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Metropolitan areas in the U.S. have become increasingly polycentric. Large employment subcenters have emerged outside of central cities, competing against the traditional city center for labor and businesses. The existing literature on land use and transportation focuses on passenger travel, providing little insight into the impact of polycentric metropolitan development patterns on freight activity. Despite a growing literature that suggests the importance of urban spatial structure for passenger travel, the relationship between employment subcenters and freight travel remains largely unexplored. In this study, we use the Los Angeles region as a case study to examine the relationship between urban spatial development patterns and freight travel. Using the National Employment Time Series (NETS), we identify employment subcenters in the greater Los Angeles region. We characterize freight activities associated with subcenters using data from the Southern California Association of Governments (SCAG). We develop a regression model that estimates freight activity as a function of geographic characteristics, including whether a location is in an employment subcenter, measures of nearby employment, access to the highway network, and proximity to intermodal freight facilities. The results indicate that employment is an important driver of freight activity, and employment subcenters have an independent effect on freight activity. The results of this study suggest that further research on urban form and freight activity should assess the effects of employment subcenters and how their particular employment composition and characteristics are associated with freight activities at the metropolitan level. Such an approach would lead to more precise policy recommendations for urban goods movement.

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Urban Spatial Structure, Employment Subcenters, and Freight Travel

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Summary

Metropolitan areas in the U.S. have become increasingly polycentric. Large employment subcenters have emerged outside of central cities, competing against the traditional city center for labor and businesses. The existing literature on land use and transportation focuses on passenger travel, providing little insight into the impact of polycentric metropolitan development patterns on freight activity. Despite a growing literature that suggests the importance of urban spatial structure for passenger travel, the relationship between employment subcenters and freight travel remains largely unexplored. In this study, we use the Los Angeles region as a case study to examine the relationship between urban spatial development patterns and freight travel. Using the National Employment Time Series (NETS), we identify employment subcenters in the greater Los Angeles region. We characterize freight activities associated with subcenters using data from the Southern California Association of Governments (SCAG). We develop a regression model that estimates freight activity as a function of geographic characteristics, including whether a location is in an employment subcenter, measures of nearby employment, access to the highway network, and proximity to intermodal freight facilities. The results indicate that employment is an important driver of freight activity, and employment subcenters have an independent effect on freight activity. The results of this study suggest that further research on urban form and freight activity should assess the effects of employment subcenters and how their particular employment composition and characteristics are associated with freight activities at the metropolitan level. Such an approach would lead to more precise policy recommendations for urban goods movement.

I. Introduction

A half-century of dispersed spatial development has intensified polycentric urban spatial patterns. In major U.S. metropolitan areas, large population and employment subcenters have emerged outside of central cities, diminishing the role of the traditional city center as a destination for businesses. While service and financial industries are more likely to locate in the central city, manufacturing and warehousing industries have decentralized to suburbs because of lower land and transport costs (Glaeser and Kahn 2001). Moreover, employment subcenters are transforming from “business only” districts into multi-use locales that often have residential, office, retail, light industrial, and warehousing uses in close proximity, competing for space on the same road network. This changing nature and context of urban development presents challenges to many businesses trying to optimize goods and service delivery within existing transportation networks.

The previous literature on land use and transportation has focused on passenger travel (Bento et al. 2005; Boarnet and Sarmiento 1998; Boarnet and Crane 2001), providing little insight into the impact of polycentric metropolitan development patterns on freight activity. There is evidence that suggests that urban spatial structure at the metropolitan level has significant impacts on passenger travel behavior (Badoe and Miller 2000; Naess 2003; Bento et al. 2005). However, as Rodrigue (2006b) and Hesse and Rodrigue (2004) have noted, freight transport and goods movement in an urban context have been understudied despite their increasing importance on the urban economy and geography. In particular, the relationship between employment subcenters and freight travel remains largely unexplored (Hesse and Rodrigue 2004; Woudsma 2001). The dearth of research on urban freight transport is unfortunate given increasing policy attention to a national freight network and its significant role as a driver of regional and national economic development (Kane and Tomer 2015).

In this study, we use the Los Angeles region as the case study to explore the relationship between urban spatial development patterns and freight travel. Los Angeles is the ideal place to study the relationship between metropolitan development patterns and freight activity because of its large number of employment subcenters compared to other metropolitan areas and the region’s long history of dispersed urban spatial development. This introduction is followed by Chapter II, which provides some of the prominent theories on urban spatial models and freight travel in urban contexts. In Chapter III, based on the theoretical background, we identify subcenters in the greater Los Angeles region using the National Employment Time Series (NETS), which has the location and industry code of all business establishments in the region. In Chapter IV, we characterize freight travel associated with major subcenters using data from the freight modeling program of the Southern California Association of Governments (SCAG), the metropolitan planning organization for the greater Los Angeles region (plus Imperial County). Chapter IV includes a descriptive summary of truck travel, hot-spot analysis of truck density in the region, and a visual analysis that shows a spatial pattern of freight flow. We also conduct correlation and regression analyses to determine which factors contribute most to the freight travel patterns we identified. Chapter V concludes with our discussion and policy implications based on the previous analyses.

This research enables us to estimate how freight travel is associated with different employment centers, providing insights into relationships between land use, industrial structure, and the use of the road and highway system by freight. The results show freight activity in the greater Los Angeles region is associated with the location of employment, and employment subcenters have an independent effect on freight activity. This research enables us to estimate how freight travel is associated with different employment centers, providing insights into relationships between land use, industrial structure, and the use of the road and highway system by freight.

II. Literature review

1. Polycentric urban model and employment subcenters

The traditional model of urban spatial structure is the monocentric urban model which assumes that all jobs are located in the city center (Alonso 1964; Muth 1969; Mills 1967). Despite its usefulness and simplicity, the monocentric urban model has been criticized as a poor description of reality. Recent work from urban economics and regional science suggests that major American cities have become increasingly polycentric, with multiple employment centers dispersed across the metropolitan area (Anas, Arnott, and Small 1998; McDonald and McMillen 1990). The definition of employment subcenters tends to vary from one city to another, but urban researchers have long sought to develop a robust method to identify employment subcenters. McDonald (1987) used a simple employment density function to identify employment subcenters in the Chicago metropolitan area. He defined subcenters as a zone whose measure of employment concentration is higher than all other zones in the surrounding area. McMillen (2001) and Craig and Ng (2001) used a similar approach using a nonparametric employment density function to identify subcenters. They identified subcenters as areas with high employment concentration where the estimated density function is increasing rather than decreasing with distance from the city center. For the Los Angeles region, Giuliano and Small (1999) developed a criteria to identify employment subcenters as a cluster of contiguous zones having a minimum employment density of 10 jobs per acre and total employment of at least 10,000 jobs. A series of follow-up studies was conducted to ensure that this cut-off point is robust and consistent over time (Giuliano et al. 2007; Redfearn 2007).

What has driven the growth of multiple employment subcenters in the Los Angeles region? Previous literature suggests that job clusters emerge where a good labor force and transportation network exist (Giuliano and Small 1999). Firms locate near available labor supply and seek to achieve economies of scale, known as “agglomeration economies.” By locating close to each other, firms benefit from externalities of agglomeration economies, e.g. access to a large labor pool, specialized and skilled labor, knowledge spillovers, and input sharing (Puga 2010; Giuliano et al. 2007). Businesses concentrate in space because of these agglomeration benefits, and the location choice of firms among these employment subcenters is influenced by the agglomeration economies/diseconomies in each subcenter, which in turn depend on the spatial distribution of production and consumption and the existing transportation network. With the exception of one TRB report (Bassok et al. 2013), most of the theoretical and empirical work on employment subcenters has been centered on the phenomenon itself with little discussion about how the changing urban spatial pattern has influenced travel behavior. This is an especially acute gap with regard to freight demand and movement at the metropolitan scale.

2. Determinants of freight travel

In understanding freight travel, it is important to make a distinction between freight generation and freight trip generation (Holguín-Veras et al. 2014). While goods movement and freight distribution is increasingly being understood within the context of integrated freight demand (Hesse and Rodrigue 2004), freight demand occurs when there is an economic activity pertaining to the production and consumption of goods. Generation of freight trips is the result of meeting this integrated freight demand by transporting goods between production, distribution, and consumption locations. Therefore, freight trip generation is not only affected by the size of an establishment (Holguín-Veras et al. 2014) but also the size and the type of shipments being delivered (Sánchez-Díaz, Holguín-Veras, and Wang 2014) as well as the freight distribution and transportation network (Hesse and Rodrigue 2004).

Holguín-Veras et al (2011) developed an OLS model to predict freight trip generation using employment size as an independent variable at the disaggregate establishment level. They assumed that a firm decides the optimal shipment size and frequency of delivery to minimize the corresponding transportation and inventory costs, and these logistic decisions may differ by industry sector. Using data from New York City, Holguín-Veras et al (2011) have shown that freight trip generation is proportional to business size for only 18% of the industry sectors that they studied. Iding et al. (2002) developed a linear regression model for various sectors of industry using a large-scale survey conducted in the Netherlands. The results indicated that while freight trips are generally proportional to establishment size, a large variability exist in freight trip generation between individual firms and the types of industry.

Sanchez-Diaz et al. (2014) explored the relationship between freight trip attraction and key features of the urban environment. Using 343 establishments in New York, the authors found that the establishment’s location has a significant effect on freight trip generation. They found a significant autocorrelation in retail establishments, suggesting that location, e.g. proximity to large employment peers or high density retail establishments, plays an important role in attracting freight trips. Furthermore, Sanchez-Diaz et al. (2014) found that freight trip attraction is better modeled as a nonlinear function of employment and other locational variables. Taken together, these studies suggest that freight trip generation is generally proportional to establishment size, but the types of industry and the spatial clustering of firms in certain industries play an important role in attracting freight travel.

In addition to the freight demand caused by the direct outcome of economic activities, Rodrigue (2006a) has argued that freight transport should be understood as an integrated demand, recognizing the importance of underlying economic activities (e.g. employment, population, and income). While production and consumption of goods and services play an important role in generating basic demand for goods movement, recent decentralization of warehousing and trucking activity has increasingly shaped how goods movement and distribution operate in a changing micro- and macro-economic framework

(Cidell 2010; Dablanc 2014). Much of this changing dynamic is characterized by globalization and complex supply chain management where freight transport and distribution are interdependent within the urban and regional economy (Hesse and Rodrigue 2004; Rodrigue 2006a). This changing notion of freight transport also resonates with the recent development in urban economics where understanding of urban spatial structure has changed from a monocentric model to a polycentric urban model. However, little effort has been made to understand urban freight movement within the broader context of changing urban spatial structure.

A review of the previous literature indicates that most of the theoretical and empirical work on employment subcenters has been centered on either describing the patterns or identifying the causes of urban spatial structure. Likewise, the freight movement literature has largely focused on factors of freight trip generation from the perspective of firm-level logistic and business decisions. The changing nature of urban spatial structure, especially with regard to subcentering patterns of employment, has broader implications for production, consumption, and distribution of goods and services. However, urban spatial patterns and the transportation network have rarely been examined in relation to goods movement within metropolitan areas. This report, to our knowledge, is the first attempt to understand urban goods movement from the perspective of polycentric urban development and the emergence of multi-nodal and multi-functional urban regional systems.

III. Data and Methods

1. Study area

Our study area is the Los Angeles combined statistical area (33,954 square miles), which includes the counties of Los Angeles, Ventura, Orange, San Bernardino, and Riverside (Figure 1, Los Angeles region, hereafter). The Los Angeles region is a quintessential example of polycentric urban development. There are over 17 million people living in the 34,000 square mile metropolitan region. Despite its large geographic coverage, the Los Angeles region is ranked second next to the New York metropolitan area in terms of population density (546 persons per square miles). In addition to its large size and population, the long history of dispersed development patterns in the region has created many employment subcenters.

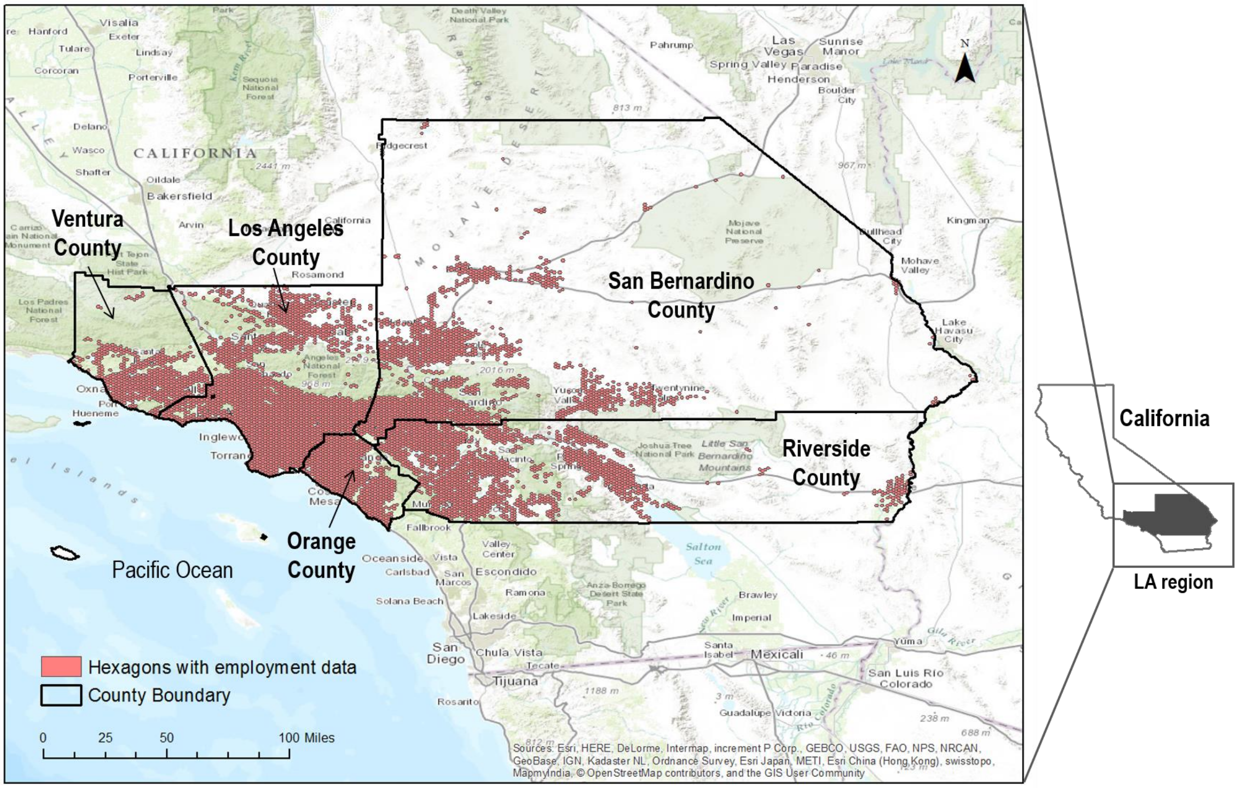

Figure 1. Study area showing the hexagons with employment data
Source: 2005 National Establishment Time Series

2. Employment subcenter data

Los Angeles is the region with the largest number of employment subcenters in the U.S. (Giuliano et al. 2012), and these employment subcenters are dispersed throughout the region. To identify employment subcenters, we used employment data from the 2005 National Establishment Time Series (NETS) database, and projected the subcenters using 1 square mile hexagons as the unit of analysis. The use of hexagons instead of traffic analysis zone (TAZ) or census tract allowed us to normalize land area with a uniform geographic shape. The NETS data contain the business name, address, total employment, and NAICS industry code of every firm in the region. We matched firms to a square mile hexagon, based on the firm's address, and used the square mile hexagons as the building blocks to identify subcenters. Only hexagons with the actual firm data from the NETS data set were matched, which essentially represent inhabited land areas (6,491 square miles) within the Los Angeles region (Figure 1).

Following the literature (Redfearn 2007; Giuliano et al. 2007; Giuliano and Small 1999), we defined employment subcenters as a cluster of contiguous zones having a minimum employment density of 10 jobs per acre and total employment (for the sum of contiguous zones in the center) of at least 10,000 jobs in the Los Angeles region (10-10 criteria). Past research has demonstrated that this is a simple and robust method (Giuliano et al., 2007). We created subcenter definitions using employment data from the 2005 National Establishment Time Series (NETS) database, and projected the subcenters using 1 mi^2 hexagons as the unit of analysis. The NETS data contain the business name, address, total employment, and NAICS industry code of every firm in the region. The use of hexagons instead of traffic analysis zone (TAZ) or census tract allowed us to normalize land area with a uniform geographic shape. Figure 2 shows the location of the employment subcenters in the Los Angeles region.

We used the 2005 data instead of the more recent 2010 NETS data to define sub-centers for two reasons. First, we prefer sub-center definitions based on a non-recession year. The steep recession that began in 2008 and continued into 2010 and beyond, by reducing employment, may cause some smaller subcenters to drop below the 10,000 jobs threshold. Believing the effect of the recession to be temporary, we prefer subcenter definitions that will show clusters of economic activity based on a pre-recession definition. Second, and relatedly, we believe it is desirable to use employment data that precedes the time period for our freight data because the formation of employment centers typically gives rise to economic activities and sparks movement of goods and people. Because the freight data are for the year 2008, the 2005 NETS data was a logical choice given our focus on the relationship between freight activity and employment subcenters. Figure 2 shows the location of the employment subcenters in the Los Angeles region. There are a total of 53 employment subcenters in the region using the 2005 data, slightly more than 48 obtained for the year 2000 by Giuliano and Redfearn (Giuliano et al. 2012), but otherwise the locations of the subcenters are very similar to earlier research.

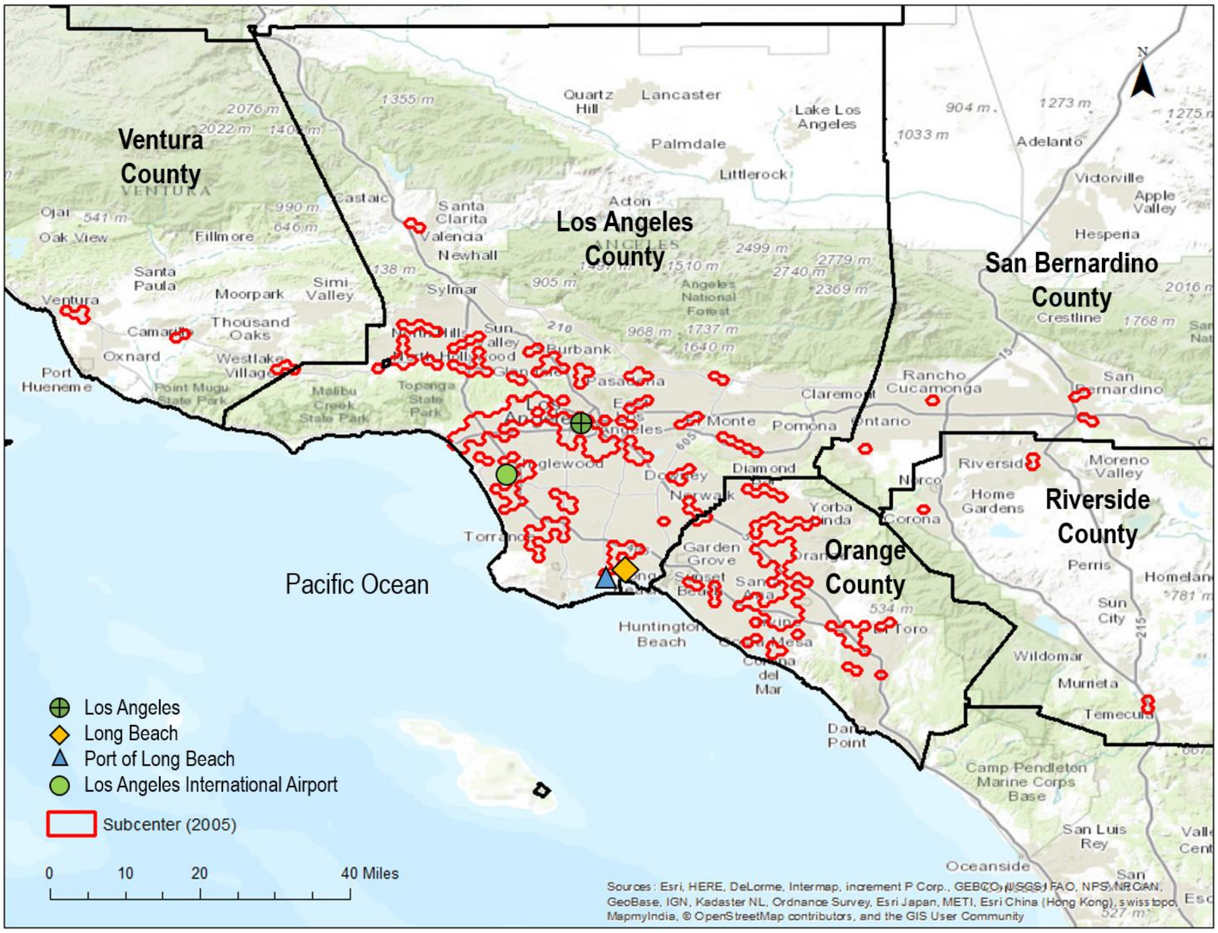

Figure 2. Employment subcenters in the Los Angeles region
Source: 2005 National Establishment Time Series

3. Freight data

The freight data are from the Southern California Association of Governments (SCAG). SCAG developed the Heavy Duty Truck (HDT) Model primarily using heavy-duty truck trip data collected by Cambridge Systematics. The HDT model provides forecasts of truck activities for three truck types: light-heavy (8,500-14,000 lbs. gross vehicle weight, GVW); medium-heavy (14,001-33,000 lbs. GVW); and heavy-heavy (>33,000 lbs. GVW). The model contains four sub-components which consist of 1) external trip generation and distribution model; 2) an internal trip generation and distribution model; 3) special trip generation and distribution model; and 4) trip assignment.

The HDT model is similar to the general four-step model except the mode choice component. The external model estimates the trip tables for interregional truck trips based on commodity flow patterns obtained from a TRANSEARCH database. TRANSEARCH is a database of freight flows in North

America that is based on industry, commodity and proprietary data exchange sources[1]. The internal model estimates trip tables for intraregional trips based on trip rates for different land uses and industry types at trip ends. Trip rates were multiplied by employment in each industry sector to obtain trip productions and attractions. The estimated rates were updated with recent surveys and third-party truck GPS data. The trip distribution process for the internal model was performed through a matrix of factors indicating trip interchange relationships among different land use types. Based on logical relationships among land use types and the use of truck GPS data, zone-to-zone gravity models were developed, generating a trip distribution pattern for each truck class.

The special generator model estimates truck activities originating from ports and intermodal rail facilities. The trip generation from the ports was developed based on activities of both container and non-container terminal trucks. This model also incorporates secondary truck trips from intermediate handling locations. The cargo trips and secondary truck trips were allocated to other destinations using the gravity model. Lastly, the trip assignment model includes both truck trip tables and the passenger trip tables. Truck trip tables are converted into passenger car equivalents (PCEs) using the PCE factors adapted from the TRB Highway Capacity Manual. The final model output consists of link-based truck flow data. The freight flow data has a total of 68,968 links, and multiple attributes are associated with each link (Figure 3). Initially, each link contained truck volume and lane numbers in two different directions. Some links had an inconsistent number of lanes across different time periods because some streets have reversible lanes where traffic travels in either direction, depending on displayed overhead signals. Lane numbers can also vary by the direction of flow because of asymmetric street configurations (e.g. one-way street).

To account for this discrepancy, we combined all lane numbers regardless of their direction and the calculation was based only on lane numbers during the peak PM period. The truck volumes were also recorded in different directions of flow, so the volumes in each direction were combined to represent both directions of flow. Some links were also dummy links which represent the artificial connection between two traffic analysis zones (TAZs). After removing these 558 dummy links, the total number of links in the final data set was 68,410.

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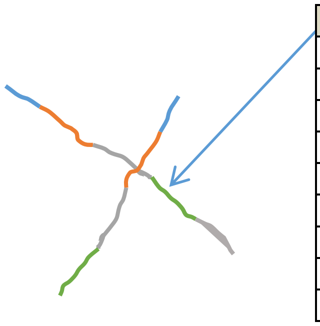
[1] https://www.ihs.com/products/transearch-freight-transportation-research.html



Freight flow links

Variable	Description
ID	Link ID
LENGTH	Length of each link in km
LANES	# of lanes in each link
FLOW_AM	Truck volume in morning
FLOW_MD	Truck volume in mid-day
FLOW_PM	Truck volume in afternoon
FLOW_EV	Truck volume in evening
FLOW_NT	Truck volume at night
. . .	. . .

Figure 3. Graphical description of the freight flow data

3.1 Freight density

Freight flow density for each link was calculated as the total truck volume divided by lane kilometers. Each link differs in its lanes and length, so this density measure adjusts the truck volume based on the number of lanes and the length of each link.

$$\text{Freight density (truck volume per lane km)} = \frac{V_{k,t,i}}{n_i \times l_i}$$

Where, k represents types of freight truck: 0=all type; 1=light duty; 2=medium duty; 3=heavy duty; t is time periods (0=all day; 1=am; 2=pm; 3=mid-day; 4=evening; 5=night); i is each freight flow link; $V_{k,t,i}$ represents per-link truck volume for k type of truck during t time periods; n_i is number of lanes for each link i;. l_i denotes length of each link i in km.

3.2 Freight travel distance

Freight travel distance associated with each link was calculated as the truck flow per link multiplied by the length of each link. Aggregate freight VKT was then calculated by summing up all freight travel distance for all links within each employment hexagon (Figure 4). The aggregate value represents the total freight distance travelled within each employment hexagon. The calculation of the VKT variable is shown in the following equation.

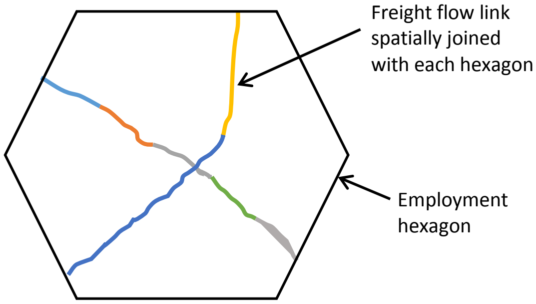


Figure 4. Geographical unit of analysis as a 1 square mile employment hexagon

$$\text{Freight VKT (truck travel distance per hexagon)} = \sum_{i}^{n} V_{k,i} \times l_i$$

Where, $V_{k,i}$ is per-link daily truck volume for k type of truck; l_i refers to length of each link i in km; k denotes types of freight truck: 1=all type; 2=light duty; 3=medium duty; 4=heavy duty; i refers to each freight flow link; and n is total number of links within one employment hexagon.

3.3 Freight data validation

The freight data obtained from the SCAG are considered the most complete data source with regard to truck activities in the Los Angeles region. The freight data are an estimation of truck activities based on a four-step modeling process which takes multiple data sources, including proprietary truck surveys and commodity flow surveys. In estimating the regional and local freight flow, SCAG calculated a trip generation rate for each traffic analysis zone (TAZ) to determine areas with high truck activities based on a number of factors, including population, employment, and land use patterns. The estimated trip generation rate was initially used for performing other modeling processes, such as trip distribution and trip assignment. We validated the data by comparing the SCAG freight data against the publicly available annual average daily truck traffic (AADT) in 2010 from California Department of Transportation.[2] The Truck AADT data were obtained from a continuous truck count sampling, which includes a partial-data, 24-hour, 7-day and continuous vehicle classification counts conducted annually on all highways in the State of California. The resulting counts were adjusted to an estimated annual average daily truck traffic by accounting for seasonal and weekly variation. The truck AADT covers only highways; therefore, we only compared data on highways.

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[2] http://www.dot.ca.gov/hq/tsip/gis/datalibrary/Metadata/TruckAADT.html

The Caltrans AADT data reflect observed freight movement, but the data are limited to trucks on highways. Using the Caltrans data, we computed an average truck AADT for each employment hexagon and compared the resulting values against the average SCAG freight flow and truck VKT on highways (excluding arterial freight traffic) for each matching hexagon. Figure 5 presents both the distribution and the correlation plots for the SCAG's freight flow and truck VKT, and the Caltrans Truck AADT. A direct comparison between the SCAG data and the Caltrans data shows that they are positively correlated (= 0.65) at the 5% significance level.

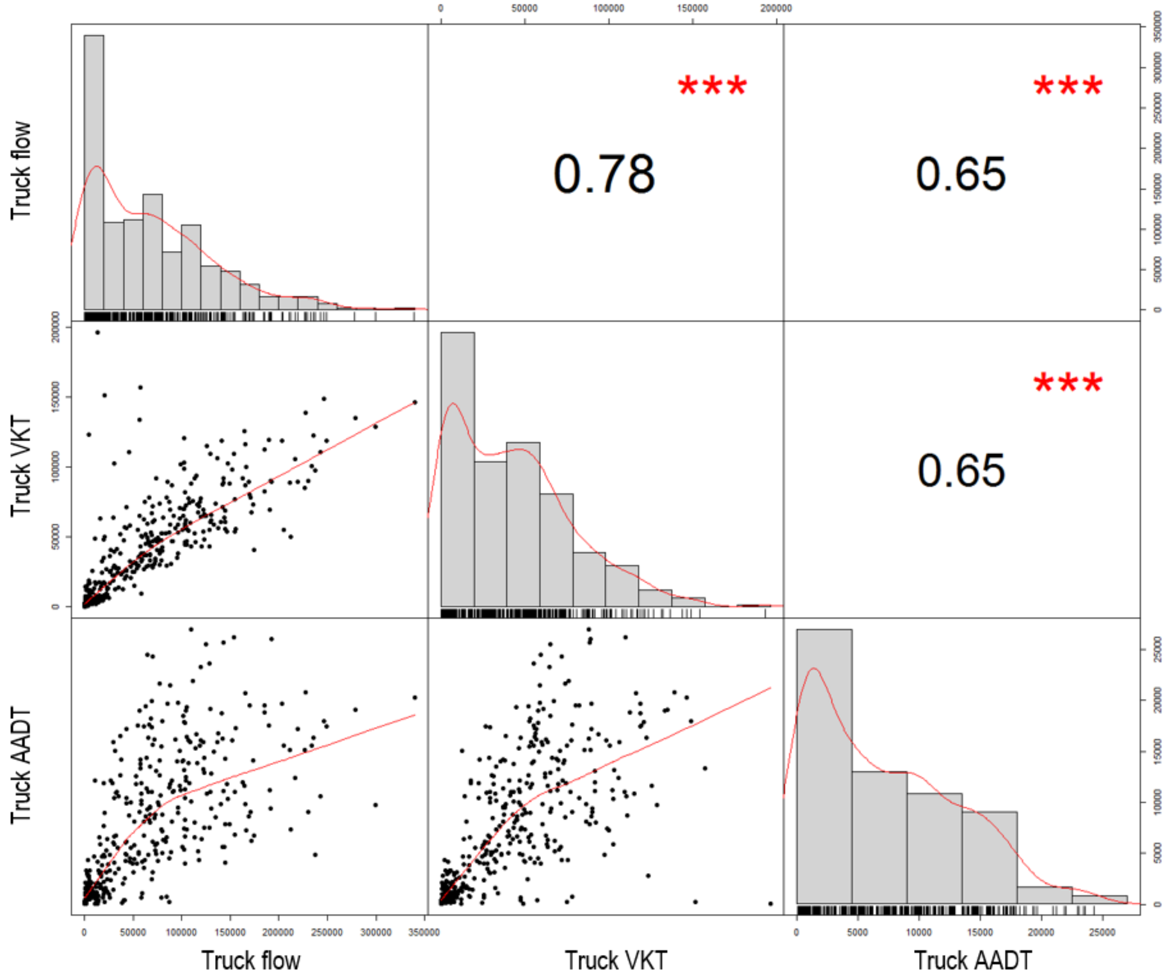

Figure 5. Correlation plots of the SCAG freight and CalTrans' truck AADT data

* The panels on the diagonal represent histograms of the variables in this order: truck flow, truck VKT, and truck AADT. The panels in the lower left of the diagonal represent scatterplots. The panels in the upper right of the diagonal represent correlation coefficients.

Source: 2008 SCAG baseline freight data; 2010 Caltrans truck traffic volumes (AADT)

The Pearson's correlation assumes that the data are normally distributed, so we performed a log- and square root-transformation to satisfy the normality assumption. Figure 6 presents the correlation results performed with the transformed data. The Caltrans Truck AADT data are highly correlated with both the SCAG's truck flow and truck VKT data, with the correlation ranging between 0.74 and 0.90 at the 5% significance level. The Pearson's correlation tests indicate that the SCAG freight data are highly correlated with the Caltrans data which are based on real truck counts. This suggests that the SCAG freight data are a reasonable data source for our study focusing on regional freight activity.

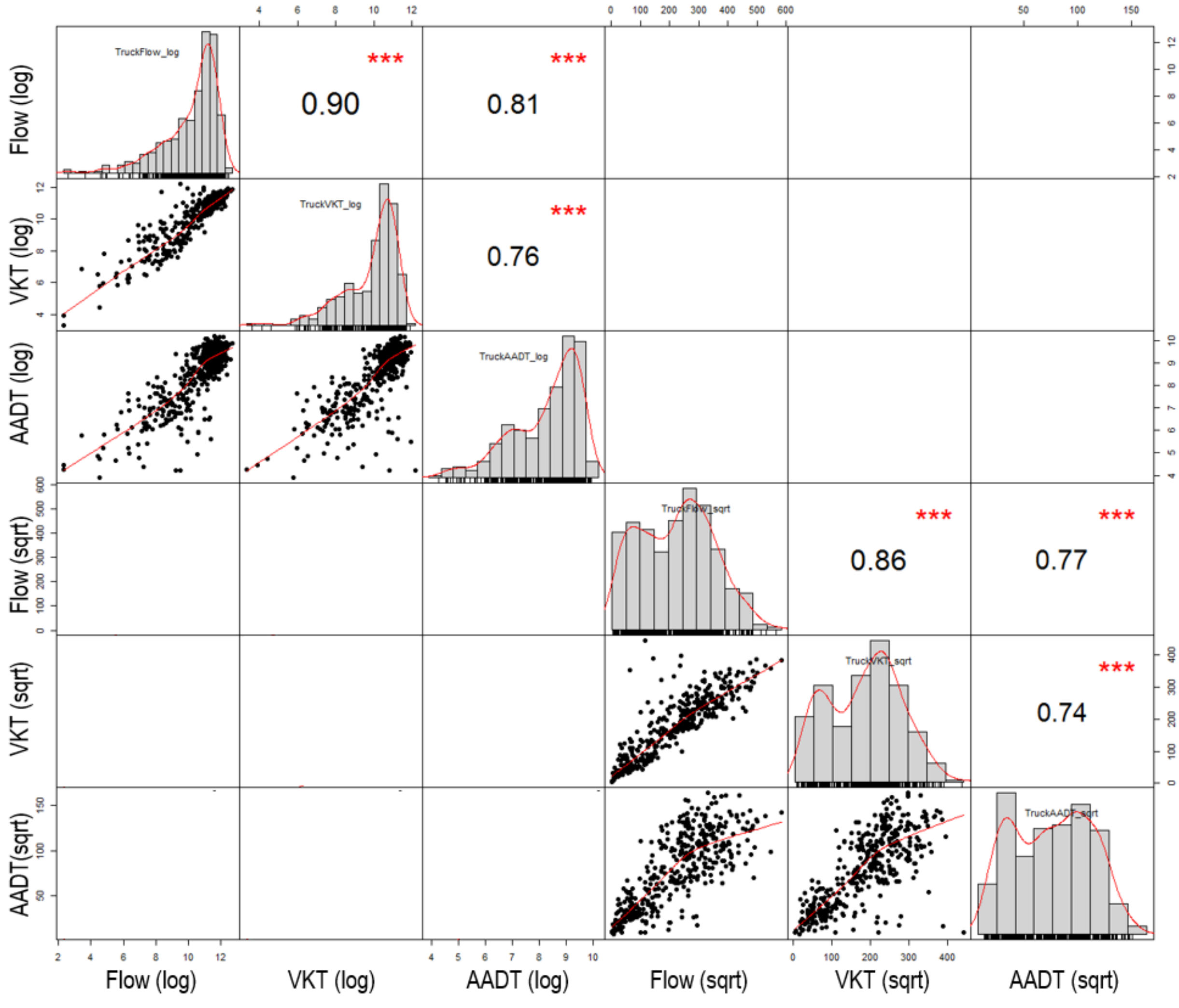

Figure 6. Correlation plots of the transformed freight flow, freight VKT, and truck AADT data

* The panels on the diagonal represent histograms of the variables in this order: logged truck flow, logged truck VKT, logged truck AADT, square root of truck flow, square root of truck VKT, and square root of truck AADT. The panels in the lower left of the diagonal represent scatterplots. The panels in the upper right of the diagonal represent correlation coefficients.

Source: 2008 SCAG baseline freight data; 2010 Caltrans truck traffic volumes (AADT)

4. Intermodal freight facility data

Intermodal freight transport utilizes two or more modes to form an integrated freight movement chain (Lowe 2005). Intermodal freight facilities serve as important transfer stations between truck trailers or between cargo containers and rail lines. These facilities typically consist of a rail yard, a container yard depot, a trucking terminal, and a warehousing facility. Large cargo containers transported by rail or truck are temporarily stored until they get shipped to other locations. Import/export goods are usually transported by truck, and interstate goods are transported to other cities by rail or truck. Because intermodal facilities act as a natural hub for heavy-duty trucks, they are important factors for freight movement at the metropolitan level.

We obtained geocoded intermodal facility data from the 2011 National Transportation Atlas Database (NTAD) maintained by U.S. Bureau of Transportation Statistics, a nationwide geographic database of transportation facilities, transportation networks, and associated infrastructure. This dataset includes spatial information for transportation modal networks and intermodal terminals, as well as the related attribute information for these features. According to the NTAD data, there are about 93 intermodal freight terminals of various sizes and functions in the Los Angeles region. Of these terminals, we selected the seven largest intermodal terminals that operate rail-to-truck and truck-to-rail transloading facilities. Four of them are operated by Union Pacific Railroad, and three are operated by the competing Burlington Northern/Sante Fe Railroad. Although the NTAD data are from 2011, we confirmed that the seven major terminals included in our analysis existed before 2005 based on the California Air Resources Board's enforcement document on major rail yards in California (California Air Resoureces Board 2005).

5. Visualization of freight activities

Freight flow can be represented as a continuous surface using interpolation. Interpolation allows for estimating unknown data using known measurements, and the most common interpolation techniques include inverse distance weighting (IDW). Previous studies have used similar interpolation techniques to estimate traffic intensity based on known traffic count data, such as annual average daily traffic (AADT) volume (Selby and Kockelman 2013; Wang and Kockelman 2009). Each link in the freight flow data represents the total number of trucks passing that link. Therefore, the link data can be regarded as the daily average truck counts for a particular link, which is similar to the AADT data. Using the similar approach for the AADT estimation, several interpolation techniques were adopted to create a surface of freight flow for the Los Angeles region.

To perform interpolation, the freight link data were first converted into point data using the centroid of the link as the geometric location of the point. These converted points were linearly interpolated using the inverse distance weighting (IDW) method, a deterministic approach to interpolate unknown points by assigning higher values for points close to known points and lower values for points far from the known points, hence the name inverse distance weighting.

6. Regression model development

In order to assess the effect that employment subcenters have on freight activity, we developed an ordinary least squares (OLS) model with heteroskedasticity robust standard errors. This entails discerning between the effect from employment subcenters and total employment in a hexagon and adjacent hexagons, while controlling for other land use variables such as the presence of freeways. We use hexagons as the unit of analysis. By limiting the analysis to those hexagons that registered employment, we used the 6,491 1 mi^2 hexagons as the unit of analysis. This also allows us to normalize effects by land area. The model was set up as follows:

$$Y_i = \beta_0 + \sum_{j=1}^{m} \beta_j X_{ij} + \sum_{k=1}^{p} \beta_k Z_{ik} + \varepsilon_i$$

Where Y_i refers to total VKT in each hexagon i, β_0 is the intercept, X_{ij} refers to the set of variables j that pertain to employment subcenters and total employment for each hexagon i, Z_{ik} refers to the set of other control variables related to land use and urban form characteristics in each hexagon i, and ε refers to the error term.

Two subcenters are much larger than the others, both in land area and employment. These two subcenters have a large concentration of employment in professional services and appear qualitatively different from the other subcenters (Table 1).

Table 1. Subcenter summary statistics

Subcenter	**Total employment**	**Surface area in square miles**	**Share of total employment in professional services**
1	1,091,789	62.00	12.9%
2	563,287	39.00	13.2%
Other subcenters*	38,008	3.63	9.2%

* *Values in row correspond to the average in each category*

Therefore, we divided the subcenter variable into three groups: 1) a binary variable indicating whether a hexagon is in the largest subcenter, located in the Downtown Los Angeles-Wilshire Boulevard-Santa Monica corridor; 2) a binary variable indicating whether a hexagon is in the second-largest subcenter, located in central Orange County; and 3) a binary variable indicating whether a hexagon is in any of the other subcenters excluding the largest two subcenters.

Other independent variables include the level of employment and its square value in each hexagon, since employment and freight activity have been found to have a non-linear relationship (Sánchez-Díaz, Holguín-Veras, and Wang 2014). To consider employment clustering effects, the total employment in adjacent hexagons and its squared value were also included in the model. In addition, to see how different industry sectors affect freight activity, we included the share of total employment in each hexagon that is in different industry sectors using the NAICS 2-digit codes. We focused particularly on employment in agriculture, construction, manufacturing, mining, professional services, retail, transportation, utilities and wholesale as independent variables for two reasons: (1) to reduce the possibility of collinearity in the model and (2) because this set of industries provides an opportunity to distinguish the potential effect that labor-intensive and capital-intensive industries have on freight activity.

Additional control variables measure the effect of the presence of freeways in the hexagons and the distance to intermodal facilities from the centroid of a hexagon. Intermodal facilities are areas dedicated to the transshipment of freight cargo and are expected to be related to freight activity on nearby links. The effect from these facilities was represented with a continuous variable that measures the linear distance between each hexagon centroid and the nearest intermodal facility (from among the seven largest such facilities in the region), as well as binary variables that specify whether each hexagon is located within distance bands of 1 mile to 10 miles from one of the seven largest intermodal facilities. A complete description of the variables included in the regressions is shown in Appendix 1, and summary statistics for these variables are provided in Appendix 2.

IV. Results and discussion

1. Descriptive summary

A descriptive summary of daily truck flow and density is shown in Table 2. For the truck flow measures, more than 90% of the data (62,835 links) come from links that are greater 100m. The daily mean truck flow for the links greater than 100m is about 1,002 trucks per link per day. The median is 190 trucks, which is less than one fifth of the average value, indicating that the mean value is influenced by some extreme data. The maximum truck flow is 22,776 for the links greater than 100m. The daily mean truck density for the links greater than 100m is 827 trucks per lane km. The median value is 178, which is not far from one fifth of the mean value. Note that the links less than 10m have average truck density of 56,414, which is almost 70 times higher than that of the links greater than 100m. The truck density measures are largely driven by truck length and number of lanes, which make up the denominator for calculating the density. Because trucks are normally larger than 10m, calculations based on links less than 10m would not make any sense in the real world. Hence, we decided to exclude links less than 10m.

Table 2. Daily truck flow and density by link length

Measures	Length	N	Percent	Mean	SD	Median	Min	Max	Missing
Daily flow	<10m	86	0.13	413	526	251	0	2691	0
Daily flow	<20m	276	0.40	343	647	118	0	6924	0
Daily flow	<30m	332	0.49	338	768	119	0	9623	0
Daily flow	<40m	419	0.61	938	2376	278	0	17946	0
Daily flow	<50m	626	0.92	912	2111	306	0	22597	0
Daily flow	<60m	609	0.89	1008	2231	340	0	14509	0
Daily flow	<70m	700	1.02	801	1733	293	0	14440	0
Daily flow	<80m	717	1.05	809	1898	226	0	15024	0
Daily flow	<90m	894	1.31	731	1893	233	0	20073	0
Daily flow	<100m	1116	1.63	652	1579	235	0	18454	0
Daily flow	>100m	62635	91.56	1002	2503	190	0	22776	0
Daily density	<10m	86	0.13	56414	190405	17292	0	1601635	11
Daily density	<20m	276	0.40	8558	29327	3061	0	441994	19
Daily density	<30m	332	0.49	4366	9754	1856	0	94972	12
Daily density	<40m	419	0.61	7602	17911	2402	0	163004	32
Daily density	<50m	626	0.92	5459	11059	2064	0	96208	72
Daily density	<60m	609	0.89	4762	9554	1693	0	56746	55
Daily density	<70m	700	1.02	3642	7452	1443	0	52210	46
Daily density	<80m	717	1.05	3449	9053	1036	0	135575	44
Daily density	<90m	894	1.31	2688	7581	977	0	117263	42
Daily density	<100m	1116	1.63	2081	4467	854	0	46695	50
Daily density	>100m	62635	91.56	827	2320	178	0	87804	2194

Source: 2008 SCAG baseline freight data

Table 3 is a descriptive summary of daily truck flow and density that excludes links less than 10m. A summary of truck VKT data is also shown. Note that we did not exclude shorter links (<10m) when calculating the truck VKT data, because VKT is flow multiplied by link length and we believe that flow on short links can be reliable even though density for links smaller than one truck is unreliable. The data were also grouped into three truck types: light-heavy (8,500-14,000 lbs. gross vehicle weight, GVW); medium-heavy (14,001-33,000 lbs. GVW); and heavy-heavy (>33,000 lbs. GVW). Heavy-duty truck type has the highest mean daily truck flow per link (mean truck flow = 627), indicating that heavy-duty trucks make up the majority of the freight travel data. The truck flow data are highly skewed to the right, with a disproportionately large volume of data clustered at zero. This suggests that many links have little or no truck flow present on any day but some links contain very high truck activities, with daily mean values reaching up to 22,776 trucks per day.

Table 3. Daily truck flow, density, and VKT

Measures	N	Mean	SD	Median	Min	Max
Daily flow	68324	982	2456	194	0	22776
Light-duty flow	68324	199	403	63	0	3512
Medium-duty flow	68324	156	322	45	0	2729
Heavy-duty flow	68324	627	1768	79	0	17397
Daily density	68324	1085	3990	198	0	441994
Light-duty density	68324	240	660	65	0	24299
Medium-duty density	68324	190	539	46	0	21806
Heavy-duty density	68324	655	3054	80	0	433695
Daily VKT (km)	5609	12794	26711	1910	0	559342
Light-duty VKT	5609	2300	4062	555	0	50969
Medium-duty VKT	5609	1744	3178	378	0	31410
Heavy-duty VKT	5609	8750	20002	903	0	476962

Note that VKT is for hexagons while all other data are for links, hence the difference in N.

Source: 2008 SCAG baseline freight data

As is evident from the histograms of truck flow and density, the data are highly skewed to the right, with a disproportionately large volume of data clustered to zero (Figure 7). Truck density data are even more clustered toward zero (Figure 8). These plots suggest that many links have little or no truck flow present at any day but some links contain very high truck activities, with daily mean values reaching up to 22,776 trucks per day or 441,994 trucks per lane km per link per day. We manually checked that the link with the highest truck density is located near the Los Angeles/Long Beach Port where most of the truck activities are concentrated. Truck VKT data also show the similar distribution pattern as the truck flow and density, with the daily average value reaching up to 559,342 VKT (Table 3, Figure 9).

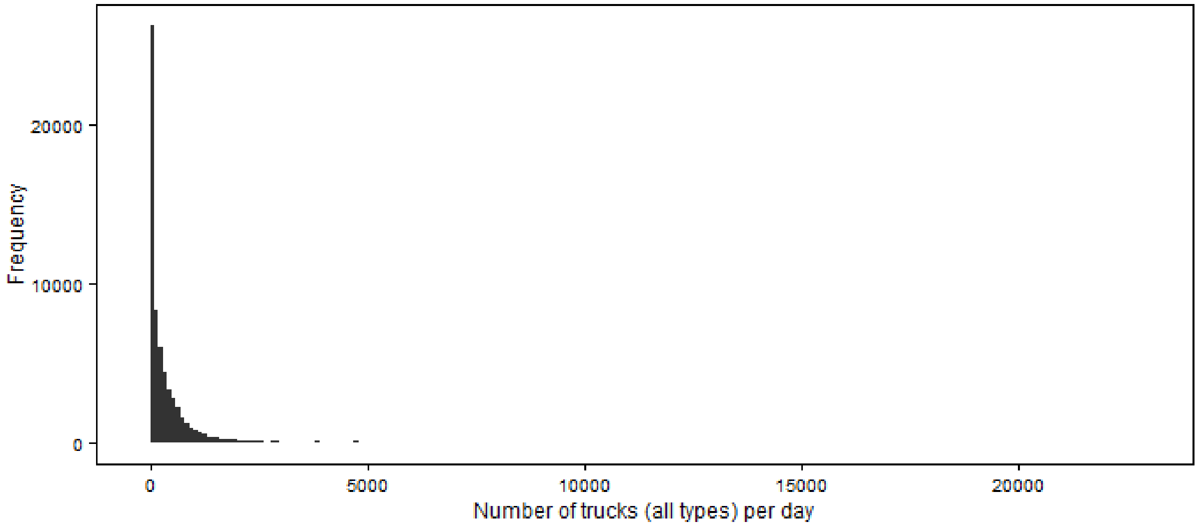

Figure 7. Histogram of daily truck flow (exclude links < 10m)
Source: 2008 SCAG baseline freight data

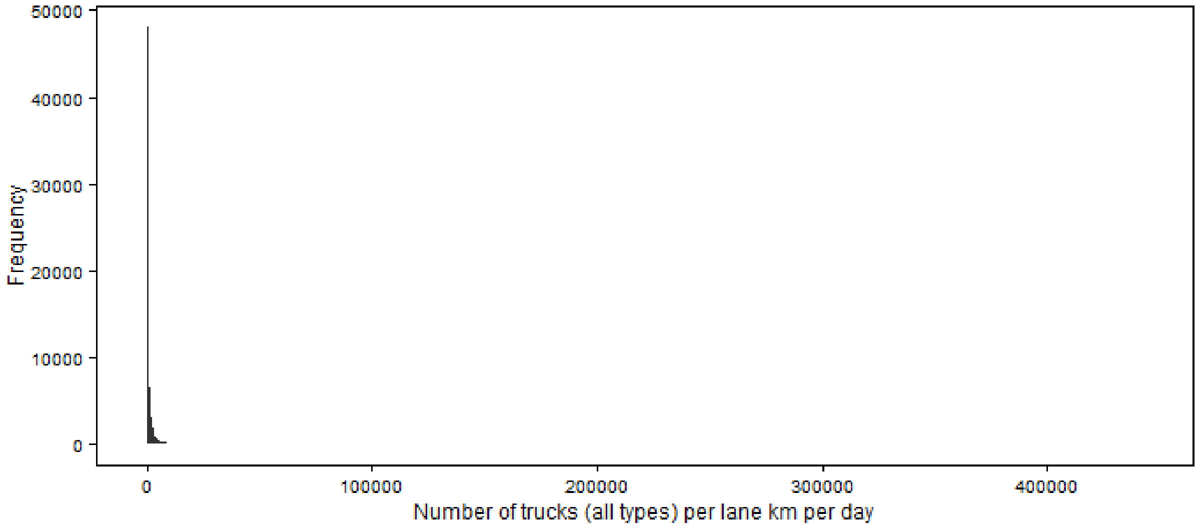

Figure 8. Histogram of daily truck density (exclude links < 10m)
Source: 2008 SCAG baseline freight data

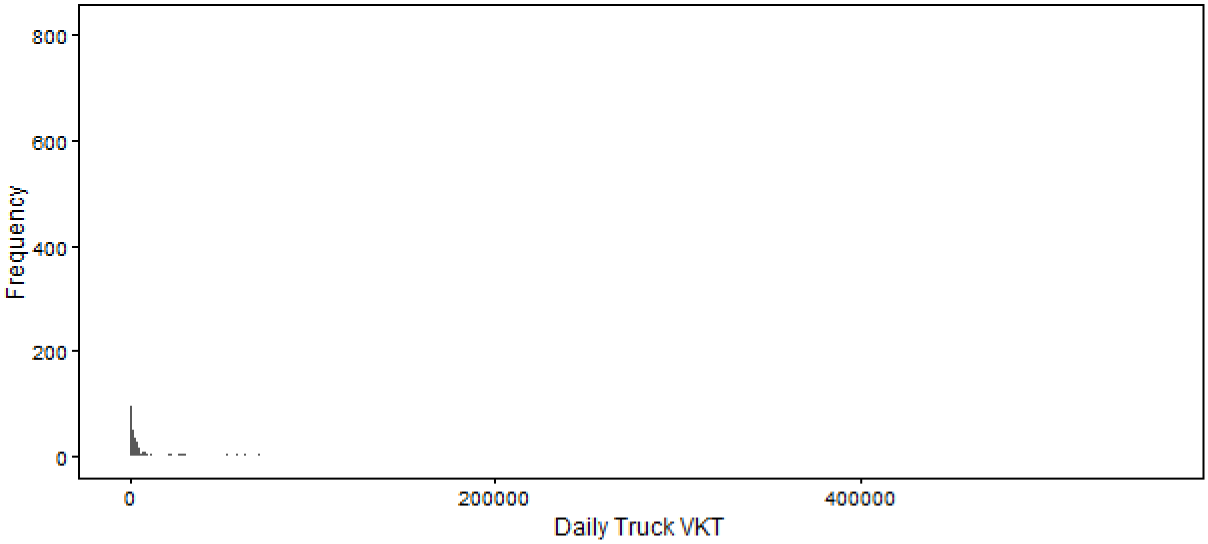

Figure 9. Histogram of daily truck VKT (exclude links < 10m)
Source: 2008 SCAG baseline freight data

To visualize these highly clustered data, we computed a percentile distribution of truck flow for three truck types (Table 4 and Figure 10). The values correspond to each of the 25th, 50th, 75th, 90th, 99th, 99.9th, 99.97th, and 100th percentile. We purposefully examined values above the 99.97th percentile because they represent the top twenty hotspots in freight activity in the Los Angeles region.

Table 4. Percentile table of truck flow (exclude links < 10m)

Variable	P_{25}	P_{50}	P_{75}	P_{90}	P_{99}	$P_{99.9}$	$P_{99.97}$	P_{100}
All truck flow	28	194	597	1894	12479	18666	20535	22776
Light truck flow	11	64	176	426	2012	2869	3089	3512
Medium truck flow	7	45	136	354	1664	2294	2430	2729
Heavy truck flow	9	78	277	1079	9119	13611	15666	17397

Source: 2008 SCAG baseline freight data

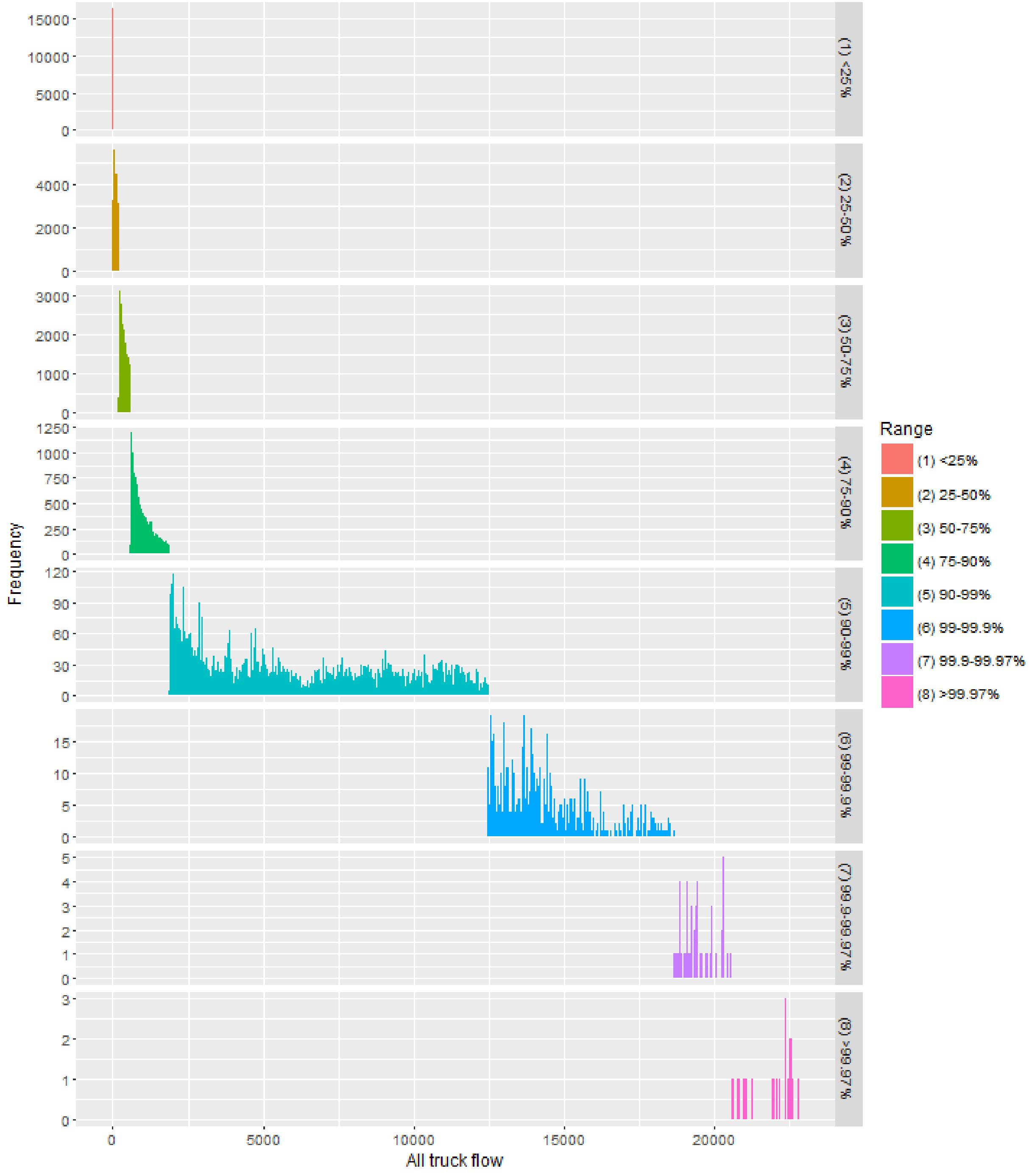

Figure 10. Percentile distribution of daily truck flow (exclude links < 10m)
Source: 2008 SCAG baseline freight data

All truck flows in each percentile range widely from 28 trucks per link per day (25th percentile) to 20,535 trucks per link per day (99.97th percentile). Truck flows are most widely distributed in the percentile range between 90th and 99.9th percentile, corresponding values ranging from 1,894 trucks per link per day to 18,666 trucks per link per day. This indicates that truck flows are not evenly distributed, but more densely distributed in a lower range and more sparsely distributed in a higher range.

Table 5 presents a percentile distribution of truck density for three truck types. Again, we observe the same patterns as the percentile distribution of truck flow – uneven distribution of data concentrated in a lower range. The truck density data are more widely distributed than the truck flow data, with all truck density ranging from 24 trucks per lane km per link per day (25th percentile) to 69,632 trucks per lane km per link per day (99.97th percentile).

Table 5. Percentile table of truck density (exclude links < 10m)

Variable	P_{25}	P_{50}	P_{75}	P_{90}	P_{99}	$P_{99.9}$	$P_{99.97}$	P_{100}
All truck density	24	198	784	2518	13791	47226	69632	441994
Light truck density	9	65	220	579	2642	8649	11895	24299
Medium truck density	5	46	171	464	2178	7056	9930	21806
Heavy truck density	7	80	368	1424	9162	34472	48286	433695

Source: 2008 SCAG baseline freight data

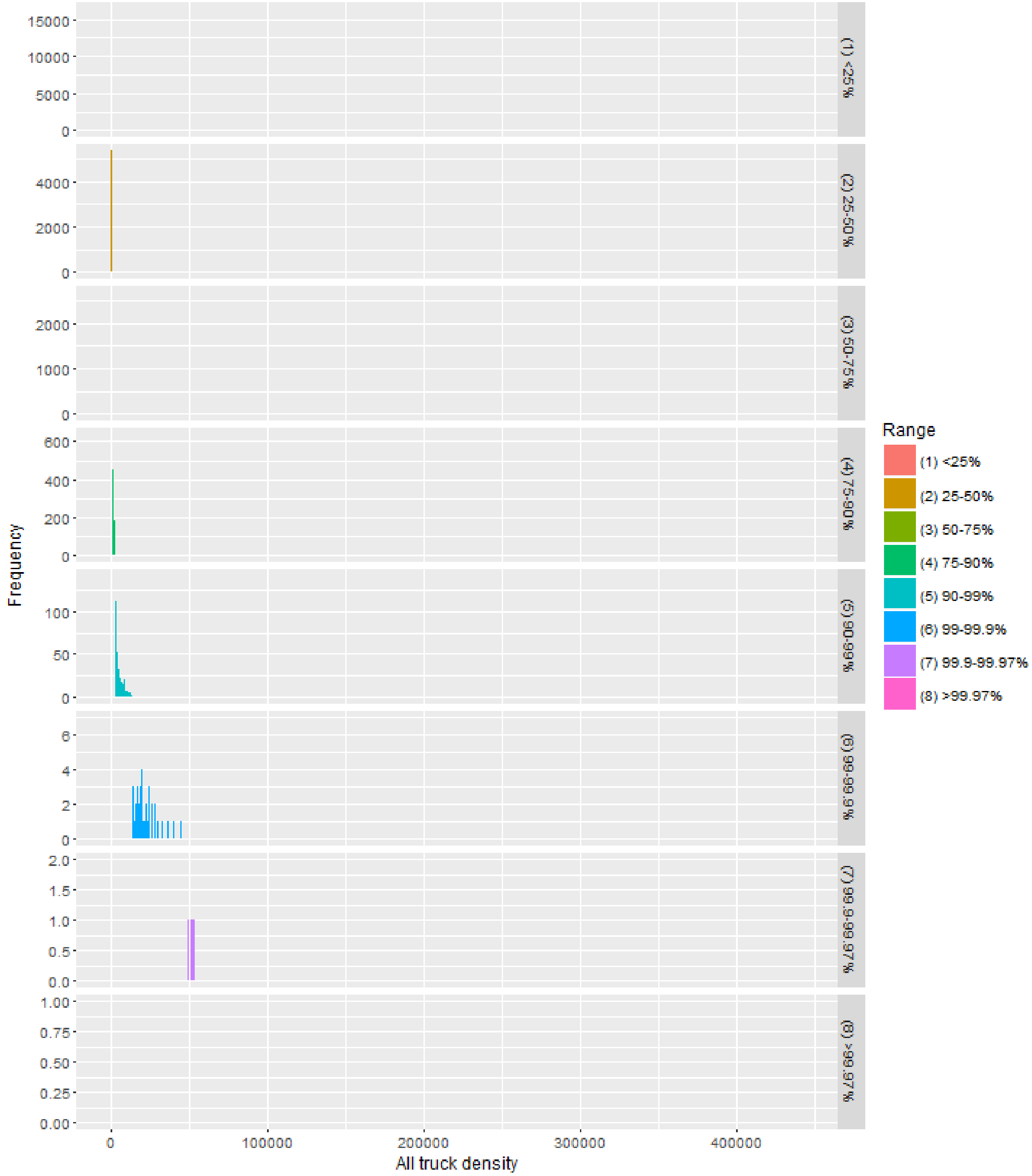

Figure 11. Percentile distribution of daily truck density (exclude links < 10m)
Source: 2008 SCAG baseline freight data

The truck flow density is more widely dispersed in the higher percentile range between 99th percentiles and above (Figure 11). The corresponding value for the 90th percentile is 2,518 trucks per lane km per link per day, and the value for the 99.9th percentile is 47,226 trucks per lane km per link per day. This indicates that the computation of the density measure, which adjust truck flows based on length and width of the link, results in suppressing the data on the range below the 99th percentile but dispersing the data on the range above the 99th percentile. Table 6 and Figure 12 show the percentile distribution of truck VKT. The unit of analysis for truck VKT is a hexagon. The truck VKT data are also skewed to the right with a long tail. The maximum VKT value (559,342) is more than ten times the value (47,474) corresponding to the 90th percentiles, indicating that the VKT data are widely dispersed above the 90th percentile values.

Table 6. Percentile table of truck VKT (exclude links < 10m)

Variable	P_{25}	P_{50}	P_{75}	P_{90}	P_{99}	$P_{99.9}$	$P_{99.97}$	P_{100}
All truck VKT	392	1910	7930	47474	113370	224683	274399	559342
Light truck VKT	137	555	1904	8228	17701	28394	34804	50969
Medium truck VKT	82	378	1462	6199	14298	24448	28449	31410
Heavy truck VKT	153	903	4604	32253	85378	179754	216433	476962

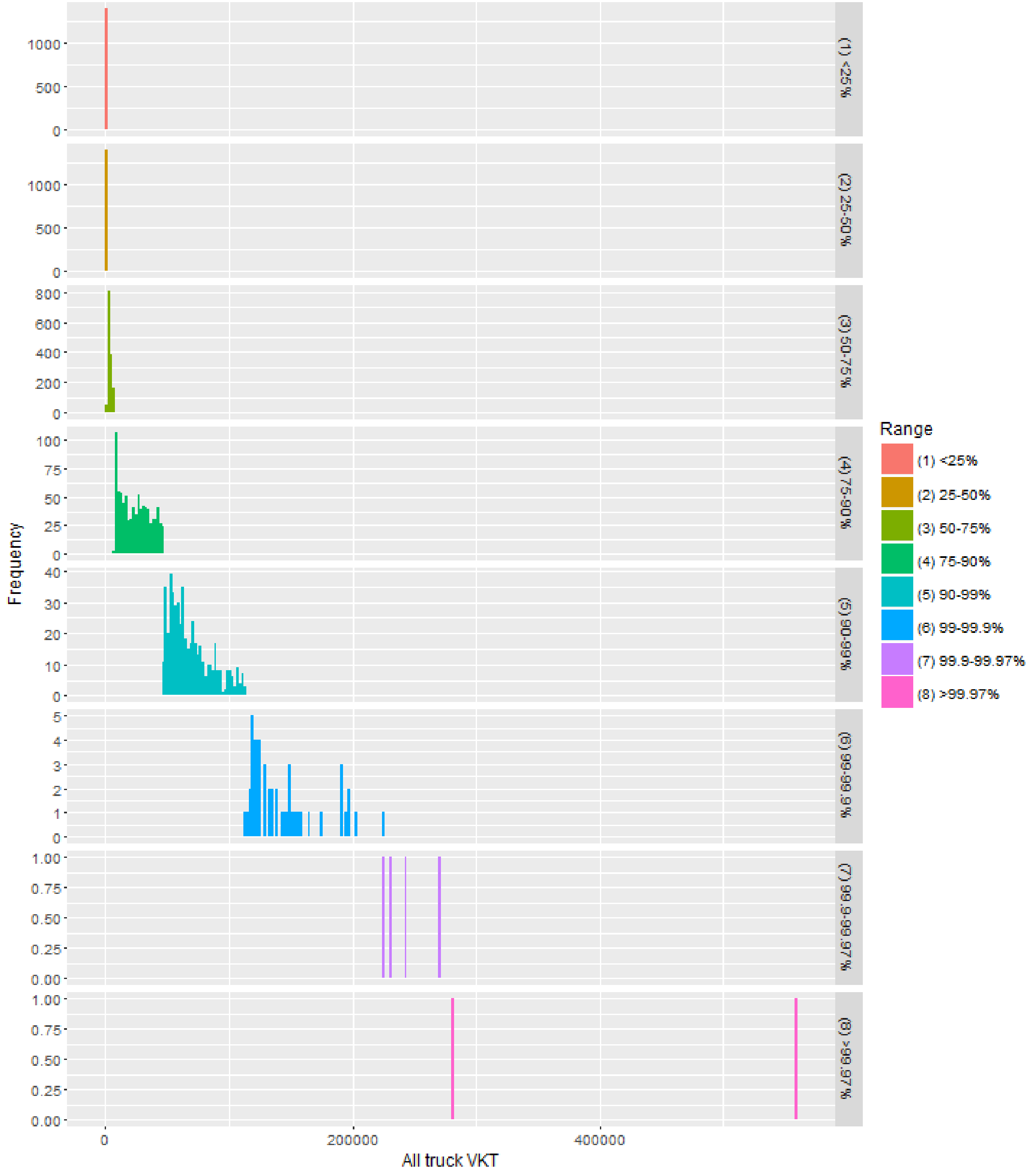

Figure 12. Percentile distribution of daily truck VKT (exclude links < 10m)
Source: 2008 SCAG baseline freight data

2. Hot-spot analysis

A hotspot analysis was performed focusing on the top twenty values in all type truck density. The top 20 values were identified for truck density measures above the 99.97th percentile rank described in Table 5.

For this hotspot analysis, truck density was used instead of truck flow because the density measure provides a standardized measure that can be compared among links with different length and lane width. Figure 13 presents the map of truck density for all truck types and the hotspots identified as the top twenty links with the highest density. For purpose of the analysis, we clustered these hotspots into six groups, assigning each group a letter A through F. We examined each cluster group in the following section.

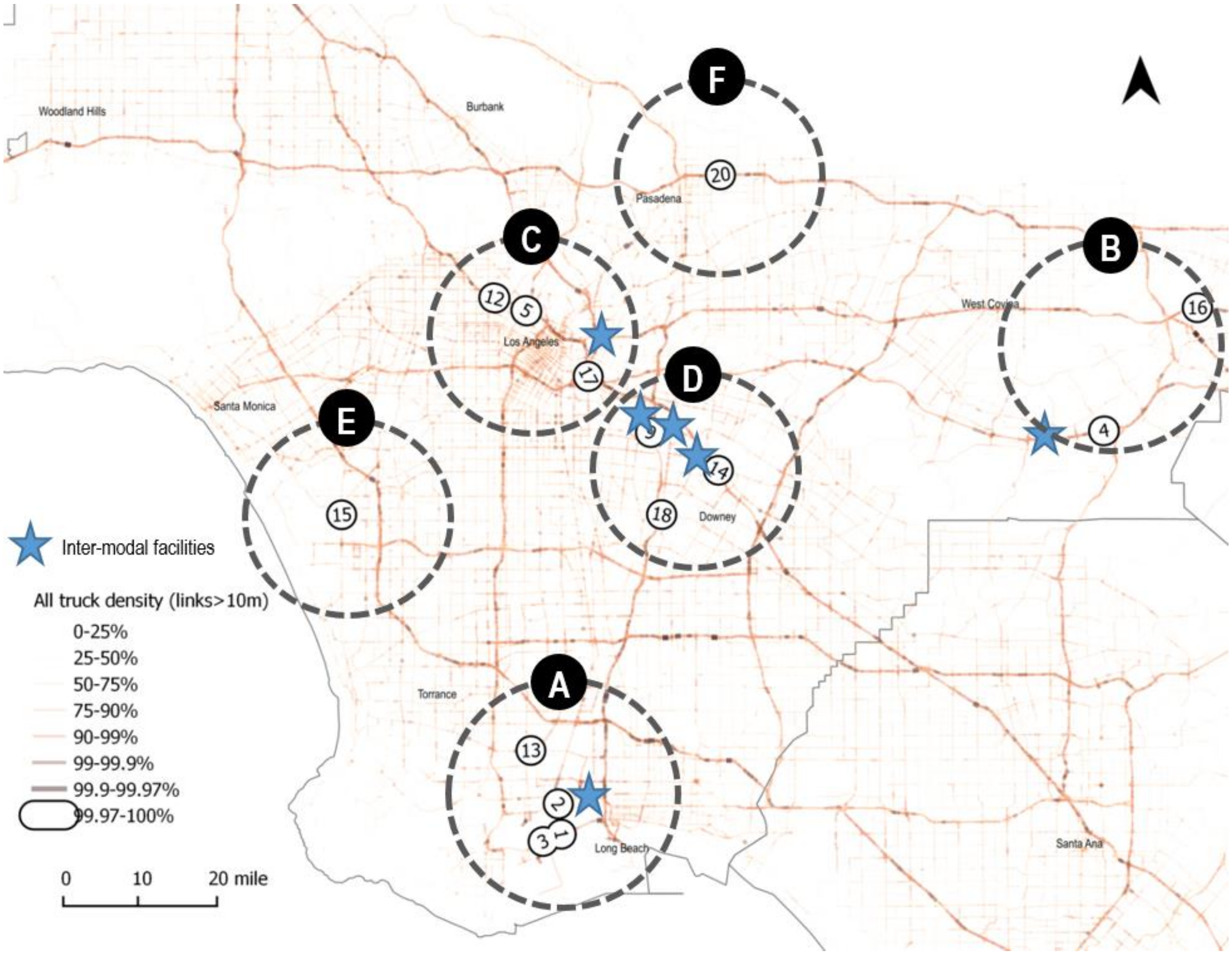

Figure 13. Top 20 all truck density and density clusters (exclude links < 10m)
* Intermodal facility in San Bernardino is not shown in this map due to space limitation.

Source: 2008 SCAG baseline freight data

Cluster A – Port of Los Angeles and Port of Long Beach

The cluster A includes four hotspots near the Long Beach port and intermodal facilities. The Port of Los Angeles and the Port of Long Beach is one of the largest container port complexes in the U.S. by volume. In 2010, about 7.8 million TEUs (twenty-foot equivalent units) of inbound and outbound loaded containers were handled in these port facilities (The Port of Los Angeles 2011). The nearby Long Beach Freeway is well integrated into the port facilities, providing direct connections among the ports, distribution centers, and the nearby intermodal facilities. Based on the 2010 traffic count data from California Department of Transportation, approximately 1,768 to 9,976 annual average daily traffic (AADT) was counted as truck traffic along the highway segment near the port facilities, a southern-most 7-mile stretch of the I-110 highway connecting the City of Long Beach and the City of Carson.

Table 7. Truck density hotspots in Cluster A

Rank	Length (km)	Lanes	Density				Volume			
			All truck	Light	Medium	Heavy	All truck	Light	Medium	Heavy
1	0.0157	1	441,994	4,277	4,022	433,695	6,924	67	63	6,794
2	0.0398	1	163,004	9,201	8,723	145,079	6,484	366	347	5,771
3	0.0385	2	147,105	4,408	3,576	139,121	11,313	339	275	10,699
13	0.0108	2	84,825	23,312	20,194	41,319	1,823	501	434	888

Source: 2008 SCAG baseline freight data

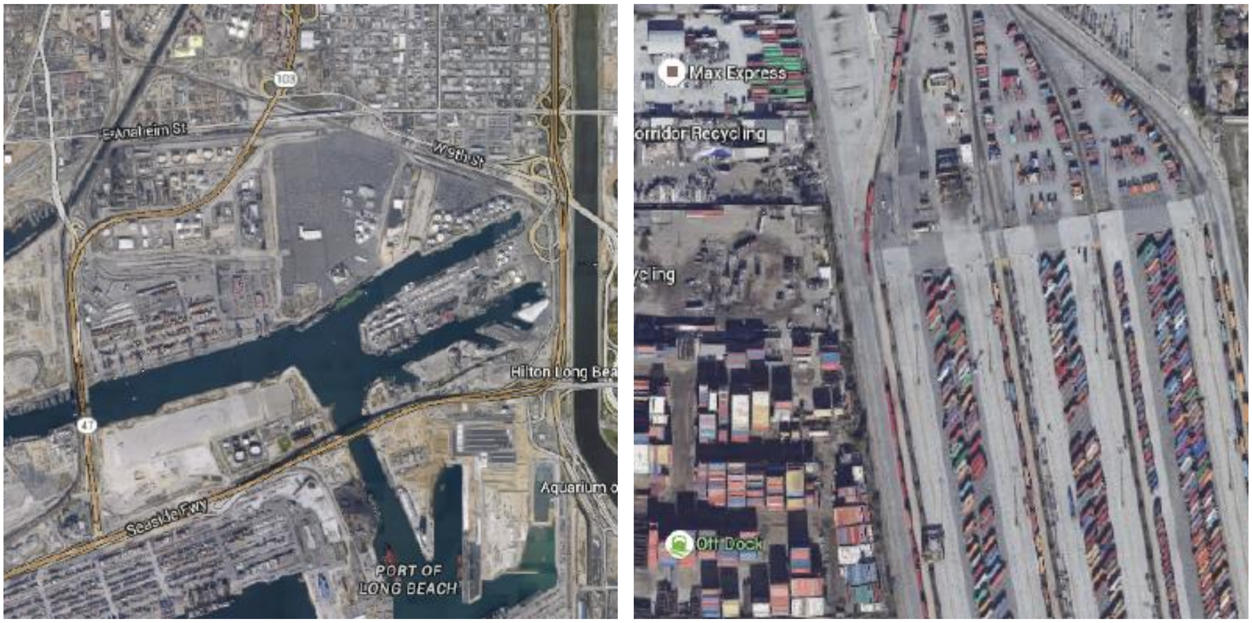

Figure 14. (a) Long Beach port facilities; (b) ICTF intermodal facility near Long Beach
Source: Google Map

Cluster B – City of Industry cluster (warehousing and manufacturing facilities)

The cluster B includes two hotspots near warehousing and manufacturing facilities. The most notable warehousing facilities are owned by General Electric and Sysco. Per the 2010 truck AADT data from Caltrans, the average truck volume in this area ranges between 4,920 and 23,770 annual average daily traffic (AADT). The region that includes these two hotspots is characterized by a mix of warehousing and manufacturing in the City of Industry. The City of Industry is the second-largest employment center in the San Gabriel Valley, and the eighth-largest employment center in Los Angeles County. The economic base is over 70% industrial, with only 800 residents and 68,000 workers commuting into the city (City of Industry 2014).· The City of Industry is a manufacturing and wholesale center, attracting a mix of different employers including food processing companies, high tech equipment producers, industrial machinery, and metalworking plants.

Table 8. Truck density hotspots in Cluster B

Rank	Length (km)	Lanes	Density				Volume			
			All truck	Light	Medium	Heavy	All truck	Light	Medium	Heavy
4	0.0713	1	135,575	23,842	19,326	92,408	9,667	1,700	1,378	6,589
16	0.0397	5	76,984	9,876	8,047	59,061	15,278	1,960	1,597	11,721

Source: 2008 SCAG baseline freight data

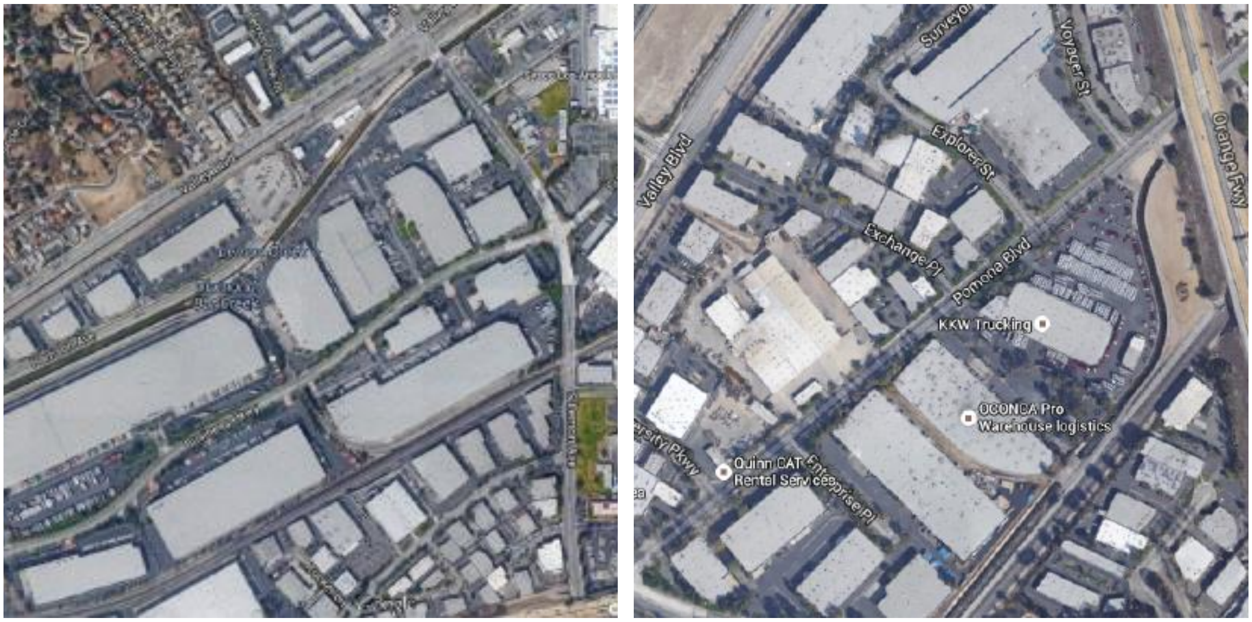

Figure 15. (a) GE warehouses and Sysco food services; (b) warehousing and trucking facilities in City of Industry, CA
Source: Google Map

Cluster C – Downtown Los Angeles (warehousing facilities and intermodal terminal)

The Cluster C is close to Downtown Los Angeles and is the most urbanized of the clusters. The City of Los Angeles designates 8% of its land for industrial use (about 19,000 acres excluding the Port of Los Angeles and LAX), and light manufacturing accounts for one-fourth of the total industrial zone (City of Los Angeles 2007). Warehousing, institutional, and retail functions make up about 30% of the industrial zone (City of Los Angeles 2007). In particular, the northeast part of Downtown Los Angeles, namely along Alameda street and Boyle Heights, is characterized by warehousing and industrial districts. These industrial districts are home to many small and mid-sized operations, attracting a broad range of employers, such as logistics, goods movement, wholesale and import trade, food distribution and fashion.

This cluster is also characterized by the Los Angeles Transportation Center (LATC) intermodal terminal operated by Union Pacific. The LATC Railyard is a cargo handling and loading facility, with a focus on domestic containers. Intermodal containers arrive at the facility by truck and are loaded onto trains for transcontinental shipment, or arrive by train and are loaded onto chassis for transport by truck to local destinations. Approximately 250,000 containers were processed in this terminal in 2005 (Yuan et al. 2007).

Table 9. Truck density hotspots in Cluster C

Rank	Length (km)	Lanes	Density				Volume			
			All truck	Light	Medium	Heavy	All truck	Light	Medium	Heavy
5	0.0846	1	117,263	24,299	18,862	74,102	9,922	2,056	1,596	6,270
12	0.1012	1	87,172	18,039	14,441	54,691	8,819	1,825	1,461	5,533
17	0.0370	2	75,926	12,607	10,754	52,565	5,613	932	795	3,886

Source: 2008 SCAG baseline freight data

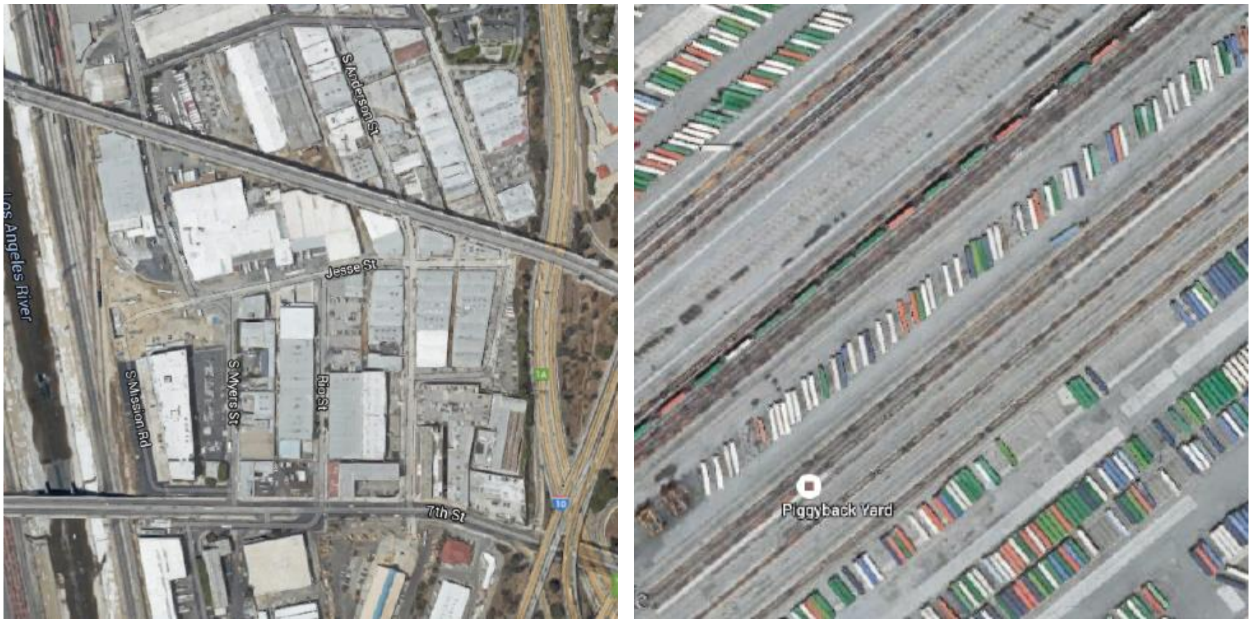

Figure 16. (a) Warehousing facilities in Downtown LA; (b) LATC intermodal facility
Source: Google Map

Cluster D – City of Commerce (manufacturing, industry and intermodal facility)

Similar to the neighboring Cluster B, the Cluster D is located near the City of Commerce. The City of Commerce is located in the “Gateway Cities” region of southeastern Los Angeles County. The city, incorporated in 1960, is 6.5 square miles in area and is comprised of about 64% industrial and commercial land uses with small pockets of residential uses. The City of Commerce is a regional center of employment in the Los Angeles region, with a business employee population of about 55,000 persons, compared to the residential population of approximately 12,993 persons.[3] Along with the industrial cluster, the City of Commerce has a large outlet shopping mall, creating both demand and supply for commercial goods movement.

There are four intermodal facilities located in the city of Commerce: Union Pacific Commerce, BNSF Hobart, BNSF Commerce Eastern, and BNSF Sheila Mechanical. These terminals serve as a major loading and distribution center for both domestic and international containers. Union Pacific Commerce Railyard and BNSF Commerce Eastern Railyard are cargo handling facilities with a focus on domestic containers, which processed approximately 350,000 containers in 2005 and 130,000 containers in 2004, respectively (Mahmood et al. 2007; Yuan et al. 2007). BNSF Hobart Railyard is the largest intermodal terminal in the United States, with a focus on international containers. An estimated 1.2 million containers were processed in this terminal in 2005. The BNSF Hobart Railyard provides container service and trailer-on-rail service, with an estimated 3,530 truck trips a day (1,289,000 trips per year) in the year 2005 (Li et al. 2007).

Table 10. Truck density hotspots in Cluster D

Rank	Length (km)	Lanes	Density				Volume			
			All truck	Light	Medium	Heavy	All truck	Light	Medium	Heavy
9	0.0253	4	94,972	9,593	9,889	75,490	9,623	972	1,002	7,649
14	0.0100	4	84,429	20,933	19,664	43,832	3,392	841	790	1,761
18	0.0352	1	73,976	19,803	16,360	37,813	2,600	696	575	1,329

Source: 2008 SCAG baseline freight data

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[3] http://www.ci.commerce.ca.us/DocumentCenter/Home/View/152

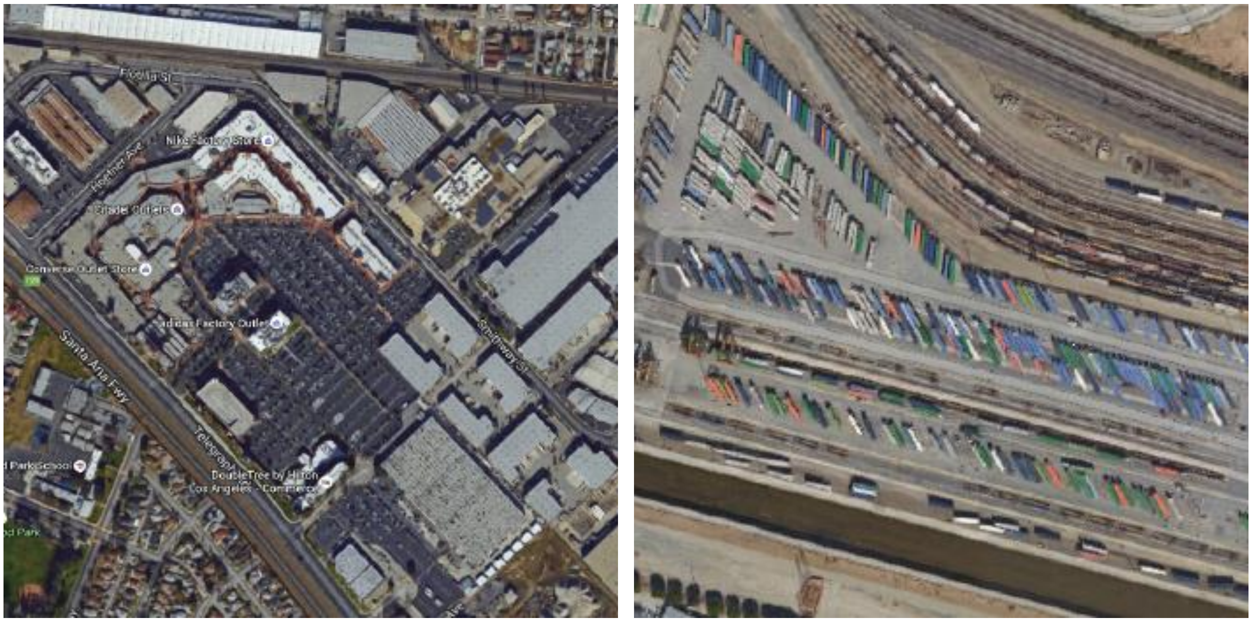

Figure 17. (a) Citadel outlet mall; (b) Intermodal facility near City of Commerce
Source: Google Map

Hotspot Clusters E and F – Los Angeles Airport and I-210 major freight corridor

Clusters E and F have no distinct industrial districts but exhibit heavy freight activities due to their unique characteristics as being a major airport and freight corridor, respectively. The cluster E has the Los Angeles International Airport, which serves as the major distribution center for air cargo. In 2008, the complex moved an estimated 1.6 million metric tons of air cargo, and the estimated weekly air cargo truck volume was 4,747 (Caltrans 2010). The truck cargo typically represents pick-up and delivery of cargo between the airport and the local service area. FedEx and UPS are the major forwarders of truck cargo to and from the airport. The cluster F represents freight activities along the I-210 highway connecting goods movement between the Los Angeles and San Bernardino areas. In particular, the junction between I-210 and I-605 exhibits one of the highest truck volumes, reaching over 20,000 daily trucks according to the Caltrans' 2010 truck AADT data.

Table 11. Truck density hotspots in Cluster E and Cluster F

Rank	Length (km)	Lanes	Density				Volume			
			All truck	Light	Medium	Heavy	All truck	Light	Medium	Heavy
15	0.0209	2	84,311	20,158	21,806	42,347	3,530	844	913	1,773
20	0.0334	6	72,170	13,005	9,071	50,094	14,440	2,602	1,815	10,023

Source: 2008 SCAG baseline freight data

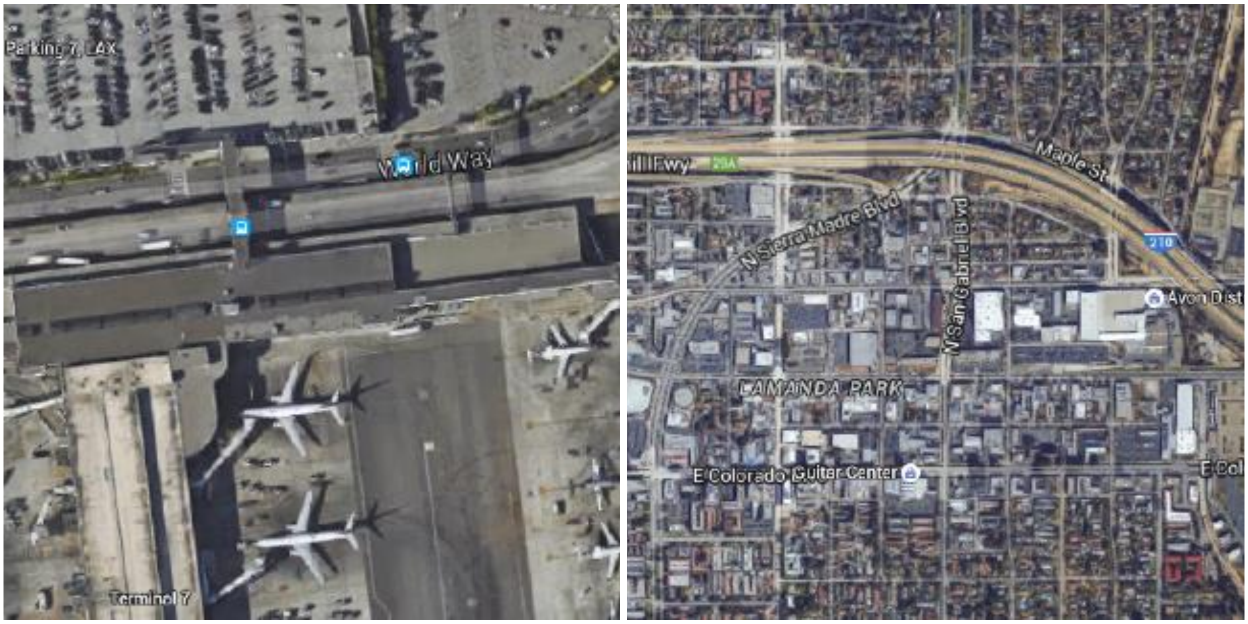

Figure 18. (a) Los Angeles Airport; and (b) Major freight corridor on I-210 highway
Source: Google Map

3. Visualization of freight travel

Figure 19 shows an interpolation of the daily freight flow using the inverse distance weighting method. The employment subcenter definitions are overlaid on top of this heat map. Freight activities are generally high on freeway networks and concentrated on the Long Beach and Los Angeles downtown areas. Together, the Port of Los Angeles and the Port of Long Beach form one of the largest container port complexes in the U.S. by volume. The nearby Long Beach Freeway is well integrated into the port facilities, providing direct connections among the ports, distribution centers, and the nearby intermodal facilities. The port and the downtown areas, being part of the regional distribution centers, typically generate a substantial volume of freight traffic. Also these locations are close to intermodal terminal facilities which serve as the major loading and distribution center for both domestic and international containers. Other locations with high freight activities include the City of Commerce and the City of Industry. These locations are regional centers of employment, characterized by a mix of warehousing and manufacturing.

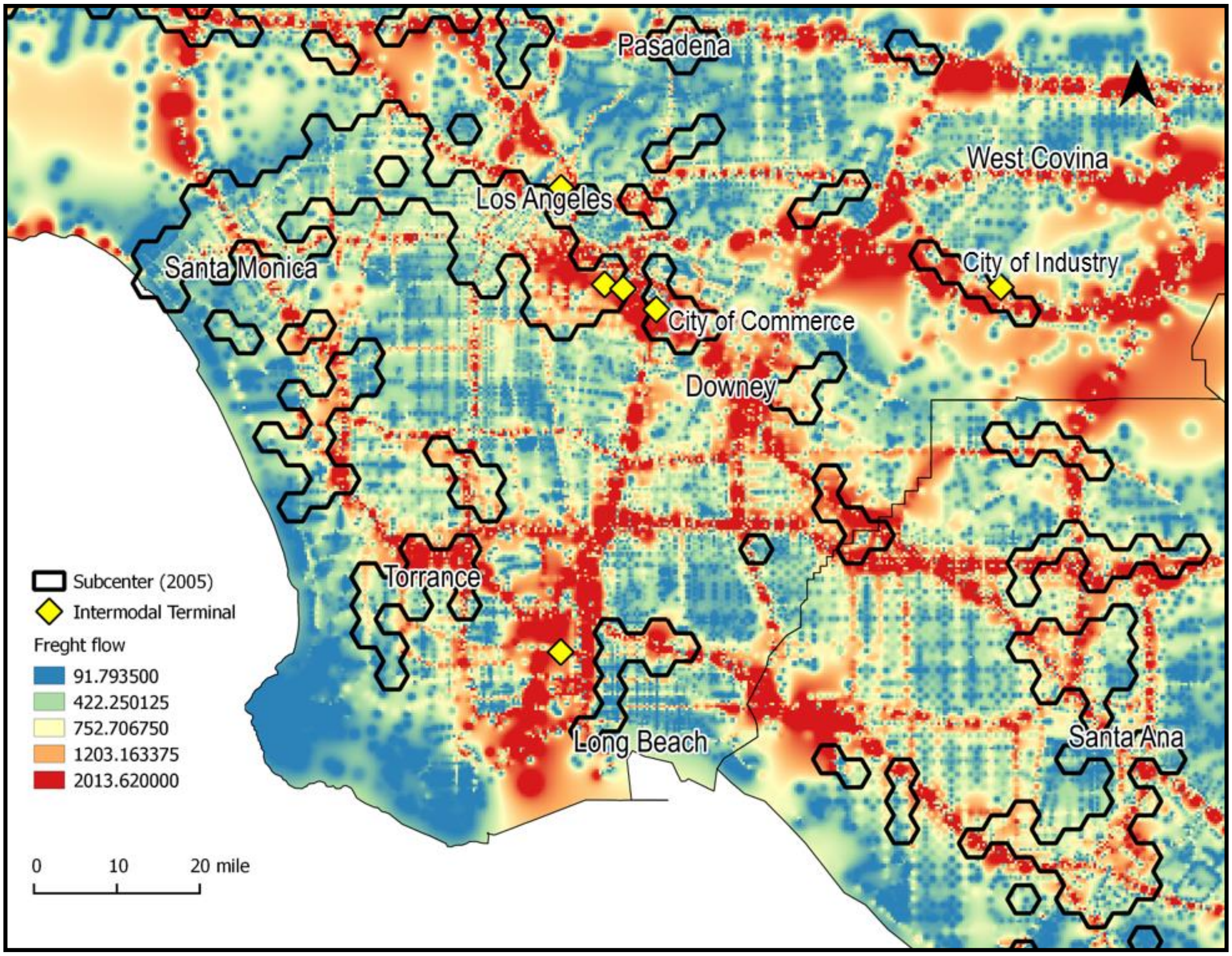

Figure 19. Heat map of freight flow using inverse distance weighting method

* Intermodal facility in San Bernardino is not shown in this map due to space limitation.

Source: 2008 SCAG baseline freight data; 2005 National Establishment Time-Series data

The heat map shows a less-apparent relationship between employment subcenters and freight activities. Except for the subcenters near the Downtown Los Angeles area and the City of Industry, some employment subcenters are located in areas with low freight activities. For example, the subcenter that stretches from Downtown Los Angeles to Santa Monica contains low freight activities. Likewise, subcenters located in Santa Ana and central Orange County have low to moderate freight activities. It is likely that some of these large subcenters are better suited for service industries which may not generate significant freight demand. Subcenters with a greater proportion of manufacturing industries may generate more freight demand and freight traffic.

4. Correlation analysis

To assess how economic activity relates to freight generation within each employment subcenter, we performed a correlation analysis (Figure 20). The analysis focuses on the association between total subcenter employment, number of establishments, total freight flow, and total freight VKT. Results show that both employment and establishment are almost perfectly correlated with freight flow and VKT, with correlation coefficients never reaching values lower than 0.96. It seems, however, that the results are largely driven by two outliers that correspond to the Wilshire Corridor and Orange County subcenters.

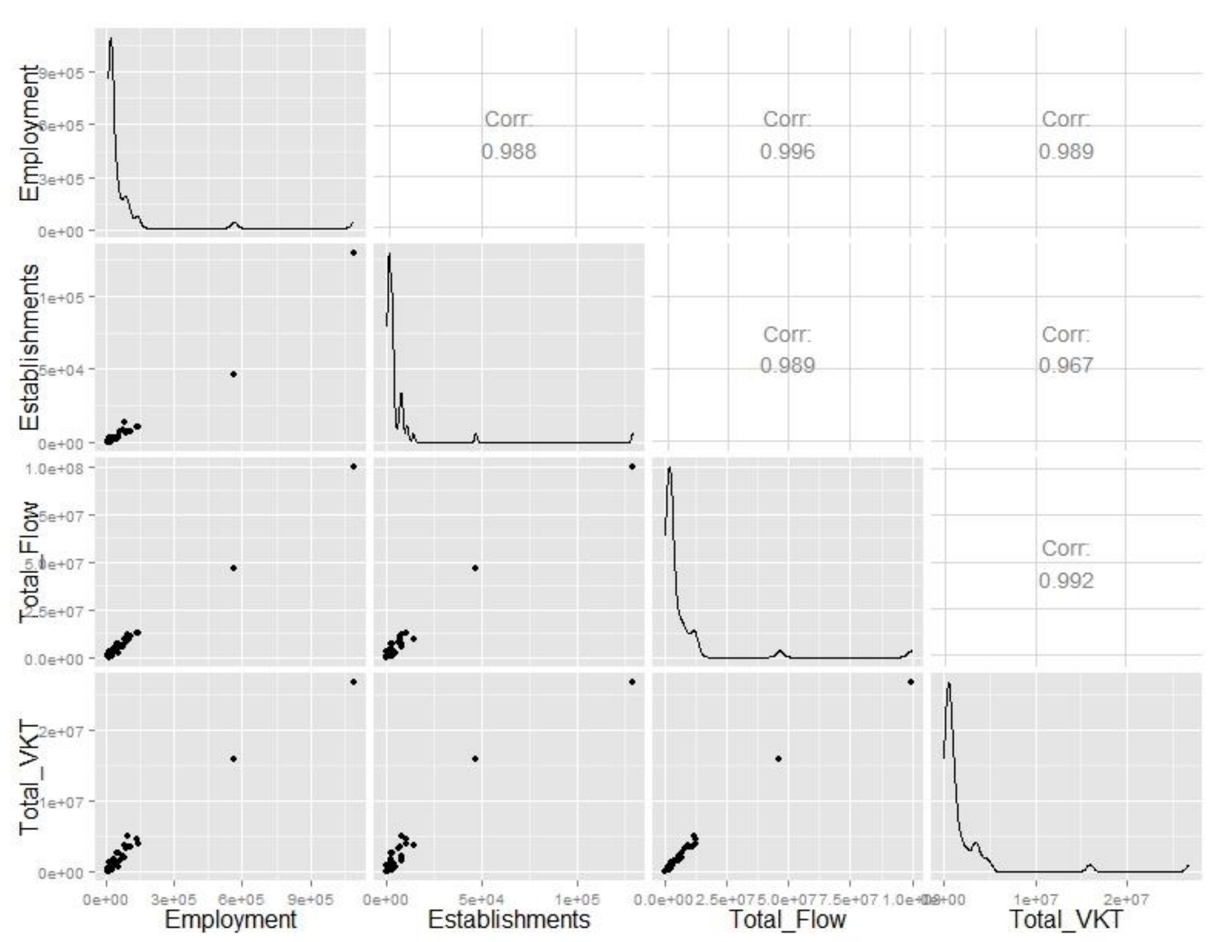

Figure 20. Correlation plots and matrix of subcenter employment, number of subcenter establishments, freight flow and freight VKT

Source: 2008 SCAG baseline freight data; 2005 National Establishment Time-Series data

Even after excluding outliers (Figure 21) subcenter employment and number of establishments continue to be highly correlated with freight flow and VKT. Subcenter employment registered correlation coefficients of 0.949 and 0.914 with freight flow and VKT, respectively. The association of total number of establishments and freight flow resulted in a correlation coefficient of 0.866, while establishments and VKT registered a coefficient of 0.843.

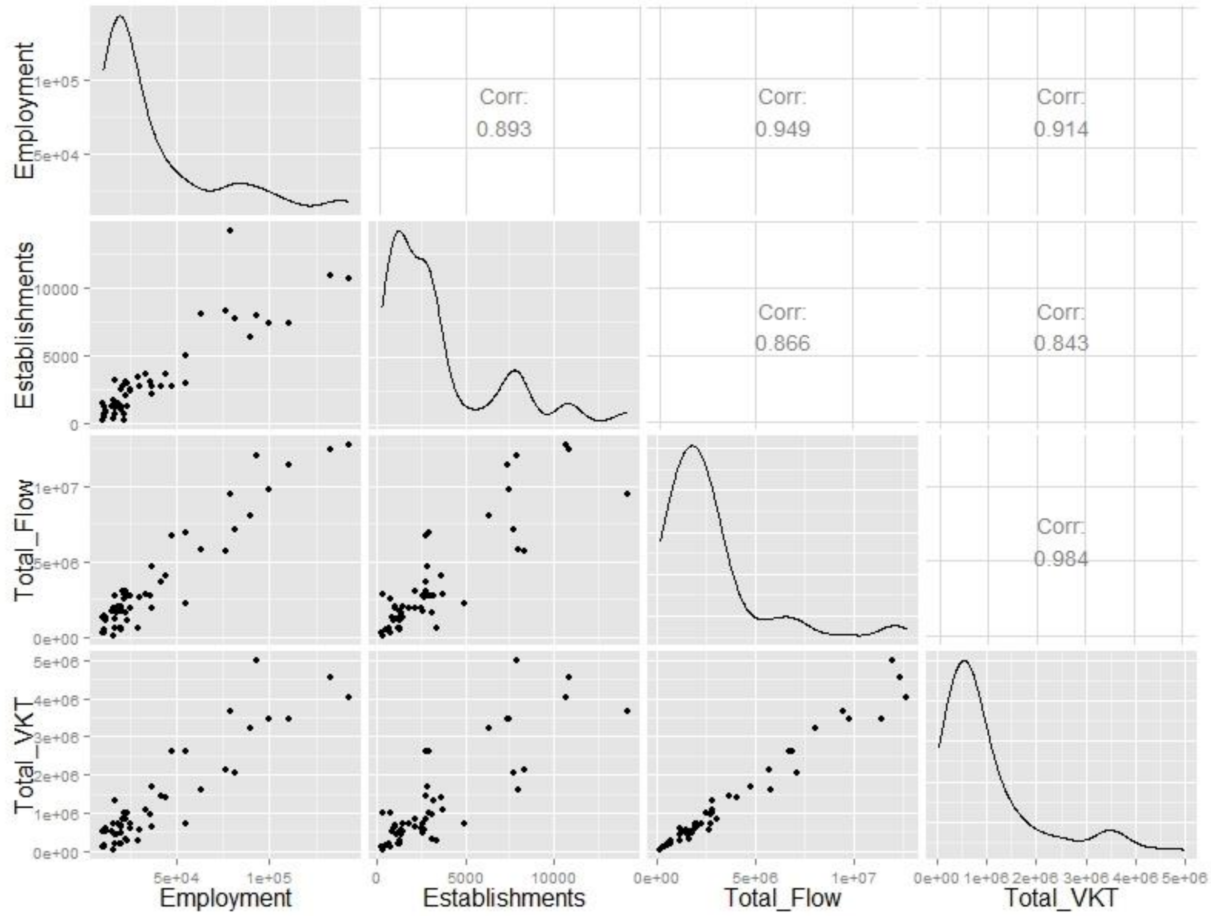

Figure 21. Correlation plots and matrix of subcenter employment, number of subcenter establishments, freight flow and freight VKT; outliers excluded

Source: 2008 SCAG baseline freight data; 2005 National Establishment Time-Series data

5. Regression analysis

Table 12 presents the results of the linear regression model. The first regression model shows that hexagons located within an employment subcenter would, on average, experience an approximately 3,600 VKT increase in freight activity. Also, a 1,000 job increase in total hexagon employment would translate into roughly an 824 VKT increase. In terms of the effect of employment share among industry sectors, larger shares in manufacture, retail, transportation, and wholesale have positive and statistically significant effects on daily freight VKT in a hexagon, while the employment share in agriculture has a negative and statistically significant effect (at the 90% confidence interval). This suggests that greater freight activity is related to more capital-intensive industries. The model suggests that the presence of a freeway in a given hexagon would increase daily freight VKT by 29,000.

Table 12. OLS regression results for daily freight VKT

	(1)	**(2)**	**(3)**	**(4)**
Constant	3205.46*** (781.18)	3602.86*** (698.77)	2714.8*** (727.46)	2166.31*** (483.60)
Subcenter	3604.4*** (1337.46)			
Subcenter 1[a]		−3941.51 (2769.19)	−9175.60*** (2943.16)	−9155.86*** (2925.18)
Subcenter 2[b]		−500.44 (2034.01)	−4591.61** (2292.47)	−4107.83* (2288.47)
Subcenter others		4863.73*** (1375.07)	3052.68** (1486.71)	3035.85** (1486.71)
Total employment	749.86*** (162.81)	507.19*** (151.19)	200.95 (174.32)	225.61 (174.38)
Total employment^2	−5.97** (2.69)	−2.21 (1.56)	−0.49 (1.56)	−0.73 (1.57)
Total employment in adjacent hexagons			150.12*** (51.15)	135.52** (52.92)
Total employment in adjacent hexagons^2			−0.14 (0.36)	−0.09 (0.38)
Share of employment in agriculture	−1902.11* (1071.71)	−942.41 (835.80)	−607.31 (846.64)	−1007.67 (865.04)
Share of employment in construction	−1969.76* (1143.11)	−1964.31** (876.05)	−1452.68* (879.93)	−1431.53 (879.39)
Share of employment in manufacturing	6998.53*** (1761.53)	4471.78*** (1603.18)	4456.36*** (1594.33)	3921.69** (1601.87)
Share of employment in mining	10638.2 (7125.16)	8433.51* (5054.65)	8690.12* (5073.23)	8075.88 (5061.94)
Share of employment in professional services	−3462.40** (1364.85)	−1814.32 (1145.97)	−1677.86 (1151.9)	−1493.41 (1149.88)
Share of employment in retail	9760.16*** (3768.08)	7171.75** (3444.12)	7111** (3450.5)	7015.13** (3475.46)
Share of employment in transportation	9571.1*** (3654.81)	7892.14*** (3007.58)	7987.88*** (2999.67)	6926.82** (3039.79)
Share of employment in utilities	−3453.84 (3890.56)	−992.60 (3096.39)	−492.81 (3084.67)	−627.42 (3083.04)

	(1)	**(2)**	**(3)**	**(4)**
Share of employment in wholesale	4799.99** (2018.64)	3497.13* (1786.28)	3283.96* (1775.52)	2910.26* (1754.15)
Presence of freeway in each hexagon	29390.6*** (1139.37)			
Presence of 1 freeway in each hexagon		51073.2*** (1599)	50819.1*** (1630.52)	50731.6*** (1641.35)
Presence of 2 freeways in each hexagon		7410.26*** (992.88)	7400.4*** (985.72)	7426.4*** (982.31)
Distance to the nearest intermodal facility (miles)	−33.62*** (12.99)	−27.27** (11.55)	−16.05 (11.65)	
Distance to intermodal facility < 1 mile				7170.9** (3109.73)
Distance to intermodal facility < 2 mile				1655.7 (2362.92)
Distance to intermodal facility < 3 mile				2262.28 (1927.25)
Distance to intermodal facility < 4 mile				−1437.61 (1758.31)
Distance to intermodal facility < 5 mile				−882.04 (1626.52)
Distance to intermodal facility < 6 mile				2181.37 (1856.36)
Distance to intermodal facility < 7 mile				270.93 (1409.29)
Distance to intermodal facility < 8 mile				142.762 (1464.5)
Distance to intermodal facility < 9 mile				1457.42 (1419.55)
Distance to intermodal facility < 10 mile				294.22 (1420.66)
Observations	6490	6490	6490	6490
R-squared	0.2840	0.4395	0.4414	0.4428
Adj. R-squared	0.2824	0.4380	0.4398	0.4403
F statistic	94.06	112.00	106.15	74.73

*Standard errors in parenthesis; * $p \leq 0.1$; ** $p \leq 0.05$, *** $p \leq 0.01$*

[a] *the largest subcenter near DTLA,* [b] *the second largest subcenter in Santa Ana*

In the second regression, we substituted the subcenter binary variable with three binary variables that specify if each hexagon is located within Subcenters 1, 2, or other subcenters. The freeway binary variable was also replaced with binary variables that specify whether there are 1 or 2 freeways present in each hexagon; no hexagon had more than 2 freeways. The result is that the explanatory power of the model was greatly improved, with the R^2 increasing from 0.28 to approximately 0.44. Furthermore, the model shows no statistically significant association between VKT and being located in either Subcenter 1 or 2, while being located in any other subcenter is associated with increased freight VKT. This confirms that Subcenters 1 and 2 are different in their relationship to freight VKT. As shown in Table 1, these two subcenters are much larger in land area and employment than the other subcenters. These two subcenters are also located close to denser urban areas than other subcenters. Combined with the different geographic features and their proximity to dense urban areas, these two subcenters are more likely to serve as activity destinations than freight destinations, resulting in little association with freight travel. In addition, the presence of only one freeway in a hexagon is associated with an average increase in freight VKT of approximately 51,000, while the presence of a two freeways increases VKT by approximately 7,400. The trends in employment and employment share observed in the previous regression are generally the same here.

Regressions 3 and 4 add variables to measure the effect that employment clustering and the distance to intermodal facilities have on total freight VKT in each hexagon. The addition of the employment clustering variables (the sum of employment in each hexagon’s six neighboring hexagons) reverses the effect of own-hexagon employment; the latter now has a statistically insignificant effect on hexagon VKT while the former shows a positive and statistically significant effect in both Regressions 3 and 4. This suggests that freight VKT is influenced by employment levels at geographies that are larger than the 1 mi^2 hexagon geography. In terms of the effect of intermodal facilities, Regression 4 shows that hexagons that are within a 1 mile distance from these facilities experience an average increase in VKT of approximately 7,700. The effects from employment share and presence of freeways remained the same, with the exception that employment share in construction (another labor intensive industry) has a negative and statistically significant effect on hexagon VKT.

V. Conclusions

1. Findings and future research

The analysis presented in this report adds to the findings from previous research conducted at the firm level. Like in previous research, we found employment to be an important driver of freight activity. However, rather than focusing on employment at the level of the firm, we examined the spatial distribution of employment, other geographic characteristics, and their relationship to freight activity.

Freight VKT is larger when a hexagon is within a mile of an intermodal facility, but the effect does not persist over longer distances. This suggests that freight activity is dispersed over the freeway and road network, a finding reinforced by the heat map shown in Figure 19. Note that the presence of a freeway in a hexagon is approximately seven times as large as the coefficient on being within a mile of an intermodal freight facility. From a policy perspective, this implies that any negative externalities associated with freight travel are more likely associated with freeways than with the intermodal facilities that are transshipment hubs. We are not suggesting to ignore the impacts of intermodal facilities, but the regressions in Table 4 suggest that highway access can be a larger determinant of freight VKT. This result reinforces the previous findings that freight activities occur not only as a direct result of economic production and consumption, but also an indirect consequence of connecting different actors and players through existing transportation networks and distribution nodes even at the metropolitan geographic scale (Hesse and Rodrigue 2004; Rodrigue 2006a). Because highway network serves both passenger and freight transport, increasing efficiency in freight travel may come at the expense of decreasing efficiency in passenger transport or increasing negative environmental externalities, such as traffic congestion and air pollution. Future freight research and modeling will need to consider this competing aspect of freight travel and passenger travel sharing the same highway network, and examine how best to address the negative externality problems arising at local and regional scales.

Looking more broadly at the economic geography of the region, employment in adjacent hexagons is positively associated with freight VKT within a hexagon, illuminating the role of freight through-traffic. Employment shares in a hexagon are associated with freight VKT in the same hexagon in ways that are generally expected, with industries associated with production or sale of goods being associated with higher freight flows. Employment subcenters, the primary motivation for our study, are independently associated with increased freight VKT, while the two largest subcenters in the region have the opposite effect. This suggests that there is differentiation in the economic function and hence in the goods movement characteristics of different employment subcenters. This latter point is a topic that we suggest is ripe for further research.

2. Research and policy implications

Our findings suggest implications for both future research and policy analysis. In terms of research, we note that the economic geography of a region clearly influences freight flows. Two implications are important. First, analyzing aggregate flows is an important topic for freight research. While that may seem obvious, for decades the literature on passenger transportation has moved from aggregate to disaggregate analyses, to illuminate behavioral elements that are obscured by aggregate, zone-level, studies. We note, though, that our understanding of freight travel requires a focus on aggregate (zone-level) analysis because policy questions about freight are often explicitly geographic in nature. Given the intricate connection between urban geography and freight activity, planners and policy-makers need to assess how urban freight travel will be linked to changes in land use or infrastructure at what is usually the level of a small geographic zone and larger metropolitan geographies. The spatial pattern of employment concentrations and the highway network clearly matter for freight travel, providing some intuitive first steps to predicting zone-level freight VKT based on the geography of a region. While that is a start, future research should also consider factors which were outside the scope of this study, such as how zoning decisions and historic development patterns are associated with freight VKT.

In terms of policy, freight VKT is both an economic driver and a source of traffic, noise, and emission externalities. The results of this research indicate that the two largest employment subcenters are associated with lower freight VKT, while other subcenters are associated with higher freight VKT. That, plus the positive effect of adjacent-hexagon employment on freight VKT, suggests that spatial concentrations of employment are associated with freight VKT. The magnitudes of the coefficients in Table 4 suggest that the effect of employment concentration could be at least half the size (or more) of the effect of being within a mile of an intermodal facility. One implication is that policy-makers should be more alert to the ways that the spatial distribution of employment shapes freight travel patterns. The policy focus should broaden beyond the more traditionally obvious intermodal facilities and highways to consider how development, including the spatial pattern of employment, is associated with freight travel patterns. The results in this paper are a start, and policy-makers would benefit from additional model building that examines the association between freight VKT and the geography of employment.

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Appendix 1. Regression variable descriptions

Variable name	Description	Variable type	Source
VKT	Daily vehicle kilometers traveled	Continuous	SCAG 2008
Subcenter	Indicates if hexagon is located in an employment subcenter	Binary; (1) if hexagon is located in subcenter and (0) if it is not	NETS 2005
Subcenter_one	Indicates if hexagon is located in Employment Subcenter 1	Binary; (1) if hexagon is located in Subcenter 1 and (0) if it is not	NETS 2005
Subcenter_two	Indicates if hexagon is located in Employment Subcenter 2	Binary; (1) if hexagon is located in Subcenter 2 and (0) if it is not	NETS 2005
Subcenter_other	Indicates if hexagon is located in an employment subcenter other than Subcenter 1 or 2	Binary; (1) if hexagon is located in subcenter other than Subcenters 1 or 2 and (0) if it is not	NETS 2005
emp	Total employment in each hexagon in thousands of jobs	Continuous	NETS 2005
emp_sq	Square of total employment per hexagon in thousands of jobs	Continuous	NETS 2005
tot_adj_emp	Total employment in adjacent hexagons in thousands of jobs	Continuous	NETS 2005
tot_adj_emp_sq	Square of total employment in adjacent hexagons in thousands of jobs	Continuous	NETS 2005
perc_Agri	Share of total hexagon employment classified by NAICS (code = 11) as agriculture, forestry, fishing, and hunting	Continuous	NETS 2005
perc_Cons	Share of total hexagon employment classified by NAICS (code = 23) as construction	Continuous	NETS 2005
perc_Manu	Share of total hexagon employment classified by NAICS (code = 31-33) as manufacturing	Continuous	NETS 2005
perc_Mini	Share of total hexagon employment classified by NAICS (code = 21) as mining activities	Continuous	NETS 2005
perc_Prof	Share of total hexagon employment classified by NAICS (code = 54) as professional, scientific, and technical services	Continuous	NETS 2005

Variable name	**Description**	**Variable type**	**Source**
perc_Reta	Share of total hexagon employment classified by NAICS (code = 44-45) as retail trade	Continuous	NETS 2005
perc_Tran	Share of total hexagon employment classified by NAICS (code = 48-49) as transportation and warehousing	Continuous	NETS 2005
perc_Util	Share of total hexagon employment classified by NAICS (code = 22) as utilities	Continuous	NETS 2005
perc_Whol	Share of total hexagon employment classified by NAICS (code = 42) as wholesale trade	Continuous	NETS 2005
FWY	Presence of freeway in each hexagon	Binary; (1) for presence of freeway and (0) for no freeway	SCAG 2008
one_FWY	Presence of only one freeway in each hexagon	Binary; (1) for presence of one freeway and (0) otherwise	SCAG 2008
two_FWY	Presence of only two freeways in each hexagon	Binary; (1) for presence of two freeways and (0) otherwise	SCAG 2008
Dist_int_fac_mi	Linear distance between hexagon centroid and intermodal facility (miles)	Continuous	NTAD 2011
dist_one	Indicates whether distance between hexagon and intermodal facility is less than or equal to 1 mile	Binary; (1) if distance is less than or equal to 1 mile and (0) if it is not	NTAD 2011
dist_two	Indicates whether distance between hexagon and intermodal facility is greater than 1 mile and less than or equal to 2 miles	Binary; (1) if distance is greater than 1 mile and less than or equal to 2 miles and (0) if it is not	NTAD 2011
dist_three	Indicates whether distance between hexagon and intermodal facility is greater than 2 miles and less than or equal to 3 miles	Binary; (1) if distance is greater than 2 miles and less than or equal to 3 miles and (0) if it is not	NTAD 2011
dist_four	Indicates whether distance between hexagon and intermodal facility is greater than 3 miles and less than or equal to 4 miles	Binary; (1) if distance is greater than 3 miles and less than or equal to 4 miles and (0) if it is not	NTAD 2011
dist_five	Indicates whether distance between hexagon and intermodal facility is greater than 4 miles and less than or equal to 5 miles	Binary; (1) if distance is greater than 4 miles and less than or equal to 5 miles and (0) if it is not	NTAD 2011
dist_six	Indicates whether distance between hexagon and intermodal facility is greater than 5 miles and less than or equal to 6 miles	Binary; (1) if distance is greater than 5 miles and less than or equal to 6 miles and (0) if it is not	NTAD 2011

Variable name	Description	Variable type	Source
dist_seven	Indicates whether distance between hexagon and intermodal facility is greater than 6 miles or less than or equal to 7 miles	Binary; (1) if distance is greater than 6 miles and less than or equal to 7 miles and (0) if it is not	NTAD 2011
dist_eight	Indicates whether distance between hexagon and intermodal facility is greater than 7 miles or less than or equal to 8 miles	Binary; (1) if distance is greater than 7 miles and less than or equal to 8 miles and (0) if it is not	NTAD 2011
dist_nine	Indicates whether distance between hexagon and intermodal facility is greater than 8 miles or less than or equal to 9 miles	Binary; (1) if distance is greater than 8 miles and less than or equal to 9 miles and (0) if it is not	NTAD 2011
dist_ten	Indicates whether distance between hexagon and intermodal facility is greater than 9 miles or less than or equal to 10 miles	Binary; (1) if distance is greater than 9 miles and less than or equal to 10 miles and (0) if it is not	NTAD 2011

Appendix 2. Regression variable summary statistics

(N=6,491 hexagons with employment)

Variable name	Mean	Median	Minimum	Maximum	Std. Dev.
VKT	11,055.464	1,322.708	0.000	559,341.587	25,213.613
Subcenter	0.098	0.000	0.000	1.000	0.297
Subcenter_one	0.015	0.000	0.000	1.000	0.121
Subcenter_two	0.011	0.000	0.000	1.000	0.103
Subcenter_other	0.072	0.000	0.000	1.000	0.259
emp	1.342	0.136	0.001	122.073	3.458
emp_sq	13.757	0.018	1.00E-06	14,901.817	202.463
tot_adj_emp	7.900	1.556	0.000	244.303	14.843
tot_adj_emp_sq	282.679	2.421	0.000	59,683.956	1,656.305
perc_Agri*	0.049	0.000	0.000	1.000	0.173
perc_Cons*	0.110	0.046	0.000	1.000	0.186
perc_Manu*	0.071	0.016	0.000	1.000	0.145
perc_Mini*	0.004	0.000	0.000	1.000	0.047
perc_Prof*	0.077	0.040	0.000	1.000	0.131
perc_Reta*	0.098	0.056	0.000	1.000	0.150
perc_Tran*	0.034	0.003	0.000	1.000	0.108
perc_Util*	0.006	0.000	0.000	1.000	0.054
perc_Whol*	0.050	0.016	0.000	1.000	0.112
FWY	0.208	0.000	0.000	1.000	0.406
one_FWY	0.108	0.000	0.000	1.000	0.310
two_FWY	0.101	0.000	0.000	1.000	0.301
Dist_int_fac_mi	30.046	25.761	0.096	182.574	26.143

Variable name	**Mean**	**Median**	**Minimum**	**Maximum**	**Std. Dev.**
dist_one	0.014	0.000	0.000	1.000	0.119
dist_two	0.020	0.000	0.000	1.000	0.142
dist_three	0.022	0.000	0.000	1.000	0.145
dist_four	0.024	0.000	0.000	1.000	0.154
dist_five	0.026	0.000	0.000	1.000	0.161
dist_six	0.027	0.000	0.000	1.000	0.162
dist_seven	0.028	0.000	0.000	1.000	0.165
dist_eight	0.029	0.000	0.000	1.000	0.167
dist_nine	0.028	0.000	0.000	1.000	0.166
dist_ten	0.028	0.000	0.000	1.000	0.164

* A value of 1 (100%) for share of employment of each NAICS industry corresponds a low number of firms (never greater than 4) identified in hexagons where this value was registered.