Understanding freight flows in cities I: Does density crowd out freight intensive activities?

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ABSTRACT

This paper explores the relationship between employment density and freight activities. We consider density to be a proxy for land rents. High land rents deter land intensive activities. Thus manufacturing, wholesaling or warehousing are less likely to locate near the city core where land rents are highest. The literature shows that industry mix varies with density; only activities that benefit sufficiently from external economies are willing to pay the high rents that density implies. Freight intensive activities (e.g. warehousing and distribution) face the added disadvantage of congestion, limited road space, and often regulatory constraints in city cores. We therefore expect that freight intensive activities should also be less likely to locate in high rent areas. We use Los Angeles as our case study. We identify employment concentrations and categorize industry sectors by freight trip generation. We then examine spatial patterns of freight trip intensity. We find that 1) freight intensive activities locate more frequently outside of centers; 2) sector mix differs across centers, and hence freight intensity mix differs across centers; 3) larger centers are more differentiated than smaller centers; and 4) there is a general trend of increasing freight intensity with distance from the center.

INTRODUCTION

The volume of freight moving within and across metropolitan areas is increasing due to continued globalization, changing consumer and business preferences, and the rise of e-commerce (Dablanc and Rodrigue, 2017). Freight movements are a problem in cities around the world. Though essential for the functioning of metropolitan areas, freight generates air pollution, noise, and GHG emissions, and contributes to congestion (Giuliano et al, 2013). Efforts to manage freight are constrained by lack of data, methodological tools, and a general lack of understanding of the dynamics of freight demand and supply in the metropolitan context.

In this paper we focus on the relationship between spatial structure and freight activity. Our ultimate goal is to explore whether density, a proxy for land rents, affects freight operations of businesses. We expect that high rents change operations in ways that generate more freight trips. The only way to test this relationship directly is with firm specific data from many locations that vary with respect to density, but no such data is available. We therefore explore a related question: is the location of freight intensive industry sectors related to density?

We hypothesize that freight intensive activities are less likely to locate in high density areas. We present a conceptual framework based on standard urban economics, in which land rents determine population and employment density. We argue that high density should deter location of both land intensive activities and freight intensive activities due to high rents, congestion, and limited road capacity.

We use the Los Angeles region as our case study. Los Angeles is well known for its polycentric urban form; it has many employment centers with varying levels of density. We identify categories of "freight intensive" industry sectors and test whether these sectors are located inside or outside employment centers, and whether location within centers is related to density. We find a clear pattern of low freight intensity sectors location positively related to density, medium freight intensity sectors location negatively related to density, and a mixed pattern for high freight intensity sectors. The high freight intensity sectors constitute a very small share of total employment (about 3%), and thus are subject to more random variation.

The remainder of the paper is organized as follows. Section 2 presents the conceptual framework and research approach. We lay out the logic for expecting differences in sector location and firm operations as a function of density. Section 3 presents data and methods. Results are presented in Section 4, and we offer some conclusions and next steps in the final section.

PROJECT OBJECTIVE

In previous work we developed the concept of the freight landscape (Giuliano, Kang, and Yuan, 2015; Rodrigue, Dablanc and Giuliano, 2016). We argued that the freight landscape, represented by the joint distribution of population and economic activity in a metropolitan area, could be a proxy for freight activity and intensity. We conducted case studies of the Los Angeles and San Francisco regions to empirically test the relationship between freight flows on the transport network and development density – the combined density of employment and population. Using a traffic density measure (vehicle kilometers traveled per square kilometer), we found that truck traffic density is positively related to employment density, and for any given level of employment density, negatively related to population density (Giuliano, Kang, Yuan and Hutson, 2015). We used calibrated network simulation model output to conduct the analysis. We extend this work by looking more closely at freight flows and density in the context of urban economic principles.

In this paper we examine whether urban economics can provide further insights on the relationship between freight activity and land use. Per the standard model, density is a proxy for land value, and as land value increases, land is used more intensively. Thus land intensive activities are crowded out of high density areas. Similarly, freight intensive activities should be crowded out by high rents, congestion, and limited road capacity. There is another possible impact of high land prices. Do they have an additional *indirect* effect on freight activity? That is, do firms adapt to high rents by adjusting business practices? If so, do these adjustments lead to more or less truck activity?

PROJECT DESCRIPTION

Conceptual Framework

The standard urban model explains the structure of a city as a function of demand for proximity to jobs and other economic opportunities. Households choose a combination of rent and transport costs to maximize utility. The closer to jobs, the more rent per housing unit will be paid. The simplest model assumes a single employment location. Demand for access leads to a land rent gradient with maximum value at the center. Assuming homogeneous households, land rents determine population density. The shape of the gradient depends on transport costs; if transport costs are high, there is more demand for proximal location, and rent per unit will be higher. The rent gradient will have a high peak density, and the rate of decline with be steep. If transport costs are low, the rent gradient will have a lower peak density, and the rate of decline will be less steep. Empirical research generally supports the model. Cities around the world have the highest land prices and population density near the center, and historically cities have grown outward as transport costs have declined. [1]

The standard urban model is of course highly stylized. Employment is distributed throughout the city, and the location choices of firms and households are far more complex than the simple trade-off of transport cost and rent implies. Nevertheless, the land rent gradient explains many features of urban spatial structure, for example the scarcity of road space relative to demand in city cores, the smaller average size of dwelling units in city cores, or the location of land intensive activities in suburban or exurban areas.

Density and employment mix

Because different economic activities have different demands for space, it follows that industry mix will vary across city locations. Activities that have a greater demand for accessibility, due to the benefits of agglomeration economies or demand for market access, will be more willing to pay higher rents to realize these benefits. Evidence that employment mix varies by location is extensive (e.g. Anderson and Bogart, 2001; Agarwal, Giuliano and Redfearn, 2012). In general, the most dense areas specialize in financial services, business services, and other knowledge-intensive activities. Employment mix clearly has an effect on freight activity; indeed freight trip generation methods are based on employment or establishment counts and industry sector (Iding, Meester and Tavasszy, 2002; ITE, 2008; Holguin-Veras et al., 2012). Thus the different mix of employment inside and outside the city core should lead to different patterns of freight activity.

The density of economic activity, as measured by employment density, implies greater density of freight trips in the city core relative to outside the city core, all else equal. But industry sectors with the greatest freight trip generation rates, such as large warehouse and distribution facilities, are likely to be priced out by high rents, because such sectors tend to be land

[1] For a review on urban theory and spatial structure, see Anas, Arnott and Small, 1998.

intensive. Transportation intensive industry sectors should also avoid high congestion locations. The mix of economic activity may be such that the sectors most likely to locate in the core also have lower trip generation rates. It is therefore unclear whether density would be positively or negatively related to freight trips for all economic activity.

Indirect effects

The travel behavior literature shows that daily passenger trip frequency is stable across density, and somewhat lower at the highest densities (greater than 10,000 per square mile in US). Trips are shorter (in distance) and taken more frequently by public transport or non-motorized modes (Santos et al, 2011). These differences are due to proximity (more accessibility to opportunities) and transport costs (road congestion). We hypothesize that density also affects freight, but in more complex ways. For example, there is no opportunity for efficiency analogous to shifting trips from private vehicles to public transport (consolidation of deliveries across providers is an analogous strategy, but to date few such consolidations exist, even in the most dense urban cores).

With rare exceptions, existing freight trip generation rates implicitly assume that any given economic activity of the same size and characteristics has the same freight trip generation, no matter where located in the metropolitan area (e.g., Holguin-Veras et al, 2012). If this were the case, we could simply generate a freight trip generation matrix based on industry sector and ordered by distance from the city core and test whether trips decline systematically with distance. The observed relationship would reflect shifts in industry mix that may be related to the land price gradient. This approach does not account for an indirect effect of density.

Should we expect an indirect effect of density? Businesses must be able to generate sufficient revenues to pay for all input costs, including rent. As rent increases, all else equal, space must be used more intensively. Commercial office activities may allocate less space per employee and minimize non-revenue generating uses such as storage space or lobbies. Retail establishments need more customer activity (sales) per unit of space. Aisles become more narrow (a pedestrian equivalent to less road space), and inventory space may be minimized. Inventory space may be traded for more frequent deliveries of consumer products. These changes imply higher trip generation rates for both freight and passengers. More commute trips per space unit will be generated by the office building, and more shopping trips per space unit will be generated by retail establishments. At the same time, more delivery trips will be generated as a result of less inventory holding, because it will be cheaper to pay for more deliveries than to pay for more space.

There is some evidence that freight is less efficient in the urban core due to 1) restrictions on routes and delivery time windows; 2) parking and loading limitations, 3) a larger share of small deliveries (including home deliveries), and 4) inventory and replenishment practices of urban retailers (Holguin-Veras, et al, 2005; Xing et al, 2010; Bomar, Becker and Stollof, 2009). There is limited evidence that freight activity and congestion are associated with density. Studies of New York City show very high rates of deliveries to restaurants in Manhattan (Holguin-Veras et al., 2005), as well as higher rates of illegal truck parking in Manhattan than other parts of the city (Bomar, Becker and Stollof, 2009).

RESEARCH APPROACH

The basic research question is whether density, as a proxy for land rent, affects freight operations, holding industry sector constant. For example, does Target or a business services firm operate differently in the city core than in the suburbs? A few case studies of specific businesses, such as restaurants, exist (eg. Holguin-Veras, et al., 2011; Lawson et al., 2012; Sanchez-Diaz, 2016; Sanchez-Diaz, Gonzales-Feliu and Ambrosini, 2016), but there is no comprehensive database that would allow testing our research question directly for an entire urban area. We therefore must take an indirect approach.

The question we address in this paper is whether differences in industry mix across the metropolitan area reflect differences in freight trip or volume intensity. Although prior research shows that industry mix changes with density, we do not know whether these changes are associated with freight intensity. High rents and congestion should deter freight intensive activities from location in or near the city center. For example, we expect warehousing, distribution, or transportation activities to locate away from the center. We test this question by categorizing industry sectors by average freight trip generation rates and examining the spatial distribution of employment by industry sector inside and outside employment centers.

DATA AND MODELS

We use the Los Angeles region as our case study area. The Los Angeles region is the second largest US metropolitan area, with 2010 population of about 18 million and employment of about 7 million. The region includes five counties covering 88,048 square kilometers. It is a US Census Combined Statistical Area (CSA) comprised of three Metropolitan Statistical Areas (MSAs) distributed across five counties. The Los Angeles-Long Beach-Anaheim, CA MSA has the highest average population density of any MSA in the US, 1,037 persons per square kilometer. The region is also noted for its polycentric urban form: it is characterized by a corridor of high employment density that extends from the downtown west to the coast, and numerous employment clusters around the region (Giuliano et al, 2007). The Los Angeles region is also a major global trade hub. The Los Angeles/Long Beach port complex is the largest container port complex in the US, with trade in 2015 of $450 billion; the majority of this cargo is moved into and out of the port by truck. The Los Angeles airport is the fifth largest air freight center in the US, handling $96.3 billion in air freight in 2014. The region's size, diversity, and trade intensity make it an appropriate case for testing freight and urban form relationships. We restrict our analyses to the urbanized area, because the region also includes vast areas of desert and forest.

Data Sources

We use two sources of data. The first is the 2010 Longitudinal Employer-Household Dynamics (LEHD) which provides employment counts in two-digit NAICS industry sectors at the census tract level. All employment but uniformed military, self-employed workers, and informally employed workers are included in LEHD. Its data sources are Unemployment Insurance Wage Data, the Quarterly Census of Employment in Wages, and the Office of Personnel Management data. All data were converted from census tract geography to Transportation Analysis Zones (TAZs), spatial units that are approximately the same size as census tracts. We use TAZs rather than census tracts because tract boundaries often follow major roadways, making it difficult to assign traffic to spatial units. The conversion from census tracts to TAZs was conducted by aerial apportioning. There are 3,999 TAZs in the five county region; after cleaning for missing data and sparsely populated areas, we have 3789 TAZs for analysis.

Our data on freight trip generation is drawn from the Southern California Association of Governments (SCAG) 2008 Baseline Regional Model, which includes a heavy duty truck model. The truck model forecasts truck trips for three HDT weight classes: light-heavy (8,500 to 14,000 lbs. gross vehicle weight (GVW)); medium-heavy (14,001 to 33,000 lbs. GVW); and heavy-heavy (>33,000 lbs. GVW). According to EPA Emission Classification standards, this dataset covers most of the freight trucks except for certain small-size delivery vans and pickups. Given that small delivery vehicles are mostly used in goods movement within city centers, this dataset likely underestimates the volumes of freight flows in city core areas.

Controlling for Polycentricity

Los Angeles is well known for its polycentric urban structure (Giuliano and Small, 1991; McMillen, 2001; Agarwal, Giuliano and Redfearn, 2012). It has many employment centers that have been demonstrated to have an effect on the spatial distribution of employment. Therefore we must consider multiple employment centers in our analysis. Employment centers are defined as areas with high employment concentration that are large enough to potentially exert an influence on employment distributions. We use the Giuliano and Small (1991) method for identifying employment centers. It is simple to calculate and widely used in the literature. The method uses cutoffs for density and scale (total jobs). We use two categories of centers: TAZs that together have a job density above 10 jobs per acre and at least 10,000 jobs, and TAZs that together have a job density above 20 jobs per acre and at least 20,000 jobs. We call them 10/10 and 20/20 centers respectively. The more restrictive definition captures only the largest and most dense employment concentrations, and thus should be more specialized than the 10/10 centers.

The irregularities in the shape of TAZs requires rules to determine adjacency. We consider any two TAZs to be adjacent if they have at least one boundary point in common. Figures 1 and 2 map the centers, and Tables 1 and 2 give basic descriptive information on the centers. Figure 1 shows an arc of centers from the Santa Monica coast to Southeast Los Angeles. A second concentration is in Orange County, along the I-5 corridor and the South Coast Metro area. The

20/20 centers are also concentrated in these two areas. There are many more 10/10 centers than 20/20 centers, and the 10/10 centers account for about twice the share of jobs as the 20/20 centers. Given that 10/10 centers and 20/20 centers occupy only 3.6% and 0.8% of the total land area respectively, the concentration of jobs in these centers is quite high. Among both groups of centers, there are no centers with more than 500 thousand jobs, and most of them have less than 50 thousand jobs. The average job density decreases with the size of center. The average density for 100K-500K centers is almost twice of that for 50K-100K centers, but the differences are much smaller between 50K-100K and 20K-50K centers.

TABLE 1: Number, total employment, and employment share of centers

	10/10	20/20
Total number of centers	53	20
Total employment in centers	2,544,127	1,239,265
Share employment in centers	36.5%	17.8%

TABLE 2: Center size and average density

	10/10		20/20	
Employment	N of centers	Ave density (job/acre)	N of centers	Ave density (job/acre)
100K – 500K	6	41.8	3	99.4
50K – 100K	4	21.5	4	54.1
20K – 50K	20	20.8	13	48.7
10K – 20K	19	15.5		N/A

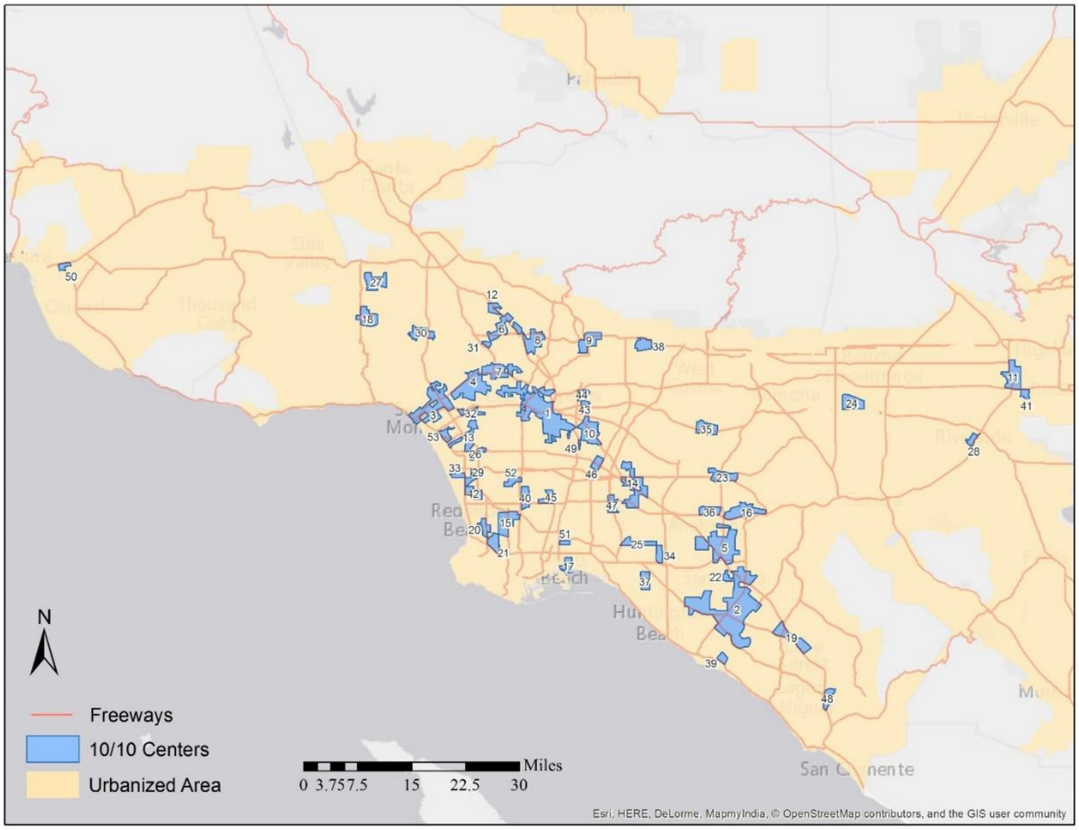

Figure 1 Location of 10/10 centers in the Los Angeles region

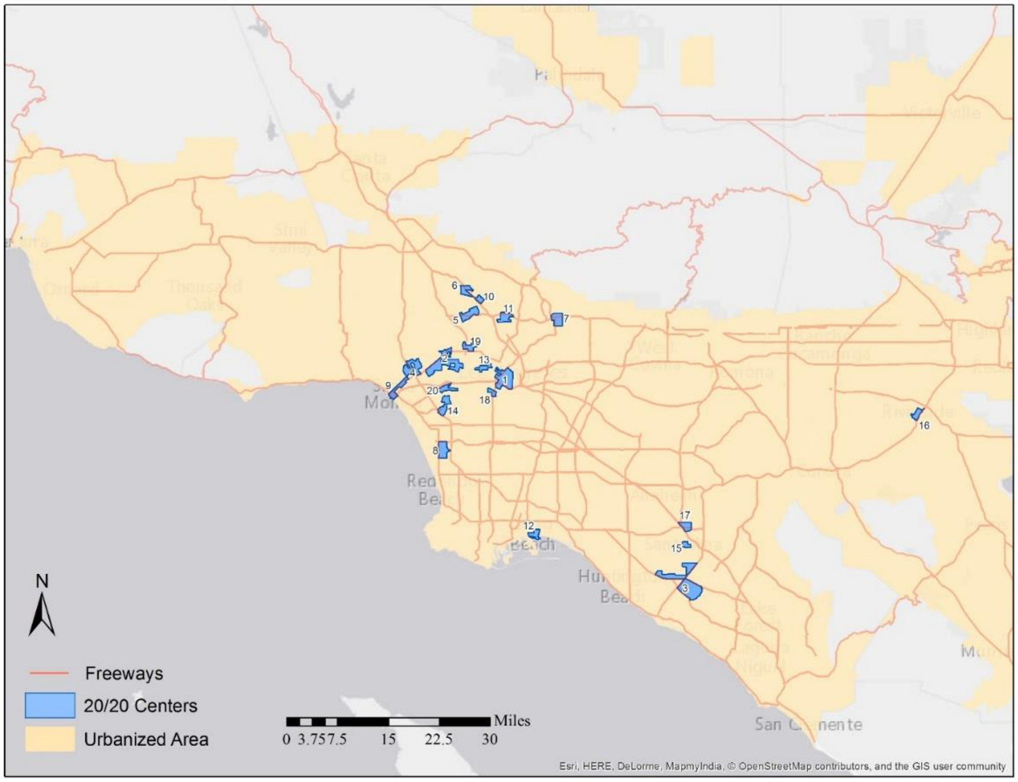

Figure 2 Location of 20/20 centers in the Los Angeles region

To illustrate industry sector specialization, we compare the shares of the LEHD sectors in the two groups of centers, as well as outside of centers (Table 3). We do not show agriculture or resource extraction because these activities do not take place in centers. The grey shading highlights sectors that are more concentrated in centers, and the blue shading highlights sectors that are less concentrated in centers. Both groups of centers are more specialized in sectors including Information, Financial activities, Professional and business services, Management of Companies and Enterprises, Administrative and support, and Public Administration compared to TAZs outside of these centers. Many of these are the traditional information based services highly reliant on agglomeration economies. Population serving activities (retail, education, and other services) are less concentrated in centers. The 20/20 centers show a higher degree of specialization, as expected. While manufacturing is more concentrated in the 10/10 centers, the opposite is observed for the 20/20 centers, reflecting the effect of higher density and land rents. Wholesale trade shows the same pattern. Transportation is slightly less concentrated in both groups of centers.

TABLE 3: Industry shares inside and outside centers [NOTE these are column %]

Sector	10/10 Centers	outside 10/10 Centers	20/20 Centers	outside 20/20 Centers
Utilities	0.5%	0.6%	0.6%	0.6%
Construction	2.2%	4.6%	0.9%	4.5%
Manufacturing	8.9%	5.9%	3.8%	6.3%
Wholesale Trade	5.5%	3.9%	3.7%	4.1%
Retail Trade	9.5%	12.5%	7.7%	12.4%
Transportation and Warehousing	2.4%	2.6%	2.0%	2.6%
Information	5.9%	1.4%	10.0%	1.5%
Financial Activities	5.1%	2.6%	5.5%	2.8%
Real Estate and Rental and Leasing	2.2%	2.0%	2.2%	2.0%
Professional and Business Services	8.2%	4.4%	11.3%	4.5%
Management of Companies and Enterprises	1.6%	0.8%	1.7%	0.8%
Administrative and Support	7.6%	5.3%	7.2%	5.5%
Educational Services	6.9%	13.8%	7.1%	13.3%
Health Care and Social Assistance	11.9%	11.6%	13.2%	11.5%
Arts, Entertainment, and Recreation	2.2%	2.0%	2.3%	2.0%
Accommodation and Food Services	8.3%	10.7%	8.5%	10.6%
Other Services	6.4%	12.0%	4.8%	11.7%
Public Administration	4.6%	1.9%	6.8%	2.0%

In previous work we found that centers have different functions within the regional space economy (Giuliano and Small, 1991; Agarwal, Giuliano and Redfearn, 2012). Center function is evidenced by industry mix, which would influence freight intensity. We therefore conduct a cluster analysis on the centers to determine whether such differentiation still exists, using 20/20 centers and 10/10 centers respectively. We used K-means cluster analysis and identified 5 groups of centers in both cases. Table 4 shows the number of 10/10 centers in each cluster group with some examples, and provides brief descriptions of each group. Figure 3 shows the distribution of groups of 10/10 centers. Group 1 includes business centers (e.g. Westwood/Santa Monica, Wilshire West, Glendale, and Pasadena). Group 2 includes centers with mixed employment, such as Downtown LA and Long Beach. Group 3 includes manufacturing and wholesale centers. Group 4 includes information centers such as Burbank and Culver City. Group 5 contains centers specialized in health, education and public administration.

Table 5 lists 20/20 centers by cluster group, and provides brief descriptions of each group. Figure 4 shows the distribution of groups of 20/20 centers. Group 1 includes high tech centers (Mid-Wilshire and Santa Monica, LAX, and the ports (Long Beach). Group 2 includes centers with the region’s largest universities, UCLA and USC. Group 3 includes many of the region’s media and entertainment centers. Group 4 includes two central cities with relatively little private employment. Group 5 is similar to Group 1, but has much lower shares of manufacturing and transportation.

TABLE 4: 10/10 centers by cluster group

Cluster group	Number of Centers (examples)
Group 1: Business (Retail, Finance, Real Estate, Professional, Accommodation)	17 (Westwood/Santa Monica, Wilshire West, Orange/Anaheim, Hollywood, Glendale, Pasadena)
Group 2: Mixed (Transport, Education, Public)	8 (Downtown LA, San Bernardino , Long Beach, Santa Ana)
Group 3: Manufacturing, Wholesale, Services	18 (Irvine/SNA/Costa Mesa, Commerce , La Mirada/Norwalk , Carson)
Group 4: Information	5(Burbank, Burbank North, Culver City South)
Group 5: Health, education, public administration	5 (Riverside, Loma Linda)

TABLE 5: 20/20 centers by cluster group

Cluster group	Centers*
Group 1: Mixed (manufacturing, transportation, information, professional services, accommodation	Wilshire West (2), LAX (8), Santa Monica (9), Long Beach (12), Hollywood (19)
Group 2: Education/health	Westwood (4), LA South(18)
Group 3: Information/media	Burbank(5), Burbank North(6), Burbank East (10), Culver City South (14), Culver City (20)
Group 4: Public administration/health	Santa Ana (15), Riverside (16)
Group 5: Retail/professional/finance	LA downtown (1), Irvine/SNA (3), Pasadena (7), Glendale (11), Wilshire East (13), Orange (17)

* Number indicates rank by total employment

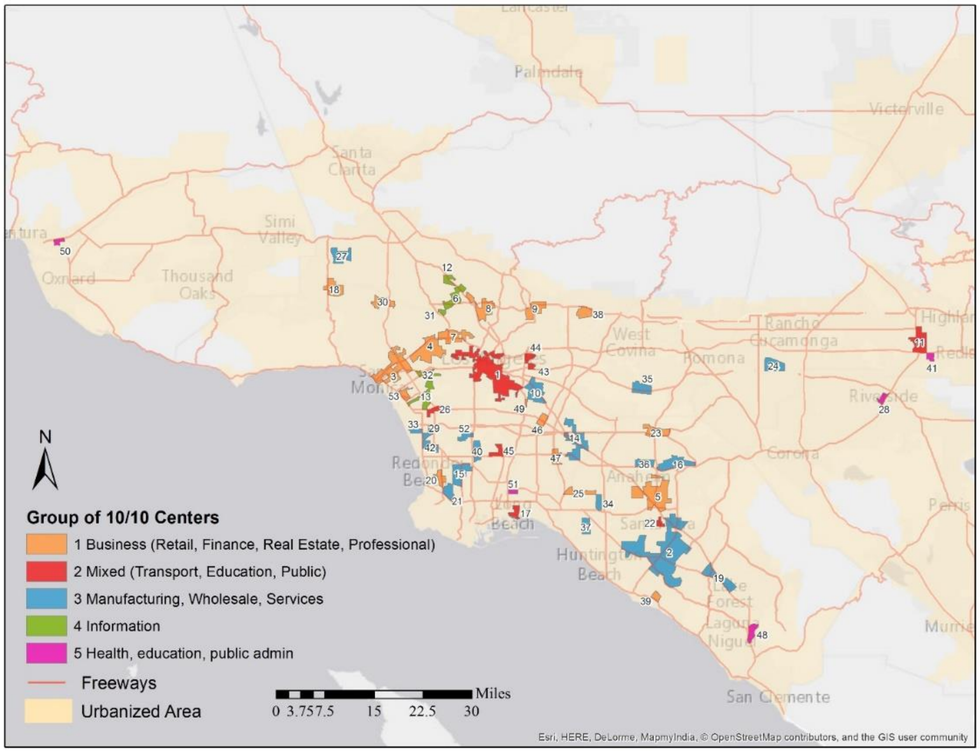

Figure 3 Distribution of groups of 10/10 Centers in the Los Angeles region

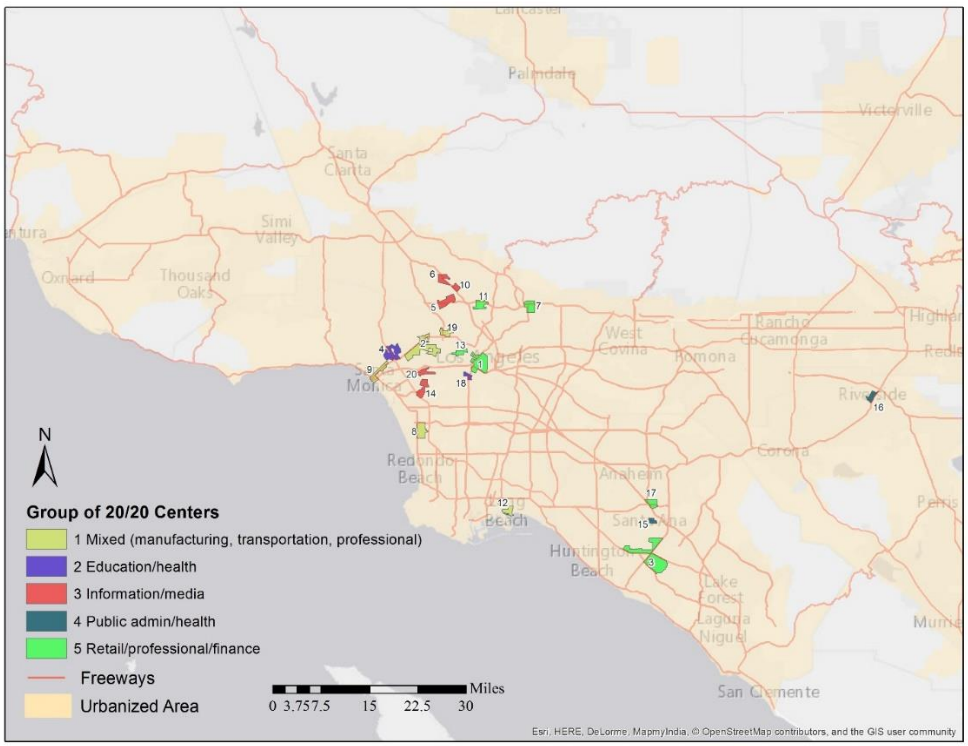

Figure 4 Distribution of groups of 20/20 Centers in the Los Angeles region

RESULTS

Freight intensive sectors inside vs outside center

We first test whether freight intensive sectors are more likely to locate inside or outside of centers.
The SCAG model has only three industry sector categories for freight truck trip generation. Although more detailed categories have been used for other metro areas, only the SCAG categories have been tested for Los Angeles. We therefore use the SCAG categories. We allocated the 20 two-digit LEHD data into three groups of freight intensity based on the SCAG trip generation rates. We used natural breaks in the rate data to define groups. See Table 6.

Table 6: Categories for freight trip generation rates

Category	Combined trip rate range*
High: transportation, warehousing, utilities	0.1583 – 0.3206
Medium: agriculture, mining, construction, manufacturing, retail, wholesale	0.0613 – 0.0968
Low: public administration, all services, health care, arts and entertainment	0.0095 – 0.0296

*trip generationrate is truck trips per employee

Table 7 gives the shares for both groups of centers and for outside centers, and Table 8 gives results of Anova tests. Although there are slightly more high freight intensity activities outside of centers, the difference is not significant. The high intensity sectors make up a very small proportion of all jobs. Differences for the medium and low groups are marginally significant for 10/10 centers, and significant for 20/20 centers. Differences are in the expected directions: more low intensity activities in centers, and more medium intensity activities outside of centers, with all differences greater for the 20/20 centers. Figure 5 maps the centers on top of the concentration of high freight intensity sectors. The 10/10 centers are outlined in red, and the 20/20 centers are outlined in blue. It can be seen that with few exceptions, high freight intensity activity is most concentrated outside of the center boundaries. We have modest evidence that industry mix inside and outside of centers reflects differences in freight intensity.

TABLE 7: Sector shares by freight intensity

Freight intensity	10/10 Centers	outside 10/10 Centers	20/20 Centers	outside 20/20 Centers
High	2.9%	3.2%	2.6%	3.2%
Medium	26.4%	28.3%	16.6%	28.6%
Low	70.8%	68.5%	80.8%	68.2%

Table 8: Anova test results

	In vs. Out 10/10 centers		In vs. Out 20/20 centers	
	F value	Prob. >F	F value	Prob. >F
High	1.33	0.25	0.85	0.36
Medium	2.94	0.09	52.58	0.00
Low	3.77	0.05	47.15	0.00

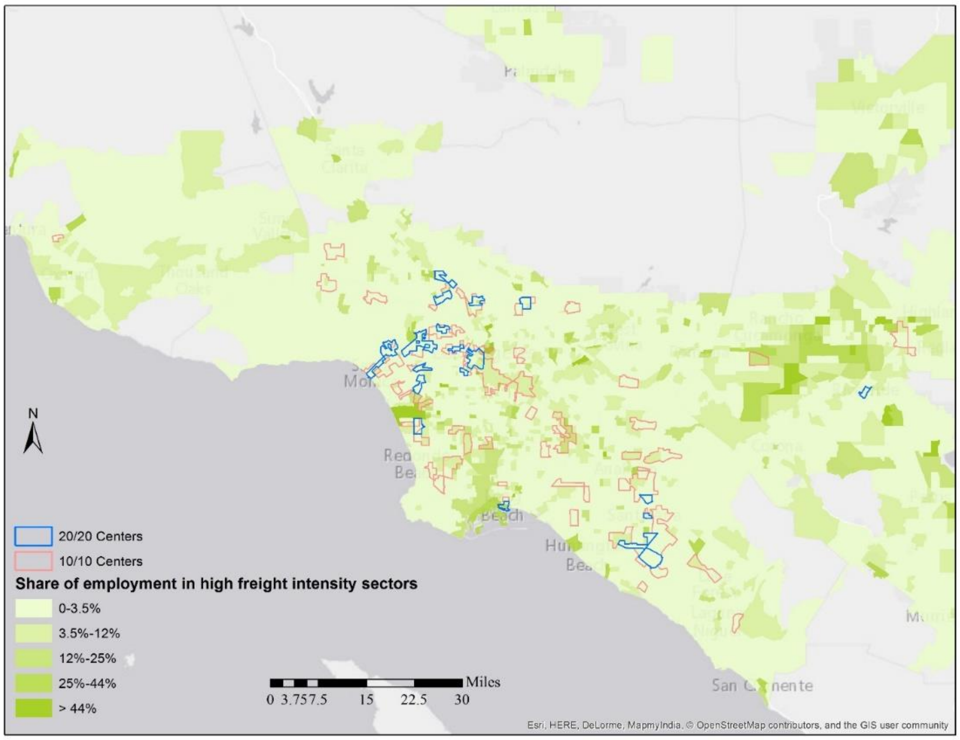

Figure 5: Share of employment in high freight intensity sectors and location of 10/10 and 20/20 centers

Freight intensive sectors within centers

Next we test whether the location of freight intensive activities varies within centers. Each center has a peak density track. Are those freight intensive activities within centers more likely to locate away from the peak density tract? Our centers are not monocentric. That is, they do not have density gradients that decline constantly with distance from the peak in every direction. The larger centers are "lumpy", with multiple peaks, though one peak can always be identified as the highest. For this test we use only those centers that are made up of more than one tract. We compare the average share of each freight intensity group within the peak tract and in the remainder of the center.

Tables 9 and 10 show the results. Although the percentages are all as expected, none of the differences for 10/10 centers is significant. For 20/20 centers, the medium and low categories are significantly different. Of particular note is the medium category, likely reflecting that even when manufacturing or wholesaling is located within a center, it is not located in the densest part of the center.

TABLE 9: Freight intensity within centers, inside and outside peak density tract

	10/10		20/20	
Freight intensity	Inside peak tract	Outside peak tract	Inside peak tract	Outside peak tract
High	3.5%	3.2%	3.8%	3.2%
Medium	25.9%	28.2%	9.6%	28.2%
Low	70.6%	68.7%	86.6%	68.6%

Table 10: Anova test results

	In vs. Out 10/10 peaks		In vs. Out 20/20 peaks	
	F value	Prob. >F	F value	Prob. >F
High	0.11	0.73	0.16	0.69
Medium	0.72	0.40	18.49	0.00
Low	0.43	0.51	14.08	0.00

Freight intensive sectors across center types

We use the results of the cluster analysis to examine whether freight intensity associated with industry mix is more evident in one type of center than another. For the 10/10 centers we use all groups: groups 1 (business), 2 (mixed), 3 (manufacturing), 4 (information) and 5 (health/education). See Table 11. Groups 4 and 5 stand out, with almost all activity in the low intensity category. The manufacturing centers (Group 3) are clearly identified with the large share of medium freight intensity employment. We conducted multiple Anova tests and found that Group 3 is significantly different from all other groups, and Group 2 is significantly different from Groups 4 and 5 (results not shown).

Table 11: Sector shares by cluster group, freight intensity, 10/10 centers

Freight intensity	Group 1	Group 2	Group 3	Group 4	Group 5
High	1%	8%	5%	1%	0%
Medium	23%	14%	53%	10%	5%
Low	76%	78%	42%	89%	94%

For the 20/20 centers we use only groups 1 (mixed), 3 (information) and 5 (retail/professional) because of the small numbers in the other categories (Table 12). Group 3 comes closest to the theoretical concept of center, and its shares across the intensity categories are quite different from Groups 1 and 5. Pairwise Anova tests show no significant differences mainly due to small sample size (results not shown). These results indicate that differences in center function are reflected in differences in freight intensity.

Table 12: Sector shares by cluster group, freight intensity, 20/20 centers

Freight intensity	Group 1	Group 3	Group 5
High	7%	1%	3%
Medium	17%	10%	17%
Low	76%	89%	81%

Freight intensive sectors and distance from center

Finally we return to freight intensity and distance from the center. Through the effect of density (as proxy for land value), we would expect that high and medium freight intensity sectors would increase with distance from the center, and low freight intensity sectors would decrease with distance from the center. We use Groups 1, 3, and 5 of the 20/20 centers and calculate the mix of sectors by freight intensity as a function of distance (miles) from the peak zone (Table 13). Group 1, the mixed centers, shows the expected trend for low freight intensity, but not for medium or high. Group 3, the information/media centers, comes closest to expectations. Almost all of the activity in the peak zones are low freight intensity, and the high and medium categories are consistent with expectations. Group 5 results are as expected for the medium and low intensity categories, but not for the high intensity category. These results suggest that our prototypical centers – the information centers – have a spatial organization consistent with theory. For the other types of centers, the low and medium freight intensity distribution is consistent with expectations, but the high intensity distribution is not. Whether this is the result of random variation in a very small overall share, or historical development patterns is unknown.

Table 13: Freight intensity and distance from peak zone

Group 1 Mixed			
	Freight intensity		
Distance	High	Medium	Low
0	2.12%	18.78%	79.11%
1	1.64%	23.20%	75.17%
2	1.16%	23.82%	75.02%
3	1.49%	21.79%	76.72%
5	3.43%	20.75%	75.82%
10	2.91%	29.73%	67.37%
Group 3 Information/media			
Distance	High	Medium	Low
0	0.33%	5.93%	93.74%
1	0.97%	24.58%	74.44%
2	2.12%	25.46%	72.42%
3	2.55%	25.98%	71.47%
5	4.21%	26.18%	69.61%
10	2.45%	24.91%	72.64%
Group 5 Retail/professional			
Distance	High	Medium	Low
0	5.36%	12.80%	81.84%
1	1.94%	13.38%	84.68%
2	2.41%	20.33%	77.25%
3	3.16%	21.86%	74.98%
5	1.75%	23.00%	75.25%
10	2.35%	27.15%	70.49%

CONCLUSIONS

We have explored the first part of our question on whether freight intensity is related to density. We argued that density has two possible effects: a crowding out of freight intensive activities from city cores due to high rents and congestion, and an effect on industry operations in response to high rents. This paper explored the first effect. Using the Los Angeles region, we identified two categories of employment centers – essentially "cities" – since each represents a unique peak and influences land use surrounding the peak. We find that in a general way these centers behave as expected. High freight intensive activities more frequently locate outside of centers, and the largest centers have relatively small shares of such activities. As expected, the largest and most dense centers are more differentiated from non-center areas than the smaller centers. However, centers are not homogeneous; they have different industry mixes and different functions in the space economy. Our information/media centers came closest to theoretical expectations. They have the largest share of low freight intensity activities and the smallest share of medium and high freight intensive activities. They also show the clearest relationship of freight intensity mix with distance from the peak zone.

We have provided descriptive evidence that freight intensity is related to density. The next step is to estimate freight intensity gradients to more formally test this relationship. The more challenging question is whether density affects industry operations. The effect of changing industry mix, which reduces freight intensity as density increases, could be offset by tradeoffs between inventory holding and delivery frequency.

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