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Providing affordable housing and reducing greenhouse gases are common goals in cities worldwide. Transit-oriented development (TO D) can provide an opportunity to make incremental progress on both fronts, by building affordable housing near transit and by providing alternative transport modes such that households reduce driving. While the existing literature has focused on the relationship between TOD and housing and TOD and greenhouse gas emission reduction as separate issues, it has seldom touched on the possibility that TOD could address both goals jointly. We provide evidence to show that focusing on either housing affordability or greenhouse gas emission reduction in isolation can lead to strategies that achieve one goal to the detriment of the other. Using the case of Los Angeles, we develop a scenario planning model that allows simultaneous consideration of housing and transportation goals, and illustrates the tradeoffs of different policy approaches. The results show that larger increases in residential densities combined with a small inclusionary housing requirement yields greater benefits, in terms of both reduced driving and more affordable housing, than would a higher inclusionary percentage with smaller increases in density.

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Developing Affordable Housing Guidelines Near Rail Transit in Los Angeles

Final Report
METRANS Project 15−13

December 2016

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Abstract

Providing affordable housing and reducing greenhouse gases are common goals in cities worldwide. Transit-oriented development (TOD) can provide an opportunity to make incremental progress on both fronts, by building affordable housing near transit and by providing alternative transport modes such that households reduce driving. While the existing literature has focused on the relationship between TOD and housing and TOD and greenhouse gas emission reduction as separate issues, it has seldom touched on the possibility that TOD could address both goals jointly. We provide evidence to show that focusing on either housing affordability or greenhouse gas emission reduction in isolation can lead to strategies that achieve one goal to the detriment of the other. Using the case of Los Angeles, we develop a scenario planning model that allows simultaneous consideration of housing and transportation goals, and illustrates the tradeoffs of different policy approaches. The results show that larger increases in residential densities combined with a small inclusionary housing requirement yields greater benefits, in terms of both reduced driving and more affordable housing, than would a higher inclusionary percentage with smaller increases in density.

Disclosure

The project entitled "Developing Affordable Housing Guidelines Near Rail Transit in Los Angeles" was funded in entirety under this contract to California Department of Transportation. The PI of the project was Dr. Raphael Bostic and the Co-PI was Dr. Marlon Boarnet, both of whom are from the Sol Price School of Public Policy at the University of Southern California. The project was carried out during the period: 08/15/2015 – 12/31/2016. The total amount of funding was $99,983.

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1. Introduction

This research is motivated by a tension that exists between two important urban policy goals. First, cities are concerned with providing housing for low-income residents. Many metropolitan areas are suffering from an inadequate supply of housing for residents whose low income makes them dependent both on public transportation and on the availability of affordable housing. Second, as policymakers grow increasingly aware of and tasked with combating climate change, they desire to increase the use of public transit—and decrease driving in personal vehicles—to reduce greenhouse gas emissions. Transit-Oriented Development (TOD) – a strategy of building residential, commercial, and other infrastructure within a half-mile[1] perimeter of a transit station – seeks to balance these two goals by providing an appropriate mix of housing options near public transportation that would also serve to reduce the use of personal vehicles. The tension arises from the fact that high-income households drive more in absolute terms than low-income households, and thus provide a higher capacity to reduce greenhouse gases when living in TODs, by switching a portion of their daily travel from driving to public transit. Yet, a policy that increases housing options for high-income residents in a TOD area also tends to decrease the potential availability of affordable housing. As a result, tradeoffs exist between encouraging affordability and transit access and encouraging optimal greenhouse gas reduction. This research provides planners, stakeholders, and other interested parties with a tool to examine the tradeoffs between affordable housing and environmental benefits under different

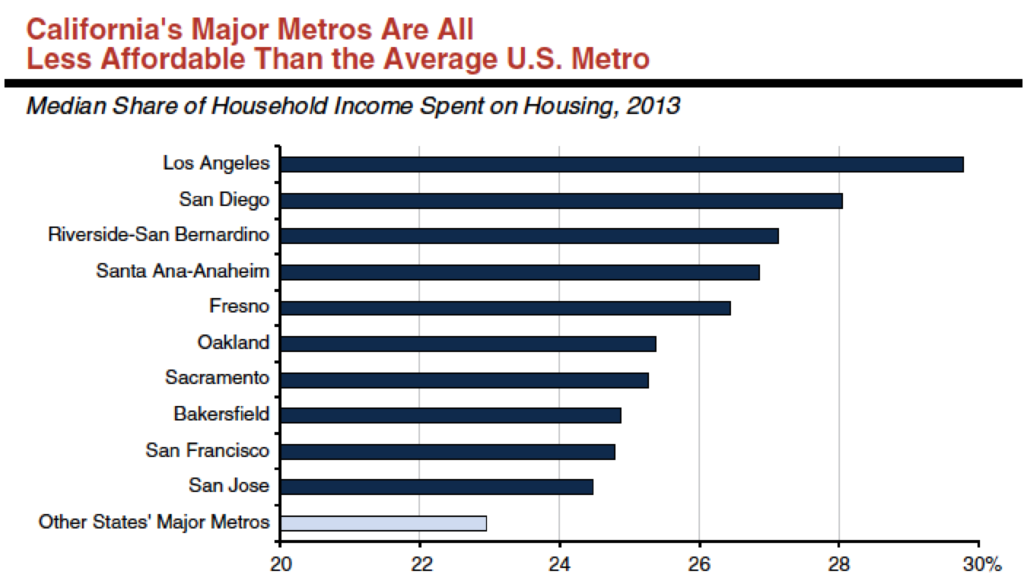
[1] TOD is defined as "a type of community development that includes a mixture of housing, office, retail and/or other amenities integrated into a walkable neighborhood and located within a half-mile of quality public transportation" (Reconnecting America, n.d.)

TOD scenarios. These tradeoffs are modeled in the context of the rail station areas of the Los Angeles County Metropolitan Transportation Authority (LA Metro).

The first section of this report describes the context of the problem and how previous studies of affordable housing and transit development have approached the issue. We focus especially on studies in California and of the Los Angeles metropolitan area. The next section discusses the data this report uses to build the development scenarios as well as some of the limitations of those data. Next, the report sketches out in detail the model that creates the development scenarios and then analyzes the potential policy implications that these scenarios uncover. Finally, the report concludes with the most important takeaways for planners and policymakers in Southern California and in other metropolitan areas, as well as a discussion of how planners might be able to implement this research in a useful way. In short, this study provides researchers with a tool to estimate VMT and affordable housing at a system-wide level, allowing policymakers to create a portfolio of development scenarios that can preserve both goals, that is, both the adequate availability of affordable housing and meaningful reductions in greenhouse gas emissions.

2. Research Context

The Los Angeles metropolitan area provides the ideal context to study transit-oriented development (TOD) in general, and the tradeoffs between affordability and environmental sustainability in particular. The Los Angeles area is currently undertaking a massive expansion of its subway and light-rail network, increasing the number of stations from 80 in 2005 to 110 by the year 2040.[2] At the same time, however, the city is suffering a crisis in affordable housing. To cite one stark example, in 2012 the median home price in Los Angeles was more than double what a household of median income could afford (Los Angeles Department of City Planning 2013). More broadly, the amount that an average household spends on housing as a percentage of its income (a statistic known as the housing burden) is nearly 30% in Los Angeles metropolitan area (Taylor 2015). As Figure 1 shows, the affordability gap for all households is higher in Los Angeles than the U.S. metropolitan area average and is the highest among major metropolitan areas in California. In considering just Los Angeles' renters in 2014, housing burdens have grown for both low-income and moderate-income households since 2006 (Ellen and Karfunkel 2016). In context, Los Angeles renters are not alone in their increased rental burden: a 2016 study comparing the eleven largest metropolitan areas in the U.S. found that in 8 of the 11, over 50 percent of renters paid 30 percent or more of income toward rent and 25 percent or renters paid 50 or more percent toward rent (Ellen and Karfunkel 2016).



Source: Taylor (2015)

[2] This research project focuses on subway and light rail transit as the transit piece of transit-oriented development. Future projects could expand this study to commuter rail, bus-rapid transit, or city buses. The description of the Los Angeles rail system refers to the plan before the November 2016 passage of Los Angeles County's Measure M.

Figure 1
Affordability and Housing Burdens in California's Metropolitan Areas

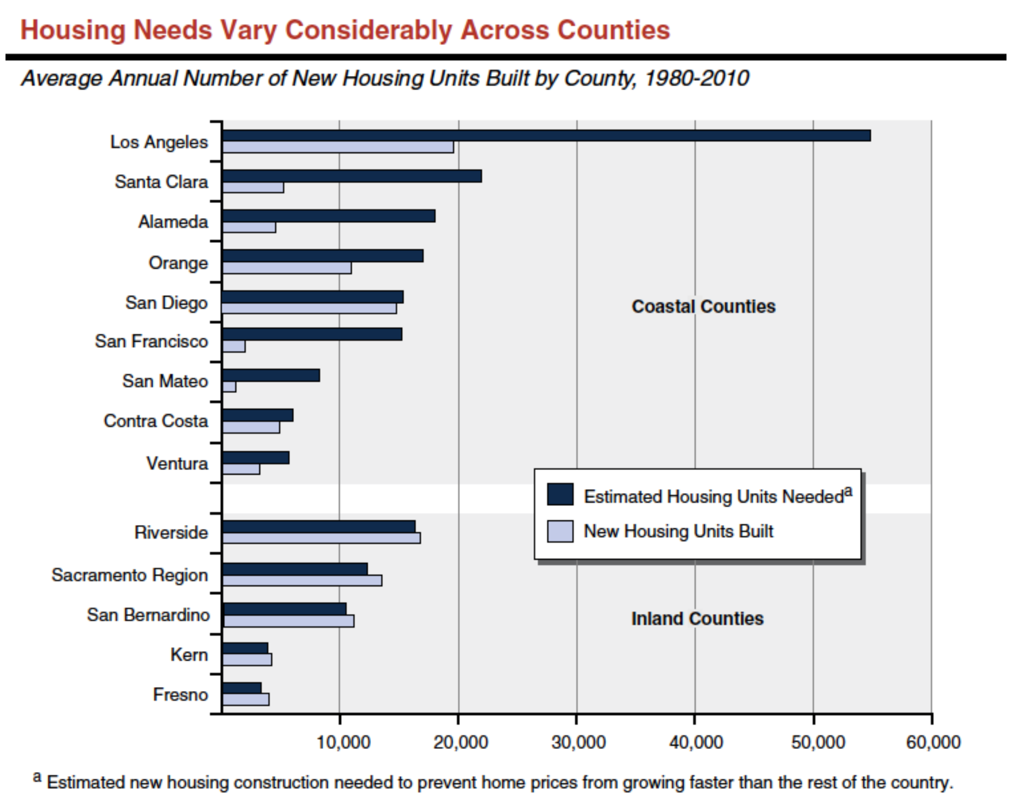
Observers expect the expansion of Los Angeles' rail networks to bring numerous benefits for low-income residents, many of whom are more likely to depend on public transit in the first place. Data from multiple sources, including the Federal Highway Administration (2011), the California Household Travel Survey (2013a), and the California Housing Partnership and Transform (2014) all show that low-income residents are more likely to use public transportation and less likely to drive personal vehicles. This finding is corroborated by a study by Boarnet et al (2015), which showed that LA Metro rail stations are located in neighborhoods with higher proportions of lower-income, immigrant, and minority households, groups which are on average more likely to patronize transit.

New stations are also expected to bring benefits to residents by revitalizing the neighborhoods surrounding the new rail stations. Recent estimates by the Southern California Association of Governments (SCAG) suggest that over half of future housing and employment growth during the next 20 years will take place within a half mile of a well-serviced rail or bus station (or corridor), according to their 2012 Regional Transportation Plan (SCAG 2012, p. 131). SCAG and other experts foresee the development around transit stations as a double opportunity, one of both economic revitalization and of improving the region's transportation conditions (SCAG 2012, Los Angeles Metro 2009).

The affordable housing crisis in Los Angeles is a longstanding and growing problem. An affordable home for the 2012 median-income Los Angeles resident was $190,000, but the median 2012 home price in Los Angeles was $400,000 (Los Angeles Department of City Planning 2013). To add to this, rents in Los Angeles have increased by more than 20% from

1990 to 2010, while incomes have slightly declined during this same period, creating a higher housing burden on households (Collinson 2011).

The undersupply of housing relative to demand is one reason for the lack of housing affordability in Los Angeles. Figure 2 illustrates the undersupply of housing in Los Angeles compared to that of other California metropolitan areas. Los Angeles Mayor Eric Garcetti has proposed constructing 100,000 new units between 2014 and 2021 (Taylor 2015, Logan 2015). This proposal, however, which would construct units at a rate of 12,500 per year, is far above what the city currently undertakes; since 2000 the city has only approved permits at the rate of 7,500 per year (US HUD (a), n.d.).



Source: Taylor (2015)

Figure 2

Housing Supply and Demand, California Metropolitan Areas

Housing affordability problems are not unique to Los Angeles, and the interaction between affordable housing deficits and TOD has given rise to a literature centering on three different aspects of the issue—environmental sustainability, TOD-area housing prices, and displacement of low-income TOD residents. Regarding environmental sustainability, previous studies indicate that TOD promises meaningful reductions in greenhouse gases by reducing the usage of personal vehicles, particularly when TOD increases access to various travel destinations and encourages more compact development (Cervero and Murakami 2010, Hankey and Marshall 2009). Research into TOD's effects on housing prices indicate a moderate increase in property values in TOD areas, due to increased accessibility and amenities (Wardrip 2011, Cervero and Duncan 2004, Duncan 2011). Properties that are especially close to the stations, however—one to three blocks (Cervero 2006) or within 300 feet (Kilpatrick et al 2007)—tend to experience decreases in value due to the added noise, congestion, and air pollution. Housing price increases in TOD areas may decrease housing affordability without a commensurate increase in resident incomes. If new, higher-income residents move in, gentrification may occur. Without an expansion of the housing supply in a TOD area, prior residents and / or low-income households may become displaced. The direct evidence on displacement in TOD is scant and measurement of displacement, as a whole, poses methodological challenges (Zuk et al 2015).

Various advocacy and policy groups have suggested a dual goal for TOD – increased affordable housing and reduced greenhouse gas emissions. For instance, the California Housing Partnership Corporation (CHPC) and Transform have argued that housing policy should pursue low-cost rental and ownership opportunities near transit, facilitating the linked goals of driving reduction and affordable housing (CHPC and Transform 2014). These organizations have argued that, from an environmental perspective, housing low-income residents near transit reduces their daily driving by 25-30 percent within one half-mile of transit stations and by 50 percent if households locate within one quarter-mile of the station (CHPC and Transform 2014). They also stress the financial hardship of owning a car, which can be partially alleviated by living in a TOD (CHPC and Transform 2014). This approach bolsters ridership as well, which can benefit transit agencies.

Two advocacy organizations, the Center for Transit-Oriented Development (CTOD) and Reconnecting America, have worked to operationalize TOD development by focusing on the dual goals of emissions reduction and affordable housing. In 2010, CTOD released a "Performance Based TOD Guidebook" to aid local and regional governments in planning and executing successful TODs. This guidebook presupposes the existence of a variety of densities and uses in station areas and sorts stations in various U.S. transit networks into their greenhouse gas emission reduction potential (CTOD 2010a). In the CTOD report, reductions in emissions are from reduced vehicle miles travelled (VMT) – a cumulative measure of miles a household drives per day (CTOD 2010a, CTOD 2010b). In 2007, Reconnecting America conducted a report for the Metropolitan Transportation Commission (MTC) of the San Francisco Bay Area that detailed TOD development guidelines and typologies (Reconnecting America 2007). This report categorized TODs into seven place-type characteristics and gave specific guidelines for densities of building, employment and population densities, as well as a mix of uses (Reconnecting America 2007).

In the California context, state law requires metropolitan planning organizations to demonstrate how their plans are consistent with reductions in greenhouse gas emissions from mobile sources over time.[3] The California Sustainable Communities and Climate Protection Act of 2008 (SB 375) sets targets for emissions reduction in the form of VMT reduction at the regional level (ARB n.d.). Regional transportation and metropolitan planning agencies are

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[3] Mobile sources of greenhouse gas emissions are those that move, such as cars or trucks, as opposed to stationary sources such as power plants.

charged with reaching these targets. SCAG's recent regional transportation plan reflects goals for such reductions: a 9 percent per capita emissions reduction by 2020 and a 16 percent reduction by 2035 (SCAG 2012), both of which exceed the SB 375 targets. Both SB 375 and regional plans link environmental policy and local planning by directing development to transit corridors, i.e., building and enhancing TODs, with the aim of reducing emissions (ARB n.d., SCAG 2012). Advocacy organizations such as CTOD and Reconnecting America have supported efforts such as SCAG's by proposing a typology-based and scenario-based development model (CTOD 2010a, CTOD 2010b, Reconnecting America 2007). Such a modeling approach recognizes that station-area neighborhoods across the system differ by type. Thus, there is a need to categorize station areas, so that planners in each area can share best practices and standards. As an example, Reconnecting America (2007) has categorized TOD areas in the Bay Area by their development potential and has also included emissions reduction potential.

While TOD seems like an attractive solution to both reducing vehicle emissions and creating affordable housing, there may be previously unforeseen tension between these goals. The relationship between these two goals is less straightforward than often thought. Higher income households tend to drive more than lower income households, according to the 2010-2012 California Household Travel Survey (CHTS) (see Table 1). For that reason, and as Table 1 demonstrates, the potential reduction in VMT for households that locate near public transit is much greater for higher income households. In fact, the numbers in Table 1 indicate that VMT reductions for households in the \$100-150K income range are potentially more than double that of households in the \$0-35K annual income range. These numbers are indicative only of cross-sectional patterns, and do not serve as an estimate of what would happen if persons moved to TOD areas. The data in Table 1 do, however, serve as a useful starting point for our research here, where we develop a model designed to estimate the potential tradeoffs between VMT and affordable housing under different TOD scenarios.

Distance to rail → **Annual Household Income ↓**	**Actual daily VMT, households within 0.5 mile radius of Metro rail stations**	**Sample size of households within 0.5 mile radius of Metro rail stations**	**Actual daily VMT, households beyond 0.5 mile radius of Metro rail stations**	**Sample size of households beyond 0.5 mile radius of Metro rail stations**	**Difference in VMT**
$0-10,000	6.35	57	12.84	593	-6.49
$10,001-$35,000	16.20	181	23.38	2,797	-7.18
$35,001-$50,000	23.82	70	32.96	1,549	-9.13
$50,001-$100,000	31.97	131	42.65	4,376	-10.68
$100,001-$150,000	34.35	38	49.86	2,289	-15.51
$150,001-$250,000	57.52	24	59.14	1,400	-1.62
All income levels	23.93	501	39.10	13,004	-15.18

Source: Author calculations based on Caltrans (2013a) data

Table 1

Actual household daily VMT values, averages for household income bands in the SCAG region

3. Data Sources and Study Area

This study focuses only on the LA Metro system and its 80 stations throughout the metropolitan area.[4] A map of the network with the stations at the time of research is provided in Figure 3. Notably not included are a number of alternatives to the LA Metro rail network such as the LA Metro Bus Rapid Transit system and the Metrolink commuter rail network. Also, due to limitations on employment data, our study only focuses on 63 out of the 80 stations (See Figure 5 for a visual representation of in-sample versus out of sample station areas). These 63 stations do,

[4] At the time of research, only 80 stations were open. At the time of publication, 93 stations were open.

however, provide variation in neighborhood characteristics such as density, land use, employment, demography, and other characteristics relevant to TOD planning.

Data for this research come primarily from four sources. First, the CHTS collects travel diary information for a sample of households in the state. The 2010-2012 Survey was used to construct estimates of Vehicle Miles Traveled (VMT), which serves as an estimate of household greenhouse gas emissions (California Department of Transportation 2013a). Second, the CHTS

Source: LA Metro

Figure 3

The LA Metro light rail and subway system, 2014

data were combined with GIS-based highway and transit location data, including SCAG data on station locations (SCAG 2015b), to construct accurate estimates of VMT for households and their location in relation to transit stations. The method we used to estimate VMT is described in detail in Step 6, below. Third, we used census data to gather information about the housing makeup and demographics of areas surrounding LA Metro stations (U.S. Census Bureau 2000, 2011). Because the boundaries of census tracts do not correspond neatly to the station areas of interest, we employed the methods of Boarnet et al (2015) to estimate the characteristics of the areas immediately surrounding the stations. This method is summarized in Step 2, below. Finally, employment data come from Infogroup's 2011-vintage InfoUSA database.[5] This database lists employment establishment data by address and number of employees.

4. Building the Scenario Model

A scenario model tests the tradeoffs between various future development choices. The variables of interest vary widely by model, and the models themselves range from simple two-variable implementations like Tonguz et al. (2009), to multivariable implementations like UrbanSim that can create detailed models including many relevant characteristics relating to land use, transportation, and environmental planning (Waddell 2002).

Our model focuses on the tradeoffs between scenarios involving two variables: housing affordability and VMT. VMT, as previously mentioned, is a proxy for greenhouse gas emissions. The model itself can be broken down into two parts, illustrated in Figure 4. First, the model generates the number and rent level of new housing units that each station area is able to accommodate by employing station typologies based on the most relevant neighborhood characteristics. Second, the model uses these housing unit numbers to generate the estimated changes in VMT that would result depending on the affordability mix of the housing units constructed.

[5] Database provided via SCAG.

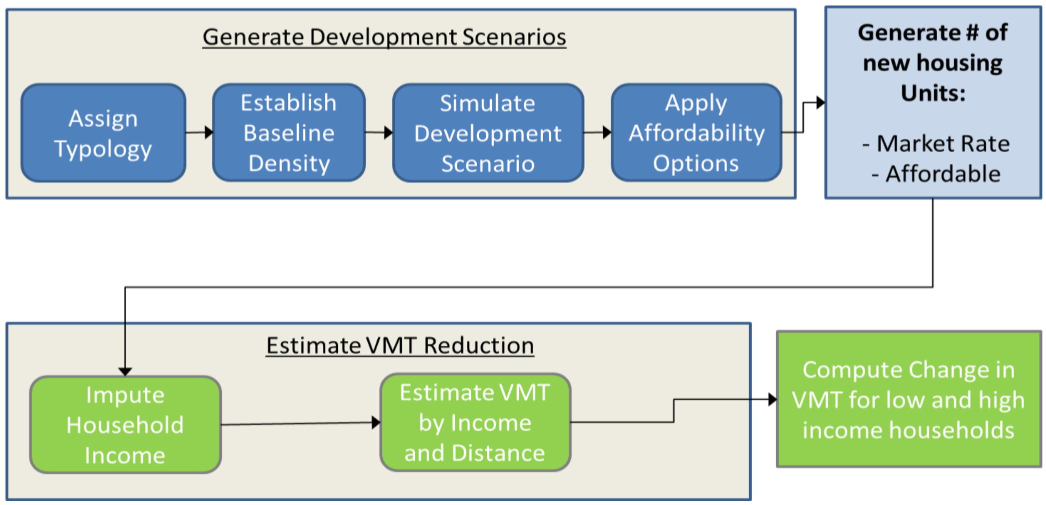


Figure 4
The scenario model approach

4.1 Model Part 1 – Develop station typologies and housing development scenarios

The first four steps of the model are concerned with setting up station area typologies and then generating housing development scenarios based on those typologies. Specifically, the housing development scenarios differ in terms of development density and percentage of housing units that are affordable.

Step 1: Define typologies

The 63 stations of our study area are in neighborhoods with a variety of different densities, land uses, and demographic makeups. The key first step is to determine which station area criteria are most relevant for the scenario model, and then to group the stations by these criteria. The previous literature has found several different characteristics useful for this grouping process. For example, in their station area planning manual for the Bay Area transit system in 2007, Reconnecting America and the MTC created a set of seven typologies based on five station area characteristics. The criteria they used were the mix of housing, the target number of new housing units, net housing density, target jobs creation number, and minimum floor to area ratio (Reconnecting America 2007). These criteria appeal to the need for the consideration of local community characteristics (future building and housing mix and target new units), local market conditions (net housing density), and the understanding that not every TOD is (or will be) an employment pole (target jobs and minimum floor to area ratio) (Reconnecting America 2007). Their neighborhood types range from regional center (highest jobs and housing density) to transit neighborhood (lowest jobs and housing density).

Studies that focus specifically on the Los Angeles transit system have developed typologies of nine types (CTOD 2010a) and four types (LA Metro 2012). CTOD (2010a) used two input variables to determine their nine typologies: intensity of use (residents plus employees in a half-mile radius of station) and mix (ratio of employees to residents in a half-mile radius of station) and included commuter rail, LA Metro rail, and LA Metro Bus Rapid Transit stations in their analysis. Their typologies range from suburban neighborhoods (low intensity / low ratio of workers to residents), to mixed use center (moderate intensity / moderate ratio of workers to residents), to CBD/special district (high intensity and employee-resident ratio). LA Metro's Countywide Sustainability Planning Policy and Implementation Plan (2012) used three criteria to categorize stations into their five typologies: residential density (households per acre), job centrality (the number of jobs and their distance from each census tract), and average annual VMT per household. Their categorization resulted in four station area types: regional center, sub-regional / neighborhood / district centers, special use or suburban/rural communities, and clusters of moderate residential density with low job centrality.

Given the work already done by these organizations, this study builds on their collective approaches. We adapt the input criteria in CTOD (2010a) to define five station area typologies most similar to LA Metro (2012). The two input criteria are: intensity of station area use and ratio of employment to residents. Data for these for station areas were obtained by spatial interpolation following Boarnet (2015) (see step 2 for detailed explanations). After consulting prior research (CTOD 2010a, LA Metro 2012, Reconnecting America 2007), we constructed cutoff values for each of these two criteria, then assigned typologies based on these thresholds. This resulted in five typologies: high density downtown, central place, neighborhood center, single family home area, and industrial / employment center. Table 2 shows the cutoff values for each typology. Figure 5 shows the typologies mapped against the LA Metro rail network. Figure 6 shows the distribution of stations based on our two criteria values.

The High-Density Downtowns typology represents the locus of the highest density development, skewing toward a focus on employment (though residential uses are also represented). Predictably, stations in downtown Los Angeles and downtown Long Beach neighborhoods are categorized as High-Density Downtowns. On the low end of the density spectrum, Single Family Home Areas are characterized by generally low density residential development (for Los Angeles standards) and little to no commercial employment. Single Family Home Areas were scattered throughout the system, including next to the Universal City / Studio City, South Pasadena, Redondo Beach, and Lincoln Heights station areas. The Industrial / Employment typology represents areas with nearly zero residential developments and characterized by large industrial or transportation uses, and are found exclusively on the Green Line near LAX. The last two typologies, Central Places and Neighborhood Centers embody a gradient of medium density and a mix residential and employment uses. As shown in Figure 6, neighborhood centers do contain a strong multi-family housing component and some neighborhood retail and small office uses, but not anything coming close to a downtown-feeling development. These are embodied by station areas in Boyle Heights, East Los Angeles, and along the Blue Line in Southeast Los Angeles, and Compton. In contrast, Central Places are more commercially oriented, with higher levels of residential density, tending toward, but not fully approaching the Downtown typology (see Figure 6). Central Place station areas were found in East Hollywood, Koreatown, Exposition Park / University Park, South Central, and parts of Pasadena and Long Beach.

Criteria → **Station Area Typology**	**Employment mix** (ratio of workers to residents)	**Intensity** (population +employees)	**Number of Qualifying Stations System-wide**
1. High Density Downtown	>1.5	>45,000	8
2. Central Place	<0.5	>21,000	24
	0.5-1.5	>12,000	
	>1.5	12,000-45,000	
3. Neighborhood Center	<0.5	12,000-21,000	19
	0.5-1.5	<12,000	
4. Single Family Home Area	<0.5	<12,000	8
5. Industrial / Employment Center	>1.5	<12,000	4

Table 2
LA Metro rail station typologies and criteria value thresholds

Figure 5
LA Metro stations by typology

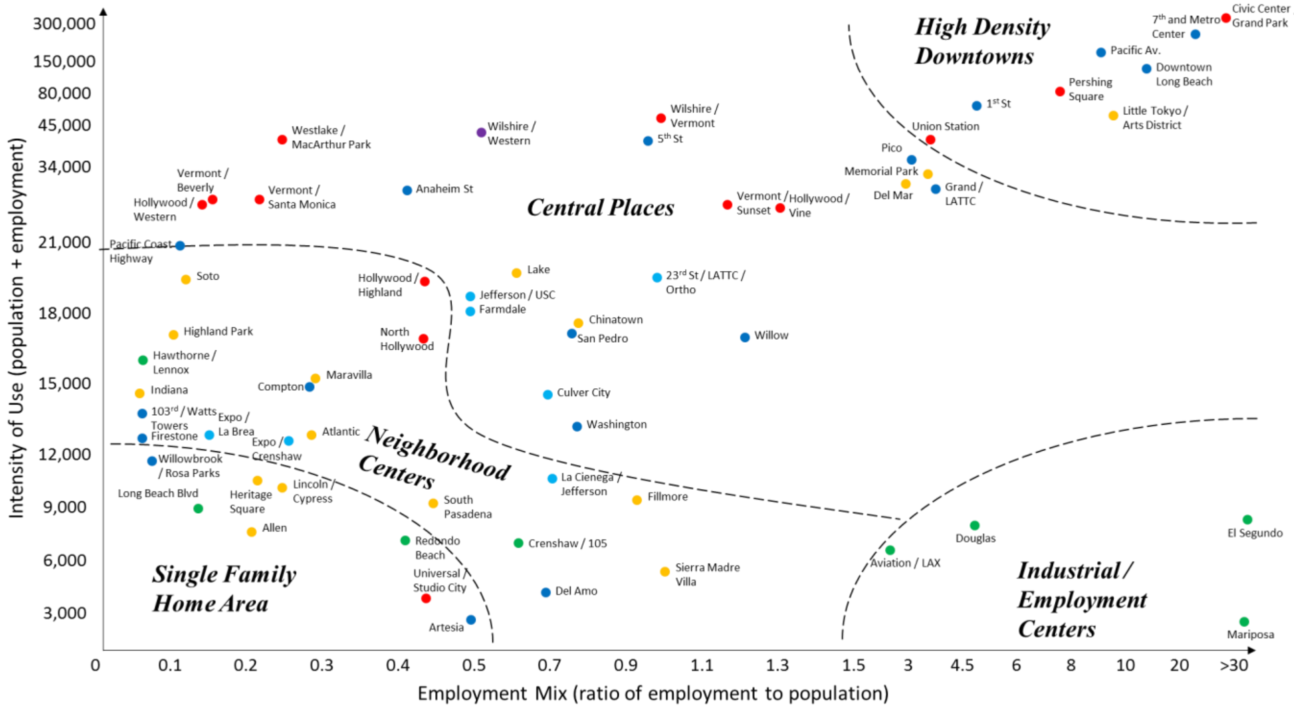


Figure 6

Los Angeles Metro station area typology chart

In order to further validate our choice of criteria, we conducted interviews with a variety of experts, listed on Table 3. These interviewees confirmed our selection of employment mix and station intensity as the most relevant variables. Experts even suggested that the applicability of these criteria may extend, with appropriate calibration of cutoff values, to metro areas other than Los Angeles.

Stakeholder Group	**Organization**	**Interviewee**
Environmental Groups	Natural Resources Defense Council (NRDC)	Shelley Poticha, Director of Urban Solutions Catherine Cox Blair, Senior Policy Advocate for Urban Solutions
Federal Government	US HUD	Harriet Tregoning, Director of Office of Economic Resilience

Housing Finance	Enterprise Community Partners, Inc.	Melinda Pollack, VP TOD John Hersey, Program Officer
Land Use Policy Advocates	Lincoln Institute of Land Use Policy	Armando Carbonell, Chair of the Dept. of Planning and Urban Form
Smart Growth Advocates	Funders Network for Smart Growth and Livable Communities	Geoff Anderson, President and CEO Ann Fowler Wallace, Director of Programs
	Center for Neighborhood Technology	Scott Bernstein, President and Co-Founder Jacky Grimshaw, Vice President of Policy

Table 3
Expert interviews

Step 2: Define station area and establish baseline densities

We defined a station area as a circle of half-mile radius, uniform in all directions and centered on the station location. We then gathered data for each station circle, including employment, population, number of households, median household income, number of owner- and renter-occupied units (by year structure built), and median gross rent (by year structure built).

The employment data from InfoUSA includes the addresses of employer-establishments as well as the number of employees at each location. The address data allowed us to geocode employee locations and to create a shapefile that could be intersected with the station area information to determine how many employees were within each station area circle. As mentioned, this data was incomplete for 17 out of the 80 total light rail stations, and we were therefore unable to assign typologies for those stations.

Housing and population data are at the tract level, but because most station areas are comprised of multiple census tracts we used a spatial interpolation method to estimate the values contained within the station areas (following Boarnet et al. 2015). Specifically, to determine estimated population, household, or housing unit count *C* for station area *S* within the boundaries of a station area, we used

$$C_s = \sum_{n=1}^{N} \frac{C_n A_{ns}}{A_n}$$

Where:
S contains *N* census tracts in full or in part;
Census tract is denoted by *n (n=1, 2… N)*;
C_n = population, household, or housing unit count of census tract *n* (available directly from census data);
A_n = total area of census tract *n*;
A_{ns} = area of census tract *n* contained within station area *S*

The results from this formula then also allowed us to calculate housing unit density for each station area. We took the housing unit numbers obtained by spatial interpolation and divided them by the total number of acres in a station area. Table 4 reports the average residential housing unit density in units per acre by station and Table 5 reports this metric aggregated at the typology level.

Where the census data only provide an average measure M_n at the census tract level (e.g., median household income, median gross rent, etc.), the aggregate average value at the station area level is derived as:

$$M_s = \sum_{n=1}^{N} \frac{M_n P_{ns}}{P_s}$$

Where:
P_s = estimated total number of units or observations within station area S, for which the average measure is being derived (e.g., households in case of household income);

P_{ns} = estimated number of units or observations in census tract *n* contained within station area *S*

The results from the above data collection procedure are contained in Table 4, which shows our demographic data for every LA Metro station.

Having obtained the input data, we next classify LA Metro stations into the typologies described in Table 2: eight station areas are classified as high-density downtowns, 24 are central places, 19 are centers, eight are single-family home areas, and four are industrial / employment areas. Figure 6 (above) plots these stations on the axes of intensity of use and the employment-residential mix which were used in calculating the typologies. This chart reveals several clusters:

- Low worker to resident ratio and middle net use intensity (mainly in the neighborhood center typology);
- Medium intensity areas with a parity of workers and residents (mainly in the central place classification); and
- High employment to resident ratio areas, mainly falling in the high-density downtowns and industrial / employment center classifications.

Train Line	Station	Median Gross Rent	Total Occupied Housing Units	Popul-ation	Employ-ment	Residential density (units / acre)	Employ-ment Mix (emp / pop)	Intensity (pop + emp)	Typology
BLUE	103rd St. / Watts Towers	985	3084	13428	1098	6.1	0.1	14526	Neighborhood Center
BLUE	1st St.	1052	6231	11968	55592	12.4	4.6	67560	High Density Downtown
BLUE	5th St.	942	8295	18606	18762	16.5	1.0	37368	Central Place
BLUE	7th St. / Metro Center	1110	6589	11093	233221	13.1	21.0	244314	High Density Downtown
BLUE	Anaheim St.	903	6353	20490	8112	12.6	0.4	28602	Central Place
BLUE	Artesia	1089	618	2538	1269	1.2	0.5	3807	Neighborhood Center
BLUE	Compton	981	2863	11735	3508	5.7	0.3	15244	Neighborhood Center
BLUE	Del Amo	1080	792	2869	2151	1.6	0.7	5020	Neighborhood Center
BLUE	Downtown Long Beach	1077	5495	10556	119359	10.9	11.3	129914	High Density Downtown
BLUE	Firestone	1029	2845	12596	1055	5.7	0.1	13652	Neighborhood Center
BLUE	Florence	970	3207	13800	—	6.4	—	13800	Not in sample
BLUE	Grand / LATTC	721	2173	6032	21344	4.3	3.5	27376	Central Place

BLUE	Pacific Av.	951	7613	16777	139307	15.1	8.3	156085	High Density Downtown
BLUE	Pacific Coast Hwy.	963	5135	19810	2077	10.2	0.1	21887	Central Place
BLUE	Pico	1295	3550	7491	25599	7.1	3.4	33090	Central Place
BLUE	San Pedro St.	873	2278	9652	8272	4.5	0.9	17923	Central Place
BLUE	Slauson	802	2569	11214	—	5.1	—	11214	Not in sample
BLUE	Vernon	948	2473	11234	—	4.9	—	11234	Not in sample
BLUE	Wardlow	1207	2579	7543	—	5.1	—	7543	Not in sample
BLUE	Washington	1117	1678	7291	6523	3.3	0.9	13813	Central Place
BLUE	Willow St.	1071	2275	7816	9282	4.5	1.2	17098	Central Place
BLUE	Willowbrook / Rosa Parks	930	2479	10796	1085	4.9	0.1	11881	Single Family Home Area
EXPO	Culver City	1346	3727	8297	6261	7.4	0.8	14558	Central Place
EXPO	Expo / Crenshaw	1014	3565	9584	2396	7.1	0.2	11980	Single Family Home Area
EXPO	Expo / La Brea	1004	3885	10929	1818	7.7	0.2	12747	Neighborhood Center
EXPO	Expo / Vermont	1004	2978	12285	—	5.9	—	12285	Not in sample
EXPO	Expo / Western	1033	4188	15281	—	8.3	—	15281	Not in sample
EXPO	Expo Park / USC	1088	1697	9865	—	3.4	—	9865	Not in sample
EXPO	Farmdale	1021	4260	11555	6432	8.5	0.6	17987	Central Place
EXPO	Jefferson / USC	1207	1941	11812	6425	3.9	0.5	18237	Central Place
EXPO	La Cienega / Jefferson	1049	2264	5957	4533	4.5	0.8	10490	Neighborhood Center
EXPO	LATTC / Ortho Institute	969	2396	9790	9883	4.8	1.0	19674	Central Place
GOLD	Allen	1272	2594	6373	1528	5.2	0.2	7901	Single Family Home Area
GOLD	Atlantic	904	2428	9379	2963	4.8	0.3	12342	Neighborhood Center
GOLD	Chinatown	876	2725	10166	8203	5.4	0.8	18369	Central Place
GOLD	Del Mar	1607	4581	7863	24868	9.1	3.2	32731	Central Place
GOLD	East LA Civic Center	933	2787	11373	—	5.5	—	11373	Not in sample
GOLD	Fillmore	1567	2884	5512	5125	5.7	0.9	10638	Neighborhood Center
GOLD	Heritage Square	1052	2410	8359	1817	4.8	0.2	10176	Single Family Home Area
GOLD	Highland Park	1065	4535	14413	1696	9.0	0.1	16109	Neighborhood Center
GOLD	Indiana	992	3577	14140	1466	7.1	0.1	15606	Neighborhood Center
GOLD	Lake	1311	5272	11599	8750	10.5	0.8	20349	Central Place
GOLD	Lincoln / Cypress	1009	2281	7639	2001	4.5	0.3	9640	Single Family Home Area
GOLD	Little Tokyo	937	2789	6645	54146	5.5	8.1	60790	High Density Downtown
GOLD	Maravilla	995	2780	11547	3898	5.5	0.3	15445	Neighborhood Center
GOLD	Mariachi Plaza	859	2836	9987	—	5.6	—	9987	Not in sample
GOLD	Memorial Park	1548	3844	7413	29273	7.6	3.9	36685	Central Place
GOLD	Pico / Aliso	873	2024	6849	—	4.0	—	6849	Not in sample
GOLD	Sierra Madre Villa	1505	1159	3199	3426	2.3	1.1	6625	Neighborhood Center
GOLD	Soto	920	4716	17801	2549	9.4	0.1	20350	Neighborhood Center
GOLD	South Pasadena	1404	2664	6528	3030	5.3	0.5	9558	Single Family Home Area
GOLD	Southwest Museum	1053	2121	6956	—	4.2	—	6956	Not in sample
GOLD	Union Station	928	1586	10531	37696	3.2	3.6	48227	High Density Downtown
GREEN	Avalon	1127	2461	10007	—	4.9	—	10007	Not in sample

GREEN	Aviation / LAX	1245	678	2081	5708	1.3	2.7	7789	Industrial / Employment Center
GREEN	Crenshaw	1281	1367	4582	2537	2.7	0.6	7119	Neighborhood Center
GREEN	Douglas	1966	586	1496	7165	1.2	4.8	8661	Industrial / Employment Center
GREEN	El Segundo	2001	11	28	9049	0.0	327.7	9077	Industrial / Employment Center
GREEN	Harbor Freeway	1084	2742	9986	—	5.5	—	9986	Not in sample
GREEN	Hawthorne / Lennox	1059	4075	15404	1525	8.1	0.1	16929	Neighborhood Center
GREEN	Lakewood Bl.	1194	2406	8709	—	4.8	—	8709	Not in sample
GREEN	Long Beach Bl.	1015	2244	11398	1539	4.5	0.1	12937	Neighborhood Center
GREEN	Mariposa	1573	0	1	2468	0.0	2468.5	2469	Industrial / Employment Center
GREEN	Norwalk	1371	1913	7295	—	3.8	—	7295	Not in sample
GREEN	Redondo Beach	1569	1826	5347	2175	3.6	0.4	7522	Single Family Home Area
GREEN	Vermont / Athens	950	2720	8667	—	5.4	—	8667	Not in sample
RP	Civic Center / Grand Park	1127	6108	10745	305872	12.2	28.5	316617	High Density Downtown
RP	Hollywood / Highland	1174	8734	14654	6296	17.4	0.4	20950	Neighborhood Center
RP	Hollywood / Vine	1077	7565	14204	18377	15.0	1.3	32582	Central Place
RP	Hollywood / Western	1015	9869	22737	3839	19.6	0.2	26577	Central Place
RP	North Hollywood	1295	5562	12485	5482	11.1	0.4	17967	Neighborhood Center
RP	Pershing Square	1073	9244	13276	80270	18.4	6.0	93546	High Density Downtown
RP	Universal City / Studio City	1682	2755	4795	2092	5.5	0.4	6887	Single Family Home Area
RP	Vermont / Beverly	996	8150	23167	3931	16.2	0.2	27098	Central Place
RP	Vermont / Santa Monica	964	7704	22095	5184	15.3	0.2	27279	Central Place
RP	Vermont / Sunset	1063	6977	16529	18860	13.9	1.1	35389	Central Place
RP	Westlake / MacArthur Park	786	12451	36121	8500	24.8	0.2	44621	Central Place
RP	Wilshire / Normandie	1043	15976	38045	—	31.8	—	38045	Not in sample
RP	Wilshire / Vermont	1012	13809	34121	36107	27.5	1.1	70228	Central Place
RP	Wilshire / Western	1091	13743	32136	15491	27.3	0.5	47627	Central Place

Sources: U.S. Census Bureau, 2010 census; Infogroup, "Reference USA" database; SCAG transit shapefile; Author Calculations for Intensity, Employment Mix, and spatial interpolation of census variables

Table 4
LA Metro station area demographics, criteria values, and typology type

Step 3: Simulate housing development scenarios

The next step was to develop a systematic method of generating targets for new housing units in each station area, basing those targets on the assigned station area typologies. First, we took the baseline residential unit density that we had calculated previously, then compared this number to the types of densities supported by LA Metro Countywide Sustainability Policy

(2012) for their accessibility cluster types (these are listed in Table 5, column 3). We then created two housing development scenarios, one of “moderate densification” and one of “aggressive densification”. Under the moderate densification scenario, we reference the densities supported by LA Metro (2012) as the proposed maximum and minimum target density values. Specifically, the highest density typology was set at the top of LA Metro’s range of supported density, while the lowest density typology was set at LA Metro’s lowest. We set the remaining typologies at the midpoint between LA Metro’s highest and lowest supported density. For the aggressive densification scenario, we simply doubled the targets of the moderate density scenario. While this target may seem overly aggressive at first glance, note that many station areas have already surpassed these targets (Refer to Table 4 for current densities). Table 5, column 5 summarizes this scenario.

These target density figures provide us with the ability to calculate targets for new housing units. To do so, we generate new housing units for a station area by raising the existing housing unit density (Table 4) to that suggested by each scenario in its typology (Table 5).[6] For example, the Fillmore station on the Gold Line is identified as a neighborhood center and has a current density of 5.7 dwelling units per acre which represents 2,884 total housing units. Its moderate densification scenario raises the density to 7.0 dwelling units per acre which represents 3,518 total housing units, meaning there are 634 new units; the aggressive densification scenario raises density to 14.0 dwelling units per acre for a total of 7037 total housing units or 4,153 new units. If a station area has a density at or above the recommended scenario density, no new units are added.

[6] This current report focuses on generating new rental housing units, for modeling simplicity. However, the method and intuition easily extend to include owner-occupied units as well.

We calculate the net new housing units for each station and sum them up by scenario type. Column 3 of Table 6 shows that the moderate scenario yields 58,375 net new housing units in Los Angeles County TODs while the aggressive scenario yields 273,222 net new housing units.

Station Area Typology	**Average Current Density** (du/acre)	**Densities Supported by LA Metro Sustainability's Policy** (du/acre)	**"Moderate Scenario" Density Targets** (du/acre)	**"Aggressive Scenario" Density Targets** (du/acre)
1. High Density Downtown	11.4	>14	14	28
2. Central Place	11.7	7-14	10.5	21
3. Neighborhood Center	6.3	0-14	7	14
4. Single Family Home Area	5.1	0-7	3.5	7
5. Industrial / Employment Center	0.6	<2	0	0

NOTE: Average current density was obtained from author calculations. Densities supported by LA Metro's Sustainability Policy are obtained from LA Metro (2012).

Table 5

Current and modeled scenario residential densities (dwelling units / acre) by typology type

Step 4: Apply Affordability Options

With a net new number of housing units for each station area for each scenario in hand, we divide these new units into affordable and market-rate units. As we noted above, exclusive pursuit of the environmental goal of reducing greenhouse gases can potentially adversely affect the availability of affordable housing. Thus, policymakers might want to explicitly reserve a percentage of the new units for people with lower incomes, a policy commonly known as inclusionary zoning/housing, to make some progress on this policy objective as well. Our model explores variation in outcomes across different inclusionary policy choices. We utilize two inclusionary percentage rules as affordability options: (i) 20% of net new units are affordable and (ii) 60% of net new units are affordable. The inclusionary percentage is applied to all rail station areas. The 20% level is reminiscent of many city-wide inclusionary zoning policies as well as density bonus policies. The 60% level is similar to that required by certain mixed-income housing programs such as the Low-Income Housing Tax Credit (LIHTC) program.

Given a development, the model divides the total new units obtained in Table 6 column 3, into market-rate and affordable units (Table 6, columns 4 and 5) for each inclusionary option. As expected, higher density targets yield higher new unit counts. Similarly, a higher affordable percentage yields a higher number of affordable units for a given density level.

Scenario Name	**Affordability Option (Inclusionary Percentage)**	**Total New Units**	**New Market Rate Units**	**New Affordable Units**	**Net Daily VMT Change**
Moderate Densification	20% of units affordable	58,375	46,700	11,675	-371,223
	60% of units affordable	58,375	23,350	35,025	-286,998
	20% of units affordable	273,222	218,577	54,644	-1,757,701

Aggressive Densification	60% of units affordable	273,222	109,289	163,933	-1,355,864

Table 6
System-wide scenario model output: VMT change and housing units created

4.2 Part 2 – Calculate VMT changes

The final three steps take the housing unit scenarios from Part 1 and estimate the changes in VMT based on the profile of the hypothetical residents who would live in these units.

Step 5: Impute household income

As previously shown (Table 1), VMT is positively correlated with income. Our model, therefore, imputes an income level to the residents of the units based on the affordability of the unit. To generate an average income profile for new residents, we set their income at the minimum amount earned at which a household would spend 30 percent of its income on rent. This same calculation applies for both affordable and market rate units. Households paying above the 30 percent threshold are considered rent burdened by the U.S. Department of Housing and Urban Development (HUD) (U.S. HUD(b), n.d.).

We defined market rate and affordable housing rent levels as follows: *market rate* rent is defined as the median station area rent for units that are constructed after 2000; but for station areas with no new units constructed after 2000, we simply used the overall median market rent for that station area.[7] We defined *affordable* units to be 50 percent of market rate. Figure 7 shows the resulting distribution of affordable rent prices. Our process generates an average monthly rent of $558 for an affordable unit across all station areas in our sample, which appears to be a reasonable figure. For example, it compares favorably to the U.S. Department of Housing and Urban Development's Section 8 income limits and rent burden guidance. Under this guidance, a rent of $558 is affordable to all Los Angeles households except for 1-2 person households designated as "Extremely Low Income," meaning an annual household income less than $19,950 (U.S. Department of Housing and Urban Development, 2015).[8] For reference, note that the Fair Market Rent in Los Angeles County for 2015 was $1424 for a 2-bedroom unit (U.S. HUD 2015), so $558 compares favorably in terms of affordability here too. State and local estimates also lend credence to this figure. The California low-income housing tax credit (LIHTC) property rent limit calculator generates a maximum of $760 monthly for an efficiency (smaller than a 1-bedroom) which is well above our $558 figure (Novogradac & Company, 2016). Moreover, $558 is also within the Los Angeles Housing Department's affordable set-aside unit rent maximum.[9]

[7] The definitions of market rate and affordable housing use the median rent numbers as generated by the spatial interpolation method described in Step 2. Median gross rents for units built after 2000 are from the interpolation of median census tract rents into each half-mile station area using ACS 2009-2013 data.
[8] $558 is affordable to nearly all Section 8-eligible families. The 2015 US HUD annual income limits for the Los Angeles-Long Beach MSA for a 1-person household (smallest possible) at a "Low Income" designation is $46,500, of which 30% monthly rent burden is $1162 at a "Very Low Income" designation is $29,050, of which 30 percent monthly rent burden is $726. Even a three-person household at an "Extremely Low Income" designation for a 3-person household is $22,450 would be able to afford the $558 monthly rents, as 30 percent monthly rent burden for this category is $561.
[9] $558 is affordable compared to monthly maximum rents proposed by the Los Angeles Housing Department for Density-Bonus related affordable unit set-asides. (Los Angeles Department of City Planning. "Affordable Housing Incentives Guidelines" p. 15)

Source: Author Calculations

Figure 7
Histogram of implied affordable rent prices by station area

We impute new resident income as the minimum annual income that a household must earn to pay 30 percent of its income in rent. This creates two new resident profiles for each station area: a set of residents earning incomes of which 30 percent will cover rent in a unit affordable in that station area and a set of residents earning incomes of which 30 percent will cover rents in a market rate unit in that station area. System-wide, this process generates an income profile for new households for each station area for both affordable and market rate units.

Step 6: Model changes in VMT by household income

In the next step of our model, we compare VMT for households residing inside and outside of TODs. To obtain these figures, we use the trip length variable for each household in the 2010-2012 California Household Travel Survey sample. We estimate VMT for households by aggregating trip lengths for all trips in household-owned and not owned vehicles, and we excluded trips by multiple members of a household in the same vehicle to avoid double counting. Households in the survey have location data, and we use this information to compare household VMT between households within station areas and those outside. We excluded all households with incomplete data, meaning those households that do not have data on all six of our explanatory variables (listed on Table 7). We also excluded households with incomes over $250,000 due to insufficient observations. The resulting sample, therefore, was comprised of 13,659 household observations. Table 1 shows the unadjusted VMT values by income strata in the SCAG sample.

To provide further accuracy, however, we used a regression model to predict the size of household effects on VMT. We chose a Tobit regression specification because the sample includes censored data for our dependent variable—22% of surveyed households had zero VMT on the survey day. The set of explanatory variables are those pertaining to the most relevant household characteristics, including income, household size, the number of household members who are employed, and the distance of a household to the nearest LA Metro or Metrolink (i.e. commuter rail) station.

The model is as follows:

$$Y_i \begin{cases} Y_i^* \text{ if } Y_i^* > 0 \\ 0 \text{ if } Y_i^* \leq 0 \end{cases}$$

$$\text{Where } Y_i^* = \beta_0 + \sum_{j=1}^{m} \beta_j W_{ij} + \sum_{k=1}^{n} \beta_k X_{ik} + \sum_{j=1}^{m} \sum_{k=1}^{n} \beta_{jk} W_{ij} X_{ik} + \sum_{l=1}^{p} \beta_q Z_{il} + \varepsilon_i$$

Where:
Y_i = household daily VMT in miles; Y_i* is its latent variable,
W_{ij} = household income band dummy variables,
X_{ik} = distance variables = 1 if the household lives within a half-mile of an LA Metro or Metrolink station (there are separate variables for the half-mile distance from LA Metro and Metrolink stations, due to the differences between two systems),
Z_{il} = household characteristics ("i" indexes households).

The equations above show a two step process. First, the dependent variable, Y_i, which stands for household daily VMT in miles, is characterized as binary: 0 if household VMT is 0 and Y_i*, if it is above zero. Second, Y_i*, is regressed on a set of income category dummy variables (1 if the household is in that income category, 0 if not), a set of distance dummy variables (1 if the hosuehold lives within a half-mile of an LA Metro or Metrolink station), an interaction term between the income category dummy variables and the distance to Metro station dummy variable, and a set of household characteristics inlcuding household size, number of vehicles, and percent of persons employed. The specific definitions of the variables for household characteristics are shown in Table 7. Importantly, the interaction terms, $W_{ij}X_{ik}$, are a set of interaction variables (using the household income dummies and the rail proximity dummies) that allow us to model the effect of living within a half-mile of a rail station.

Variable name	**Description**	**Variable type**
Const	Intercept	Continuous
half_mile	Household is within or outside a half-mile radius from the transit station	Dummy (1 = within half-mile radius)
inc_10k	Household has annual income equal to or less than $10,000 a year	Dummy (1 = yes)
inc_10to35k	Household has annual income equal to or less than $35,000 but greater than $10,000 a year	Dummy (1 = yes)
inc_35to50k	Household has annual income equal to or less than $50,000 but greater than $35,000 a year	Dummy (1 = yes)
inc_50to100k	Household has annual income equal to or less than $100,000 but greater than $50,000 a year	Dummy (1 = yes)
inc_100to150k	Household has annual income equal to or less than $150,000 but greater than $100,000 a year	Dummy (1 = yes)

Variable name	Description	Variable type
halfmile_inc10k	Household is within a half-mile radius from the transit station and has annual income equal to or less than $10,000 a year	Dummy (1 = yes)
halfmile_inc10to35k	Household is within a half-mile radius from the transit station and has annual income equal to or less than $35,000 but greater than $10,000 a year	Dummy (1 = yes)
halfmile_inc35to50k	Household is within a half-mile radius from the transit station and has annual income equal to or less than $50,000 but greater than $35,000 a year	Dummy (1 = yes)
halfmile_inc50to100k	Household is within a half-mile radius from the transit station and has annual income equal to or less than $100,000 but greater than $50,000 a year	Dummy (1 = yes)
halfmile_inc100to150k	Household is within a half-mile radius from the transit station and has annual income equal to or less than $150,000 but greater than $100,000 a year	Dummy (1 = yes)
halfmile_commuting_rail	Household is within or outside a half-mile radius from commuting rail transit station	Dummy (1 = within half-mile radius)
hhveh	Number of household vehicles	Continuous
hhsize	Number of persons in the household	Continuous
hhemp	Number of household members that are employed	Continuous

Table 7
VMT model variable list and description

Table 8 shows the result of four regression models for our sample (columns numbered 1-4). Regression 1 shows the effect of household income and household characteristics on VMT. Being a higher household income is associated with higher VMT, and household size, the number of household vehicles, and the number of workers in the household are all positively associated with VMT. Regression 2 adds the distance variables. Regression 2 shows that living within a half-mile distance from LA Metro rail stations is associated with a reduction in VMT. Regression 3 replaces the half-mile LA Metro and Metrolink dummy variables with the interaction variables between household income and distance to LA Metro rail stations. At every income band up to $150,000 per year, living within a half-mile of a rail station is statistically significantly associated with lower household VMT, although the income – half-mile interaction variables are in some cases significant at the ten percent level. Finally, Regression 4 shows how all variables are associated with household daily VMT. Due to collinearity with the half-mile dummy variables, the income – half-mile interaction variables are not individually statistically significant in Regression 4. But the combined half-mile dummy variables and the income – half-mile interactions are jointly significant, as indicated by a likelihood ratio test that compares the joint significance of the variables that are in Regression 4 but not in Regression 1 (Table 9). This test indicates that the interactions can be used to predict fitted values, and that the joint effect of residence near rail and household income is statistically significant.

	(1)	(2)	(3)	(4)
Const	-2.72 (1.96)	-2.15 (1.97)	-2.35 (1.96)	-2.46 (1.98)
half_mile		-10.12*** (2.59)		4.77 (9.77)
inc_10k	-36.92*** (2.87)	-36.25*** (2.87)	-35.59*** (2.97)	-35.49*** (2.98)
inc_10to35k	-21.34*** (1.84)	-20.92*** (1.84)	-20.66*** (1.86)	-20.56*** (1.87)
inc_35to50k	-11.63*** (1.97)	-11.34*** (1.97)	-11.15*** (1.99)	-11.06*** (2.01)
inc_50to100k	-4.99*** (1.62)	-4.84*** (1.61)	-4.65*** (1.62)	-4.55*** (1.63)
inc_100to150k	-2.21 (1.76)	-2.19 (1.76)	-1.90 (1.77)	-1.81 (1.78)
halfmile_inc10k			-15.13* (1.96)	-19.64 (12.60)

	(1)	(2)	(3)	(4)
halfmile_inc10to35k			-11.29*** (4.01)	-15.78 (10.48)
halfmile_inc35to50k			-10.11* (5.90)	-14.58 (11.34)
halfmile_inc50to100k			-10.04** (4.13)	-14.51 (10.53)
halfmile_inc100to150k			-13.64* (7.11)	-17.98 (12.03)
halfmile_commuting_rail		-1.31 (5.12)		-1.23 (5.14)
hhveh	11.57*** (0.60)	11.37*** (0.60)	11.36*** (0.60)	11.37*** (0.60)
hhsize	3.84*** (0.38)	3.80*** (0.37)	3.81*** (0.37)	3.81*** (0.37)
hhemp	8.82*** (0.65)	8.95*** (0.65)	8.95*** (0.65)	8.94*** (0.65)
Log(scale)	3.95	3.95	3.95	3.95
Observations	13659	13659	13659	13659
Log-likelihood	-5.96E+04	-5.96E+04	-5.96E+04	-5.96E+04
Wald-statistic	2879	2899	2901	2901
Wald p-value	2.22E-16	2.22E-16	2.22E-16	2.22E-16

Dependent variable is household daily VMT.
Standard errors in parenthesis
*Significance codes: *** $p < 0.01$; ** $0.01 \le p < 0.05$; * $0.05 \le p \le 0.1$*

Table 8
Regression model results

Regression	Number of degrees of freedom	Log-likelihood	Resulting degrees of freedom	Chi squared	Pr(>Chi squared)
(1)	10	-59602			
(4)	17	-59590	7	24.362	0.001***

*Significance codes: *** $p < 0.01$; ** $0.01 \le p < 0.05$; * $0.05 \le p \le 0.1$*

Table 9
Likelihood ratio significance test (Regression 4 versus Regression 1)

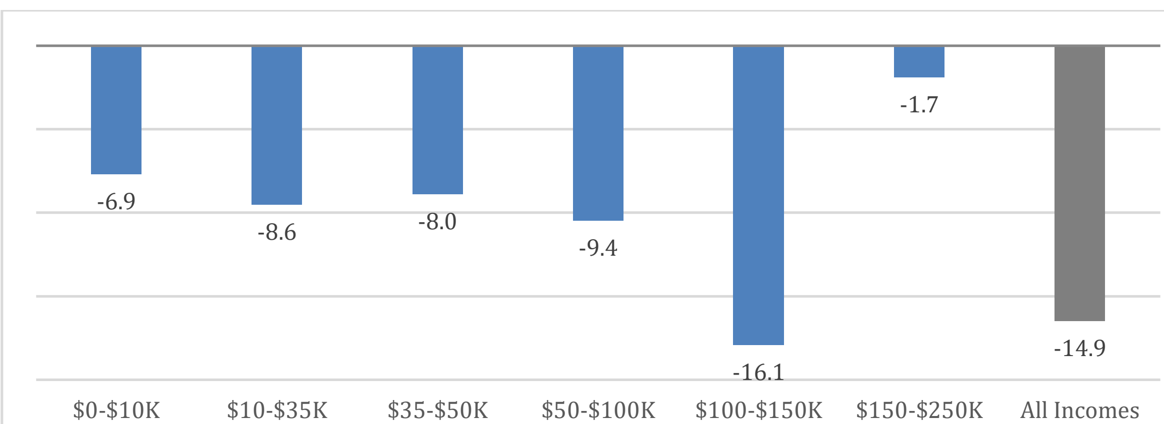
We used the results for the latent variable in Regression 4 to generate predicted values for household VMT (i.e. from Equation 1, we predicted Y_i from Y_i*). Regression 4, unlike Regression 3, allows us to predict VMT for households with incomes larger than $150,000, and for that reason we prefer to use the predicted values from Regression 4 in the scenario model. The predicted values in Table 10 show that the same relationship holds from the actual data (Table 1); higher income households reduce VMT the most when living near transit.

Distance to rail → **Annual Household Income ↓**	**Predicted VMT, households within 0.5 mile radius of Metro rail stations**	**Sample size of households within 0.5 mile radius of Metro rail stations**	**Predicted VMT, households beyond 0.5 mile radius of Metro rail stations**	**Sample size of households beyond 0.5 mile radius of Metro rail stations**	**Difference in VMT**
$0-10,000	8.90	57	15.83	593	-6.92
$10,001-$35,000	18.20	181	26.76	2,797	-8.57
$35,001-$50,000	28.85	70	36.86	1,549	-8.01
$50,001-$100,000	36.61	131	46.04	4,376	-9.43
$100,001-$150,000	36.58	38	52.73	2,289	-16.15
$150,001-$250,000	55.43	24	57.13	1,400	-1.70
All income levels	26.93	501	41.79	13,004	-14.86

Table 10
Predicted household daily VMT values by income band
(from Table 8, Regression 4; samples sizes are in parentheses)

Because the regression controls for income and rail proximity, the predictions are specific to each income band. Figure 8 illustrates the VMT changes by income band. Most noteworthy is that upper-middle class households ($100-150K in annual income) have the largest reductions in VMT, and these reductions are almost double that of lower-income households. Overall the average predicted reduction is 14.9 miles, which is similar to the unadjusted CHTS average of 15.2.

It is important to note that higher-income households tend to have higher baseline VMT than lower-income households. Thus, it follows that higher-income households may have more VMT to reduce, in absolute terms than lower-income households. Thus, they may contribute more to reducing GHG emissions. That said, lower-income households, by moving to TODs, may reduce their share of VMT by higher percentages than higher-income individuals, which may leave them with lower transportation costs, which is also a positive outcome. These overall findings are consistent with Boarnet et al (2015) which surveyed new movers to Los Angeles' Expo Line station areas and a control group of new movers to surrounding neighborhoods. The study found that new movers to TODs reduce their overall VMT compared to control groups (Boarnet et al 2015). They also found that new movers increase the number of train trips made compared to residents who resided within half-mile of stations prior to the Expo Line's opening (Boarnet et al 2015). However, more research would be required to generalize these results beyond these specific cases.



Source: Authors' analysis of data from Caltrans (2013a)

Figure 8

Predicted change in VMT (miles per household per day) for each income bracket, predicted value for households outside 0.5 mile radius from rail transit stations minus value for households within 0.5 mile radius from rail transit stations.

Of course, this model assumes that households do not move to station areas because of unobserved characteristics. Previous studies, however, have demonstrated the value of cross-sectional estimates and indicate that the risk of selection bias is low (Brownstone 2008; Cao, Mokhtarian, and Handy 2009; Duranton & Turner 2016).

Step 7: Compute system-wide daily VMT differences

The final step of our model is to obtain an overall picture of the change in VMT and, therefore, the total potential reductions in greenhouse gas emissions. This step is straightforward: we simply add up all VMT changes predicted under each development scenario. We first sum all changes due to new households moving into station areas under a given scenario, then, to obtain a system-wide value, we add up the changes from all station areas. Table 11 (and Table 6, column 6) show the results of these calculations. The largest system-wide VMT reduction occurs in the aggressive densification, 20 percent affordability scenario, with a net annual VMT reduction of 641 million miles, and on average a 6.4-mile daily reduction per unit. In general, both aggressive densification scenarios reduce nearly five times as many vehicle miles travelled than the moderate densification scenarios. The moderate 20 percent affordability scenario yields a system-wide reduction of 134.4 million miles annually and a 6.3-mile daily reduction per unit. The higher inclusionary percentage scenarios also reduce VMT but the rates are not as high as for the lower inclusionary percentage scenarios.

Scenario Name	Affordability Option (Inclusionary Percentage)	Total New Units	Net Daily VMT Change	Net Annual VMT Change	Per Unit Daily VMT Change	Per Unit Annual VMT Change

Moderate Densification	20% of units affordable	58,375	-371,223	-134.4 million	-6.3	-2,321
	60% of units affordable	58,375	-286,998	-104.8 million	-4.9	-1,794
Aggressive Densification	20% of units affordable	273,222	-1,757,701	-641.6 million	-6.4	-2,348
	60% of units affordable	273,222	-1,355,864	-494.9 million	-5.0	-1,811

Table 11
Modelled VMT change details

5. Deployment and Implementation

The most important finding of our research is that data suggests there is indeed a tradeoff between the equity goal of affordable housing and the environmental goal of greenhouse gas emission reduction. In the extreme, a policymaker seeking to maximize the environmental benefit of housing near transit would provide no affordable housing options at all and instead generate TOD scenarios that target higher income residents exclusively. Of course, we do not suggest that, and we simply point out that possibility to illustrate the possibility of tension between near-station affordable housing and VMT reduction goals. Yet our scenario model illustrates ways forward that can give attention to both goals. The implications of this research apply beyond Los Angeles to all metropolitan areas struggling to find solutions to these countervailing goals.

Overall, the scenario model reveals some important relationships that have policy implications. First, as expected, higher income households (those earning more than $50,000 annually) living in TOD areas reduce VMT slightly more than lower income households, regardless of the densification scenario one chooses. Second, higher density development reduces VMT much more than lower density, regardless of the chosen affordability mix. Finally, the high-density scenarios produce more affordable housing than the low-density scenarios, regardless of the affordable housing percentage target. For instance, under the aggressive development scenario even the lower inclusionary target (i.e. 20 percent) calls for 54,644 affordable rate units, while the moderate densification target generates at most 35,025, that is, even under the higher inclusionary target. As long as neighborhoods are sufficiently dense, the tradeoff between environmental and housing affordability interests evaporates. However, many of Los Angeles' current TOD neighborhoods have not reached that level of density and so the emissions – affordability tradeoff remains an important consideration.

These last results suggest that policymakers may want to advocate for high densification scenarios with lower affordable housing targets. This would generate more total affordable housing than moderate densification while also providing substantial VMT reduction because it still targets some higher income households to move to TOD areas. The increased densities proposed by both the moderate and aggressive development scenarios are feasible for Los Angeles. The existing residential density in station areas is 8.1 dwelling units (du) per acre. The moderate scenario raises the average residential density within a half-mile of stations by only 1.5 du / acre or an 18 percent increase in TOD density to an average of 9.6 du/acre. The aggressive scenario would increase density in half-mile TODs to 14.9 du / acre, or an average increase in density within a half-mile of stations of 6.8 du / acre (84 percent). Figure 9 shows that many station areas already meet the Moderate scenario targets. Figure 10 shows that some station areas are well on their way to meeting the Aggressive scenario. Therefore, planners may be well served in focusing on station areas with the greatest potential to promote higher density with a low inclusionary percentage.

To put such policies in place, planners may want to choose an approach similar to the "20/50" affordability scheme common for low-income housing tax credit (LIHTC) projects.[10] This approach would have the additional benefit of creating more mixed-income neighborhoods, which have many appealing features. Zielenbach and Voith (2010) showed that mixed-income developments have positive effects on neighborhood economic conditions. Others have theorized that mixed-income communities help fight urban poverty by providing greater access to higher quality amenities and transforming informal social norms (Joseph et al., 2007). Further, this broad density-oriented strategy should be palatable to developers, many of whom are interested in building denser residential and mixed-use buildings.

High development density can generate other problems, however, and these may present difficulties to planners seeking to implement such policies. For instance, high residential density may increase traffic congestion in TOD areas, negatively influencing public perceptions of the development and creating political headwinds. Also, if the affordable housing targets are not properly enforced, the area can gentrify and displace prior residents. And even with proper enforcement, mixed-income residential development can alter commercial development patterns in ways that defeat the equity goal by effectively shutting out low-income consumers. Understanding the potential displacement-related effects of VMT reduction as well as other equity issues should be a consideration for future research.

Some of the most important considerations for deployment and implementation are potential fiscal and political roadblocks. Planners may need to get creative and search for

[10] The 20/50 approach means that 20 percent of the units have rents that are affordable to households with incomes at 50 percent of the area's median income.

funding sources that can incentivize high-density development, such as the Low-Income Housing Tax Credit, subsidies, or developer bonuses. They also need to anticipate political pushback. The political environment in Los Angeles, for instance, appears to be increasingly hostile to high-density developments, as evidenced by the emergence of the Neighborhood Integrity Initiative of the Coalition to Preserve L.A. This Initiative would create a two-year moratorium on out-of-plan unit increases for developments and would reduce planners' abilities to approve project-specific exceptions (Zahniser 2015). Such political difficulties can only be overcome through community engagement, strong leadership, and coordination between community organizations, businesses, developers, and parcel owners. Planners will need to coordinate with these groups as they develop plans for each station area, tailoring plans to the needs of the each individual station while also incorporating overall, system-wide goals.

There are other land use and planning considerations in making TODs effective at both reducing emissions and providing affordable homes. The concept of first and last mile connections considers the ease and efficiency of travelling between the transit station and the home or workplace. 91 percent of these connections to LA Metro Rail and Bus Rapid Transit stations involve modes other than driving – bicycling, walking, bus, or skateboard (LA Metro

Figure 9: Residential Density by Los Angeles Metro Station Area: Existing vs. Needed to Reach *Moderate* Scenario Target

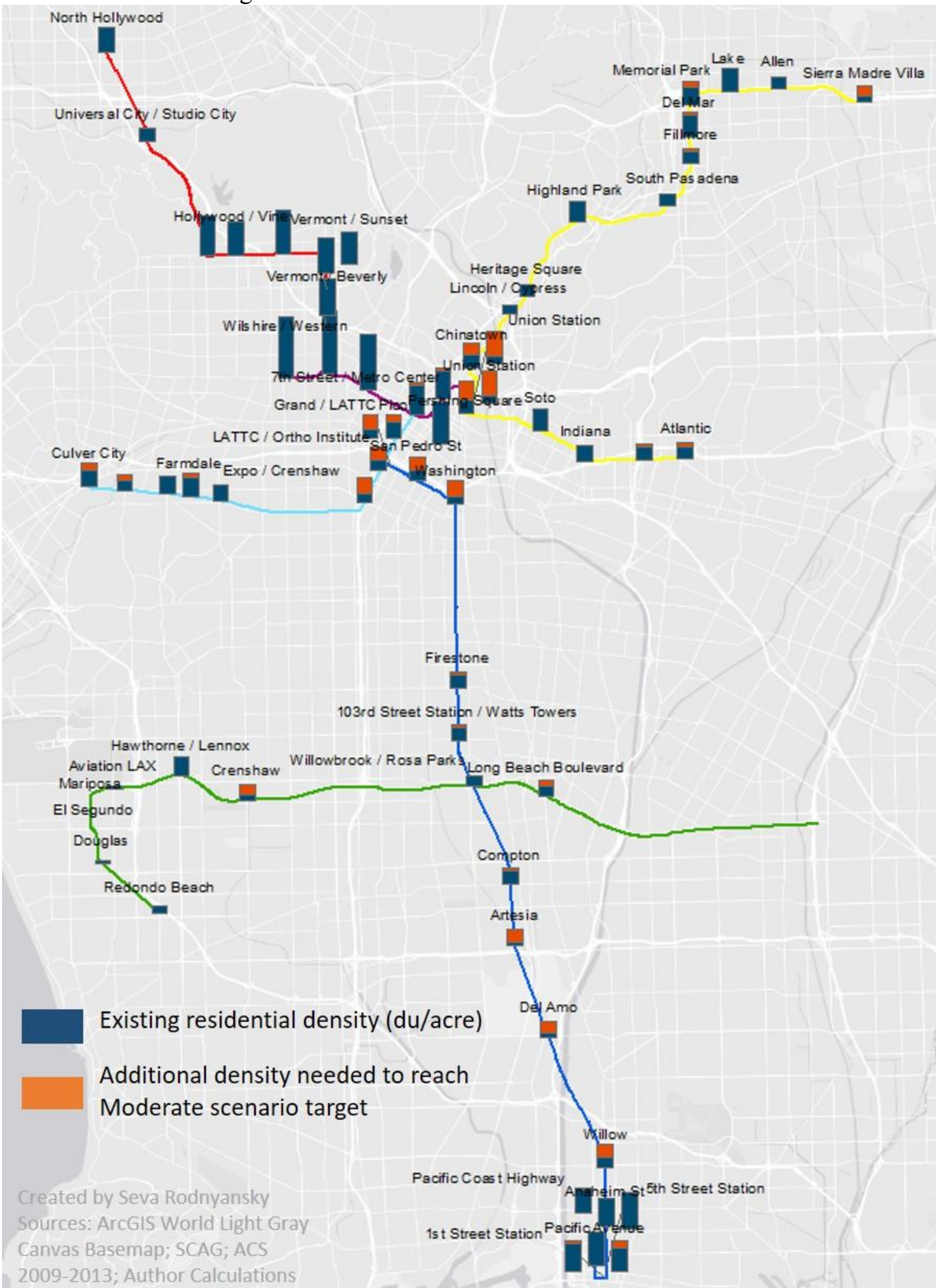
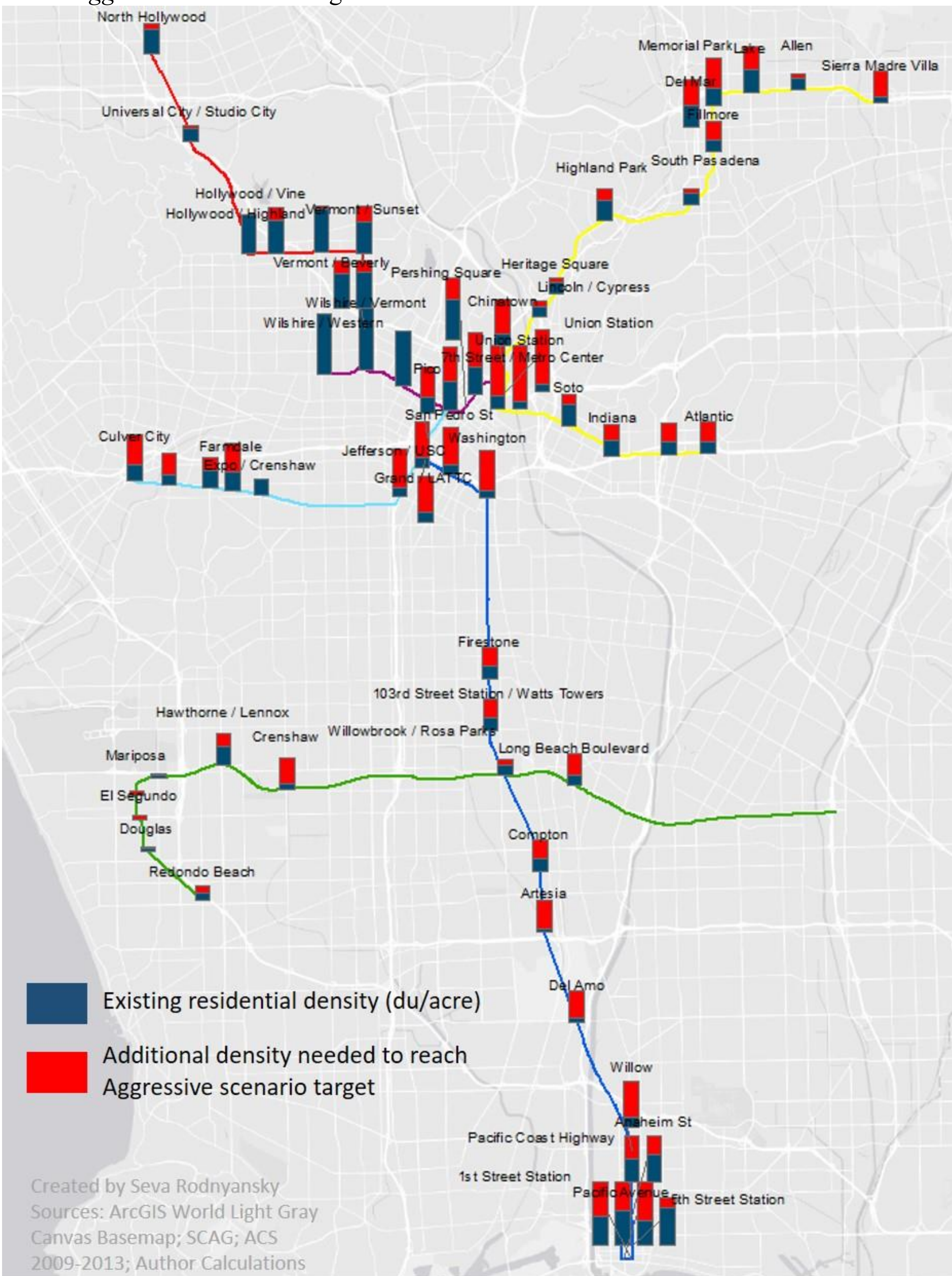


Figure 10: Residential Density by Los Angeles Metro Station Area: Existing vs. Needed to Reach *Aggressive* Scenario Target



and SCAG 2014). Providing adequate first and last mile access for non-drivers can improve the effectiveness of rail transit investments and of TOD developments and can increase access to employment opportunities for transit-dependent households. In fact, a recent study in San Diego showed that adequate provision of first and last mile approaches to transit increases job accessibility by nearly three times (Boarnet et al 2016). In general, TODs afford planners and transit agencies an opportunity to incorporate a variety of transportation modes into the fabric of the neighborhood. A deeper look at these considerations and their influence on the tradeoff between environmental and housing goals should be undertaken in future research projects.

Our use of stylized development scenarios and typologies is intended to be illustrative. Planners looking to create an implementable development plan using this approach will have to augment it with a construction cost analysis to determine feasible density thresholds. Site availability and politics will be critical factors as well. This model is not without limitations, as it only considers one region, one mode, and two outcome variables; it also does not predict ridership changes from the new households in TOD neighborhoods, nor does it assess displacement considerations on existing households. That said, our framework is nimble and versatile – it can be extended to assess tradeoffs between other variables and to incorporate more stations into the analysis.

There are several potential areas for future research. The model and methodology could be expanded to include other metropolitan areas, transit systems, or modes; however, this will require additional work in understanding the typology criteria parameters for those locations and in understanding the appropriate densities for the scenarios in those contexts. Also, the method could be extended to directly estimate air quality benefits of TODs. The research could also, with some effort, explore the tradeoffs between system efficiency and environmental concerns.

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