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Residential development and near-roadway air pollution: Assessing risk and mitigation in San Jose, California



C.J. Gabbe*, Efren Oxlaj, James Wang

Department of Environmental Studies and Sciences, Santa Clara University, 500 El Camino Real, Santa Clara, CA, 95053, USA

ABSTRACT

Air pollution from high-traffic roadways has been connected with serious health conditions and premature death. While housing is commonly built near America's busiest roadways, we know little about the application of mitigation measures that could reduce residents' exposure to transportation-related pollution. This paper assesses the high-traffic roadway proximity of new housing in San Jose (California) and mitigation measures by public and private sector actors. We studied San Jose's 39 largest residential developments approved between 2008 and 2016. We examined project approval documents; visited development sites; measured proximity using geographic information systems (GIS); assessed aerial and Google Street View imagery; and collected data on green building certifications. Many of these developments were near freeways or major highways; about 4% of new housing units were within 500 feet of a high-traffic roadway, and 45% of new units were within 1500 feet of such roads. Public and private sector actors implemented limited mitigation measures. California's state government updated its building energy code and constructed soundwalls along some freeways. Some real estate developers also included green building features that may improve indoor air quality. But, there were no local regulations specifically guiding residential development along high-traffic roadways. In general, public and private sector mitigation measures were limited and uncoordinated. This research informs policymakers' efforts to reduce transportation-related pollution exposure and improve public health.

1. Introduction

Housing is commonly built near freeways and other high-traffic roadways in American cities. California leads the nation, with 40% of its population living within one-third of a mile of a high-traffic road, compared with 19% nationally (Rowangould, 2013). People of color and people with lower incomes are more likely to live in neighborhoods with higher pollution levels of all kinds, including transportation-related emissions, making this an environmental justice issue (Cushing et al., 2015; Morello-Frosch et al., 2011; Pastor et al., 2005).

There is growing evidence about how air pollution harms human health. Air pollution from high-traffic roadways has been associated with coronary heart disease, respiratory problems, and premature death. But, different pollutants exhibit different dispersion patterns. While some pollutants decay sharply near major roadways (e.g., ultrafine particles, black carbon, and oxides of nitrogen), others do not (e.g., PM_{2.5}) (Karner et al., 2010; Padró-Martínez et al., 2012).

There is little evidence about how policymakers mitigate residents' air pollution exposure from transportation sources, and this is important to study because of the health effects from traffic-related air pollution. This paper assesses near-roadway air pollution indicators for new housing in San Jose (California), and identifies mitigation measures by public and private sector actors. We analyzed all residential developments of at least 50 housing units completed between 2008 and 2016 (comprising 12,676 housing units in total). A sizable share of new units was built close to freeways and highways in San Jose. About 4% of new housing units were within 500 feet and 45% of new units were within 1500 feet of a high-traffic roadway. Of the 5723 new units within the 1500-foot buffer, 385 units (7%) were built for low-income families or seniors; these households may be particularly vulnerable to air pollution.

* Corresponding author.

E-mail addresses: cgabbe@scu.edu (C.J. Gabbe), eoxlajtambito@scu.edu (E. Oxlaj), jwang5@scu.edu (J. Wang).<https://doi.org/10.1016/j.jth.2019.03.011>

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Public and private sector actors engaged in limited and uncoordinated mitigation of near-roadway air pollution. Residents in these new housing developments likely experienced lower indoor pollution levels than residents of older buildings in equivalent locations due to California's building energy code updates and the state's construction of soundwalls along freeways. Developers who seek green building certification or exceed minimum air filtration requirements for other reasons may also improve indoor air quality. But local zoning commonly permitting housing adjacent to freeways and the lack of municipal mitigation policies remain issues. While much of the new housing in San Jose – including affordable housing – is being built near freeways, only limited measures are being taken to protect the health of households living near these roadways. Planners and policymakers have an opportunity to develop policies and programs to reduce transportation-related pollution and mitigate pollution exposure.

2. Understanding near-roadway pollution and housing development

Although there is mounting evidence about the causes and health consequences of air pollution from motor vehicles, we know surprisingly little about zoning and housing development near high-traffic roadways. Housing is a permitted land use near most high-traffic roadways, as evidenced by the sizable share of Americans – and particularly Californians – living near such roadways (Rowangould, 2013). For example, Gabbe (2018) found that zoning allowed housing on more than 90% of parcels near freeways in Los Angeles. Compact development could reduce regional emissions while increasing the number of households living near high-traffic roadways in central locations (Bae et al., 2007; Frank and Engelke, 2005; Kaza et al., 2011; Marshall et al., 2009; Schweitzer and Zhou, 2010).

2.1. Pollutants, patterns, and health effects

Common air pollutants from vehicle emissions include particulate matter, nitrogen dioxide, carbon dioxide, sulfur, carbon monoxide, and benzene (Karner et al., 2010). Less obvious are non-exhaust emissions caused by tire and brake wear, including from electric vehicles (Timmers and Achten, 2016). The six criteria air pollutants regulated by the EPA's National Ambient Air Quality Standards are ground-level ozone, particulate matter, nitrogen dioxide, carbon monoxide, lead, and sulfur dioxide (U.S. Environmental Protection Agency, 2016b). California's Ambient Air Quality standards are more stringent and regulate four additional pollutants including visibility reducing particles, sulfates, hydrogen sulfide, and vinyl chloride (California Air Resources Board, 2016). For example, California prohibits exceeding $50 \mu\text{g}/\text{m}^3$ 24-h average concentrations for PM_{10} while the EPA's standards set a limit of $150 \mu\text{g}/\text{m}^3$ (California Air Resources Board, 2016).

Air pollution exposure is harmful to human health, increasing morbidity and premature mortality from cardiovascular diseases, including heart disease, heart attacks, and heart failure (Anderson et al., 2012; Delfino et al., 2005). Air pollution – of which particulate matter has been most studied – has been connected with a host of respiratory and pulmonary problems, including asthma, chronic obstructive pulmonary disease, and reduced lung function (Anderson et al., 2012; Bernstein et al., 2004; Brugge et al., 2007; Brunekreef and Holgate, 2002; Kampa and Castanas, 2008; Laumbach and Kipen, 2012; Nel, 2005; Pope and Dockery, 2006; Rückerl et al., 2011). There is also evidence connecting particulate matter with strokes, specifically ischemic strokes, which are caused by obstructed cerebral arteries (Anderson et al., 2012; Hong et al., 2002; Kettunen et al., 2007; Lisabeth et al., 2008; Shah et al., 2015).

While most studies have focused on adults, there is a growing understanding of how air pollution affects fetal health (Glinianaia et al., 2004b), infant mortality (Glinianaia et al., 2004a; Šrám et al., 2005), and chronic disease in children, including asthma and bronchitis (Schwartz, 2004). Carbon monoxide and ozone exposure have been associated with increased risk for some birth defects (Ritz et al., 2002). Carbon monoxide, ozone, and particulate matter exposure have also been connected with premature births and low birth weights (Ritz et al., 2007; Wilhelm and Ritz, 2003).

Certain population groups are more exposed to air pollution and at greater risk of health harms. People of color and those with low incomes are more likely to live in areas with worse air quality (Bae et al., 2007; Houston et al., 2004; Pastor et al., 2004, 2005; Sider et al., 2015; Stewart et al., 2014). Infants and children, older people, and those with a variety of underlying health conditions may be particularly susceptible to the negative effects of air pollution; low socioeconomic status may exacerbate individuals' susceptibility (O'Neill et al., 2003; Pope and Dockery, 2006).

Pollution dispersion depends on a combination of factors. Levels of some pollutants (e.g., carbon monoxide and certain ultra-fine particulates) decrease rapidly over distance, with at least a 50% drop within 150 m (Karner et al., 2010; Patton et al., 2014a, b). Other pollutants (e.g., fine particulates, nitrogen dioxide, and benzene) drop off more gradually (Karner et al., 2010; Kimbrough et al., 2013). Particulate levels are generally highest for the first 100–200 m downwind of the roadway and tend to fall to background levels within 300–500 m (Karner et al., 2010; Kimbrough et al., 2013; Massoli et al., 2012; Zhou and Levy, 2007; Zhu et al., 2002). Dispersion patterns can vary considerably depending on wind speed and direction, time of day, season, and other factors (Brugge et al., 2007; Zhou and Levy, 2007). Pollutant concentrations are generally higher in cold temperatures, in winter, in low wind speeds, and in the morning (Kimbrough et al., 2013; Padró-Martínez et al., 2012; Patton et al., 2014a, b; Patton et al., 2014a, b).

There is a complex and context-sensitive relationship between the dispersion factors listed above and local pollution levels. Massoli et al. (2012), for example, observed more temporal patterns for NO_2 than spatial patterns. In urban street canyons, as another example, wind direction changes can increase pollutant concentrations at higher levels above the street (Karra et al., 2011) and high wind speeds may decrease average concentrations at the street level (Ming et al., 2018).

Noise pollution also negatively affects residents near high-traffic roadways. While recent studies have found varying correlations between environmental noise and air pollution, results suggest that noise pollution causes health problems independently from air pollution (Stansfeld, 2015). Long-term health harms from excessive noise exposure include impaired hearing, elevated hypertension

in adults, ischemic heart disease, increased annoyance, and disrupted sleep (Kim et al., 2012; Passchier-Vermeer and Passchier, 2000; Stansfeld, 2015).

Scholars and policymakers have defined high-traffic roadways in different ways. Many have defined high-traffic roadways using 25,000 or 50,000 annual average daily traffic (AADT) thresholds (Green et al., 2004; Houston et al., 2006, 2013; Ong et al., 2006; Rowangould, 2013). Others have focused on roadways with more than 1000 daily trucks (Ryan et al., 2005) or on areas with high traffic densities (Janssen et al., 2001; Lipfert et al., 2006). Planners and policymakers tend to define “high-traffic” as somewhere in the 50,000 to 100,000 AADT range. One Federal Highway Administration study defined high-traffic as 50,000 AADT, while acknowledging considerable variability among state departments of transportation (Fekpe et al., 2004). The California Air Resources Board defines high-traffic as 50,000 AADT in rural areas and 100,000 AADT in urban areas (California Air Resources Board, 2017).

2.2. Efficacy of site-level mitigation strategies

Mitigation strategies are interventions that reduce residents’ exposure to air pollution. The main interventions to reduce near-roadway pollution exposure include reducing emissions through cleaner fuels, more efficient vehicles, reduced vehicle travel, and improved road performance; separating people from emissions; and employing other mitigation strategies (US Department of Transportation, 2015).

There is emerging evidence about the efficacy of on-site and near-site mitigation strategies. Brugge et al. (2015) labeled strategies as “good” if pollutant concentrations decreased by more than 40%, “moderate” if concentrations fell less than 40%, and inconclusive if evidence was insufficient. “Good” strategies included indoor air filtration, building insulation and soundproofing. “Moderate” strategies included site design, and placing or planting physical barriers – soundwalls and dense vegetation – between roadways and residences (Brugge et al., 2015).

Soundwalls and dense vegetation are barriers that may reduce pollution levels next to major roadways, depending on the design of the barrier and meteorological conditions. Soundwalls can reduce pollution levels by up to 50% within 150–300 m [492–984 feet] downwind of a major roadway (Baldauf et al., 2008, 2016; Hagler et al., 2012). The barriers in the literature generally range in height from 4.5 m (Baldauf et al., 2016) to 6 m (Bowker et al., 2007; Hagler et al., 2012).

Vegetative barriers are less effective – and the results are more variable – than soundwalls. Hagler et al. (2012), for example, studied one site with evergreen and another with deciduous tree stands, and found mixed results for ultrafine particle concentrations. The effectiveness of vegetative barriers depends on the proximity to the roadway, type of vegetation, amount of leaf cover, the thickness of the tree stands, and effect on air flow patterns (Brantley et al., 2014; Hagler et al., 2012; Janhäll, 2015). Additionally, while vegetative barriers may disperse air pollutants vertically, there can be higher pollutant concentrations in vegetated street canyons due to reduced air flow (Janhäll, 2015). Vegetative barriers may also allow the deposition of pollutants, and this varies by particle size (Janhäll, 2015). The combination of a noise barrier and vegetative barrier may produce the best results, but further research is needed (Baldauf et al., 2008; Lee et al., 2018; Paulson et al., 2017; Van Renterghem et al., 2015).

Indoor air quality is a function of indoor and outdoor pollution sources, and ventilation and filtration factors (Bhangar et al., 2011). The two main categories of air filtration for residences are whole house systems and portable systems, and whole house systems seem to be more effective (Sublett et al., 2010). The most common filtration rating system is the Minimum Efficiency Reporting Value (MERV) rating from the American Society of Heating, Refrigeration and Air Conditioner Engineers (National Air Filtration Association, 2017; Sublett et al., 2010). Filters are rated from MERV 1 to MERV 20, with common residential ratings between MERV 1 and MERV 8 (National Air Filtration Association, 2017). Filters rated at MERV 12 or MERV 13 or above tend to be most effective at removing ultrafine particles and PM_{2.5}, but these filters do not remove gaseous pollutants (Brown et al., 2014; Singer et al., 2017; Stephens and Siegel, 2013; Sublett et al., 2010). Additionally, filter effectiveness requires regular maintenance and replacement; most American households buy inexpensive filters and rarely replace them (Sublett et al., 2010).

City, county, and state transportation agencies may change the design or regulation of roadways to reduce emissions. Design features may promote a better free flow of vehicles because stop-and-go driving leads to more emissions (Ahn et al., 2009; Ahn and Rakha, 2009; Pandian et al., 2009; Rakha et al., 2000). These features include roundabouts at some intersections instead of stop signs or lights, and coordinated traffic signal timing (Ahn et al., 2009; Coelho et al., 2006; De Coensel et al., 2012; Madireddy et al., 2011; Stevanovic et al., 2009). Roundabouts, though relatively uncommon in the U.S., may be an effective strategy; roundabouts decreased PM_{2.5} levels by up to 40% near two intersections in Keene, New Hampshire (Garceau, 2018). Transportation agencies may also reduce speed limits, given growing evidence that speeds above 55 miles per hour lead to greater emissions (Bel and Rosell, 2013; Dijkema et al., 2008; Rakha et al., 2000).

3. San Jose, CA as a case to better understand zoning and housing development near major roadways

San Jose, California is a growing city of more than 1 million people in the heart of Silicon Valley (U.S. Census Bureau, 2016). San Jose grew by about 130,000 people between 2000 and 2016 (U.S. Census Bureau, 2000, 2016). Santa Clara County’s population is primarily white (45%) and Asian (35%); more than one-quarter of residents identify as Hispanic or Latino (U.S. Census Bureau, 2017). About 60% of the city’s housing built between 2000 and 2016 was attached or multifamily, and the city aims to focus growth in designated urban villages (City of San José, 2011; U.S. Census Bureau, 2016b). Residents of Santa Clara County, of which San Jose is the largest city, spend an average of 28 min commuting to work and the majority (75%) drive alone; most commuters (86%) also work within the county (U.S. Census Bureau, 2017). About 82% of the vehicles registered in the county are autos, while trucks make up 12% of registered vehicles (California Department of Motor Vehicles, 2017). Metropolitan San Jose is one of the nation’s top

markets for electric vehicle sales share, with electric vehicles accounting for more than 13% of new vehicle sales in 2017 (Lutsey, 2018).

While California has the largest share of near-roadway residents of any state, several cities and the state government have adopted initiatives to address traffic-related air pollution. The California Air Resources Board (CARB) is the lead agency in addressing near-roadway air pollution. CARB produced several reports and commissioned research on mitigation measures, and its focus shifted from a buffering strategy to one encouraging pollution mitigation (California Air Resources Board, 2005, 2017). For instance, CARB-funded research on soundwalls suggested air pollution mitigation may be a co-benefit of noise-reducing solid barriers (Paulson et al., 2017). Also, California banned new school construction within 500 feet of a freeway in 2003 – although the law allows exceptions under limited circumstances – and discourages sensitive uses, including residential development, in these areas (California Air Resources Board, 2005, 2010). But, zoning designations and housing development approvals near freeways are primarily a municipal responsibility.

San Jose does not have any local policies pertaining to near roadway housing construction, although several other major California cities do. San Francisco and Los Angeles adopted specific policies to reduce air pollution exposure in new housing. In 2008, San Francisco began requiring air filtration systems of MERV 13 for new development in areas where $PM_{2.5}$ concentrations exceed $10 \mu\text{g}/\text{m}^3$ or where the risk of cancer from lifetime exposure to air pollutants exceeds 100 in a million (City and County of San Francisco, 2014). The city created, and regularly updates, maps showing parts of the city with high pollution levels, and locations within 500 feet of a freeway (City and County of San Francisco, 2014). In 2016, Los Angeles updated its building code to require new buildings within a 1000 feet radius of a freeway be equipped with air filters of MERV 13 (City of Los Angeles, 2016). Los Angeles also created “Clean Up Green Up” districts for Boyle Heights, Pacoima/Sun Valley, and Wilmington, aimed at reducing the negative health impacts from industrial facilities, and freight transportation and other vehicle sources in these neighborhoods (City of Los Angeles, 2016).

4. Data and methods

Detailed records of new San Jose multifamily development formed the basis of our analysis. We started with the city of San Jose's list of completed major residential development projects with at least 50 dwelling units submitted after January 1, 2008 and completed or deemed as likely to develop in the near future (City of San Jose, 2016a, b). This dataset includes 39 residential developments with a total of 12,676 units. Of these, 29 are multifamily, two are a mixture of single-family and multifamily, and eight are single-family only. We used the city's permitting website to download project plans for each development (City of San Jose, 2016a, b). We reviewed these records to identify attributes of each development, including market-rate and affordable housing units, residential density, other land uses on-site, off-street parking spaces, and open space provision.

A combination of federal and county traffic counts was used to identify high-traffic roadways. Highway Performance Monitoring System data include AADT for all state and federal highways (U.S. Federal Highway Administration, 2012). The data do not include traffic counts for Santa Clara County's expressways, which we obtained for 2016 and digitized separately (Santa Clara County, 2017). We added indicator variables for roadways with over 50,000 AADT, which we define as high-traffic roadways. This definition is consistent with that of the Federal Highway Administration, and California's definition for rural roads (California Air Resources Board, 2017; Fekpe et al., 2004). Again, we note that California's definition for high-traffic urban roads is 100,000 AADT (California Air Resources Board, 2017).

Traffic density and diesel particulate estimates were available by Census tract from the state's CalEnviroScreen dataset (California Environmental Protection Agency, 2017). Traffic density was calculated based on traffic volumes for all roads within 150 m of each Census tract in 2013 (California Environmental Protection Agency, 2017). We estimated diesel particulates using a California Air Resources Board emissions model (California Environmental Protection Agency, 2017). We analyzed diesel particulates – of which key mobile sources are trucks and buses – because they are a carcinogenic air contaminant for which data were available (California Environmental Protection Agency, 2017). For both the traffic density and diesel particulate measures, CalEnviroScreen includes percentiles for each tract on a statewide basis.

We measured the distance from each development to the nearest high-traffic roadway and assigned each development to the Census tract within which it fell. We used ArcGIS software to measure the Euclidean distance from the centroid of each parcel to the road centerline. We chose this approach because it represented the average distance of a unit in the development from the high-traffic roadway.

We collected data on mitigation measures including roundabouts, speed limits, soundwalls, and dense vegetation. Roundabouts were visually assessed using Google aerial imagery of a 1500-foot buffer around each housing development. Speed limits were based on posted speeds (Santa Clara County, 2018). Soundwalls and dense vegetation between high-traffic roadways and housing developments were identified using field observations and Google Streetview. Each development was assigned with an indicator variable representing if there was a full soundwall between the housing development and a high-traffic roadway within 1500 feet.¹ Each housing development was also assigned with a categorical variable reflecting whether it had no dense vegetation, partial dense vegetation or dense vegetation. Our definition of dense vegetation was based on USDOT example images (U.S. Environmental Protection Agency, 2016a).

¹ Although comprehensive soundwall spatial data were not available from Caltrans at the time of writing, we validated this method using data provided by Caltrans for one freeway segment.

Table 1
Housing units by type and high-traffic roadway proximity.

High-traffic roadway proximity	Affordable housing		Market-rate housing		All housing	
	Units	Share of total	Units	Share of total	Units	Share of total
0–500 feet	290	51%	234	2%	524	4%
0 - 1500 feet	385	67%	5338	44%	5723	45%
Any distance	573		12,103		12,676	

Data were not available for the type of air filtration system and filter MERV rating. We identified developments that were certified green buildings through the Leadership in Energy and Environmental Design (LEED) program (U.S. Green Building Council, 2019). LEED certification can be achieved at levels of “certified”, “silver”, “gold”, and “platinum” based on a number of required and voluntary criteria. Most multifamily buildings certified through the LEED program would have filters rated at least MERV 6 or MERV 8, depending on the building characteristics, and MERV 13 or higher for additional credits (U.S. Green Building Council, 2019). While the LEED program has a major focus on reducing indoor sources of air pollution, the program’s enhanced indoor air quality strategies include additional optional measures to prevent contamination from the outdoor sources (U.S. Green Building Council, 2019).

5. Results

We now describe our results in terms of roadway proximity, traffic density and diesel pollution, and mitigation measures.

5.1. Roadway proximity

A limited share of housing was within 500 feet of a high-traffic roadway, as shown in Table 1. There was one affordable housing development and one market-rate development in this high-risk buffer. The affordable housing development was a 290-unit development adjacent to I-880. This development included income-restricted housing for seniors and families with children. The market-rate housing development was an upscale apartment building in downtown San Jose one block north of I-280. These developments included about 4% of the new housing units in our sample, with half of the new affordable units.

A larger share of San Jose’s new housing fell within 1500 feet of a high-traffic roadway, as illustrated in Fig. 1. San Jose approved 17 developments, with 385 affordable units and 5338 market-rate units, within the 1500 foot buffer. This represented about 45% of the new units in our study, including two-thirds of the new affordable units. These units were predominantly multifamily, but three developments included single-family housing or townhomes.

While many of the new housing units were built near freeways, they were also often in transit-oriented developments. Transit-oriented development refers to new residential and/or employment uses built within a short walk of a rail transit station or other frequent-service transit stops. These developments are important to identify because San Jose and the state of California want more development to occur near the most frequent public transit. About 27% of all new units (including about two-thirds of affordable units) were within a half mile of rail transit and 1500 feet of a high-traffic roadway. This included 3062 market-rate units in ten developments and 385 affordable units in two developments.

We did not formally incorporate wind data into our analysis, but note that most of the near-roadway developments were downwind from a high-traffic roadway, at least part of the time. Wind data show that prevailing winds were primarily from the northwest direction, but sometimes came from the southeast in parts of San Jose and during the winter (Reyff, 2009).

5.2. Traffic density and diesel particulates

Neighborhoods with the highest traffic densities tended to be along the most travelled freeways and at junctions of several freeways or expressways. Most of the housing units in our study were built in Census tracts at or above the 75th percentile of traffic density in California (Table 2). This included all of the affordable and nearly 67% of the market-rate units. None of the affordable units and nearly 38% of the market-rate units were at or above the state’s 85th percentile.

CalEnviroScreen includes modeled levels of diesel particulates, and the areas of San Jose with the highest levels included most of central San Jose, including downtown; north San Jose; and the neighborhoods around San Jose’s airport. Table 3 shows the percentiles of diesel particulates in terms of all California Census tracts. About 83% of affordable units and nearly 88% of market-rate units were in the 75th percentile of diesel particulates. Perhaps more alarmingly, 83% of affordable units and 78% of market-rate units were in tracts at or above the 85th percentile in diesel particulates.

5.3. Mitigation measures

Soundwalls were the most common mitigation measure, as summarized in Table 4 below. We observed soundwalls typically made of reinforced concrete that appeared between 8 and 16 feet in height, which are standard for Caltrans (California Department of Transportation, 2017). Neither of the two developments within 500 feet of a high-traffic roadway – including the affordable 1st and Rosemary Family and Senior Housing – had a nearby soundwall. Of the 15 developments between 500 and 1500 feet from a high-

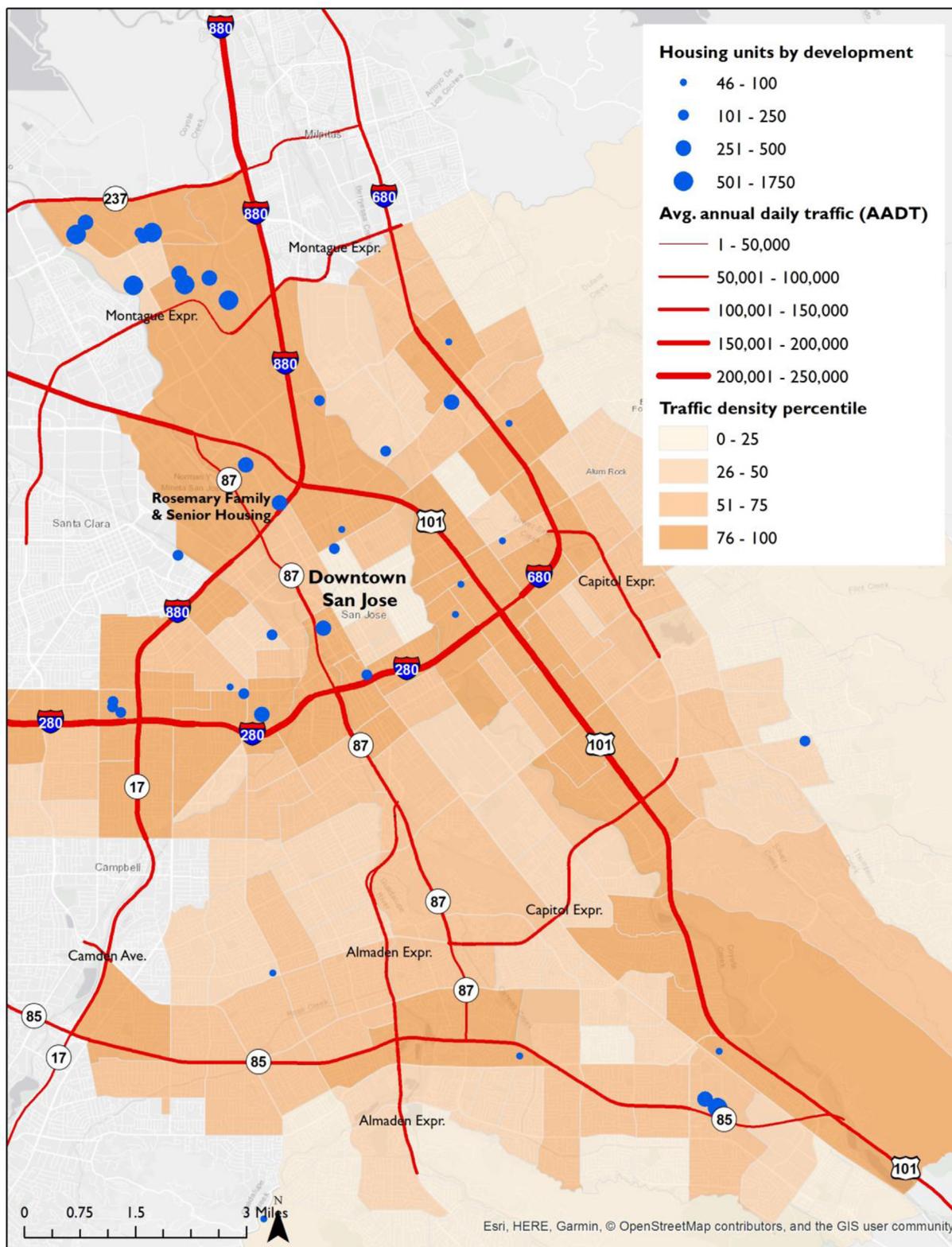


Fig. 1. New housing developments, high-traffic roadways, and traffic density.
 Note: Map only includes traffic counts for expressways, highways, and freeways.

Table 2
Housing units by type and Census tract traffic density percentile.

Traffic density percentile (based on all California tracts)	Affordable housing		Market-rate housing		All housing	
	Units	Share of total	Units	Share of total	Units	Share of total
75th percentile	573	100%	8056	66.6%	8629	68.1%
85th percentile	0	0%	4535	37.5%	4535	35.8%
Any percentile	573		12,103		12,676	

Table 3
Housing units by type and Census tract diesel particulate percentile.

Diesel particulate percentile (based on all California tracts)	Affordable housing		Market-rate housing		All housing	
	Units	Share of total	Units	Share of total	Units	Share of total
75th percentile	478	83.4%	10,607	87.6%	11,085	87.5%
85th percentile	478	83.4%	9458	78.1%	9936	78.4%
Any percentile	573		12,103		12,676	

Table 4
Prevalence of mitigation measures by distance to the nearest high-traffic roadway.

Mitigation measure	Distance from high-traffic roadway		
	< 500 feet	501 - 1500 feet	1501 + feet
Soundwall barrier	0/2	11/15	N/A
Dense vegetative barrier	0/2	2/15*	N/A
High-traffic roadway speeds of 35–55 mph	0/2	2/15	N/A
LEED certification**	1/2	2/15	6/22

* partial dense vegetation.

** or in certification process at time of writing.

traffic roadway, 11 had a nearby soundwall. These developments include 2476 of the 5475 housing units within 1500 feet of a high-traffic roadway. The developments with adjacent soundwalls included all of those along I-680 and SR-85, and some along I-280 and US-101.

Dense vegetative barriers separating housing from roadways were uncommon among new San Jose developments. Only two of the 17 developments within 1500 of major roadways were protected by partial dense vegetation. Neither of the two developments within 500 feet were near dense vegetation, nor were any of the affordable housing units within the 1500 foot buffer.

There was limited evidence of mitigation measures to reduce speeds and improve traffic flow. While speeds of 35–55 miles per hour minimize traffic emissions and fuel consumption, nearly all of the near-roadway developments were near higher speed roads. Of the 17 developments within 1500 feet of a high-traffic roadway, 15 were near roads with speed limits of 65 mph. One development was near SR-87, with a 55 mph speed limit, and another development was near the Montague Expressway, with a speed limit of 45 mph. Roundabouts have been shown to improve traffic flow, but none of the developments had a roundabout within 1500 feet.

As mentioned above, we were unable to obtain comprehensive data about the air filtration systems installed in these new developments. Developers presumably met the minimum California Energy Code standards of MERV 6 or higher (State of California, 2016). We note that MERV 6 filters are ineffective at filtering the particulates mentioned previously. Additionally, some of the developments were certified as green buildings, and these new housing developments might include energy efficiency or indoor air quality features exceeding the state's requirements. Nine of the 39 developments in the dataset (23%) were either certified under the LEED green building rating system or were in the process of certification at the time of writing. These developments would be more likely to include additional indoor air quality measures. Interviews and surveys of developers, property managers, and residents – along with visual inspections of the condition of air filters – would be useful in future research.

6. Discussion

A large share of San Jose's new housing was built near high-traffic roadways. While a limited amount of new housing was built directly next to freeways or within a 500-foot buffer, it was more common for new housing to be built within 1500 feet of high-traffic roads. Much of urban California is covered with freeways; many desirable areas for new development, including downtown San Jose, are surrounded by high-traffic roadways. For policymakers, San Jose illustrates the prevalence of residential development near freeways, and the importance of mitigation strategies. Our two main contributions for urban planning and public health scholars are (1) explaining housing development trends near high-traffic roadways, and (2) building an evidence base about pollution mitigation

for new housing developments near major roadways.

Distance buffers should be supplemented with modeled air quality measures. Pollution levels within any given distance of a roadway depend on the pollutant, wind speed and direction, and time of day. Our results show that some near-freeway locations were also in neighborhoods with high traffic densities from nearby arterials or significant diesel truck traffic. These data illustrate the cumulative impacts from proximity to one or more freeways, along with high-traffic arterials.

Even if a freeway is out of sight, housing may be in an invisible danger zone for air pollution. If housing is just far enough away from the freeway that there is reduced visual and noise impact, developers may be less likely to include mitigation strategies such as increased soundproofing and residents may open their windows instead of filtering air through an HVAC system. This might occur if housing is in a location with high pollution levels while being somewhat distant from the pollution source.

While the simplest solution might be to prohibit housing development near freeways, the issue is more complicated. Restricting housing supply in areas with strong drivers of demand – accessibility to employment and local amenities – would increase housing prices. Many new residential developments in San Jose were built adjacent to high-traffic roadways in neighborhoods with permissive zoning, the city's best transportation access by different modes, and highest land values.

San Jose's general plan seeks to direct growth to the city's downtown and designated urban villages, which are the best-served neighborhoods by rail and other public transit. San Jose aims to reduce single-occupancy commute trips to and from San Jose from 78% in 2008 to 40% in 2040 by shifting many drive-alone trips to transit, walking, and bicycling (City of San José, 2011). However, many sites near rail transit also happen to be near high-traffic roadways; these sites have desirable public transportation accessibility but may be subject to elevated air pollution levels. This is a result of past decisions to build freeways through urban neighborhoods, and more recent decisions to build some rail transit in freeway rights-of-way.

Near-roadway air pollution is an environmental justice issue because people with lower incomes and people of color are disproportionately burdened by such pollution. Here it is also important to differentiate between existing and new housing. In San Jose some of the highest poverty and freeway-adjacent neighborhoods are south and east of downtown San Jose. Many of the new housing units being built near freeways are upscale and presumably being rented or purchased by affluent households. The new housing that raises the most public health concern is affordable housing in high-traffic areas. In San Jose, most of the city's new affordable housing developments were near high-traffic roads, and residents of these units may face cumulative effects from various environmental stressors.

The most prominent such example comes from the 1st and Rosemary Family and Senior affordable apartments. The development was built next to the I-880 freeway but is also across from a light rail station. There is also a major shortage of affordable housing, and this development serves this need. Moreover, the building was certified as LEED Gold, and may have included some mitigation elements in the building design to lessen indoor air pollution levels.

Physical barriers between roadways and housing were inconsistent. Soundwalls were most prevalent, but considerable sections of freeways did not have soundwalls. For state and regional transportation agencies, demand for soundwalls exceeded available funding. Vegetation along roadways was inconsistent and was seldom dense enough to serve as an effective barrier. The pollution-mitigating effects of soundwalls are larger – and better established in the literature – but vegetation may provide additional co-benefits and ecosystem services, making this strategy useful too. Both soundwalls and dense vegetation have the biggest effects closest to high-traffic roadways, so it makes sense to begin implementation in those areas, and particularly near affordable housing and lower-income neighborhoods.

Mitigation in buildings occurred on a piecemeal basis. California's requirements for air filtration in the state's energy code sets the floor for new construction, and this floor was raised during the study period. A share of developers may have exceeded these requirements by building to green building standards or for other reasons. San Jose did not have any additional air filtration requirements for near-roadway sites, unlike the cities of San Francisco and Los Angeles.

An important limitation of our research is that we lacked data necessary to analyze potential health outcomes. While pollution exposure can increase mortality rates and affect other health outcomes, the effects depend on pollutants and pollution levels, the exposure of residents to these pollutants, and other factors (Anderson et al., 2012; Finkelstein et al., 2004). Health risk assessment requires emissions modeling, air quality modeling, and exposure modeling (Zhang and Batterman, 2013). Future analyses should incorporate data from such models to study the health effects of pollutants including NO_x, CO, and PM. This would help us to better understand the actual health effects of San Jose's near-roadway housing construction.

There were several other limitations. First, the Census tract data that we included did not sufficiently capture the fine-scale variation in near-roadway pollution levels. Second, we were unable to obtain the air filtration characteristics of each residential development or how often the filters were replaced. Third, we did not know if LEED certified buildings included additional indoor air quality measures because the program does not require developers to make their certification scorecards publicly available, and some of the projects that were in the process of being certified at the time of writing may not achieve final certification. Further research should survey developers to better understand their decisions about air filtration system selection and maintenance.

These results present a policy conundrum. A large share of new housing continues to be being built near roadways, adding to the existing supply of near-roadway housing. There is clearly some health risk associated with this housing. Meanwhile, there are inadequate mitigation measures in place for existing and new housing near high-traffic roadways. While one policy approach might be to ban all new housing in these areas, that is likely to hinder housing affordability and transit ridership goals. This is because housing supply in the Bay Area is already constrained, leading to high and rising housing prices, and much of the new housing being built is both freeway-oriented (a bad thing in terms of health, though potentially an amenity if residents desire freeway accessibility) and transit-oriented (a good thing for residents' accessibility).

There are opportunities for policy interventions to encourage mitigation efforts, which can benefit both existing and new

buildings. The lack of standardized mitigation measures suggests a policy opportunity to develop a health-promoting overlay zone. Local policymakers can develop regulations to mitigate air and noise pollution exposure and promote health in near-roadway neighborhoods. San Francisco and Los Angeles represent two initial municipal approaches to near-roadway housing regulation; the former focuses on PM_{2.5} while the latter uses distance-based measures. A model health overlay zone should account for additional pollutants and their associated dispersion patterns. The mitigation components of this overlay could include additional indoor air filtration requirements, site design review, landscaping requirements, and public notification and signage. This would augment California's strict building code and energy requirements to protect residents from air pollution. State policymakers could also sufficiently fund, design, install, and maintain soundwalls along all urban freeways, and vegetative barriers, where appropriate. Lastly, we need better data that are accessible to researchers, homebuyers, and renters.

7. Conclusions

Despite growing evidence about the harmful effects of near-roadway air pollution, we know little about zoning and housing development near high-traffic roadways. This paper fills that gap by analyzing high-traffic roadway proximity of new housing, and the mitigation measures employed by public and private sector actors.

Ultimately land use planning can lessen the impacts of near-roadway pollution, but policymakers must address the root of the problem, which are the sources of emissions themselves. This means reducing vehicle miles travelled and requiring vehicles with little or no tailpipe emissions. But, even if the entire vehicle fleet was composed of electric vehicles, we would still need to consider near-roadway pollution because of particulates from brake and tire wear and road dust. In other words, we must continue to reduce vehicle travel, and mitigate pollution from transportation sources.

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