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# Parking Infrastructure: A Constraint on or Opportunity for Urban Redevelopment?

## A Study of Los Angeles County Parking Supply and Growth

Mikhail Chester , Andrew Fraser , Juan Matute, Carolyn Flower, and Ram Pendyala 

**Problem, research strategy, and findings:** Many cities have adopted minimum parking requirements, but there is relatively poor information about how parking infrastructure has grown. We estimate how parking has grown in Los Angeles County (CA) from 1900 to 2010 and how parking infrastructure evolves, affects urban form, and relates to changes in automobile travel using building and roadway growth models. We find that since 1975 the ratio of residential off-street parking spaces to automobiles in Los Angeles County is close to 1.0 and the greatest density of parking spaces is in the urban core, while most new growth in parking occurs outside of the core. In total, 14% of Los Angeles County's incorporated land is committed to parking. Uncertainty in our space inventory is attributed to our building growth model, on-street space length, and the assumption that parking spaces were created as per the requirements.

**Takeaway for practice:** The continued use of minimum parking requirements is likely to encourage automobile use at a time when metropolitan areas are actively seeking to manage congestion and increase transit use, biking, and walking. Widely discussed ways to reform parking policies may be less than effective if planners do not consider the remaining incentives to auto use created by the existing parking infrastructure. Planners

Los Angeles County (LA County, CA), like many other urban areas in the United States, has extensive parking infrastructure that has been expanding for nearly a century, in large measure because of the minimum parking requirements that accompany most new development or redevelopment projects. Most municipal zoning regulations require developers to provide a minimum number of parking spaces based on the size and purpose of the development and on historical relationships between specific land uses and parking needs (Weinberger, Kaehny, & Rufo, 2010). There is growing recognition that minimum parking requirements exacerbate all problems created by the car. These requirements often create abundant "free" or low-cost parking, lowering the time and money costs of driving (Hess, 2001) and leading to higher vehicle ownership, more traffic congestion, poor air quality, more household spending on mobility, often unrecognized equity issues, and underused land (Shoup, 2006, 2011; Weinberger, 2012; Willson, 1995). Analyzing the 2010 California Household Travel Survey (CHTS), we find that

should encourage the conversion of existing parking facilities to alternative uses.

**Keywords:** parking, infrastructure growth, Los Angeles

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98% of automobile trips within the Los Angeles metropolitan area start or end with free parking (CHTS, 2013).

Many scholars and planners suggest multiple ways in which planners can reduce parking requirements for future developments or substitute other developer obligations for additional parking such as significant cycling, carpooling, and transit facilities (Shoup, 1999a; Willson, 2013). Yet, even if minimum parking requirements were significantly reduced today, most metropolitan areas, like LA County, already have extensive on- and off-street parking infrastructure. Knowing the location and magnitude of the existing parking infrastructure is a key element in comprehensively reforming municipal parking policies in ways that go well beyond changing minimum parking requirements. We find, however, that it is difficult to determine how much parking is available in LA County, or in most places in the United States, at a scale where it would be useful for making policy decisions.

To address this deficiency, we estimate how and where parking infrastructure has grown across LA County from 1900 to 2010. To provide additional insights into the relationship between parking and automobility, we assess how this infrastructure has evolved in relation to the number of licensed vehicles, the amount of travel those vehicles undertake, and land use. We find that the growth in the number of parking spaces peaked between 1950 and 1980; the rate of growth has been slowing since. From 1950 to 1975, LA County provided more parking spaces than the number of cars; however, since 1975, the ratio of residential off-street parking spaces to automobiles has hovered around unity. We find that the greatest density of parking spaces remains in the urban core where high-quality public transit exists. However, most new growth in parking has occurred outside of the core and is associated with greater automobile ownership and use.

The magnitude of the existing investment in parking in LA County, and likely in many other metropolitan areas, suggests that reforming existing minimum parking requirements alone will not be sufficient to dampen the incentives to driving provided by the current parking supply. We suggest that planners seeking to reform municipal parking policies also should take seriously a policy of converting existing parking infrastructure into other land uses ranging from affordable housing to commercial, industrial, recreational, and residential uses, already happening informally (and illegally) in Los Angeles and perhaps other large metropolitan areas.

Converting parking infrastructure to other land uses as part of comprehensive reform of municipal parking policies will meet two planning goals. First, doing so will further reduce the perverse incentives to additional auto use created by the current parking infrastructure, incentives that will

exist even if minimum parking requirements are reduced. Second, converting parking to alternative land uses will increase development opportunities, creating affordable and other housing, providing incubator space for small businesses, and offering recreational options in built-up areas while encouraging walking, cycling, and mass transit use.

In this study, we first briefly review the literature on the impact of abundant and low-cost parking on auto use and evaluate the ways in which researchers have attempted to measure the extent and location of parking infrastructure within metropolitan areas. We then discuss the history of the growth of parking infrastructure in LA County and estimate the number, type, and location of on- and off-street parking throughout the county. The next section evaluates the relationship between the growth of parking and changes in roadway supply and vehicle travel. We then evaluate how much land is used only for parking. We conclude by stressing the need for planners not only to reform existing minimum parking requirements in ways that support public transit use, higher-density development, and development in the core rather than the periphery, but also to actively work to convert existing parking infrastructure to alternative uses.

## Is There Too Much Parking?

Most cities include detailed parking requirements in their zoning ordinances; they typically require developers to provide a minimum number of parking spaces, with that number based on the size, purpose, and location of the development. These numerical requirements are generally based on historical patterns of the relationship between key land uses and auto travel to those land uses (Institute of Transportation Engineers, 2010). In the last three decades, many scholars and practitioners have severely criticized minimum parking requirements because they are often based on auto travel to suburban land uses (Manville & Williams 2012; Shoup 1999b, 2011). As such, these requirements lead to an oversupply of cheap or free parking that provides incentives for people to drive even when other options are available. There are also equity issues: The real costs of providing parking are incorporated into the price of other goods and services purchased by a wide variety of consumers who may not have used those parking facilities.

To address all these issues, many planning scholars have called for a variety of new parking policies that begin with reducing minimum parking requirements, but go far beyond. Additional suggested policies include correctly pricing existing free or low-cost parking, dynamically altering parking prices to reflect congestion and temporal demands,

developing shared-parking schemes, tailoring parking requirements at the project level to respond to localized needs and resources, and imposing maximum parking limits (Manville & Williams, 2012; Millard-Ball, Weinberger, & Hampshire, 2014; Pierce & Shoup, 2013; Weinberger, Kaehny, & Rufo, 2010). Some of these options, particularly pricing policies, can affect the use of existing parking facilities. However, many of these policy changes would only correct the overprovision of parking in the future; they would leave the perverse incentives provided by current infrastructure largely unchanged. Given the magnitude of existing parking facilities, revising current parking requirements going forward is only part of the solution. While some scholars have noted how much land is devoted to parking cars, few have addressed how existing parking infrastructure can reduce the effectiveness of other suggested policy changes.

To reform parking policy in meaningful ways, and to address the implications of the large existing supply of parking, planners require comprehensive information on the amount and type of parking infrastructure and its location in a metropolitan area. There is, however, relatively little information on how much parking exists in cities and how this infrastructure evolved over time. Furthermore, we lack accurate information on how parking infrastructure has evolved with other key factors such as the location of employment, land uses, sociodemographic factors (including activity demand, income, job specialization, job potential, job location, land use, demographics, and fuel prices, to name a few) to contribute to travel demand is very limited.

Substantial research examines the significance of each of these factors. However, we have relatively poor site-specific or granular longitudinal and geospatial information on parking supply, thereby limiting our ability to understand the effects of providing this infrastructure. Common approaches to estimating the number of parking spaces at local scales include space counts (Chatman, 2013; Shoup, 2011), satellite imagery processing (Akbari, Shea Rose, & Taha, 2003; Davis, Pijanowski, Robinson, & Engel, 2010; Weinberger, 2012), and the use of property databases (Cutter & Franco, 2012). Many studies focus on quantifying parking in the central business district (CBD); for example, Kenworthy and Laube (1999) collected CBD parking space estimates from 1960 to 1990 for 44 global cities. At regional scales, satellite imagery has been used (Davis, Pijanowski, Robinson, & Kidwell, 2010).

The results of these studies do not provide enough information to allow planners to fashion new parking policies and requirements, in part because they fail to provide insights at the appropriate scale of how parking infrastructure affects urban form and how automobile access and use have changed as parking increases. We

develop new methods using digital urban data sets to improve the understanding of how and where parking infrastructure has grown. Assessing the impacts of mandatory parking requirements should provide additional insight into how automobile use changes relative to the provision of new parking infrastructure. Data on the amount and distribution of parking across a metropolitan area are a crucial component of developing a comprehensive approach to parking management.

Thus, a key component of our research is our assessment of the magnitude and location of parking infrastructure in LA County. We also focus on the relationship between the growth of parking infrastructure and land use changes and auto use.

## Estimating the Growth of Parking Infrastructure in Los Angeles County

### LA County and the Automobile

In the last 100 years, many U.S. communities, particularly in the south and west, have invested extensively in automobile infrastructure. Central to this automobile investment is parking infrastructure. LA County is a valuable case study of how parking infrastructure investments were made as well as the impact of those investments on auto travel and land use because the county's growth after 1920 largely coincided with the maturation of the American automotive industry. Fortunately, LA County's rapid growth also coincided with the beginning of governmental efforts to collect census data and comprehensive information on households, vehicle availability, and infrastructure data (California Department of Motor Vehicles, 2010; U.S. Federal Highway Administration, 2013, U.S. Census Bureau, 2010), which allow us to undertake these evaluations.

LA County, with nearly 10 million people in 2010, is part of the largest metropolitan region in the southwest (U.S. Census Bureau, 2010). The metropolitan statistical area that LA County forms with Long Beach and Anaheim is the second largest in the United States. LA County itself covers 4,700 square miles and contains 88 incorporated cities and some unincorporated lands. Some of those 88 cities have well-developed cores or downtowns, and others are typical bedroom communities; a few have almost no residents but a large industrial base. The 88 cities range from the City of Industry, with 29 residents but massive industries, to the City of Los Angeles, with nearly 4 million people.

Widespread adoption of the automobile in the 1920s resulted in significant congestion in downtowns and



around other activity centers, prompting public and private agencies to develop plans to control vehicle traffic (Wachs, 1984). The urban form that existed in American cities at the beginning of the 20th century was characterized by short blocks, narrow streets, organic and complex road networks, and high building density that was ill-suited for automobiles (Muller, 2004). In the 1930s, the cities in LA County began using minimum parking requirements in zoning ordinances to address traffic congestion (City of Los Angeles, 1935). The ordinances required new development or redevelopment projects to provide specific amounts of parking related to their size and activity. This was considered an effective way for cities to keep vehicles off the road, reduce illegal parking, avoid the spillover of cars into adjacent residential neighborhoods, and prevent cruising for vacant street spaces (Shoup & Pickrell, 1978). Other cities in LA County adopted similar ordinances over time as they experienced traffic congestion in their downtowns and activity centers. Today, while LA County zoning regulations specify minimum parking requirements, the individual requirements of the 88 cities usually supersede the LA County zoning ordinances.

LA County experiences a high level of per capita automobile travel relative to its density, which may be due to the decentralized nature of the cities' densities along freeway corridors (Garreau, 2011; Sorensen et al., 2008). LA County currently has more lane-miles of arterials, highways, and interstates per square mile than any other U.S. metro area (U.S. Federal Highway Administration, 2013). But the area occupied by roads is just a fraction of land devoted to automobiles; Manville and Shoup (2005) find that the city of Los Angeles, for example, offers more abundant and free parking than many other cities. This infrastructure is scattered throughout the metropolitan area in on-street parking spaces and off-street parking lots and structures.

To gain an idea of the magnitude of the challenges posed to those seeking to reform parking policy to address the significant challenge posed by the car in urban areas, we calculate how parking infrastructure has grown in LA County. We provide insight into how this often-forgotten infrastructure evolves, affects land use and urban form, and has changed in relation to other factors that contribute to automobile travel. While the parking situation in LA County may be exceptional, we suspect that many metropolitan regions face similar challenges: a very large supply of existing parking spaces that will be unaffected by most changes in minimum parking requirements.

We separately estimate the amount and location of off-street and on-street parking. We do this partially because we use different methods for each type of parking, but also

because each type of parking offers planners different opportunities for conversion into more appropriate land uses.

## Estimating Off-Street Parking in Los Angeles County

We develop a decade-by-decade assessment of the changes in off-street residential, off-street nonresidential, and on-street parking spaces from 1900 to the present using estimates of roadway and building stock in each decade with off-street and on-street parking design and requirements.

We define off-street residential parking as home driveways and dedicated covered spaces. Off-street nonresidential are surface lot or structure spaces associated with nonresidential buildings and parcels whose sole use is as a surface lot or parking structure. On-street spaces include both metered and non-metered curbside parking that is sometimes marked but mostly unmarked. The inventory includes formal (asphalt or concrete) infrastructure only. It is possible that ad hoc infrastructure exists, such as parking in front yards or in lots that are not designated as parking. While we do not account for this ad hoc infrastructure, we acknowledge that it could be significant.

Our analysis is temporally and spatially (at the census tract scale) resolute and relies largely upon existing infrastructure growth models developed by Fraser and Chester (2015) for roadways and Reyna and Chester (2015) for buildings dating from 1900 to 2010. We use a decadal time resolution because the U.S. Census reports the number of buildings by vintage at the beginning of each decade. We discuss our methodological approach in detail in the Technical Appendix, including infrastructure growth model design, validation, and uncertainty. We provide an overview of these methods here.

We review current and historical requirements as well as research on minimum off-street parking requirements in LA County and its cities. Residential parking requirements are developed from historical zoning codes and amendments (City of Los Angeles, 1946; Whittemore, 2012). For nonresidential structures, we use the historical requirements reported by Cutter and Franco (2012) for commercial, industrial, warehouse, mini-shopping, furniture and appliance, and general and discount wholesaler, which are based on 1946 to 2001 City of Los Angeles parking requirements. We review current minimum off-street parking requirements for 47 building use codes in 19 of the 88 cities in LA County (summarized in the Technical Appendix). The requirements encompass a variety of measures, including number of spaces per area of commercial space, per hospital bed, and per seat (City of Los Angeles, 2010; Los Angeles County, 2014). We find that there is significant consistency across the requirements. We use the

Table 1. Historical off-street parking space requirements in Los Angeles County.

Property use	Pre-1936	1936–1960	Post-1960
<b>RESIDENTIAL</b>			
Single-family home	1 per DU	2 per DU	3 per DU
Condominium	0	DU≤10 then 1 per DU, DU>10 then 1.25 per DU	DU≤10 then 2 per DU, DU>10 then 2.5 per DU
Duplex (2 DU)	0	1 per DU	2 per DU
Duplex (3–4 DU)	1 per DU	1.5 per DU	2 per DU
Duplex (5+ DU)	0.5 per DU	1 per DU	1.5 per DU
Manufactured home	1.5 per DU	1.5 per DU	1.5 per DU
Mobile home	1 per DU	1.5 per DU	2 per DU
Apartment	0	1 per DU	2 per DU
<b>NONRESIDENTIAL</b>			
Animal kennel, auto service centers, banks and service shops, department store, supermarkets, miscellaneous commercial, mortuary, neighborhood shopping, regional shopping, retail store, service station, film/television/radio, nursery/greenhouse	1 per 500 sq. ft.	1 per 500 sq. ft.	1 per 250 sq. ft.
Art centers, museums, theatres, entertainment, library, churches, community facilities, social clubs	1 per 70 sq. ft.	1 per 70 sq. ft.	1 per 35 sq. ft.
Bowling center	30	30	45
Fast food	1 per 70 sq. ft.	1 per 70 sq. ft.	1 per 33 sq. ft.
Heavy industrial, light manufacturing, utility government building, hotels, motels, rooming house, senior car facility, hotels, motels, rooming house, senior car facility	1 per 1,000 sq. ft.	1 per 1,000 sq. ft.	1 per 500 sq. ft.
Office, high-rise office, wholesale outlet	1 per 800 sq. ft.	1 per 800 sq. ft.	1 per 400 sq. ft.
Medical facilities	1 per 400 sq. ft.	1 per 400 sq. ft.	1 per 200 sq. ft.
Parking lot/structure	1 per 330 sq. ft.	1 per 330 sq. ft.	1 per 330 sq. ft.
Restaurant, bar, skating rink	1 per 200 sq. ft.	1 per 200 sq. ft.	1 per 100 sq. ft.
Warehouse	1 per 2,000 sq. ft.	1 per 2,000 sq. ft.	1 per 1,000 sq. ft.
Golf course	90	90	180
Hospital	1 per 1,200 sq. ft.	1 per 1,200 sq. ft.	1 per 600 sq. ft.
Education	1 per 2,000 sq. ft.	1 per 2,000 sq. ft.	1 per 1,000 sq. ft.
Boat slips	0.15 per Slip	0.15 per Slip	0.3 per Slip
Open storage	4+1 per 12,000 sq. ft.	4+1 per 12,000 sq. ft.	4+1 per 6,000 sq. ft.

Notes: Residential and nonresidential minimum off-street parking requirements are shown for three time periods. Residential requirements are based on dwelling units (DUs), while nonresidential often focus on per square foot (sq. ft.) measures. Requirements are selected from a review of minimum parking requirements of 19 cities in the county where the median matches closely to the city of Los Angeles (see Technical Appendix). Facility-specific requirements are compiled from Los Angeles County (2014), City of Los Angeles (2014), and Cutter and Franco (2012).

median of these requirements for each land use, which matches to the city of Los Angeles. Given that the city of Los Angeles is one of the oldest in LA County, it is likely that other cities have adopted their requirements (Weinberger et al., 2010). Table 1 shows our summary of current and historical minimum residential and nonresidential off-street requirements by property use.

We combine the LA County Assessor Database, which details property use and building characteristics, with time period-specific minimum parking requirements to estimate parking associated with residential and nonresidential land

uses. For residential structures, our off-street parking estimates include dwelling unit–dedicated covered spaces across the eight building categories, driveways for single-family homes, and guest spaces for multifamily buildings; these are reported in Table 1. For nonresidential structures, we use the requirements reported in Table 1 to assess parking requirements across 47 building use codes. We then assign the requirements from these three time periods to building estimates in each historical year.

Our methodology relies on the existing Reyna and Chester (2015) building construction and deconstruction

model to estimate how off-street parking infrastructure has changed over time in LA County. This model allows us to estimate how land use has changed over LA County's 100-year history. Reyna and Chester developed a doubly constrained convergence model to estimate changes in building stock based on historical U.S. Census reporting of buildings by vintage and the current stock reported in the assessor database (Los Angeles County, 2010). The growth factor model produces estimates of the number of buildings by vintage for each decade (i.e., 2000, 1990, 1980, etc.) in LA County's history. We discuss this model in detail in the Technical Appendix, including its validation.

Using the model results, we apply the minimum off-street parking requirements in place during each of the three time periods based on year of construction to estimate the number of spaces associated with residential and commercial land uses in the past. It is also possible that developers build more than the minimum parking requirements, although this is unlikely given the high value of land in LA County. We assume that every parking space provided by a standalone parking lot or structure fulfills the parking requirement of a nearby commercial establishment. The result is a spatially explicit inventory of residential and nonresidential parking for every census tract for each decade since 1900.

### Estimating On-Street Parking in Los Angeles County

We identify when roadway segments were constructed by creating a statistical analysis of near-link building ages to assess the historical growth in on-street parking. We base our modeling of the growth of the roadway network on the work of Fraser and Chester (2015). For each travel analysis zone, we assess the distribution of building age and then assign the mean age less one standard deviation to nearby links, with the assumption that buildings and roads were constructed around the same time. We then use a GIS analysis to exclude portions of roadways that would not have on-street parking, such as intersections, fire hydrants, bus stops, and driveways (City of Los Angeles, 2010). We then use the remaining curbside length available for on-street parking to estimate the quantity of parking spaces, assuming 20 feet for unmarked spaces, 22 feet per marked spaces in series, and 26 feet for single marked spaces (the latter two are based on design requirements from several cities in the county). We provide the details of the modeling in the Technical Appendix. The result is a spatially explicit understanding of changes in curbside parking by decade.

There are some possible weaknesses in our approach. We were not able to locate rich historical data to validate

certain assumptions; we acknowledge that there may be uncertainty in our results. This uncertainty is most likely to be affected by our 1) building growth model, 2) average on-street unmarked space length, and 3) assumption that parking spaces were created as per the requirements reported in Table 1. Our building growth model estimates that in past decades there were more buildings in each census tract than in 2010. We assume an unmarked on-street space length of 20 feet; had we assumed a shorter length, the results would have been more spaces in our on-street inventory. Using a greater length (assuming ample space between vehicles) does not decrease our space inventory significantly. Finally, it is possible that developers did not provide the required minimum parking spaces, either due to lack of oversight or because certain facilities received exemptions to the standard, or because mandated spaces were later converted to alternative uses.

We do not have a direct way of validating the balance of these variables, but we can validate our results against historical parking space counts for the CBD from 1960 through 1990 as reported by Kenworthy and Laube (1999) and the ParkMe database, a website that reports public and private parking lots and structures. We find that our methods produce results consistent with these data sources; we further discuss the uncertainty and validation issues in the Technical Appendix.

### The Relationship Between Parking and Auto Use

To provide insight to planners, we evaluate the relationship between the growth of parking and changes in roadway supply and vehicle travel. We first describe the makeup and growth of parking infrastructure at the county level and then characterize how this growth has occurred within the county. We evaluate these trends at three geographic levels: the incorporated area (essentially the urbanized area), the urban core, and the CBD.

We define the urban core as the downtown of the city of Los Angeles and its surroundings. The CBD is defined as the downtown of Los Angeles, which is bounded by Interstate 10 and the 101 and 110 freeways. These areas are delineated in Figure 1. We discuss the planning and policy implications of how parking supply has changed in relation to roadway supply, vehicle travel, and available vehicles, factors that have been shown to contribute to automobile use. Available vehicles are reported by the U.S. Census and are different from registered vehicles in that a responding household may be using an out-of-county (or even out-of-state) vehicle at the time.



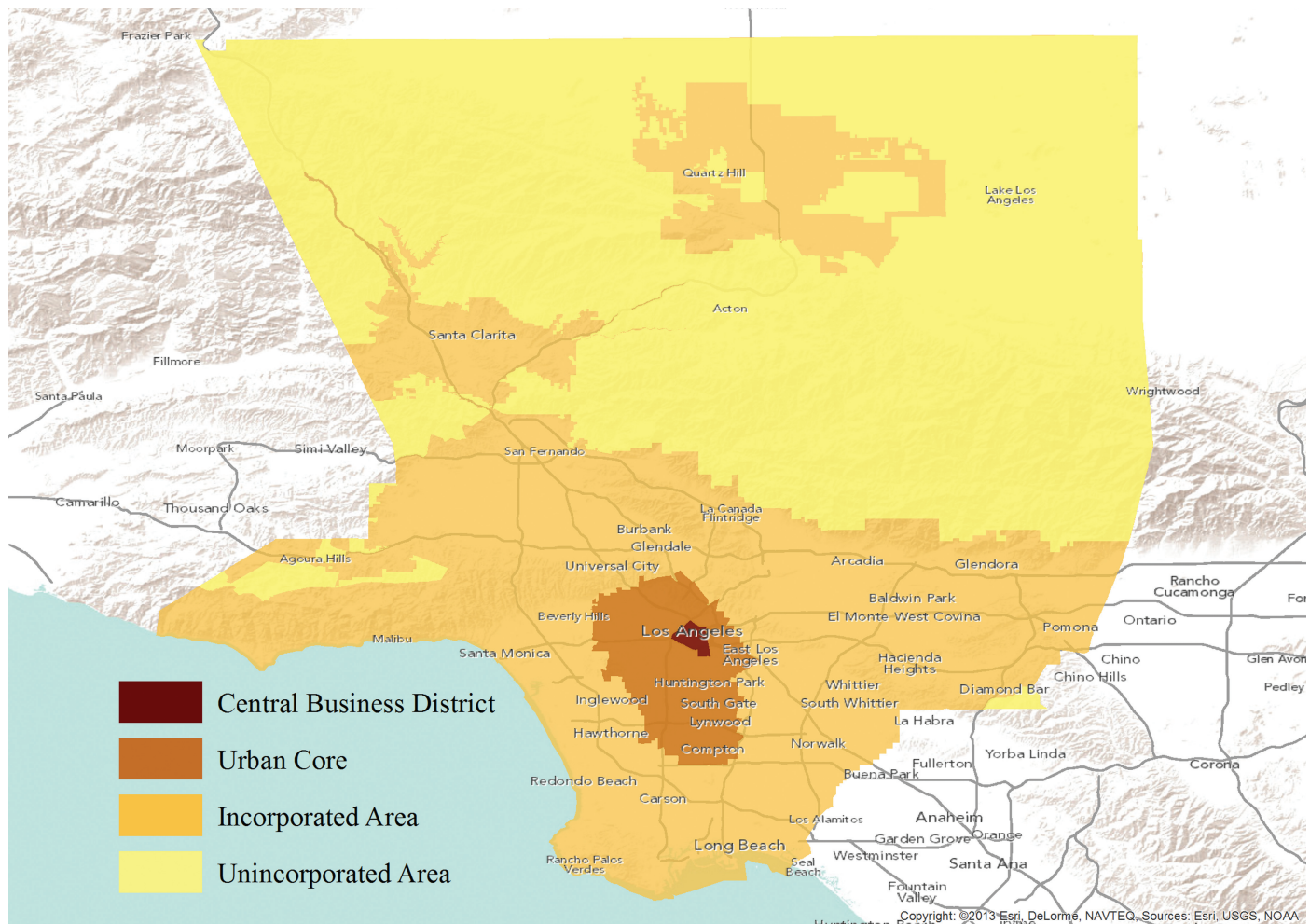


Figure 1. Regions of Los Angeles County. Los Angeles County is shown as the shaded region. The urban core and central business district capture the oldest and downtown areas of Los Angeles County. The incorporated region is shown as the second lightest gray in print and as light orange in the color version available online.

To tease out the relationship of parking to key measures of auto use, we first estimate the number of parking spaces in LA County and the historical patterns of growth in parking spaces. We then compare the growth in parking spaces to the growth in lane-miles of roads and highways in LA County. Finally, we compare the growth of parking spaces to the growth of vehicle miles traveled (VMT).

We estimate that there were 18.6 million parking spaces in LA County in 2010, which includes 5.5 million residential off-street, 9.6 million nonresidential off-street, and 3.6 million on-street spaces. There are approximately 200 square miles of parking infrastructure of one type or another covering 14% of the incorporated land area of the county, 1.4 times larger than the 140 square miles devoted to streets and freeways. This means that there are 3.3 spaces for each of the 5.6 million vehicles in the county (California Department of Motor Vehicles, 2010), or 1.0 residential off-street space, 1.7 nonresidential off-street spaces, and

0.6 on-street space. In other words, there is 1.0 on-street parking space for every 1.5 vehicles in the county.

Figure 2 shows that between 1950 and 1980, the number of parking spaces in the county increased by roughly 310,000 per year. Between 1980 and 2010, the average annual increase in parking spaces declined to around 130,000 spaces. By 1990, the growth of residential off-street and on-street spaces slowed as infrastructure matured. Current increases in parking spaces are the result of nonresidential off-street parking largely constructed outside of the urban core.

Our research shows that LA County has allocated more land for the storage of automobiles than it has lane-miles of streets and roads. We find that, since 1945 (when vehicle travel data first become available), the growth of nonresidential and total parking spaces has outpaced the growth of roadway lane-miles, but is less than the growth of VMT. However, our finding that the growth of parking

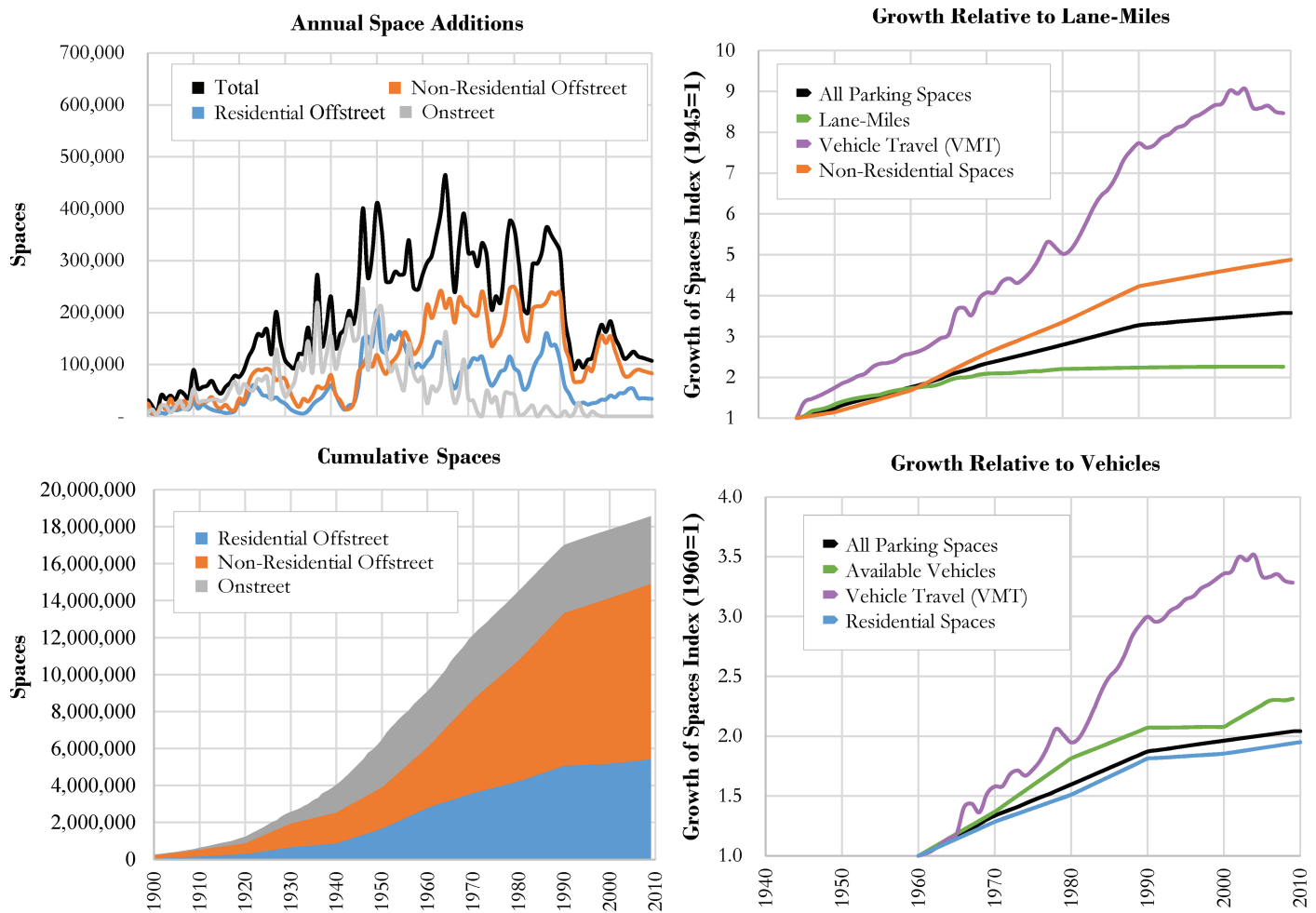


Figure 2. Growth of Los Angeles County's parking infrastructure (left) and growth rates of parking infrastructure relative to supply of traveled way infrastructure and demand (vehicle miles of travel). The left column figures are shown from 1900 to 2010 with residential off-street, nonresidential off-street, on-street, and total spaces. The right column figures are shown from 1940 to 2010. The index is created by dividing the series value by its historical baseline (1945 value for lane-miles and 1960 value for vehicles). A color version of the figure is available online.

supply has outpaced the growth of streets and highways shows how extensively infrastructure is supplied when the cost of parking is shifted to developers at no direct cost to cities.

To understand how much parking is used, we compare the ratio of residential off-street spaces with available vehicles in LA County. Since 1960, the growth of vehicles has outpaced the growth of all parking. In 1960 (when data first become available on vehicle availability in the county), there were 2.8 million residential off-street spaces and 2.4 million vehicles. By 1975, the number of vehicles available was about equal to the number of residential off-street spaces. Since 1975, there have been fluctuations above (up to 1.03 in the 1990s) and below 1.0 (down to 0.95 in the early 1980s), but these small differences could be an artifact of our model. Despite these variations, the ratio of vehicles to residential park-

ing spaces has hovered around unity. This means that at least since the early 2000s, residential off-street spaces have been fully saturated, and it is likely that on-street spaces address the extra demand. However, since 1960, the growth in vehicles has outpaced the growth in residential parking spaces, which may be a response to an earlier oversupply of parking spaces in response to mandatory parking requirements. As households purchased more personal vehicles, VMT grew at a rate that outpaced increases in highway supply.

We also assess how automobile access changes with parking infrastructure supply to give insight into how individual areas (at the census tract level) respond to what we conclude is an over- or under-provision of spaces. By 2010, the countywide ratio of residential off-street parking spaces to available vehicles leveled off at 0.97 after peaking between 1996 and 2002. This occurred even as the county



added 320,000 total residential spaces in the same period. In 2010, the average household in LA County had 1.75 vehicles; however, there was wide variation in household vehicle ownership across the county. Households inside the urban core had an average of 1.42 vehicles, while those outside the core had 1.85 vehicles (American Community Survey, 2010; U.S. Census, 2010). In 2010, the average ratio of residential off-street spaces per vehicle was 0.91, with a standard deviation of 0.41.

The ratio of vehicle to cars would converge toward 1.0 if tracts with ratios below 1.0 transitioned to fewer vehicles per parking space (either shedding household vehicles or sorting low-vehicle households into low-parking-availability neighborhoods) while tracts with ratios above 1.0 added vehicles relative to additions in parking supply. In the period between 1970 (when spatially explicit vehicle availability data emerge) and 2010, the number of vehicles per residential off-street parking spaces is almost 1.0 in 73% of tracts.

We cannot identify a spatial pattern in which convergence between available parking spaces and the number of vehicles occurs. However, the rate at which the number of available vehicles or the number of spaces changes is greater outside of the urban core. Available vehicles grew 1.1 times faster, and the number of residential off-street spaces 1.4 times faster, outside of the urban core than inside the core. We suspect that there is more free or underpriced parking outside of the urban core than inside. A large body of research concludes that free or underpriced parking encourages automobile adoption (Chatman, 2013; Guo, 2013; Potoglu & Kanaroglou, 2008; Weinberger, Seaman, & Johnson, 2009), and our results suggest that there may be sorting of households and vehicles as residential parking supply changes.

## The Location of Parking Spaces in Los Angeles County

The growth of parking infrastructure has varied across LA County depending on market demand for residential and nonresidential development, changes in off-street minimum parking requirements, and the demand for vehicle parking itself. Although modern LA County grew rapidly after 1950, the growth in parking infrastructure varied across the county, with differences in development patterns and population growth within the 88 individual cities as well as the unincorporated regions of the county. Figure 3 shows the change in the number of parking spaces by census tract since 1950, a year in which there were 6.5 million total parking spaces, or roughly 35% of the

2010 infrastructure supply, and the population (4.2 million) was 42% of what it is was in 2010.

Between 1950 and 2010, LA County gained 12 million total parking spaces. Most of the growth occurred outside of the urban core, as shown in the top row of Figure 3, because downtown Los Angeles was largely developed by 1950 and has experienced only modest growth since. The urban core has some of the oldest parking infrastructure in the county and has experienced marginal growth in residential and total parking spaces in the 60-year period beginning in 1950. The growth of residential off-street parking has largely occurred in areas outside the core, in neighborhoods with historically higher automobile ownership.

There is a difference between where the highest concentration of parking spaces is located in the county and where the fastest growth has occurred. As shown in the bottom row of Figure 3, the highest density of all parking spaces is in the urban core. The growth in the total number of parking spaces in the county has occurred mostly in areas with new streets and low-density suburban development dominated by nonresidential development. The core has been wreathed by new parking additions associated with new residential construction (Pomona Valley and Palos Verdes Peninsula), nonresidential construction (Ports, City of Industry, Irwindale, and West San Fernando Valley), and nonresidential redevelopment (Southwest San Fernando Valley and West Los Angeles). The median census tract in the county has 4,900 residential off-street spaces and 11,660 total off-street spaces per square mile. Despite the variation in the rate of growth in parking infrastructure across the county, the highest densities of parking spaces are found in the urban core.

The CBD and the area west of the CBD, along the Wilshire Boulevard corridor, have the highest density of spaces, with 8,200 median residential off-street spaces and 31,000 total off-street spaces per square mile. In the CBD, there are some census tracts with 32,000 residential off-street and 260,000 total off-street spaces per square mile. With many more nonresidential than residential spaces in the urban core, we expect that commuters and shoppers are responsible for most automobile travel. The urban core also has high-quality transit service and is where regional plans predict major population, housing, and employment growth by 2035 (Southern California Association of Governments, 2012).

We calculate a coverage factor at the census tract level—the ratio of surface area committed to parking to the land area—to provide insights into how the amount of land devoted to parking has changed over time and across census tracts in LA County. We develop the coverage factor assessment to show how much land is dedicated to parking,

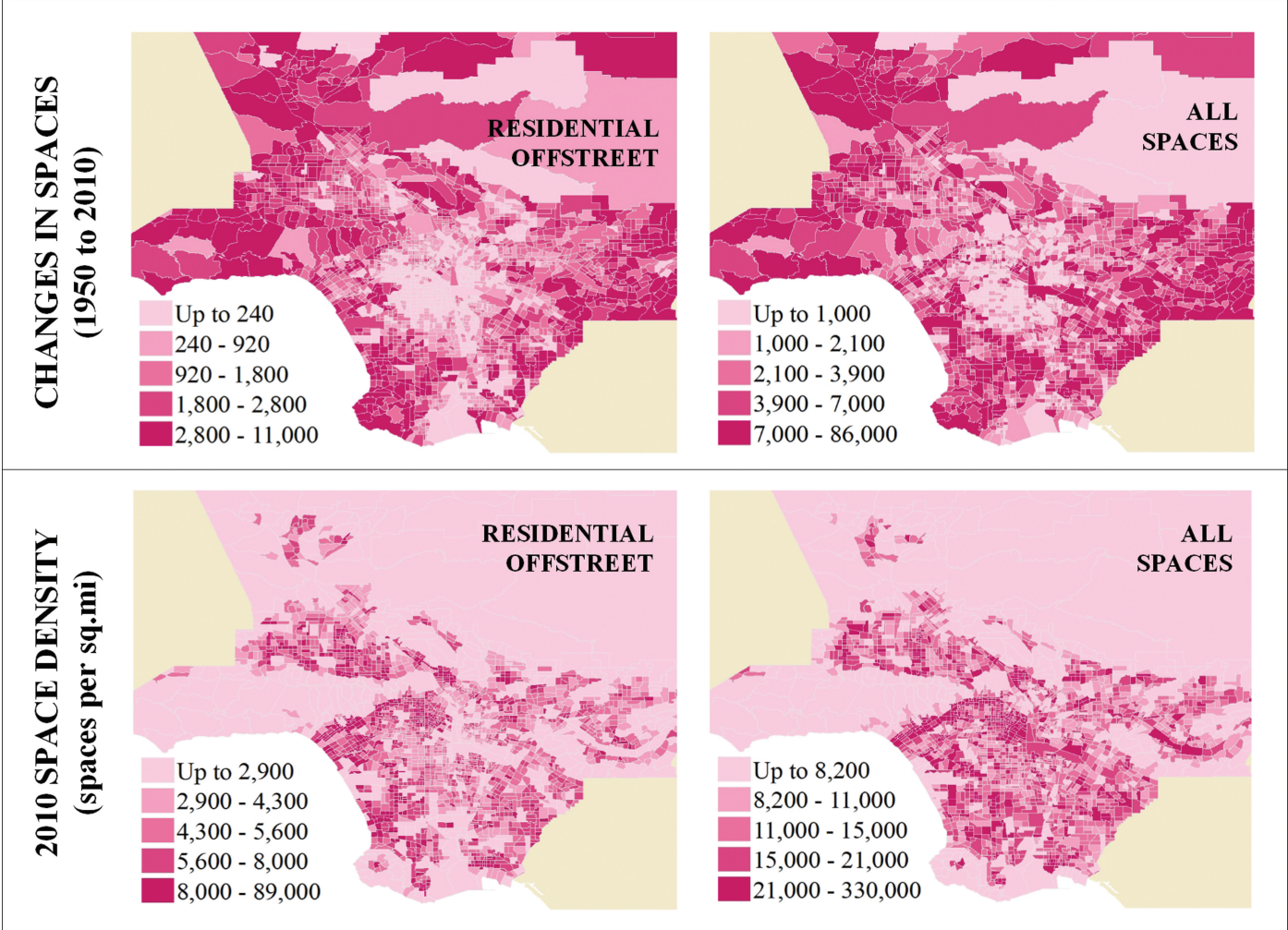


Figure 3. Changes in parking spaces (1950–2010) and parking space density. The top row shows changes in residential and all (residential off-street, nonresidential off-street, and on-street) spaces between 1950 and 2010. Growth in spaces largely occurred outside of the urban core. The bottom row shows space density (spaces per square mile). The highest density of spaces can be seen in the CBD and west of CBD (Wilshire corridor) regions.

which serves as an indicator of the opportunities and challenges for redevelopment. As shown in Figure 4, we find that in 2010 the urbanized area of LA County had a median coverage factor of 0.16: For every 100 acres of land, there are 16 acres used for parking of any kind. The median coverage factor has more than doubled since 1950 (when it was 0.07) largely due to the addition of nonresidential off-street space outside the urban core. We also find that the median CBD coverage factor (in 2010) is 0.80, consistent with Manville and Shoup’s (2005) estimate of 0.81. Moreover, in 2010 the urban core contained 19 of the 28 census tracts in the county that had a coverage factor exceeding 1.0; that is, those that have multistory parking structures on relatively small land areas.

The results indicate that while parking infrastructure has been extensively developed across the county in response to minimum parking requirements, there is signifi-

cant investment in multistory above- or below-ground structures in the CBD, an area with high land value and good public transit service.

### The Impact of Mandatory Parking Requirements

We assess how on-street, off-street residential, and off-street nonresidential parking in LA County have grown from 1900 to 2010 and investigate how automobile access and use have changed as parking infrastructure has grown. We find that there were 18.6 million spaces in LA County in 2010 or 3.3 spaces per vehicle, 9.6 million of which were off-street nonresidential. Peak parking infrastructure deployment occurred between 1950 and 1980, when the county was adding approximately 310,000 spaces per year,



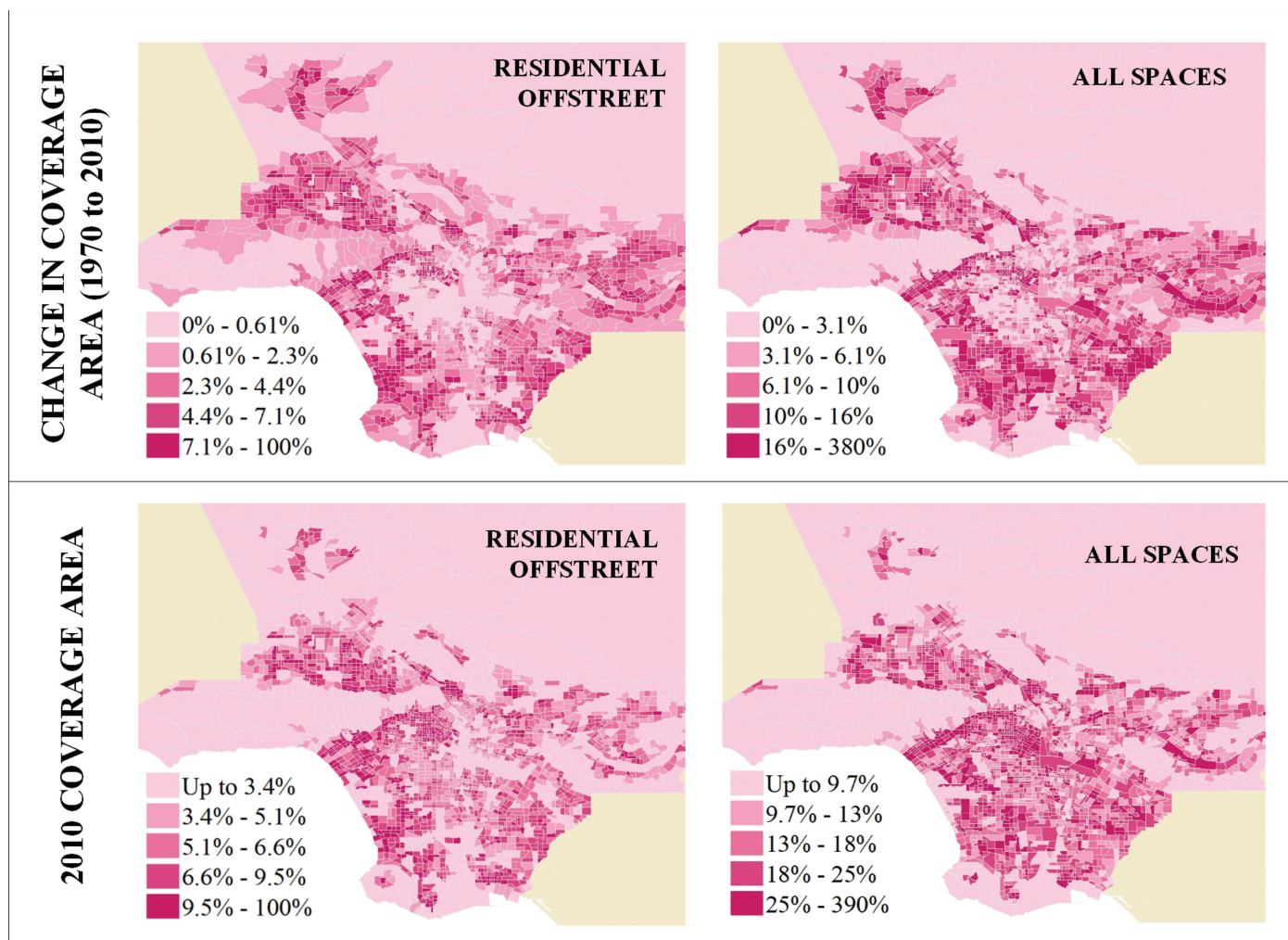


Figure 4. Coverage area. The top row shows the change in parking area to land area for residential off-street (left) and total (right) spaces from 1970 to 2010. The urban core experiences less change for both space types than the rest of LA County. The bottom row shows the 2010 coverage areas for residential off-street (left) and total (right) spaces. The 2010 coverage areas subfigures are similar to parking space density subfigures in Figure 3 but weighted by multistory structures.

but has been slowing; the total roadway supply and number of buildings have not significantly increased since 1990. Since 1945, we find that the growth of parking has outpaced the growth of roadway supply, which may be a contributing factor to the increasing demand for travel and worsening congestion in the region.

In the first half of the 20th century, LA County minimum parking requirements resulted in more parking being deployed than there were vehicles, but the growth in vehicles has since 1960 outpaced that of parking; by 1975, the number of vehicles in the county was about equal to the number of residential off-street spaces. This ratio has hovered around unity since, signifying that minimum off-street requirements have been a success at keeping vehicles off the road, but have likely contributed to more vehicles and ultimately more VMT. Furthermore, we find that residential sorting occurs when census tracts within

LA County have more or less parking than there are vehicles. Since 1970, the number of vehicles and the number of residential off-street spaces have converged in 73% of census tracts in the county.

Within LA County we see significant variations in the number of spaces and the density of parking spaces. There is abundant parking where high-quality transit exists, which is likely to work against transit, walking, and biking. Since 1950, most growth in parking infrastructure has occurred outside of the urban core, largely associated with lower-density residential and commercial development. In 2010, the coverage factor (the ratio of parking area to land area) was 0.16, more than double that of 1950. In the CBD, there are 19 census tracts where the coverage factor exceeds 1.0, indicating that extensive efforts have been made to ensure adequate parking supply; these have significant impacts on land use.

Our findings suggest that minimum off-street parking requirements have been a success at encouraging greater automobility and probably a failure at lowering traffic congestion, one of the original objectives of such requirements. Before 1975, vehicle adoption accelerated to fill excess residential off-street spaces; after 1975, the vehicle–residential off-street space ratio has hovered around unity. Over time, the number of vehicles changes to fully use the infrastructure available. While we did not directly assess whether parking contributes to congestion, the concentrated release of vehicles from densely provided parking infrastructure obviously can affect congestion on nearby roadways.

There are some problems with our approach and methods; we assess the technical difficulties in the Technical Appendix. For example, we cannot distinguish between free and priced parking; however, given the makeup of spaces in our inventory and data that show that most trips made in LA County use free parking, it is logical to assume that most spaces in LA County are free. Furthermore, it is unclear from this research whether developers would continue to build parking in excess of current requirements even if requirements were lowered because they (or their funding sources) believe there is demand for that infrastructure. But it is clear that the growth of parking infrastructure in the past century is directly associated with vehicle access, which in turn likely has contributed at some level to the growth in vehicle travel. Mandated parking infrastructure has affected land use by dedicating space to automobile storage, changing urban form.

## Barriers to Comprehensive Parking Reform

There is an abundant supply of parking throughout the metropolitan area (most of which is likely free) although the annual growth in parking infrastructure in LA County is slowing. This extensive parking infrastructure has affected land use in ways that may not be easy to change: 14% of LA County's incorporated land area is dedicated to automobile storage. The existing parking infrastructure is likely to work against policy initiatives to curb the use of the car, reduce auto congestion, increase transit usage, and address equity issues, even if minimum parking requirements on development are reduced or reformed.

As other scholars have done, we suggest that planners and policymakers must consider how the growth of parking infrastructure leads to greater automobility, develop new approaches to parking mandates including adopting maximum parking restrictions, and seek to accommodate new growth through redevelopment at the core rather than new

construction at the periphery. Moreover, many scholars have noted that mandatory parking requirements drive up the cost of housing, suggesting that planners consider the implications for affordable housing. For example, an advocacy group estimates that New York City's plan to change zoning regulations to allow fewer parking spaces for senior housing in transit zones will save \$1 million for every 100-unit building, the cost of 25 parking spaces (Fee 2015; Ramey 2015).

Policymakers should also focus attention on reforming parking policies in specific locations. For example, cities should reassess mandatory parking requirements in high-density areas with good public transit service to act as a deterrent to automobile use and an incentive to transit use. In LA County, jurisdictions along the existing and proposed rail lines should seriously consider changing their parking mandates to support the rail system. LA County is in the midst of a massive expansion of the rail transit network (with five lines to open within the next decade), and there are efforts to locate new housing and jobs near high-quality public transit. Cities in these areas should reduce the mandatory requirements for redevelopment projects along the lines or set maximum requirements.

Our research, however, goes beyond these well-discussed policy paradigms. Our findings show the need for planners to recognize that current parking infrastructure may substantially reduce the positive impacts of even major municipal parking reforms. To address the “drag” of existing parking infrastructure, and to capture new opportunities for affordable housing and development, planners must also focus on how that parking infrastructure can be transitioned to alternative land uses. Land now dedicated to parking can be converted to housing, small business incubators, industrial and commercial use, and recreational facilities. Surface lots can be replaced with buildings (and in fact are often placeholders for additional construction).

While parking structures designed specifically for the automobile may offer the greatest opportunity for alternative uses, residential parking, specifically home garages, also have a high potential for conversion into living quarters and rental units as well as small home-based businesses. LA County residents have already taken advantage of their mandated garages and off-street parking to do so (Wegmann, 2014). In 2009, the *Los Angeles Times* reported that in Compton, a largely African American and Latino city of 93,000 in LA County, more than one-third of garages had been converted to living spaces, although officials continually threatened to crack down on the practice (Garrison, 2009).

The owners of apartment buildings have also subdivided existing apartments into smaller units without the mandated parking. In June 2015, the *Los Angeles Times*

reported that City of Los Angeles officials were proposing a citywide amnesty process for landlords that would legalize their existing “bootlegged” apartments after years of debate about the practice. The *Times* reported, however, that the barriers to legalizing these apartments were not safety or construction issues, but “the city codes that mandate a minimum number of parking spaces” (Reyes, 2015). The amnesty plan was not met with universal approval; the *Times* reported that some neighborhood associations were vehemently opposed, noting that many areas already faced “vociferous parking disputes.”

## Developing Comprehensive Parking Reforms

Minimum parking requirements have long been a cultural mainstay, but there is accumulating evidence of their long-term negative impacts. The requirements were codified at a time when automobiles were a new technology and we lacked a systematic understanding of the consequences of providing abundant and underpriced parking. Planners and policymakers must consider a range of strategies to reduce parking infrastructure to address the negative impact of the automobile. But, more importantly, planners must recognize how influential the existing extensive parking infrastructure will be on the effectiveness of those policies. Unless planners recognize the need to convert existing parking into other uses, even major reform in parking policies may be ineffective.

Planners must recognize and support a variety of options for converting surface lots and home garages into different land uses. Multistory structures, largely concentrated in the CBD, may offer the greatest financial challenges, while there may be resident opposition in residential areas. But the conversion of excess parking spaces into commercial, employment, and housing options provides opportunities to address the many challenges posed by the automobile, to better use our urban form, and to improve accessibility for those who cannot rely so heavily on personal automobiles.

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## Technical Appendix

### Estimating Historical Land Use Change

We use a doubly constrained growth factor approach for Los Angeles County (LA County) developed by Reyna and Chester (2015) that estimates the number of buildings constructed and demolished by vintage from 1900 to 2010. Using the 2010 assessor database and historical decadal censuses, the model converges on a matrix-based solution of estimates of building turnover (Table A-1). Each cell in the matrix is the construction or demolition of dwelling units by vintage in a given decade.

The model variables are:

$C_v$ : number of dwelling units constructed of vintage  $v$

$D_{v,d}$ : number of dwelling units constructed of vintage  $v$  demolished in decade  $d$

$\Delta S_d$ : change in the total dwelling units in the stock in decade  $d$

$R_v$ : number of dwelling units of vintage decade  $v$  remaining in the 2008 stock

$b_v$ : a given vintage

$y_d$ : a decade of assessment.

Table A-1. Historical dwelling unit construction and demolition estimation matrix.

Changes in dwelling units by year							
		Pre-1900	1901–1910	1911–1920	$y_d$	2001–2010	2010 totals
Initial construction year	Pre-1900	$C_{1900}$	$-D_{1900,1910}$	$-D_{1900,1920}$	$-D_{1900,d}$	$-D_{1900,2008}$	$R_{1900}$
	1901–1910	0	$C_{1910}$	$-D_{1910,1920}$	$-D_{1910,d}$	$-D_{1910,2008}$	$R_{1910}$
	1911–1920	0	0	$C_{1920}$	$-D_{1920,d}$	$-D_{1920,2008}$	$R_{1920}$
	—	—	—	—	—	—	—
	$b_v$	0	0	0	$C_v$	$-D_{v,2008}$	$R_v$
	—	—	—	—	—	—	—
	2000–2008	0	0	0	0	$C_{2008}$	$R_{2008}$
Change in units		$\Delta S_{1900}$	$\Delta S_{1901-1910}$	$\Delta S_{1911-1921}$	$\Delta S_d$	$\Delta S_{2001-2008}$	$\Sigma_v R_v = \Sigma_d \Delta S_d$

The addition of dwelling units by vintage ( $C_v$ ) is obtained from historical decadal censuses and the 2010 totals ( $R_v$ ) are from the assessor database. Starting with initial weights occupying the demolition cells ( $D_v$ ), the iterative program first takes the ratio of the expected row demolition ( $R_v - C_v$ ) over the row sum ( $\Sigma_v D_{v,d}$ ). Demolition values in the row are then multiplied by this ratio. The same procedure is used for the columns ( $\Delta S_d - C_d$  and  $\Sigma_v D_{v,d}$ , respectively). Iterations terminate when the total error between the expected and actual demolition sums is minimized. Model formulation including constraints, rules for convergence, and convergence threshold are discussed extensively in Reyna and Chester (2015). We do not run this model in this study, but strictly use the outputs.

Reyna and Chester (2015) validate their model results by comparing their building age distributions against those reported by the census in historical reports. They also find that their estimated historical distributions of buildings

match those reported in historical reports, for example, Henson and Beckett (1944).

### Growth of the Los Angeles Roadway Network

We use model results from Fraser and Chester (2015), who estimate the growth of the LA County roadway network to estimate the deployment of on-street parking. Local roadways constitute the majority of an urban roadway network, yet there is generally no information on when they were deployed. While some information exists for when higher classifications (interstate, highway, arterial) were constructed, this is not the case for lower classifications. Fraser and Chester (2015) developed a statistical analysis of building vintages across LA County census tracts using the 2008 county assessor database. A distribution of building vintages is developed for each census tract. Assuming that roadways were constructed in concert with some of the first buildings in a neighborhood, Fraser and Chester (2015) assign all roadways

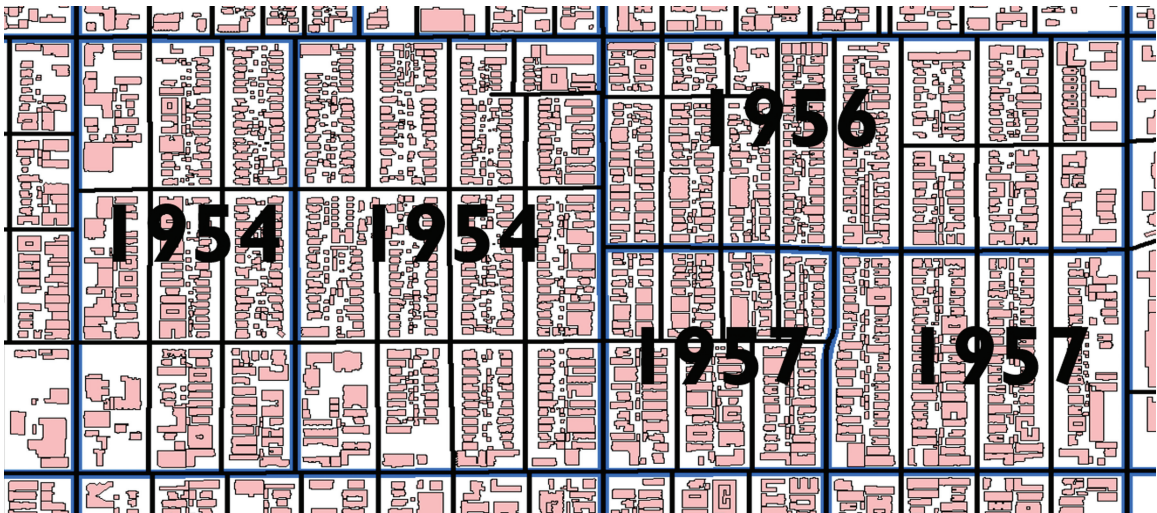


Figure A-1. Roadway link construction year assignments. For each neighborhood, a distribution of building vintages is developed using the Los Angeles County assessor database. Roadways in each neighborhood are assigned a vintage of the distribution mean minus one standard deviation.



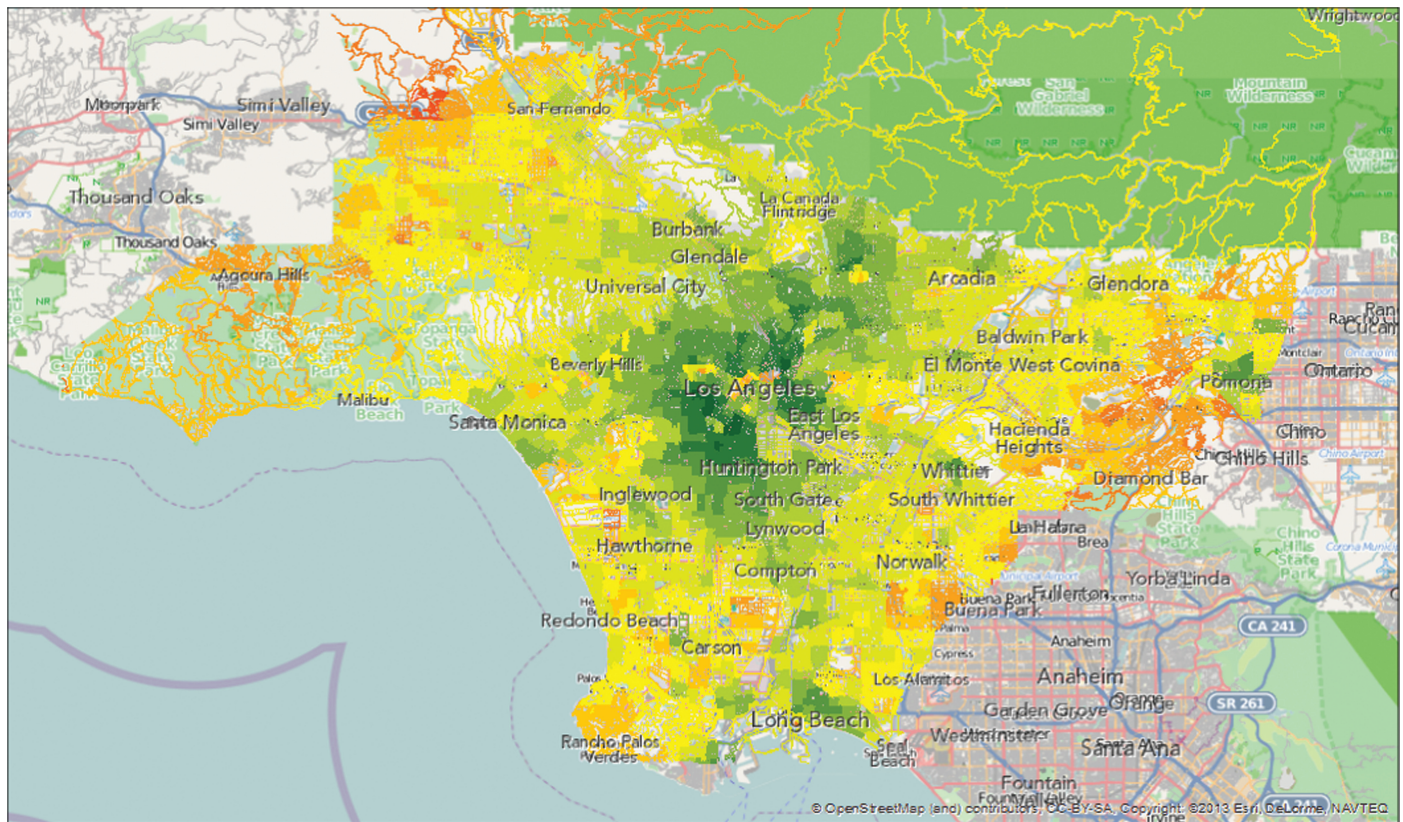


Figure A-2. Growth of Los Angeles's roadway network. The oldest portions of the network are darker shades (dark gray in print and green in the color version available online), and the newest are lighter shades (light gray in print and yellow and orange in the color version available online). Roadway network growth largely occurs from downtown Los Angeles outwards. Source: Fraser and Chester, 2015.

within a census tract the distribution mean minus one standard deviation age (illustrated in Figure A-1).

As such, the growth of the roadway network matches closely to the building growth patterns of the city (Figure A-2). Where information exists on the precise construction year of higher classifications (such as highways and freeways), Fraser and Chester (2015) use this information.

### On-Street Parking

After development of a historical inventory of the roadway network, we estimate an on-street space inventory. Street lengths where parking is prohibited near intersections, fire hydrants, bus stops, and driveways were removed from the roadway network through GIS analysis. Point locations for intersections and fire hydrants were coupled with no parking provisions specified by the Los Angeles Municipal Code (LAMC) (Los Angeles County Fire Department, 2012). LAMC prohibits parking within 25 feet of any intersection and 15 feet of any fire hydrant (City of Los Angeles, 2015). In addition, LAMC prohibits parking at public bus stops. Bus stop locations, with an assumed length of 100 feet, were determined using Google Transit

Data Feed for all transit agencies operating in Los Angeles County (Google, 2015). Finally, residential and commercial driveways, with an assumed width of 20 and 30 feet, respectively, were assigned to individual land parcels. These driveway lengths were then removed from adjacent roadway links.

We use an average space length of 20 feet for unmarked curbside parking, 26 feet for single marked spaces (likely metered), and 22 feet for multiple marked spaces (also likely metered). The latter two estimates are based on regulations from several cities in LA County. The use of 20 feet for unmarked curbside parking is based on surveys of aerial photos from the area. We weight the three space types assuming that 90% of curbside on-street parking is unmetered, 9% is metered with multiple spaces in series, and 1% is metered as a single space. The uncertainty in space size given the length assumptions is discussed in the Uncertainty section.

### Off-Street Parking Requirements

We find consistency across minimum parking requirements of cities in LA County after reviewing requirements

Table A-2. Residential and commercial minimum off-street parking requirements.

	Residential (minimum required spaces per unit)							Commercial (1 space per × square feet)							
	Single-family home	Multifamily (bedrooms)						General retail	Office	Restaurant	Banks	Manufacturing and industrial	Warehouse	Assembly and places of worship	Medical services
		Studio	1	2	3	4	Guest parking (per unit)								
Los Angeles	2	1	2	2	2	2	0.25	250	400	100	250	500	1000	35	200
Alhambra	2	2	2	2	2	2	0.2	200	250	120	–	500	–	6 <sup>b</sup>	200
Arcadia	2	2	2	2	2	2	0.5	200	250	100	250	500	500	5 <sup>b</sup>	200
Culver City	2	1	1	2	2	3	0.25	350	350	100	250	500	1000	5 <sup>b</sup>	350
Diamond Bar	2	1	2	2	2.5	3	0.25	250	400	100	300	500	1000	3 <sup>b</sup>	250
Downey	2	2	2	2	2	2	0.5	250	300	100	250	500	800	5 <sup>b</sup>	200
El Monte	2	1	1.7	2	2.5	2.5	0.25	250	250	150	–	500	500	40	–
Glendale	2	2	2	2	2.5	3	0.25	250	370	100	250	500	1000	5 <sup>b</sup>	200
Inglewood	2	2	2	2	2	2	0.33	300	300	150	150	500	1000	5 <sup>b</sup>	200
Lancaster	2	1.5	1.5	2	2	2	0.25	250	250	100	250	–	–	5 <sup>b</sup>	150
Long Beach	2	1	2	2	2	2	0.25	250	250	100	200	500	1000	3.3 <sup>b</sup>	200
Manhattan Beach	2	1	2	2	2	2	0.25	200	300	50	300	400	1500	100	200
Pasadena	2	1	2	2	2	2	0.1	333	333	100	333	500	–	4 <sup>b</sup>	250
Pomona	2	1	1.5	2	2.5	3	0.25	250	250	150	–	500	1000	35	200
Rancho Palos Verdes	2	1	1	2	2	2	25% <sup>a</sup>	250	275	75	250	–	–	3 <sup>b</sup>	250
San Fernando	2	1.5	1.5	2	2.5	3	0.2	300	300	100	–	750	750	5 <sup>b</sup>	–
Santa Clarita	2	1	2	2	2	2	0.5	250	250	100	250	500	1000	5 <sup>b</sup>	200
Torrance	2	2	2	2	3	3	0.2	200	300	100	175	400	1500	5 <sup>b</sup>	200
West Covina	2	2	2	2	2	2	10% <sup>a</sup>	250	300	3.5 <sup>b</sup>	–	500	500	2.5 <sup>b</sup>	150
MEDIAN	2	1	2	2	2	2	0.25	250	300	100	250	500	1000	–	200
MINIMUM	2	1	1	2	2	2	0.1	200	250	50	150	400	500	2.5	150
MAXIMUM	2	2	2	2	3	3	0.5	350	400	150	333	750	1000	100	350

Notes:

a. Guest parking required is based on the total number of dwelling unit required spaces.

b. Parking spaces required per X fixed seats.

Sources: City of Alhambra, 2015; City of Arcadia, 2015; City of Diamond Bar, 2015; City of Downey, 2015; City of El Monte, 2015; City of Glendale, 2015; City of Inglewood, 2015; City of Lancaster, 2015; City of Long Beach, 2015; City of Los Angeles, 2015; City of Manhattan Beach, 2015; City of Pasadena, 2015; City of Pomona, 2015; City of Rancho Palos Verdes, 2015; City of San Fernando, 2015; City of Santa Clarita, 2015; City of Torrance, 2015; City of West Covina, 2015; Culver City, 2015.

for 19 of the largest (by population) municipalities. We find that the city of Los Angeles requirements are representative of the median standards in the county (Table A-2). This supports the literature, which suggests that cities often adopt requirements from each other (Weinberger, Kaehny, & Rufo, 2010) or are based on the Institute of Transportation Engineers' (2015) *Parking Generation* manual. The median minimum parking requirements associated were uniformly applied across the 88

municipalities that make up LA County. Table A-2 compares the parking requirements of these cities.

## Uncertainty

We consider model and parameter uncertainty in our results and how it might affect our findings. Model uncertainty is most likely to result from the use of the Reyna and Chester (2015) building infrastructure growth model results. The Reyna and Chester model estimates the

number of dwelling units of particular vintages at various times in LA County's history to show how new infrastructure is turned over, resulting in present day stock. The Reyna and Chester model relies largely on residential (the predominant building structures) building stock estimates to generate decay curves of initial infrastructure stock of a particular vintage. While the model has been validated against multiple sources (in particular, historical U.S. Census data and reports of distributions of building stock ages), without high spatial and temporal historical data of building distributions it is difficult to quantitatively assess this uncertainty. Secondly, model uncertainty may also result from the specifications of the roadway network growth model by Fraser and Chester (2015). The Fraser and Chester model estimates the age of roadway links within LA County by assigning those links a year of construction around the time the first buildings in the neighborhood were constructed. We estimate that there is less model uncertainty from the use of these results since there exists more historical information on the public roadway network, which Fraser and Chester use to validate their model. However, similar to buildings, the quantitative assessment of this model uncertainty is challenging.

Parameter uncertainty is likely to arise from a variety of factors used throughout the estimation of LA County's parking spaces. While minimum parking requirements are required for residential and nonresidential facilities, there is no way of systematically knowing (across space and time) whether precisely this much parking was deployed. As previously discussed, we do validate our results to confirm

that we are reasonably estimating historical parking; however, some parking existed before it was required, and some developers manage to get variances. Furthermore, land (such as home lawns) may be used as parking, but are not designated as parking. There are many variables at play—some that we can think of, and others that we may not have thought of—that may result in actual parking deviating from the minimum required. However, given that land is likely more valuable for other uses than for parking, and that nonresidential off-street parking constitutes a large share of total spaces, we estimate that using the minimum required for nonresidential off-street parking is likely a reasonable approximation. The greatest uncertainty in our on-street space estimates lies in the use of 20 feet as the length of unmarked spaces. A smaller length of space will decrease the amount of on-street parking that exists across the city. The effect of various space lengths on on-street parking is shown in Figure A-3, and would not significantly change the conclusions in this article.

It is difficult to estimate whether the net effect of the parameter and scenario uncertainty results in more or less total parking than our base estimates, but we can qualitatively estimate how each category will be affected. Where smaller cars are parked bumper to bumper on the curbside, we estimate that our on-street estimates are likely conservative. However, if cities in LA County tend to have a larger share of marked (and likely metered) spaces than the 10% we estimate, then our on-street estimates are likely liberal. Residential off-street spaces were estimated based on minimum parking regulations and driveway size.

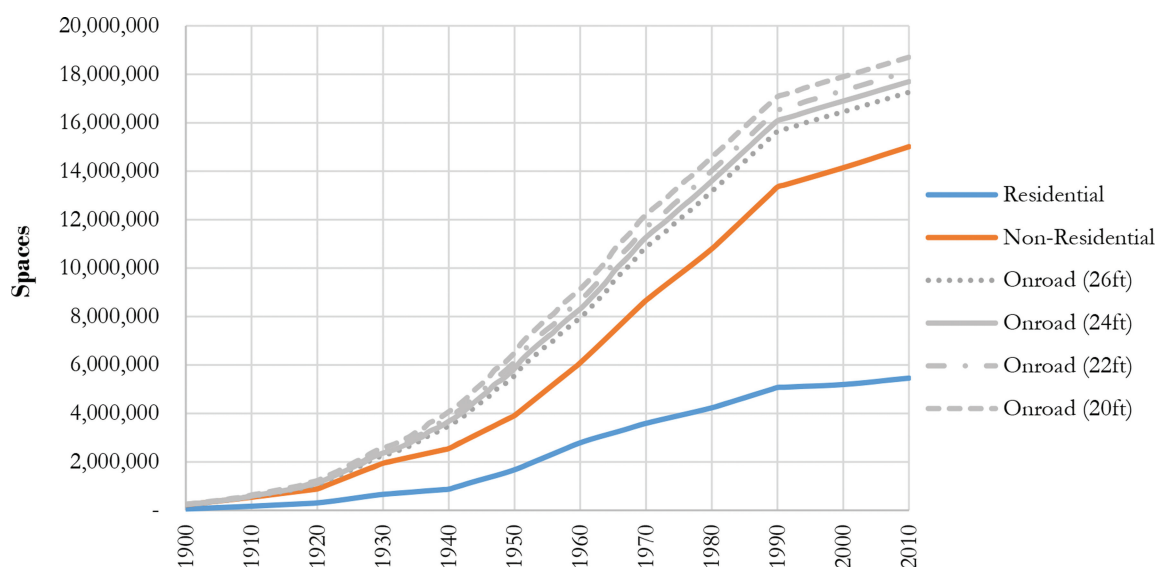


Figure A-3. Uncertainty in on-street spaces by space length. We use 20 feet as an estimate of unmarked space length and show how variations in this length affect the inventory. A longer average space length results in fewer on-street spaces. The difference between an average space length of 20 feet and 26 feet is 1.5 million spaces.



Neighborhoods where inhabitants park on lawns and landscaping, or store cars behind homes, would increase parking spaces, making our results conservative. Finally, nonresidential off-street parking is largely based on parking requirements associated with the facility size (measured as area or the number of facilities). Given the competing forces of developers getting variances and other developers possibly building more than the minimum, it is difficult to assess whether we are over- or underestimating in this category. However, as mentioned previously, given that land value is often higher when not used for parking, we estimate that on average, parking is deployed close to the minimum specified in regulations.

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