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Distribution facilities in California: A dynamic landscape and equity considerations

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Abstract: This work studies the distribution of warehouses and distribution centers (W&DCs) in California and analyzes their potential relationships with disadvantaged communities (DACs). Through aggregated spatial analyses and econometric modeling, the research compares the concentration of W&DCs in five metropolitan planning organizations (MPOs) in California. The analyses show that the weighted geometric centers of W&DCs have shifted slightly toward city central areas in all five MPOs in the last few years, contrasting to the logistics sprawl trends evidenced in previous research. In the Bay Area and Southern California, W&DCs are more prevalent in areas with higher pollution burden, according to the CalEnviroScreen (CS) score. In Southern California, the study analyzes disaggregate industrial real estate data of 49,697 property transactions (properties sold) between 1989 and 2018. On average, the size of the facilities transacted have decreased, especially for those closer to the urban center. These results are confirmed using parametric and non-parametric data analyses. During recent years, smaller and closer (to the urban core) facilities represent the largest share in the transactions, consistent with the trends in e-commerce and its associated distribution requirements. Moreover, the data show a disproportionate sitting of facilities in areas where DACs reside. The paper ends with a discussion of policy and planning recommendations.

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1 Introduction

Freight contributes to economic development, provides access to goods, and allows for the functioning of our societies; however, the flows of freight vehicles bring air pollutants emissions, noise, congestion, and other negative externalities. Traditionally, freight has been associated with the flow of large vehicles to and from large freight facilities such as seaports, intermodal yards, industrial and manufacturing

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facilities, and warehouses and distribution centers. Nowadays, there has been an increased attention to flows to urban centers as part of the urban goods movement system. Nonetheless, these systems do not operate in isolation, and there are changes in the freight distribution and consumption behaviors that affect the overall system and its impacts. An important component of the freight system is the set of warehouses and distribution centers (W&DCs) that facilitate the freight flows. These facilities, and especially their location and distribution have been the subject of significant research, as such factors affect the impacts of the flows they generate.

Researchers have identified the logistics sprawl phenomenon, which refers to the case of logistic facilities moving away from urban centers to suburban areas. Several authors have conducted analyses in different metropolitan areas of the world and evidenced this phenomenon (Allen et al., 2012; Dablanc, 2014; Jaller & Pineda, 2017; Rodrigue et al., 2017; Woudsma et al., 2016; van den Heuvel et al., 2013). Overall, logistics sprawl and facility location have been amply studied, though with less emphasis on the empirical quantification of impacts; with the studies from Japan, France, and Germany among the few that have quantified the local impacts such as changes in vehicles miles traveled. Additionally, there is a lack of analyses to uncover the potential recent impacts of e-commerce on the location of W&DCs, and the associated effects to the local communities. Specifically, the research hypothesis in this paper is based on the fact that compared to traditional retailing, e-commerce is characterized by higher purchase frequencies of smaller quantities (basket sizes), that are mostly delivered to customer's homes using smaller delivery vehicles, and more significantly, deliveries are being offered under shorter time windows (Jaller & Pahwa, 2020; Pahwa & Jaller, 2020; Visser & Nemoto, 2003). Consequently, companies might have to strategically locate inventories and products closer to the customers, potentially using multiple smaller facilities (e.g., W&DCs, fulfillment centers, micro-hubs) inside highly dense areas, to guarantee reliable, fast and cheaper distribution, which results in surging demand of smaller warehouses in proximity to the consumers (Smith, 2019).

The first objective of this study is then to conduct empirical analyses with aggregate and disaggregate data about the concentration of W&DCs and industrial real estate transactions to identify changes in market trends. Specifically, the study analyzes if such expected logistics behaviors are in fact occurring in this large market by estimating general and spatio-temporal changes in the transacted facility values. Additionally, considering that previous researchers have identified environmental and social justice issues related to W&DCs, the second main objective of the work is to identify if the market changes have accentuated equity concerns by quantifying the casual interrelations between the location of these facilities and disadvantaged communities (DACs). In doing so, the study uses spatial aggregate analyses (e.g., centrographic and spatial correlation) of the distribution of W&DCs, and disaggregate analyses based on econometric modeling to quantify the effect of different factors in the location of these facilities.

The aggregate preliminary analyses evaluate the W&DCs concentration trends in five large Metropolitan Planning Organizations (MPOs) areas in California. The study identified communities of concern (e.g., DACs) using the environmental score (CalEnviroScreen 3.0) (Office of Environmental Health Hazard Assessment, 2017), and found the largest relationship between the location of W&DCs and DACs in the Southern California Association of Governments (SCAG) region. Thus, the disaggregate analyses focused on the real estate markets in the region. This research provides empirical evidence of the changes occurring in the study area, and the potential impacts.

The manuscript summarizes the relevant literature in Section 2 and describes the case study area and the data used for the analyses in Section 3, followed by the methodological approach in Section 4. Section 5 discusses the results from the aggregate and disaggregate analyses. The paper ends with a discussion and conclusions section.

2 Spatial distribution of W&DCs

The location and spatial distribution of W&DCs have received increased research interest. Overall, most of the research have used aggregate spatial analyses of the location of such facilities to measure centrality and concentration. For example, Cidell (2010) and Dablanc and Rakotonarivo (2010) analyzed concentration and decentralization of distribution facilities in the US, and France, respectively. Kang (2018) evaluated the concentration of facilities throughout the US, and found that sprawl is mainly prevalent in those metro areas with high land prices, otherwise, the effect is not significant. Dablanc and Rakotonarivo (2010) looked into freight transport terminals in Paris and found that these terminals relocated from urban cores in 1970 to outer suburban areas. Heitz et al. (2020) conducted spatial analyses of logistics facilities in Gothenburg metro area, and in the Västra Götaland regional area in Sweden between 2000 and 2014. Sakai et al. (2015) analyzed the changes in facility location, and using shipment data, also studied location impacts on vehicle miles traveled (VMT), finding that the resulting increase in VMT may be affected by the deconcentration of demand and not only because of logistics sprawl.

Dablanc and Ross (2012) analyzed the case in Atlanta, and Dablanc et al. (2014) compared the warehousing industry development patterns in Los Angeles and Seattle during 1998 to 2009 by measuring the geographic center change over the years. They found that, in Los Angeles, the average distance increased more than 6 miles between 1998 and 2009; while in Seattle, the location of the warehouses kept stable. Also in California, Giuliano and Kang (2018) conducted spatial analyses with additional findings related to the relative distance between W&DCs and other freight facilities, and populations in different areas in California. Concentrating in Southern California, Jaller and Pineda (2017) analyzed the centrographic location of W&DCs in five counties in Southern California between 1998 and 2014, and found that the concentration of W&DCs changed after the 2008-2009 major recession, with W&DCs for some sub-industries exhibiting a halt in the sprawl trend, and in some cases, even a reversal (i.e., concentrating closer to the urban core).

The other related research thrust has focused on the determinants of the location of freight facilities. Overall, the research identified land availability and affordability, proximity to transportation networks and other freight facilities, and the regulatory environment as key determinants (Andreoli et al., 2010; Bowen Jr, 2008; Dablanc, 2014; Dablanc & Ross, 2012; Giuliano et al., 2016; Jaller, Qian, et al, 2020; Olsson & Woxenius, 2012; Vlachopoulou et al., 2001). Several studies have estimated econometric models to quantify the magnitude of impact of such factors on location decisions. In Brazil, although not finding a significant sprawl phenomenon in Sao Paulo, Guerin et al. (2021) found that decisions to move warehouse are related to low cost of land, lower taxes, and adequate infrastructure with highway intersections. Jaller et al. (2017) found that the number of W&DCs in Southern California could be explained by the number of establishments in the manufacturing and transportation service industries, proximity to highways and intermodal facilities, the number of W&DCs and accommodation and food services in neighboring zip codes, population, the number of adults using public transit, and per capita income, which are findings consistent with other studies. In a large comparative assessment, Oliveira et al. (2021) collected and analyzed warehouse related information from 62 metropolitan areas to study the factors affecting the location of such facilities, and what factors may be attributable to urban variables. They found that it is important to categorize the typology of the different areas to perform comparative analyses; the concentration of urban activity affects the location of facilities; and that logistics sprawl may be more related to the type of metropolitan area than some of the individual variables (e.g., prices) identified in other analyses.

One of the key factors motivating these research has been to identify the potential impacts on mobility, land use, and commerce (Combes, 2019; Gerend, 2017; Guerin et al., 2021; Guerin & Vieira, 2018; Kang, 2020; Lin, 2019; Nahiduzzaman et al., 2019; Oliveira et al., 2021; Pettersson et al., 2016;

Strale, 2020). These studies show evidence from the Netherlands, Brazil, China, France, and Germany that e-commerce has had significant impacts on the spatial structure of cities, land use, and mobility. More recently, research interest have been on identifying new factors (e.g., e-commerce growth) and patterns that may have generated structural changes in distribution processes (Rodrigue et al., 2017; Zhu et al., 2018) and warehousing in general (Boysen et al., 2019), and extending the understanding of impacts to social and environmental justice considerations. In the US, for example, Yuan (2019) and Yang et al. (2021) evaluated and discussed the general environmental justice problems caused by the location of warehouses in the Los Angeles region, and some effects spanning from e-commerce.

In the same area, Rivera-Royero et al. (2021) analyzed vehicle count and classification data to identify changes in freight flow patterns, and highlighted the potential effects of facility concentration, economic conditions, and logistics decisions. The results show that after the major recession in 2008 and 2009, the observed changes, e.g., increases in light-heavy duty flows, could be explained by the growth in e-commerce. Recently, Pahwa and Jaller (2022) developed an optimization model to analyze the effect of facility location in the distribution of e-commerce deliveries. Their research quantified the impact on emissions and travel associated with the relative location of distribution facilities to customers, and how this location is also a determinant for the performance of alternative distribution strategies.

Overall, these relationships and impacts are still understudied, and while there is anecdotal evidence about the changes occurring in distribution networks and the location of W&DCs due to e-commerce, city logistics initiatives (e.g., alternative delivery locations, micro-hubs), there is a lack of empirical analyses to shed light into the issue.

3 Warehousing in California

This study focuses on California using both aggregate and disaggregate analyses. Specifically, aggregate preliminary analyses evaluate W&DCs concentration trends in the five largest Metropolitan Planning Organizations (MPOs) areas in the State: Southern California Association of Governments (SCAG), Metropolitan Transportation Commission (MTC), Sacramento Area Council of Governments (SACOG), San Joaquin Council of Governments (SJCOG), and San Diego Association of Governments (SANDAG). And the disaggregate analyses focused on the real estate markets in the SCAG region. The SCAG market includes the Los Angeles (Los Angeles and Ventura Counties), Inland Empire (Riverside and San Bernardino Counties), Orange (Orange County), and San Diego (San Diego County).

3.1 Number of W&DCs

The Zip Code Business Pattern (ZBP) database provides information about the number of establishments and employment at the zip code level in the US. The study used data between 1998 and 2016 for freight-related North American Industrial Classification Standards (NAICS) industry categories. W&DCs are identified by NAICS 493 (Warehousing and Storage). Additionally, Table 1 shows the 2-digit level NAICS classifications for other industries considered in the analyses (e.g., identifying the effect of other establishments and industries in a particular location).

Table 1. Freight-related NAICS industries

NAICS classification	Description
11	Agriculture, Forestry, Fishing and Hunting
21	Mining, Quarrying, and Oil and Gas Extraction
22	Utilities
23	Construction
31-33	Manufacturing
42	Wholesale Trade
44-45	Retail Trade
48-49	Transportation and Warehousing
72	Accommodation and Food Services

3.2 Infrastructure and demographic variables

To conduct the econometric analyses and based on the relevant factors that may affect the location of W&DCs, the study gathered information about the transportation infrastructure including the highway network and the location of seaports, airports, and intermodal facilities. The Intermodal Association of North America (IANA) provides information about the intermodal facilities; and data on seaports and airports is from the California Department of Transportation (Caltrans). The team estimate additional variables such as the distance from these facilities to the centroid of each zip code.

Additionally, the team gathered socio-demographic information for each zip code in the study areas. Table 2 provides a summary of key variables identified for each of the five MPO regions. The data shows the significant socio-economic differences across the various regions, and related to W&DCs, SCAG and SJCOG show the highest concentrations. Figure 1 shows the change in the total number of W&DCs in five MPOs over the period of 1998 to 2016. It is important to note that the significant change in the number of facilities in 2002 is mostly attributed to classification issues as it was the year when the NAICS replaced the Standard Industrial Classification (SIC) coding system and there is no direct cross-walk, thus some facilities changed categories. Regardless, in terms of the W&DCs quantity, SCAG shows the largest number over this period.

3.3 Environmental score and disadvantaged communities

The Office of Environmental Health Hazard Assessment (OEHHA), on behalf of the California Environmental Protection Agency (CalEPA), developed an environmental score or CalEnviroScreen 3.0 (CS). The score combines indexes for pollution burden (exposure and environmental effects) and population characteristics (sensitive population and socio-economic factor indicators) at the census tract level in California (Office of Environmental Health Hazard Assessment (OEHHA), 2017).

Table 2. Data summary (mean value per zip code)

Variable type	Variable Description	SCAG	MTC	SACOG	SANDAG	SJCOG
	Number of Zip Codes	607	303	158	114	32
Demographics	Population (1k)	30.1	24.0	15.6	27.5	21.6
	Median age, years	36.4	40.8	41.1	36.0	35.2
	White population percentage (%)	62.9	63.9	76.4	73.7	65.5
	Median household income (1k $)	61.9	84.3	59.3	66.9	57.7
	Median house value (10k $)	40.6	61.3	28.6	43.3	23.3
	Adults using public transit (1k)*	37.6	83.7	16.5	22.8	12.3
Establishments in NAICS sectors	NAICS 493 establishments	1.8	1.0	0.9	0.9	2.3
	NAICS 32 establishments	7.9	5.2	2.8	6.6	5.2
	NAICS 48 establishments	17.7	10.3	7.1	12.4	17.8
	NAICS 72 establishments	65.0	67.8	30.5	65.5	35.7
	Neighboring 493 establishments	11.9	5.7	5.7	5.5	13.4
	Neighboring 32 establishments	52.4	29.8	17.9	41.4	29.3
	Neighboring 48 establishments	115.6	57.5	46.3	75.3	99.5
	Neighboring 72 establishments	404.3	376.0	187.6	401.6	196.2
Accessibility	Distance to highway (miles)	1.1	0.9	1.6	1.1	1.0
	Distance to ports (miles)	41.5	19.3	31.7	22.9	12.1
	Distance to airports (miles)	24.8	22.7	25.8	20.1	37.8
	Distance to intermodal facilities	19.1	20.9	27.3	25.8	8.9

*Commute travel.

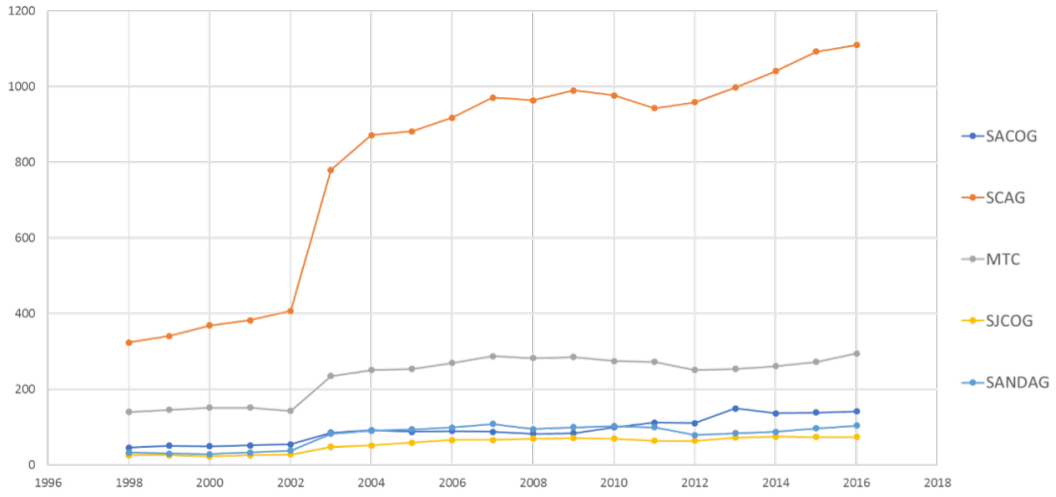

Figure 1. Changes in the numbers of W&Ds establishments

Using the CS and the definitions from Senate Bill (SB) 535 Disadvantaged Communities, the team identified communities categorized as DACs. Specifically, the top 25% scoring areas from CS along

with other areas with high amounts of pollution and low-income populations. Table 3 summarizes all the scores for the zip codes in each of the MPO areas. Consistent with the overall regional characteristics, SCAG and SJCOG show the highest CS scores, experiencing large impacts from traffic, PM 2.5 concentrations and diesel particulate matter, which translate into poor air quality conditions and negative health impacts.

Table 3. Descriptive summary of environmental scores (mean percentile value)

Component	**SCAG**	**MTC**	**SACOG**	**SANDAG**	**SJCOG**
Ozone	63.98	11.96	59.31	37.63	52.56
PM 2.5 concentration	64.61	40.46	36.16	63.40	78.57
Diesel PM	65.26	61.89	41.60	59.71	54.99
Pesticide use	39.95	39.16	60.14	40.26	82.87
Toxic releases	72.61	55.10	30.05	46.49	61.99
Traffic	68.25	60.44	39.96	63.23	53.59
Drinking water	55.80	31.55	41.87	35.47	71.19
Cleanup sites	55.77	54.19	46.04	52.42	47.69
Groundwater threats	39.77	57.22	53.69	50.59	71.47
Hazardous waste facilities	59.67	55.94	40.50	50.13	59.95
Impaired water bodies	40.85	57.96	54.13	59.08	87.39
Solid waste sites	41.47	37.67	53.34	38.61	51.15
Asthma	51.18	44.96	50.80	34.20	64.80
Cardiovascular disease	55.37	33.18	51.73	27.66	68.57
Low birth weight	58.27	49.12	43.38	44.18	68.24
Educational attainment	54.11	37.85	43.14	40.35	67.57
Housing burden	60.12	45.96	40.81	52.50	41.90
Linguistic isolation	60.76	54.63	39.63	48.26	64.18
Poverty	50.40	29.94	47.53	42.15	57.83
Unemployment	50.48	30.34	55.54	38.98	70.70
CalEnviroScreen Score	61.95	37.74	43.37	38.88	78.24

3.4 Real estate industrial transactions

This study used industrial real estate transaction data from Southern California between 1989 and 2018, accessed from the Costar Group Inc. dataset. Industrial property is one of the categories in the dataset, among other property types such as multi-family, retail, and office. Industrial buildings are used for assembly, processing, manufacturing, storage, maintenance, and distribution, among other logistics and manufacturing activities. The secondary classifications of industrial properties include distribution, manufacturing, truck terminal, service, and warehouses. In Southern California, properties are grouped in four markets based on location: the Los Angeles (Los Angeles and Ventura Counties), Inland Empire (Riverside and San Bernardino Counties), Orange (Orange County), and San Diego (San Diego County).

The data on sold properties, at the transaction level, contained property characteristics including location, transaction time and date, county, market, type, secondary classification, size, price, parking space, transaction value, and other relevant attributes. Table 4 summarizes the numbers of transactions per market per secondary industry type.

Table 4. Number of transactions per secondary industry type

Market	Los Angeles		Inland Empire		Orange	San Diego
Secondary Type \ County	Los Angeles	Ventura	Riverside	San Bernardino	Orange	San Diego
Warehouse	12,138	865	1,913	2,934	8,285	4,862
Manufacturing	3,601	402	746	303	4,014	3,696
Service	809	22	153	305	592	819
Distribution	598	32	164	192	346	352
Food Processing	207	10	12	14	57	35
Showroom	180	5	48	16	168	233
Refrigeration/Cold Storage	123	11	13	14	29	15
Truck Terminal	86	9	9	47	40	33
Telecom Hotel/Data Hosting	7	2	2	0	6	7
NA	78	1	15	22	0	0

In Southern California, between 1989 and 2018, the Costar database contained a total of 49,697 industrial property transactions, covering nine industries in four markets of six counties. Overall, warehouse and manufacturing are the two largest secondary types of all the industrial property transactions. During the study period, Los Angeles was the most active market with increased number of transactions over time. On the other hand, Orange and San Diego markets did not increase much and experience a decrease between 2015 and 2018. Warehouse transactions were more prevalent in the Inland Empire and Los Angeles, whereas manufacturing related transactions dominated in San Diego.

Transactions recorded in the CoStar database have consistently increased, from 89 included in 1989 to 3,042 in 2018, with drops around years 2000 and 2008, which correspond to recessions. It is not clear how representative the data is during the 1990s with only dozens of samples data each year, and the authors could not identify other data sources to determine the total transactions in those years. Overall, the data shows that property prices (per square footage) have continuously increase, though the great recession in 2007-2008 had significant impacts. For example, between the 1990s and 2007, the median prices increased from about $50/sf to around $130/sf; the price dropped during the crisis, and between 2009 and 2018, increased from a low $81.7/sf to $195.8/sf.

In the analysis of the size and distance change in section 5.3, the analysis was only focused on the properties of warehouses and distribution centers during 2000-2018; and the analysis of the disadvantaged communities covers all the properties.

4 Methodology

The study conducts spatial aggregate and disaggregate analyses. At the highest level of aggregation, the study conducts centrographic analyses to identify the concentration of W&DCs, through the yearly barycenter of the facilities at the zip code level. That is, the study estimates the geometric center weighted by the number of W&DCs in each zip code (Yeates, 1973; Soot, 1975). Additionally, the study explores the existence of spatial correlation through the Moran's I statistics by combining the neighboring relationship matrix of the number of facilities (Anselin, 1988; Briggs, 2010). The spatial analyses offer insights about shifts and levels of concentration of the facilities in the study area.

Additionally, the study conducts a series of disaggregate analyses. First, the study estimated econometric models (e.g., zero inflated negative binomial ZINB models) to identify the factors influencing the

location of W&DCs in specific areas. ZINB models are needed in this case because of over-dispersion in the number and location of W&DCs, and the fact that there are many zip codes with zero W&DCs. A ZINB model is a two-step regression, which combines a binary logit model and a negative binomial model. The reader is referred to Cameron and Trivedi (2009) and Cameron and Trivedi (2013) for a detail description of ZINB models. Second, using disaggregate industrial real estate data, the study estimated simple linear regression models to identify temporal changes in the price and size of sold facilities. Specifically, the analyses concentrated on the changes in the size of properties and the relative distance to downtown areas and the San Pedro Bay ports. Finally, the team implemented a binary logistic regression to identify the factors contributing to the location of the facilities transacted in disadvantage areas (Liaw & Wiener, 2002; Segal, 2004; Speiser et al., 2019).

5 Empirical results

5.1 Spatial aggregate analyses

After estimating the yearly barycenter for the W&DCs for each of the five MPOs between 1998 and 2016, the team used the downtown areas as reference to estimate changes in distances to identify potential concentrations. Figure 2 shows that in SCAG, as explained elsewhere (Jaller et al, 2017), the logistics sprawl trend that was documented during the last two decades, has not continued in the last few years, with the distance between the barycenter and the reference location even slightly decreasing. Figure 2 also shows that logistics sprawl is not clearly evident in the other four MPO regions. The difference may result from the various sizes and shapes of the regions. The geometric centers of the W&DCs in the MTC are all in the Oakland region, and they distribute as a circle around the city of San Francisco. Other MPO regions may not be as geographically large as SCAG, thus the changes in their weighted centers may not be noticeable. Observing the average distance between W&DCs and their weighted center (Figure 3), the distance does not change significantly. Considering the period after 2002 (until approximately 2011), SCAG and SANDAG exhibited a dispersion of the facilities relative to their barycenter, with MTC and SJCOG showing a constant behavior. Regarding spatial correlation, Figure 4 shows that the presence of spatial correlation became more significant over time in the SJCOG region. Conversely, SANDAG shows a weakened trend, which means that W&DCs in this region are more dispersed. Other than SJCOG and SANDAG, the changes in Moran's I indexes for MTC, SCAG, and SACOG did not show dramatic shifts. Overall, the results show that SCAG, during the study period exhibited a sprawling phenomenon in which facilities sprawled, with slight decrease in the trend in the last few years.

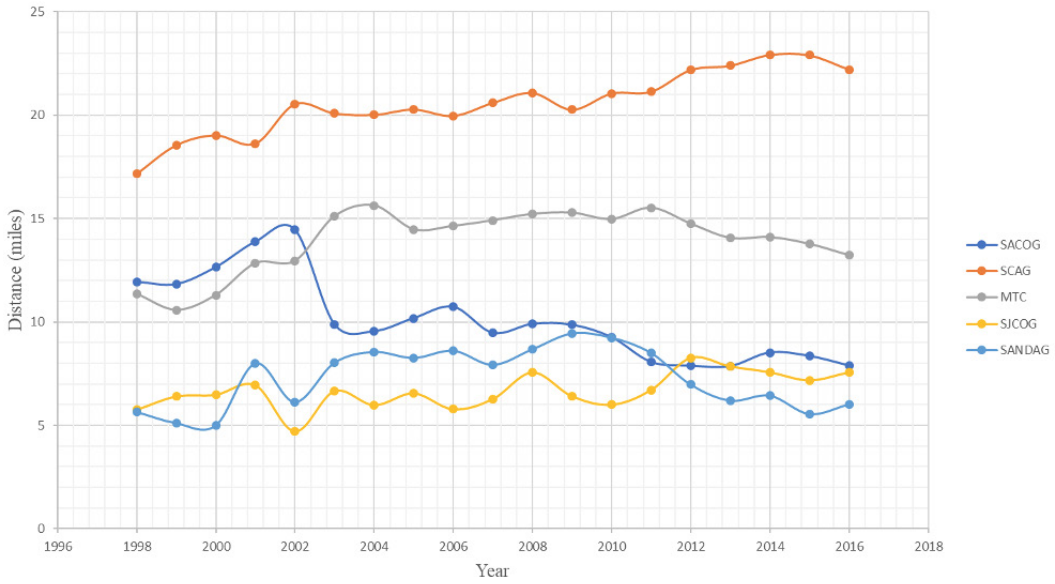

Figure 2. Distance between weighted geometric centers and reference locations

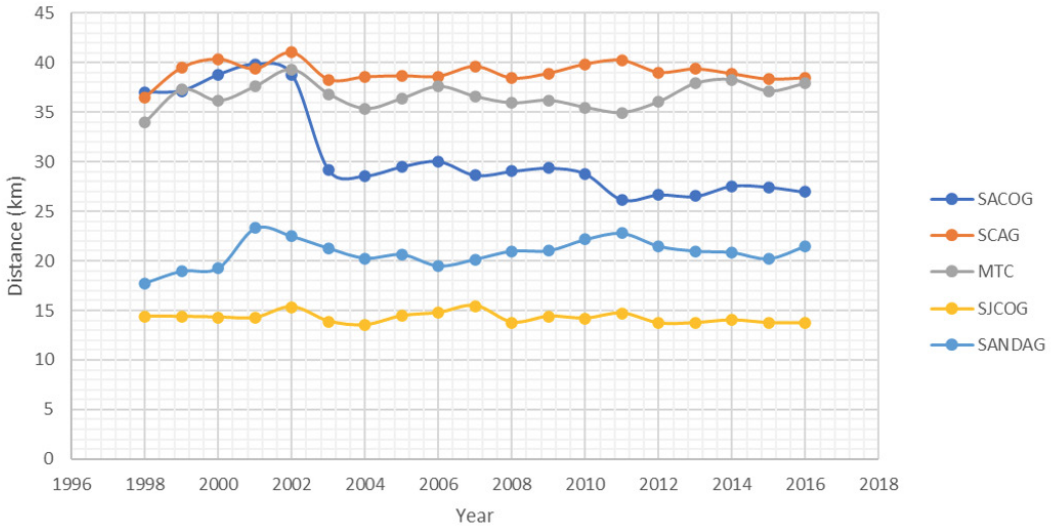

Figure 3. Average distance between all zip codes and weighted geometric centers

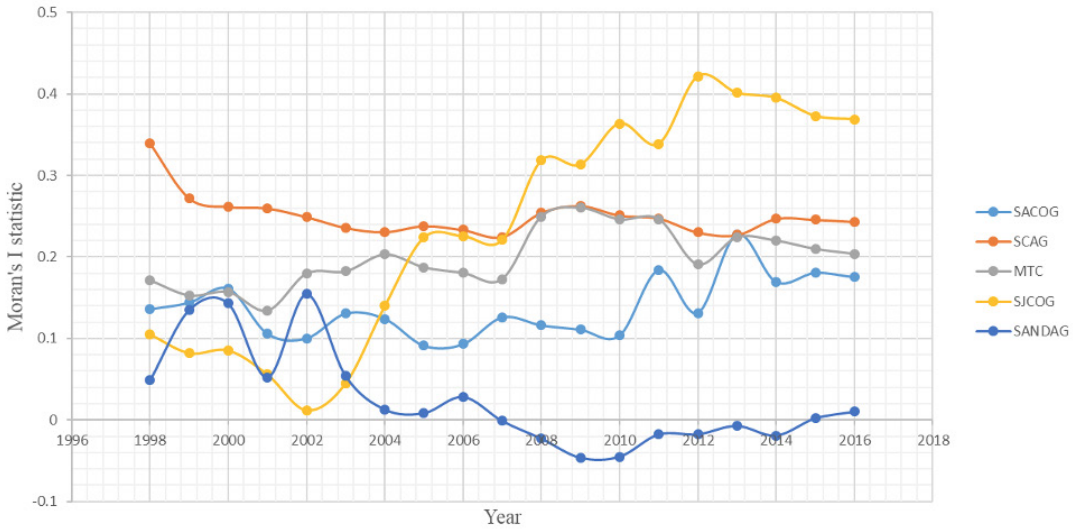

Figure 4. Moran's I statistic change between 1998 and 2016

5.2 Comparison of factors influencing the number and location of W&DCs

This study estimated the correlation between the number of establishments in NAICS 493 with the various CS indexes (e.g., ozone, PM2.5, Diesel PM, etc.). The analyses did not evidence a strong relationship between the number of W&DCs and the various CS index components. In some cases, there is correlation between W&DCs and traffic, diesel and PM2.5 (SACOG showing very large correlations). The area that shows comparatively stronger correlations among the indexes is SJCOG. Nevertheless, the number of W&DCs in a zip code area are mostly positively, though with low correlation, related to most of the environmental indexes, e.g., traffic, PM2.5, Diesel PM, cleanup sites (weighted sites), groundwater threats, and hazardous waste facilities/generators.

The next step involved identifying the factors that could explain the number of W&DCs facilities in specific locations. Table 5 show the estimated ZINB models for the five MPOs. Even though the areas without W&DCs tend to have more manufacturing establishments, for the majority of all those five MPOs, the number of manufacturing establishments is positively correlated with the number of W&DCs if an area has W&DCs. This correlation does not mean that those manufacturing establishments will necessarily use the services provided by those W&DCs. For example, some manufacturing establishments, e.g., milk bottling and ready mixed concrete production, do not need many W&DCs to storage products. However, the co-location of manufacturing establishments and W&DCs could point out to an industrial region.

Table 5. Zero-inflated negative binomial model for all five MPOs

Model	Variable (p-value)	SACOG	SJCOG	SANDAG	MTC	SCAG
1. (Inflate model) logit model: identify certain zeros	Constant	0.12 (0.88)[1]	3.20 (0.02)	15.96 (0.04)	1.63 (0.00)	33.94 (0.67)
	Median household income ($1,000)					-2.29 (0.74)
	Median house value			-0.40 (0.05)		
	Public transit users per 1000s			-0.12 (0.03)		
	Manufacturing (32)	-1.21 (0.02)	-1.00 (0.02)		-0.39 (0.00)	
	Neighboring Transportation (48) establishments					-17.78 (0.76)
	Average distance to intermodal facilities					-2.21 (0.77)
	Average distance to airport	0.06 (0.05)				
	CalEnviroscreen Score					14.755 (0.77)
2. Count model: negative binomial	Constant	-0.28 (0.57)	1.72 (0.36)	-0.19 (0.79)	-0.40 (0.59)	-1.22 (0.00)
	Median household income ($1,000)	0.00 (0.50)		-0.01 (0.12)		
	Median house value				0.00 (0.62)	
	% White population		-0.01 (0.62)			-0.01 (0.23)
	Manufacturing (32)	0.10 (0.00)	0.06 (0.23)	0.09 (0.00)		0.03 (0.00)
	Retail trade (45)					0.01 (0.00)
	Transportation (48)				0.02 (0.00)	
	Neighboring W&DC (493) establishments				0.05 (0.00)	0.02 (0.00)
	Average distance to highway					-0.15 (0.02)
	Average distance to airport	-0.01 (0.58)				
	CalEnviroscreen Score				0.01 (0.33)	0.02 (0.00)

Note: 1. the numbers in parentheses are p-value.

Although there are similarities among the explanatory factors, there are some regional differences. For some of the regions, several variables were found to be statistically significant at low confidence levels, though they were left in the model for comparison purposes. The correlation between W&DCs and the CalEnviroScreen (CS) score was statistically significant in SCAG and MTC, though the results do not show causality. Interestingly, although the CS scores did not correlate with the likelihood of sitting facilities in a specific zip code, they did correlate with the number of W&DCs in a particular zip code.

This finding is consistent with the general findings from Dessouky et al. (2008), Yuan (2018a), and Yuan (2018b) that found correlations between W&DCs and DACS. Additionally, the results show that average distances to highways and intermodal facilities, and airports play an important role in determining whether a zip code has W&DCs in the SCAG and SACOG, respectively. The results also show that, in general, facilities are located in areas with lower household income and housing values. Considering that in the SCAG region, the number of W&DCs tends to be higher as the CS score increases, the remainder of the analyses will concentrate in this region.

5.3 Industrial real estate analyses

Using the Costar data, the team conducted temporal and spatio-temporal analyses of the trends of properties sold in the four markets in the SCAG region.

Changes in the size of properties sold

To evaluate changes in the size of the warehouses and distribution centers sold during the 2000-2018 period, the team estimated the numbers of the properties in different sizes and applied simple piecewise linear regression models for the mean and median size of the properties before and after the economic recession in 2008.

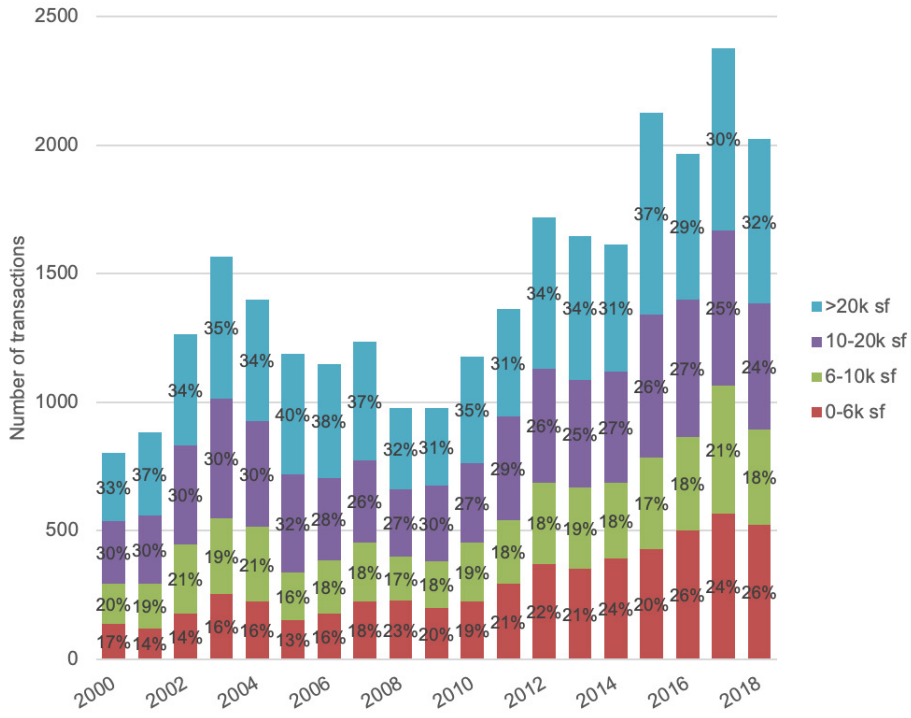

Figure 5. The number and percentage of W&DCs in different sizes in 2000-2008

As shown in Figure 5, the total number of the transactions increased from 803 in 2000 to more than two thousand W&DCs in 2018. Dividing the properties into four size groups (<6k, 6-10k, 10-20k, >20k square feet), we can see that the smaller properties increased in both number of transactions from 136 to 531 and percentage in total yearly transactions from 17% in 2000 to 26% in 2018.

Further looking into the mean and median size of the properties in the four markets, presented in Figure 6, we can see, for all the median building sizes in the four market, the ones after the recession have decreased compared to the ones before the recession.

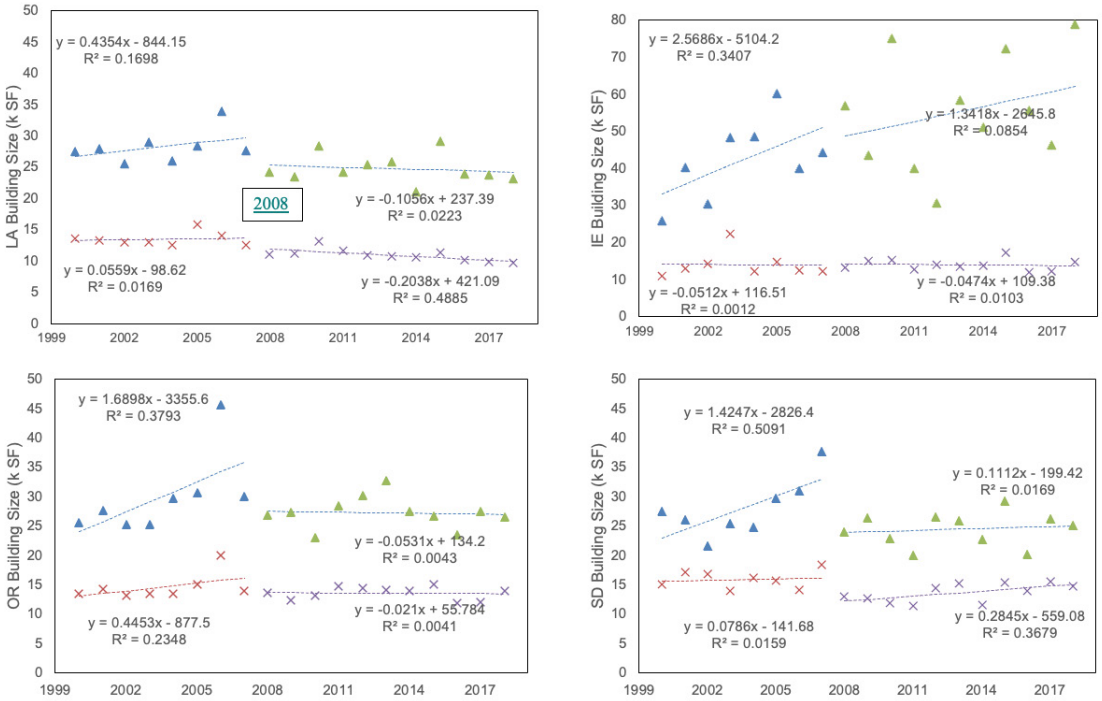

Figure 6. Building size of properties sold in the four markets between 2000 and 2018 in Southern California (upper left: Los Angeles Market; upper right: Inland Empire; lower left: Orange; lower right: San Diego. Triangles represent mean sizes and crosses represent median values.) The linear regression was done for data before 2007 (included), and after 2008 (included). The 2008 data are the first data points in the second part of the segmented data lines.

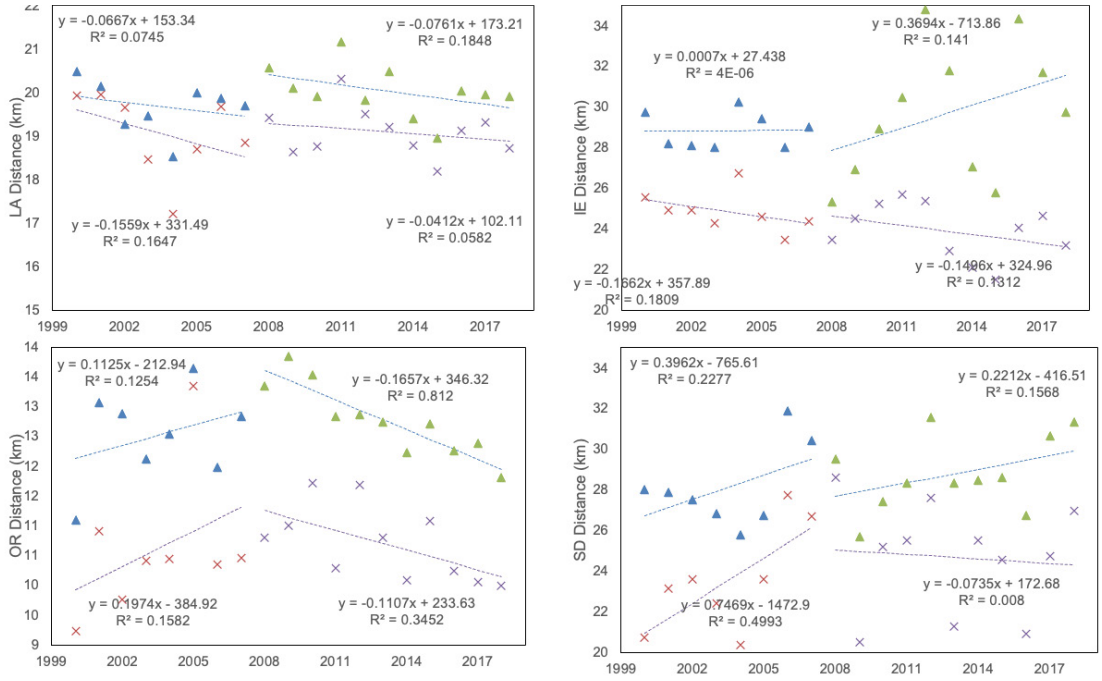

Figure 7. Distance to the center area of the sold properties in the four markets over 2000-2018 in the four markets in Southern California (upper left: Los Angeles market; upper right: Inland Empire; lower left: Orange; lower right: San Diego. Triangles represent mean distances and crosses represent median distances.). The linear regression was done for data before 2007 (included) and after 2008 (included). The 2008 data are the first data points in the second part of the segmented data lines.

The trend of the size reversed from increase to decrease for mean and median size in Los Angeles, and for median size in Inland Empire. For mean size of buildings in Inland Empire, the growth rate of the enlarging of the average building size has decreased from two thousand square feet to one thousand square feet each year. For mean and median sizes in Orange and San Diego, not only the growth rate has been decreased, but the average values are also smaller after the recession than before 2007. In the four regions, the median size of the properties in LA decreased the most, with the largest absolute value of the estimated negative slope. This trends of reduction in sizes or slowed down growth in sizes are in line with the hypothesis of the work and those observations reported by the media (Smith, 2019), and that current distribution trends generated by factors such as the growth in e-commerce have prompted a demand for smaller facilities, especially in the key consumption markets such as LA.

Relative distances to downtown areas

While the empirical evidence on the changes in sizes is significant, it is also important to understand if proximity to the consumers is also evident. To test whether the properties have been moving further or closer to the regional center areas, the team measured the relative distance of the W&DCs to the downtown area in the four markets (Hijmans et al., 2017). The reference location for facilities in the four markets in the six counties are the city halls of the largest cities in each county (Table 6), and the Euclidean distance to each property transacted per year was estimated.

Table 6. The reference points for measuring the distance between properties and city centers

Market	County	City	Latitude	Longitude
Los Angeles	Los Angeles	LA city hall	34.0539	-118.2427
	Ventura	Oxnard city hall	34.2004	-119.1804
Inland Empire	Riverside	Riverside city hall	33.9805	-117.3755
	San Bernardino	San Bernardino city hall	34.1044	-117.2923
Orange	Orange	SD city hall	32.7170	-117.1630
San Diego	San Diego	OR city hall	33.7871	-117.8505

These locations were selected to standardize the process, as selecting other locations, under different assumptions, for each specific regions would make comparisons more difficult. The analyses already make significant assumptions as partitioning the data geographically and analyzing the trends independently for various regions, when facilities in a region could serve other regions. Moreover, there could be cases in which the consumers in a region might be the driving market for the distribution from facilities in other regions. In this study, the authors explored estimating the barycenter of the population and using that as a reference. However, this geometric center was not a fixed location and introduced additional variability and noise in the analyses, thus using a fixed and identifiable location (e.g., City Halls) is a better approach. Additionally, considering that some of these regions may be polycentric, the data would need to be further divided, though in the absence of flow data, the authors considered that the trends found at this level of aggregation are sound and reflective of the behaviors in the market.

Furthermore, although these locations are used as a proxy for the concentration of demand, some of these regions may have multi-centers and density may not be uniform.

In LA, both the mean and median distance have decreased over the study periods, with the model indicating that every year, the properties sold are about 67 meters closer to the downtown before recession and 76 meters closer after the recession. On the other hand, the median distance decreased at a rate of 156 meters per year before 2008 and 41 meters per year after the recession (Figure 7). In the Inland

Empire, the mean distances were stable before recession and increased 369 meters per year after recession; the median distances decreased before and after the recession. In Orange County, the mean and median distances to the reference point have been increased before and reversed as of decreased after the recession, which also reflects that it is getting closer to the central area. The median distance increased 197 meters per year before the recession and decreased 111 meters per year after the recession. And in San Diego the mean distances to the downtown have exhibited an increased behavior, but the increase rate decreased after the recession. The mean distance increased by 396 meters per year before the recession and 221 meters per year after the recession. The median distances increased 747meters before the recession and decreased 74 meters per year after the recession.

These results complement the previous findings related to the changes in property sizes and are consistent with the aggregate analyses. There has been an increased demand for smaller and closer facilities to the main consumer markets in the SCAG region.

Relative distance to the San Pedro Bay ports

Similarly, the team estimated the relative distance of the properties sold to the San Pedro Bay Ports. Specifically, the team used the Port of Los Angeles (POLA) as reference (-118.2922, 33.7360). Figure 8 shows the mean and median distances before and after 2008. For both mean and median distance, they show increasing trend before 2008 and a decreasing trend after 2008. After the recession, the mean and the median distance of the facilities to the port decreased 511 meters and 130 meters per year respectively. This confirms the statements in the previous section.

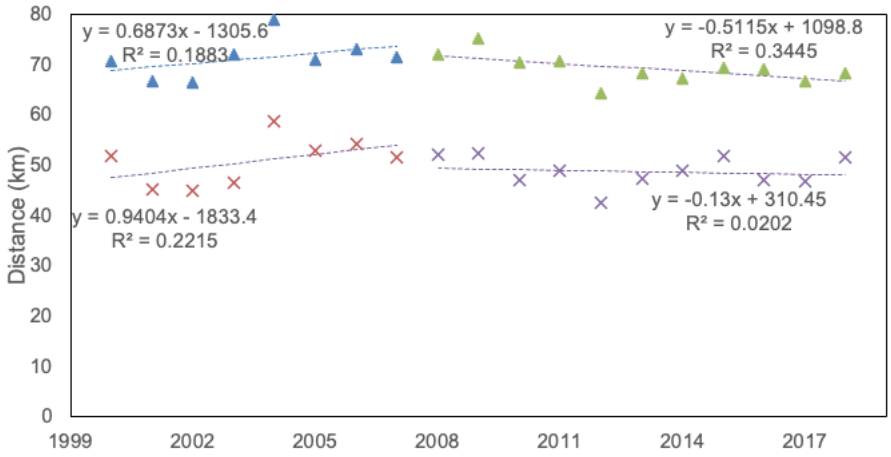

Figure 8. Mean (triangles) and median (Crosses) distance (kilometers) and piecewise linear regression of industrial properties sold in Southern California to POLA (The 2008 data are the first data points in the second part of the segmented data lines.)

5.4 W&DCs in disadvantaged communities

In this study, the authors compared the locations of all the industrial properties transacted over the thirty years with those census tracts identified as DACs in 2018. In Section 5.2, we found the CS score to be significant in determining the likelihood of having W&DCs in a ZIP and the number of warehouses. The empirical results here also show that, there is a disproportionate sitting of the transacted facilities in these communities. While in the study region, 31.1% of the census tracks are identified as DACs (Office of Environmental Health Hazard Assessment, 2017), 54.7% of the facilities locate in these communities. Lower rent could be one of the main factors, however, these facilities bring more truck traffic and

the emissions to the residents, which results in a higher exposure and health risks. The differences are more obvious in Los Angeles with 74.9% of transactions of properties located in DACs, 65.1% in the Inland Empire area, and 49.5% in Orange County. San Diego, on the other hand, only shows 15.7% of the properties located in DACs (see Figure 9). Moreover, most of the properties in freight intensive secondary industries have more properties located in DACs, with more than 50% of W&DCs located in these communities.

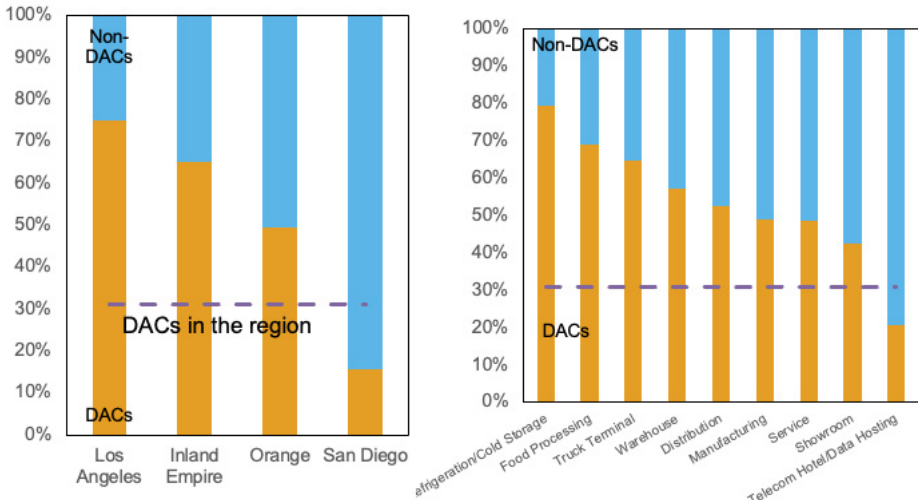

Figure 9. Ratio of properties located in disadvantaged communities

Additionally, the authors explored the factors that indicates whether facilities locate in disadvantaged communities or not using the attributes of the transacted properties through binary logistic regression method. Binary logistic regression model is commonly deployed in the choice result analysis. An odds ratio indicates that each one unit change in the independent variable would bring the coefficient (β-1) possibility of change in the dependent variable. The binary logit model (see Table 7) result reveals that the specific market, the industries of Refrigeration and truck terminal, building area, number of stories, and parking spaces are statistically significant variables affecting whether it would locate in DACs.

The results show that, compared to properties located in DACS in the Inland Empire, properties in the Los Angeles market are more likely (almost 50%) to locate in a DAC; on the other hand, they are less likely to locate in a DAC in the Orange (-47%) and San Diego (-91%) markets. Refrigeration/Cold storage (167%) and Truck Terminals (113%) are amongst the industries with the largest likelihood to locate in DACs, compared to facilities that only serve as distribution facilities. While the parking space is significantly negatively related with the possibility of locating in DAC, the odds ratio is almost ineligible to distinguish the likelihood.

Table 7. Binary logistic regression and odds ratio results

	Estimate	*Std. Error*	*z value*	*Pr(>|z|)*		*Odds ratio*	*95% Confidence Interval*	
							2.50%	**97.50%**
(Intercept)	0.726	0.085	8.516	< 2e-16	***	**2.066**	1.748	2.442
MarketName Los Angeles	0.370	0.035	10.460	< 2e-16	***	**1.448**	1.351	1.552
MarketName Orange	-0.634	0.038	-16.631	< 2e-16	***	**0.531**	0.492	0.572
MarketName San Diego	-2.442	0.048	-50.454	< 2e-16	***	**0.087**	0.079	0.096
SecondaryType Food Processing	0.484	0.172	2.812	0.0049	**	**1.622**	1.163	2.285
SecondaryType Manufacturing	0.137	0.073	1.894	0.0582	.	1.147	0.995	1.322
SecondaryType Refrigeration/ Cold Storage	0.993	0.237	4.186	0.0000	***	**2.698**	1.721	4.369
SecondaryType Service	0.053	0.091	0.577	0.5636		1.054	0.882	1.260
SecondaryType Showroom	-0.142	0.139	-1.025	0.3056		0.868	0.661	1.138
SecondaryType Telecom Hotel/ Data Hosting	-1.306	0.735	-1.777	0.0756	.	0.271	0.055	1.093
SecondaryType Truck Terminal	0.755	0.219	3.441	0.0006	***	**2.127**	1.393	3.296
SecondaryType Warehouse	0.169	0.070	2.420	0.0155	*	1.184	1.032	1.358
Sale Price	0.000	0.000	1.316	0.1881		1.000	1.000	1.000
Building Area	1.796	0.297	6.044	0.0000	***	**6.025**	3.408	10.925
Parking Spaces	-0.002	0.000	-6.250	0.0000	***	**0.999**	0.998	0.999
Stories	-0.220	0.041	-5.380	0.0000	***	**0.803**	0.741	0.870

Note: significance code: triple asterisks, P < 0.001; double asterisks, P < 0.01; single asterisk, P < 0.05; single dot, P < 0.1

Additionally, the results show that larger facilities with low number of stories are more likely to locate in DACs. This is consistent with other research that have identified the need to find available land at low prices, especially for large facilities. In this sense, the South Coast Air Quality Management District (SCAQMD, 2014) commissioned a study in 2012 to study high-cube warehouses (larger than 100,000 square feet/9025 square meters) in the region, and the associated truck impacts. This was in response to the proliferation and concentration of very large facilities in the Inland Empire. When multiple large facilities all concentrate at the low-price region, many diesel trucks would exacerbate the hazards in emissions, safety, and noise to the local communities, as well as those communities in the path to those W&DC clusters (Jaller et al., 2021). The 2021 SCAQMD warehouse rule is in response to those potential impacts.

6 Discussion and conclusions

This study enhances public understanding about the dynamic landscape of freight facilities, e.g., W&DCs, and its impacts on environmental justice. For the aggregate analysis, the research team examined key areas in California. For the disaggregate investigation, the Southern California region was selected to implement the spatial-temporal analysis, especially to identify the relationship between W&DCs and DACs. The main findings in this research are summarized around the following three factors.

6.1 W&DCs' dynamic landscape

This study applied both aggregate (e.g., weighted geometric centers and Moran's I) and disaggregate (e.g., the distance to the center area of the sold properties by the Costar data) analyses for the dynamic landscape of distribution facilities in California. Overall, the empirical analyses provide evidence to support the hypothesis, as there has been a shift in the logistics landscape, where the demand for smaller W&DCs in proximity to customers have increased.

Especially through the lens of disaggregate data, in recent years, the median distance from facilities to the downtown areas have decreased, as well as the median facility sizes transacted. Moreover, the number of transactions in areas closer to the downtowns has increased compared to those further away, especially during the last decade.

While the data do not indicate that all these facilities are only used for e-commerce related activities, the results are consistent with the market trends (e.g., omni-channel distribution). Moreover, in locations (e.g., Los Angeles), where the number of smaller and closer facility transactions has increased the most, are also the places with the largest share of these facilities located in DACs. More importantly, whether the trend of having more, smaller W&DCs closer to urban centers is a result of e-commerce, this trend will intensify congestion in and around facilities. For example, if the amount of cargo is considered constant (though demand is increasing, especially for e-commerce), the use of more and smaller facilities will result in more freight traffic, emissions, and safety issues for those communities. And while, the impacts of freight are mainly associated with the large freight facilities such as ports, terminals, manufacturing and distribution, the increase and concentration of smaller facilities closer to the customers will become large urban freight traffic generators (Jaller et al., 2015).

Additionally, the research shows that there is a deconcentration of larger freight facilities (logistics sprawl) in areas such as the Inland Empire, where larger facilities are still in high demand, and at the same time, the concentration of smaller facilities closer to the urban core in LA. Throughout the analyses, the data highlighted the impacts of the 2008-2009 recession in the industrial real estate market. Recent research showed evidence of these impacts from the freight flows and traffic perspectives (Jaller, Rivera-Royero et al., 2020).

6.2 Environmental justice and freight facilities

The study evaluated the relationships between the location of the facilities and disadvantaged communities (DACs) in the region, finding a higher probability of W&DCS to locate in DACs than non-DACs, especially for the most freight intensive sub-industry related facilities (e.g., distribution, warehouse, refrigeration/cold storage). Considering that in the study region, the number of DACs (at the census tract level) is only about 31%, the transaction data shows that the rate to locate in a DAC for some of these sub-industries to be as high as 80%, generating disproportionate negative consequences for such communities. The findings from this research complement those of Yuan (2018a) and show relationships between freight activity in general—and W&DCs in particular—and environmental justice and the potential impacts on disadvantaged communities. Not only truck related pollution emissions create problems, Yang et al. (2021) also found the truck accidents have been growing around the freight trip generators and impacting the local communities. Consistent with the findings from Yuan (2019), the higher likelihood of warehouses locating in low- and medium-income minorities communities is concerning.

These are both regional and local issues, therefore different planning agencies must develop strategies to mitigate such impacts through changes in land use, air quality regulations, and equity.

6.3 Policy suggestions on urban freight development

Overall, the study provides the following key conclusion: logistics patterns may shift over time and there is a need for continuous planning, and consideration of freight issues at the local level. The South Coast Air Quality Management District passed a rule in May 2021 requiring large warehouses (more than 100,000 square feet) to earn points by choosing from an emissions mitigation menu that includes deploying zero-emission trucks or charging infrastructures, otherwise pay a pollution fee (Barboza, 2021; Tabuchi, 2021). Currently, the rule regulates large warehouses, but at the urban planning and land use stage, local governments need to evaluate the potential impacts of the location of urban truck trip generators (such as the smaller facilities) to prevent the associated negative externalities. After the initial months of the pandemic, the demand of e-commerce and warehouses are still surging (though not at the levels experienced during those initial months), potentially bringing more smaller warehouses which are not regulated or planned. Therefore, local governments or stakeholders should design corresponding policies to deal with the challenges brought by this trend.

First, local freight action plans and freight efficient land-use planning must consider the environmental and social impacts of increased urban freight and logistics systems. Second, zoning ordinances should evaluate the trade-offs of land allocation for freight activity and other uses, acknowledging its economic benefits and at the same time, the potential unintended consequences. Finally, recognize that urban freight will be more prominent as e-commerce continues to expand, and while newer and cleaner vehicle technologies will be able to mitigate some of the impacts, increased traffic will still have a negative effect on congestion, energy consumption, safety, and accessibility. While, e-commerce trends have been growing for the last two decades, the 2020 COVID-19 pandemic accelerated the growth. Consequently, businesses will require additional distribution capacity. It is imperative, that agencies act to mitigate the potential environmental justice impacts from the intensity of freight activity in urban areas, and in DACs.

6.4 Uncertainties and further research needed

First, land availability and land use could be a potential issue that affects the location of the industrial properties and their sizes. However, due to data availability, we expect to further explore the relationship in future research and identify the effect of land-use planning on W&DC locations and their impact on the local communities.

Secondly, the authors explored environmental justice concerns by identifying the disproportionate number of transactions in DACs areas; however, there limitations in the approach. For example, there was no data available to match yearly transactions and spatial and temporal locations of DACs, as the analyses used the CS score from 2018. Further analyses could compare the locations of transacted W&DCs, their type, and freight intensity in a yearly basis, and identify whether or not these changes affect the CS score of those locations. And third, considering that truck traffic emissions is one of the contributions to air pollution, further research is needed to investigate long-term land use and freight movement with changes in CS score change in California.

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