angeles, as shown in FIGURE 4.

TABLE 8 Decentralization measure 1-3: Average distance from W&D geographic center

Metro areas		Los Angeles	San Francisco	Sacramento	San Diego
Measure 1-3 Average distance from W&D geographic center Between 2003-2013	W&Ds	9.7%	2.4%	-4.6%	-2.4%
	2003-2013 (mile)	20.7 – 22.7	28.8 – 29.5	14.7 – 14.1	12.9 – 12.6
	W&D Employment	19.2%	4.8%	19.8%	12.0%
	2003-2013 (mile)	19.3 – 23.0	25.1 – 26.3	11.4 – 13.7	8.8 – 9.8

5. 2. 2 Measure 2 Relative Decentralization

Measure 2 considers W&D location changes relative to employment and population. TABLE 9 and TABLE 10 give average distance of W&Ds to all establishments and employment respectively, and TABLE 11 gives average distance of W&Ds relative to all population. Los Angeles again stands out; relative decentralization is significant in every case, whether measuring with respect to total establishments, employment or population. For W&D establishments, the change is about 2 miles, and for W&D employment, the change is about 7 miles. Although most changes for total establishments and employment (TABLE 9 and 10) are significant (except Sacramento), the magnitude of change is much smaller in Sacramento, San Francisco and San Diego. The same pattern is observed in TABLE 10, except that there is no change for Sacramento.

Comparing the average distances in TABLEs 6 and 7 to TABLEs 9, 10 and 11 shows that W&Ds are on average located further from all establishments, all employment and all population than from the CBD and major freight nodes. These results suggest that in 2013 proximity to the metropolitan market is less of a consideration in W&D location relative to other factors. The implication is large and growing truck VMT for local deliveries. However, these long distances may be an artifact of the geographic size of the metro area. With population and employment spread over hundreds of square miles, any warehouse location will be far from some of the population or employment.

TABLE 9 Relative decentralization measure 2-1: Average distance to all establishment

Metro area		Los Angeles	San Francisco	Sacramento	San Diego
Measure 2-1 Average distance to all establishments Between 2003-2013	W&Ds	6.2%	0.9%	-7.1%	1.5%
	2003-2013 (mile)	34.3 – 36.4	39.2 – 39.6	25.6 – 23.7	18.2 – 18.5
	W&D Employment	19.0%	5.3%	0.1%	3.9%
	2003-2013 (mile)	33.8 – 40.3	42.4 – 44.7	25.7 – 25.7	16.2 – 16.9

TABLE 10 Relative decentralization measure 2-1: Average distance to all employment

Metro area		Los Angeles	San Francisco	Sacramento	San Diego
Measure 2-1 Average distance to all employment Between 2003-2013	W&Ds	6.8%	1.2%	-4.3%	1.2%
	2003-2013 (mile)	33.2 – 35.5	38.0 – 38.5	23.1 – 22.1	17.7 – 17.9
	W&D Employment	19.9%	6.0%	3.0%	4.1%
	2003-2013 (mile)	32.7 – 39.2	41.0 – 43.5	23.0 – 23.7	15.5 – 16.2

TABLE 11 Relative decentralization measure 2-2: Average distance to all population

Metro area		Los Angeles	San Francisco	Sacramento	San Diego
Measure 2-2 Average distance to all population Between 2003-2013	W&Ds	7.7%	1.0%	-5.4%	1.3%
	2003-2013 (mile)	34.7 – 37.3	39.5 – 39.9	24.3 – 22.9	19.0 – 19.2
	W&D Employment	17.8%	4.1%	0.4%	2.6%
	2003-2013 (mile)	34.0 – 40.0	41.8 – 43.5	24.2 – 24.3	17.2 – 17.7

5. 2. 3 Measure 3 Concentration

We turn now to measures of concentration. TABLE 12 gives results for the Gini Coefficient. It shows that W&D is relatively more concentrated with respect to employment than to establishments. The value of the coefficient is similar across metro areas. As noted earlier, this could be a result of land use regulations or agglomeration benefits. In 6 of the 8 cases, the Gini Coefficient increases significantly, suggesting increased concentration. However, the patterns are quite different: in two cases (LA and SD) we observe increases in both measures, with the change greater for establishments than employment. In the other two cases, the trends are opposite to one another. These different patterns are difficult to explain. The Gini Coefficient has little spatial meaning; we do not know if W&Ds are concentrated in adjacent ZIP Codes, or concentrated in many dispersed ZIP Codes. Our maps suggest the latter. These results may reflect the different spatial patterns of W&D location change.

TABLE 12 Concentration measure 3-1: Gini coefficient

Metro area		Los Angeles	San Francisco	Sacramento	San Diego
Measure 3-1 Gini coefficient for W&Ds Between 2003-2013	W&Ds	8.3%	0.7%	-5.6%	32.3%
	2003-2013 (Gini)	0.56 – 0.61	0.48 – 0.49	0.41 – 0.39	0.39 – 0.51
	W&D Employment	2.7%	-0.8%	13.1%	10.4%
	2003-2013 (Gini)	0.78 – 0.80	0.79 – 0.79	0.79 – 0.90	0.68 – 0.75

5. 2. 4 Measure 4 Relative Concentration

We generate relative concentration measures by subtracting the Gini coefficient of total employment of all industry from that of W&D employment. In TABLE 13, we present the percent change along with coefficient changes. There are three observations to be drawn from TABLE 13. First, the difference between the Gini Coefficients are near zero, indicating that there is little difference between the concentration of W&D employment and total employment. Second, the change in the difference is positive but small in all cases, suggesting slightly more concentration of W&D employment over the period relative to total employment. Third, although the percentage changes are large and significant, this is largely a function of small numbers.

TABLE 13 Relative concentration measures: Percentage change, 2003-2013, W&D Emp.

Metro area		Los Angeles	San Francisco	Sacramento	San Diego
Measure 4-1 Gini coefficient difference, W&Ds and all employment Between 2003-2013	W&D Employment	28.7% (+ 0.028)	13.3% (+ 0.010)	303.1% (+ 0.118)	101.7% (+ 0.090)
	2003-2013 (Gini)	0.098 – 0.126	0.078 – 0.088	0.039 – 0.157	-0.089 – -0.002

Another way of examining relative concentration is to compare the distribution of W&Ds to the distribution of employment density. For each metro area, we generate quartiles of employment density and then calculate the share of W&Ds in each quartile. The first quartile has the lowest employment density, and the fourth quartile the highest. The density quartile is also non-spatial, but it provides a hint of urban structure with respect to its density. The W&D shares by establishment and employment density quartile, 2003 and 2013, are shown in FIGUREs 12 and 13. Since the quartiles are based on the density distribution of each metro area, the actual densities they represent are different. For example, the highest density quartile starts at 2,950 for Los Angeles, 2,160 for San Francisco, 555 for Sacramento, and 1,567 for San Diego, all in jobs per square mile.

Figures 12 and 13 again show differences between the larger and smaller metro areas. Patterns for Los Angeles and San Francisco are similar: whether measured as establishments or employment, W&Ds have shifted from the higher density quartiles to the lower density quartiles. The pattern is particularly pronounced for San Francisco. FIGURE 12 suggests that decentralization is much greater for San Francisco, with nearly 50% of all W&Ds located in the lowest two employment density quartiles, compared to about 25% for Los Angeles. That is, Los Angeles decentralized more from 2003 to 2013, but San Francisco has a far greater proportion of decentralized W&Ds. These observations are consistent with our decentralization measure results. FIGURE 13 shows that when we use W&D employment, shares in the highest quartile are much smaller; clearly the W&D facilities located in higher density areas are smaller, as would be expected given land prices in these metro areas.

Sacramento reveals the opposite pattern; the share of W&D establishments in the highest quartile increases from about 46% to 56%. The employment change is even greater, from about 34% to 58%. The highest quartile density is much lower for Sacramento, suggesting that land prices are lower, and land supply is greater. Thus, W&D activity has options for more central location, and is not yet being "pushed" to lower density and more distant locations. In addition, labor force access is limited in very low density areas.

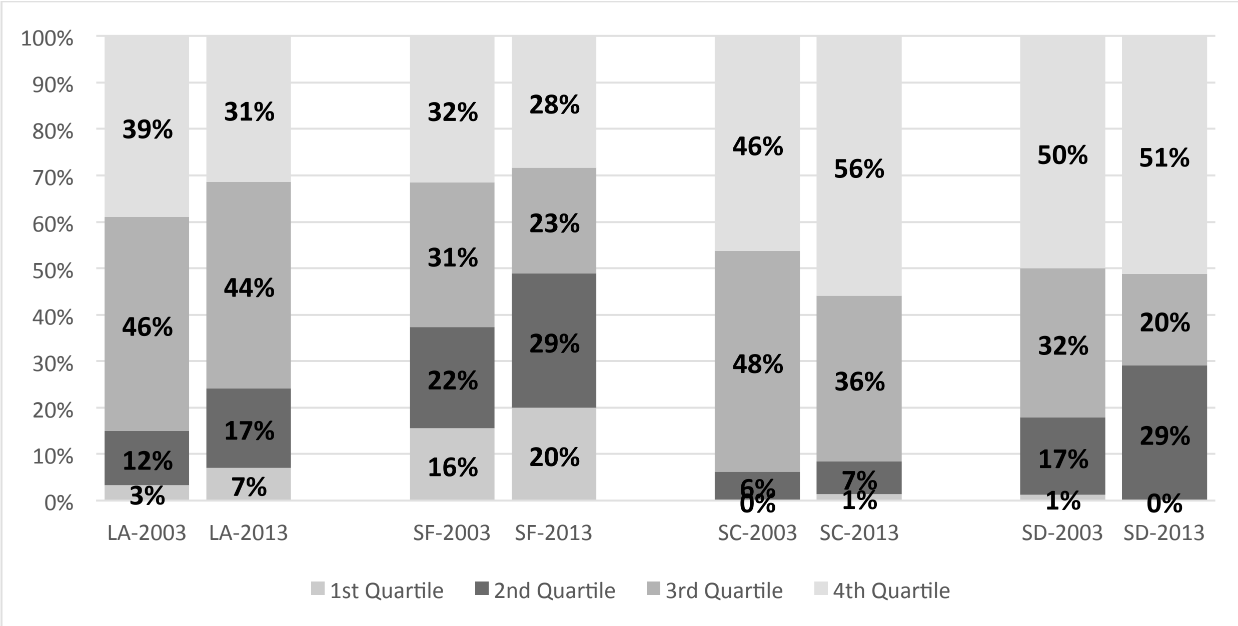

FIGURE 12 Concentration measure 3-2: W&D establishment in total employment quartiles

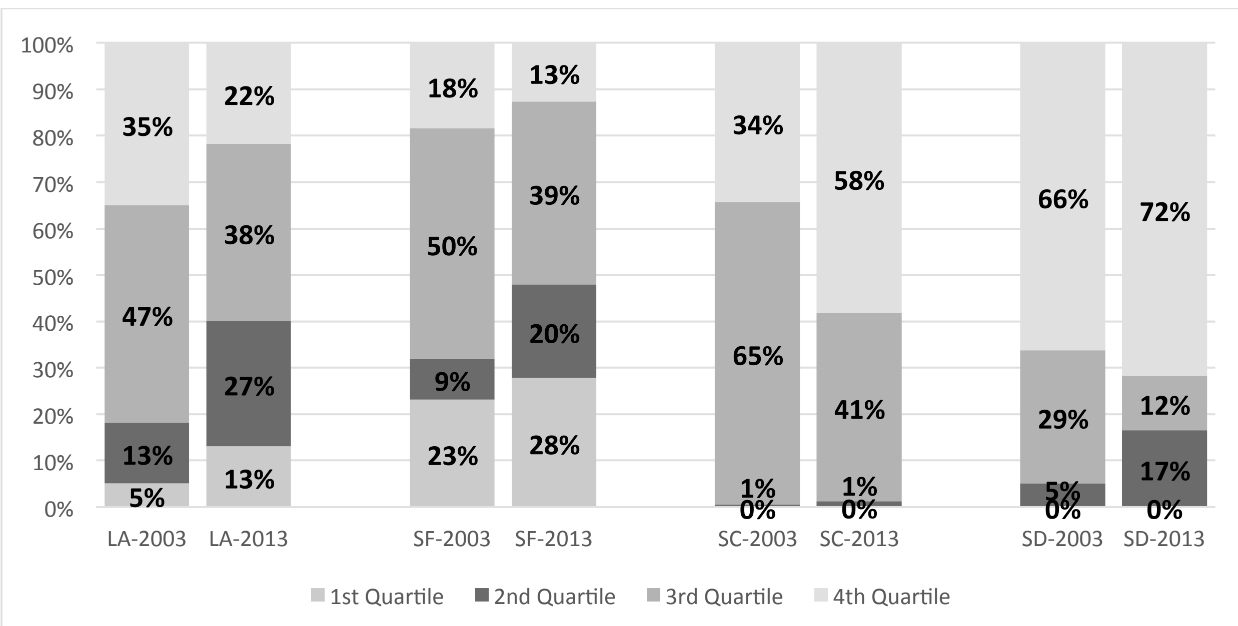

FIGURE 13 Concentration measure 3-2: W&D employment in total employment quartiles

San Diego is the one metro area that experienced almost no W&D growth over the period. Similar to Sacramento, about half of all W&D establishments are located in the highest density quartile. Measured as employment, the proportion is more than two thirds. This is consistent with growth along the coast, which is the densest part of the region (see FIGURE 11). At the same time, there is a large increase in share in the second-lowest density quartile. This reflects the emergence of the new W&D zone in north San Diego County, a suburban area that has a growing employment base.

5. 3 Results Summary

Our results present a mixed picture of W&D location changes. When measured with respect to establishments, only Los Angeles consistently shows decentralization over the period. However, when measured with respect to employment, decentralization is confirmed for all metro areas across most of our measures. Employment has decentralized more than establishments, indicating that larger facilities are more likely to locate near the periphery. We surmise that land rent and land availability are important explanatory factors. Decentralization from airports and seaports are explained by their location; only Sacramento has its major airport in a low density area, and the Los Angeles and San Francisco seaports are located in the regions' core.

Although Los Angeles showed the most decentralization, San Francisco has the most decentralized distribution of W&Ds (35 miles average distance from CBD in 2013). We surmise that the unique geography of the metro area (together with exceptionally high land prices in the core) has forced W&Ds to the periphery. The W&D spatial distributions in the two smaller metro areas are far less decentralized by all measures.

The Gini Coefficient indicates that W&Ds are relatively concentrated, and concentration is increasing. Our maps (FIGUREs 4 – 11) suggest that this may simply reflect that most warehousing is located in populated areas. W&D location with respect to employment indicates a form of spatial de-concentration for Los Angeles and San Francisco, with W&Ds shifting to lower employment density locations, but the opposite trend for the smaller metro areas.

6 DISCUSSION

6. 1 Explaining Results

What are the possible explanations for our mixed results? We identify three factors: metropolitan size, economic structure, and physical geography. First, metropolitan size (population) is correlated with density. In general, the largest metro areas have the highest peak density and average density. Density is a proxy for demand, which implies high land prices. Thus as large metropolitan areas continue to grow, the more land intensive activities (manufacturing, trade and transport) seek cheaper land away from the center. Today's metropolitan areas are polycentric; they have multiple activity clusters, and thus multiple density "peaks." Thus the shift is away from the largest activity clusters. As competition for land grows, land use regulation may "zone out" less preferred activities. For example, older industrial zones may be targeted for redevelopment to residential and commercial mixed use. These types of pressures are apparent in Los Angeles and San Francisco, but not yet for Sacramento and San Diego.

A second consideration is economic structure. As noted in Section 1, large metropolitan areas are the hubs of global commerce and serve as national and regional distribution centers. W&Ds thus serve both local and non-local markets. For W&Ds oriented to non-local markets, location within the metropolitan area may be less important than land rent, labor costs, and access to the market being served. If location near the import/export node (airport, seaport) is prohibitive, an alternative near a major interstate highway may be a good substitute.

We use the Freight Analysis Framework (FAF, 2007) to examine the role of each metro area in non-local trade. FAF data are based on the Commodity Flow Survey (CFS) data. FAF consists of internal flows (within the FAF zone), domestic (between FAF zones within the US) flows, and international (import and export) flows. California has five FAF zones: San Francisco CSA, Sacramento CSA, Los Angeles CSA, San Diego MSA, and rest of the state. Thus, a shipment between San Francisco and Sacramento is part of "domestic" flow. In TABLE 14, we present freight flow intensity measured in tonnage across the four FAF regions. The first panel of TABLE 14 gives total tonnage, and the second panel gives tonnage per capita. For all metro areas except Sacramento, internal flows account for the greatest proportion of tonnage. Foreign flows for Los Angeles are more than twice that of San Francisco, and several times higher than those of Sacramento and San Diego. The difference is not as dramatic when considering tons/capita. Although the FAF data gives only an approximate idea of freight flows, it does show that Los Angeles and San Francisco have more foreign trade than Sacramento and San Diego. In theory it should make no difference whether the non-local component of goods movement is domestic or foreign; if the market is outside the metro area, the same location considerations should apply. Thus the FAF data alone does not support different location choice logic for non-local markets.

TABLE 14 Comparison of commodity flow intensity across the four FAF regions in California

Volume (Ktons)	Internal flow	Domestic flow	Foreign flow
Los Angeles	434,377	252,711	172,300
San Francisco	230,374	154,570	62,253
Sacramento	55,293	73,048	7,242
San Diego	46,349	37,721	14,003

Share (%)	Internal flow	Domestic flow	Foreign flow
Los Angeles	51%	29%	20%
San Francisco	52%	35%	14%
Sacramento	41%	54%	5%
San Diego	47%	38%	14%

Another aspect of economic structure is industry mix. We derive one digit NAICS sector-level data from the LEHD (Longitudinal Employer-Household Dynamics in 2010). Freight flow and W&D demand should be related to industry composition. Metro areas with more trade/manufacturing industry should generate/attract more freight activities than areas with more service industry. FIGURE 14 gives industry mix for our four metro areas. The share of jobs in manufacturing and wholesale/retail/transportation/warehousing industry is higher in Los Angeles and San Francisco, as expected given their role as major trade centers.

The third factor is physical geography. The physical constraints of San Francisco contribute to high land prices and limit where development can occur. In contrast, Los Angeles has been able to spread across over 5,400 square miles. Because population and employment are distributed across such a vast area, W&Ds are relatively closer to local markets, even as they decentralize. Sacramento's geography allows a similar spread as the region grows, but low density and plentiful land availability relatively near the center does not provide the push factors for W&D decentralization. San Diego also has some physical constraints: it is located along the coast and has some hilly terrain. Thus, development is more concentrated, and at this point in the metro area's development, W&D decentralization is observed only with respect to employment.

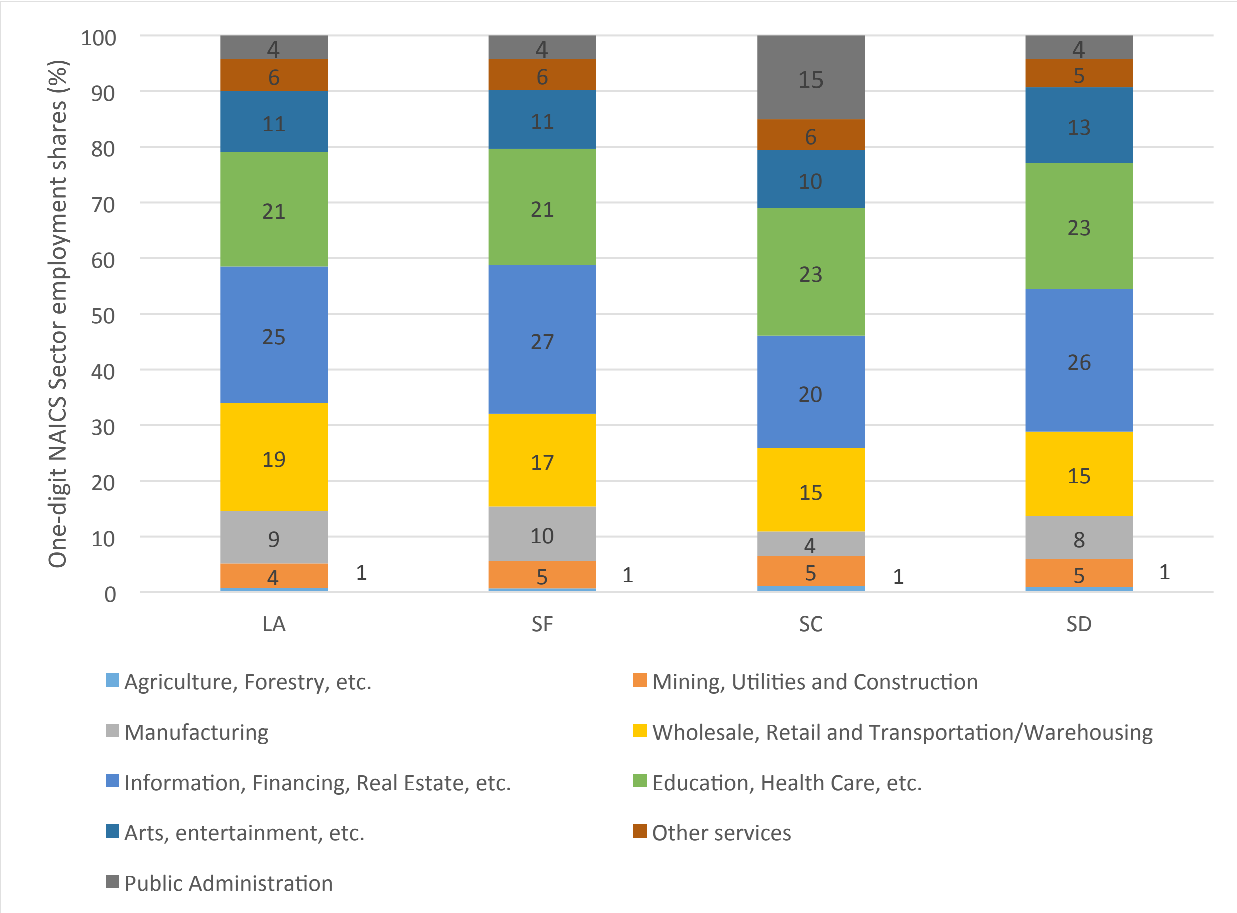

FIGURE 14 One-digit NAICS sector employment shares in the four metropolitan areas in percentage (from Giuliano, et al. , 2015)

6. 2 Implications for Truck VMT

Our examination of the changing spatial organization of the warehousing and distribution industry is intended to shed light on the implications of these changes for truck VMT in metropolitan areas. We make the following observations. First, with respect to W&D employment, there is considerable evidence of decentralization, especially in the largest metro areas. The difference in pattern between establishments and employment is consistent with larger facilities being built where land is cheaper and more available. If all W&D activity were locally oriented, this would imply more truck VMT. However, from the FAF data, internal flows by tonnage account for between 40 and 50 percent of total flows. It is possible that much of the decentralization is driven by the growth in domestic and international trade. With regional or national markets, location with respect to serving the entire market is the critical factor. As these markets expand in both scale and geographic size, we should expect W&Ds to locate in low land price areas with good access to the interstate highway system. If larger, more distant

W&Ds are oriented to external trade, we cannot conclude that decentralization leads to more truck VMT.

Second, W&Ds are located throughout the populated areas of each metro area. This is logical, both for market and labor force access. Only in San Francisco do we observe a large and growing portion (over 20% in both years) of W&Ds in areas with the lowest employment density quartiles. We also note that W&Ds located within the core areas are smaller (as implied by differences in establishment and employment measures), which likely implies more local distribution. We therefore cannot rule out that local serving W&Ds continue to seek locations near their markets. The growth in e-shopping and same day delivery should reinforce the demand for near market locations. Indeed, in the Los Angeles area, W&D rents in the center of the region have risen dramatically in the past few years.[7]

Third, it should be noted that truck VMT could change without any change in the spatial locations of W&Ds. Supply chains and product markets are constantly changing; therefore, shipment patterns are constantly changing as well. One need only think about Amazon Prime and its impact on consumer behavior to understand how quickly such patterns can change.

Our results do not provide evidence that the observed changes in spatial organization are leading to increased truck VMT. Only Los Angeles shows decentralization across all indicators, and this may be due largely to the region's growth as a center for international trade. W&Ds in the smaller metro areas are more closely located to the CBD, population, and employment. Our results lead to an obvious question: how might we examine the changes in truck VMT associated with these changes? In an ideal world, we would have full information on the type of W&D facility and the associated truck trips (e.g. all the forward and backward links in the associated supply chain that occur within the metro area) for at least two time periods. Sakai, Kawamura and Hyodo (2015) used decennial freight survey data from Tokyo to conduct such an analysis. They find that W&D decentralization is associated with increased truck travel, because of the increased distances between shipment origins and destinations. In Paris, a similar survey has been conducted, but a comprehensive analysis has not yet been performed (Dablanc and Gardrat, 2015). No such data exists within the US. Absent such data, simulations based on partial data may be the best approach.

More research is needed to understand why spatial patterns vary across metropolitan areas, and to document the extent to which decentralization is taking place in US metropolitan areas. More data on freight patterns at the sub-metropolitan level is needed if we are to develop a better understanding of the relationship between spatial organization, shipment patterns, and truck VMT.

[7] Source: CoreLogic data, calculated by the authors.

REFERENCES

Allen, J., Browne, M., & Cherrett, T. (2012). Investigating relationships between road freight transport, facility location, logistics management and urban form. *Journal of Transport Geography*, 24, 45-57.

Anas, A., Arnott, R., & Small, K. A. (1998). Urban Spatial Structure. *Journal of Economic Literature*, 36, 1426-1464.

Anderson, S., Allen, J., & Browne, M., (2005). Urban logistics: how can it meet policy makers' sustainability objectives? *Journal of Transport Geography*, 13(1), 71-81.

Arauzo-Carod, J-M., Liviano-Solis, D., & Manjon-Antolin, M. (2010). Empirical studies in industrial location: an assessment of their methods and results. *Journal of Regional Science*, 50(3), 685-711.

Bowen Jr., J., (2008). Moving places: the geography of warehousing in the US. *Journal of Transport Geography*, 16, 379–387.

Carlton, D. (1983). The location and employment choices of new firms: an econometric model with discrete and continuous endogenous variables. *The Review of Economics and Statistics*, 65(3), 440-449.

Castells, M. (1996). *The Rise of the Network Society. The Information Age: Economy, Society, and Culture, vol. 1.* Malden/Oxford: Wiley-Blackwell.

Cidell, J. (2011). Distribution centers among the rooftops: the global logistics network meets the suburban spatial imaginary, *International Journal of Urban and Regional Research*, 35(4), 832-851.

Cidell, J. (2010). Concentration and decentralization: the new geography of freight distribution in US metropolitan areas, *Journal of Transport Geography*, 18(3), 363-371.

Dablanc, L., & Rakotonarivo, D. (2010). The impacts of logistics sprawl: How does the location of parcel transport terminals affect the energy efficiency of goods' movements in Paris and what can we do about it? *Procedia Social and Behavioral Sciences*, 2, 6087-6096.

Dablanc, L., Diziain, D., & Levifve, H. (2011). Urban freight consultations in the Paris region. *European Transport Research Review*, 3(1), 47–57.

Dablanc, L., & Gardrat, M. (2015). The new Paris urban freight survey – method, main results, and potential use for urban freight elsewhere. *2015 METRANS International Urban Freight Conference*.

Dablanc, L., & Ross, C. (2012). Atlanta: A Mega Logistics Center in the Piedmont Atlantic Megaregion (PAM). *Journal of Transport Geography*, 24, 432-442.

Dablanc, L., Ogilvie, S., & Goodchild, A. (2014). Logistics Sprawl: Differential Warehousing Development Patterns in Los Angeles, California, and Seattle Washington. *TRB, Transportation Research Record (TRR)*, 17.

Giuliano, G., Hou, Y., Kang, S., & Shin, E. (2015). Accessibility, Location and Employment Center Growth. Metrans Project 11-6, Metrans Transportation Center, Sol Price School of Public Policy, University of Southern California, Los Angeles, CA.

Giuliano, G., Kang, S., Yuan, Q., & Hutson, N. (2015). The Freight Landscape: Using Secondary Data Sources to Describe Metropolitan Freight Flows. METRANS UTC 1-1B Final Report, METRANS Transportation Center, University of Southern California.

Giuliano, G., & Small, K. A., (1991). Subcenters in the Los Angeles Region. *Regional Science and Urban Economics*, 21(2), 163-182.

Hall, P., Hesse, M., & Rodrigue, J-P. (2006). Reexploring the interface between economic and transport geography. Guest editorial. Environment and Planning A, 38, 1401–1408.

Hansen, W. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners*, 35(2), 73-76.

Hesse, M. (2007). The system of flows and the restructuring of space: Elements of a geography of distribution. *Erdkunde,* 61(1), 1–12.

Hesse, M. (2006). Global chain, local pain: regional implications of global distribution networks in the German North Range. *Growth and Change*. 37(4), 570–596.

Hesse, M. (2002). Location matters. *Access. Transportation Research at the University of California*, 21, 22–26.

Hesse, M., Rodrigue, J-P. (2004). The transport geography of logistics and freight distribution. *Journal of Transport Geography*, 12(3), 171–184.

Holguín-Veras, J., Jaller, M., Destro, L., Ban, X., Lawson, C., & Levinson, H. (2011). Freight generation, freight trip generation, and perils of using constant trip rates. *Transportation Research Record: Journal of the Transportation Research Board*, 2224, 68-81.

Isard, W. (1956). *Location and Space Economy.* Cambridge, MA: MIT Press.

Knowles, R., & Hall, D. (1998). Transport deregulation and privatization. In: Hoyle, B., Knowles, R. D. (Eds.), *Modern Transport Geography*. New York, NY: Wiley.

McKinnon, A., (2009). The present and future land requirements of logistical activities. *Land Use Policy*, 26, 293–301.

McKinnon, A., (1983). The development of warehousing in England. *Geoforum*, 14(4), 389–399.

Movahedi B., Lavassani K. & Kumar V. (2009). Transition to B2B e-Marketplace Enabled Supply Chain: Readiness Assessment and Success Factors. *The International Journal of Technology, Knowledge and Society*, 5(3), 75-88.

Rivera, L., Sheffi, Y., and Welsch, R. (2014). Logistics agglomeration in the U.S. *Transportation Research Part A*, 59, 222-238.

Rodrigue, J-P. (2008). The Thruport concept and transmodal rail freight distribution in North America. *Journal of Transport Geography,* 16(4), 233–46.

Rodrigue, J-P. (2006). Transportation and the Geographical and Functional Integration of Global Production Networks. *Growth and Change*, 37(4), 510–25.

Rodrigue, J-P. (2004). Freight, gateways and mega-urban regions: the logistical integration of the BostWash Corridor, *Tijdschrift voor Sociale en Economische Geografie*, 95(2), 147-161.

Rodrigue, J-P., Slack, B., & Comtois, C. (2001). Green Logistics (The Paradoxes of). In: A. M. Brewer, K. J. Button and D. A. Hensher (eds.) (2001). *The Handbook of Logistics and Supply-Chain Management, Handbooks in Transport #2*, London: Pergamon/Elsevier.

Sakai, T., Kawamura, K., & Hyodo, T. (2015). Locational dynamics of logistics facilities: Evidence from Tokyo. *Journal of Transport Geography*, 46, 10-19.

Song, S. (1994). Modeling worker residence distribution in the Los Angeles region. *Urban Studies*, 31(9), 1533-1544.

Van den Heuvel, F., de Langen, P., van Donselaar, K., & Fransoo, J. (2013, 1). Spatial concentration and location dynamics in logistics: the case of a Dutch province. *Journal of Transport Geography*, 28, 39-48.

Van den Heuvel, F., de Langen, P., van Donselaar, K., & Fransoo, J. (2013, 2). Regional logistics land allocation policies: Stimulating spatial concentration of logistics firms. *Transport Policy*, 30, 275-282.

Van den Heuvel, F., Rivera, L., van Donselaar, K., de Jong, A., Sheffi, Y., de Langen, P., and Fransoo, J. (2014). Relationship between freight accessibility and logistics employment in US counties. *Transportation Research Part A*, 59, 91-105.

Woudsma, C., Jakubicek, P., & Dablanc, L. (2016). Logistics sprawl in North America: methodological issues and a case study in Toronto. *Transportation Research Procedia*, 12, 474-488.