Climate Smart Transportation and Communities Consortium:

Inland Empire Region

March 2021

A Research Report from UCR's Center for Environmental Research and Technology (CE-CERT) and the Center for Social Innovation (CSI)

Matthew Barth, University of California, Riverside (co-PI)
Karthick Ramakrishnan, University of California, Riverside (co-PI)
Paola Avendano, University of California, Riverside
Jill Luo, University of California, Riverside
Ayla Moretti, University of California, Riverside
Gary Rettberg, University of California, Riverside

CSTACC
Climate Smart Transportation and
Communities Consortium

Abstract

The primary goal of the Climate Smart Transportation and Communities Consortium (C-STACC) is to advance more sustainable transportation and climate-smart communities by leveraging existing knowledge, strategically generating new research, and partnering directly with government agencies, community members, non-governmental organizations, and the private sector at all stages of research and dissemination. As part of this overall effort, UC Riverside researchers have focused their efforts on Inland Southern California. This region has underutilized space, poor access to transit, significant traffic congestion, severe air pollution, lacks affordable housing, and has high levels of truck traffic associated with local warehousing. This Inland Empire Regional Initiative of the CSCC has been led by UC Riverside researchers from both the Center for Environmental Research and Technology (CE-CERT) and the Center for Social Innovation (CSI). The research team has carried out a research and engagement effort (with participation from UCLA) that focused on developing transportation strategies and policies that address transportation and air quality challenges in Inland Southern California. This effort was divided into two main focus areas: 1) the deployment of shared mobility strategies in the City of Riverside, and 2) the development of techniques to reduce the impacts of trucks associated with local goods movement. As part of the shared mobility strategies, a number of community outreach events were held (organized jointly by the City and UCR) to get input on what type of shared mobility would be best for Riverside's residents. In parallel, the research team has conducted extensive shared mobility modeling using the BEAM model, which was calibrated using localized travel demand data. Based on community input and the modeling, it was found that a zero-emission carsharing operation would have the largest impact, with the potential to shift work-based travel modes by approximate 8%, resulting in greenhouse gas reductions due to the increased use of zero-emission vehicles and a reduction in overall vehicle miles traveled. For the local goods movement effort, we conducted a number of listening sessions with a number of community partners, identifying four broad areas of concern, including: 1) air pollution and health; 2) traffic safety; 3) noise pollution and congestion; and 4) infrastructure damage and its effects on local traffic. The research team then closely examined the truck traffic in the surrounding community to the airport, and developed new "low-exposure" routing algorithms for trucks, based on knowing community demographics, sensitive receptors (schools, hospitals), truck travel patterns, and roadway exposure ratings. New low-pollution exposure routes were generated and compared to current truck traffic patterns, resulting in a 10% - 40% reduction in pollutant exposure to the community, reducing fleet fuel consumption by 3% - 5%, however at a cost of increasing fleet travel time by 10% to 30%.

About the Center for Environmental Research and Technology

The University of California-Riverside’s College of Engineering-Center for Environmental Research and Technology (CE-CERT) is an off-campus research center that consists of over 150 faculty, research staff, and students collaboratively working to be a recognized leader in education, an honest broker in research, a creative source of new technology, and a strong contributor to solving societal environmental issues, with a focus on air quality, transportation, and energy (see http://www.cert.ucr.edu).

About the Center for Social Innovation

UC Riverside’s Center for Social Innovation (CSI) provides a credible research voice that spurs civic leadership and policy innovation. Its reputation is built on the key pillars of social science, strategic policy awareness, innovation mindsets, and deep community partnerships. CSI integrates researchers, community organizations, and civic stakeholders in collaborative projects and long-term partnerships that strengthen shared values of resilience, inclusion, sustainability, and equity (see **https://socialinnovation.ucr.edu/**).

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated in the interest of information exchange. The report is funded, partially or entirely, by a grant from California’s Strategic Growth Council.

Acknowledgments

This study was funded, partially or entirely, by a grant from by a grant from California’s Strategic Growth Council. The authors would like to thank the entire multi-campus Climate Smart Transportation and Communities Consortium for provide feedback and guidance on this research. In particular, we would like to acknowledge UCLA researchers J.R. DeShazo, James DiFilippo, and Britta McOmber in support of the goods movement activities.

Table of Contents

1. Introduction

Despite considerable progress in California, transportation-related environmental impacts remain substantial and fall disproportionately on the most vulnerable populations. Approximately 90% of Californians live in areas with unhealthy air at some point during the year [American Lung Association, 2017]. Transportation is the largest source of greenhouse gas (GHG), criteria, and toxic diesel particulate matter emissions in the state [California Air Resources Board, 2017]. The transportation system harms the environment in countless other ways, such as pollutants in storm-water run-off from impervious pavements and fragmentation of wildlife habitat by highways. The challenge for California is to reduce these impacts while meeting the mobility needs of society, fostering healthy and equitable communities, and supporting economic growth. In 2018, a Climate Smart Transportation and Communities Consortium (C-STACC) was formed to tackle these challenges and advance more sustainable transportation and climate-smart communities by leveraging existing knowledge, strategically generating new research, and partnering directly with government agencies, community members, non-governmental organizations, and the private sector at all stages of research and dissemination.

1.1. C-STACC Research Aims and Objectives

As part of the Climate Change Research Program Investment Plan prepared by the Strategic Growth Council (SGC), the C-STACC has focused on accelerating and supporting climate smart communities, by integrated land use, conservation, and management into California’s climate change programs. The goal of the C-STACC is to accelerate the transition towards climate-smart, equitable communities and transportation in California. An equitable transportation system is one that offers all users affordable, convenient, and reliable access to destinations in a manner that does not create disproportionate environmental, social, or economic impacts for people on the basis of race, color, national origin, income, or other factors. C-STACC has taken a twofold approach: 1) we are expanding the research foundation that will inform strategies for reducing transportation-related GHG emissions with a focus on disadvantaged communities; and 2) we are collaborating with community-based organizations (CBOs) groups, nongovernmental organizations (NGOs), public agencies, and the private sector to translate research into strategies and policies that will reduce GHG emissions, create a more healthy and equitable society, and support economic growth. The C-STACC’s research program is organized around five interrelated areas with equity and policy engagement serving as cross-cutting themes throughout. These areas are as follows:

New Mobility: New forms of mobility are proliferating: car-sharing, ride-sharing, micro-transit, company shuttles, bike-sharing, and more. Automated vehicles will also have massive and highly uncertain environmental, economic, and equity implications for California. Key research questions include: 1) Will vehicle automation lead to more or less vehicle miles travelled (and thus more or less GHG emissions)? 2) How many travelers will be willing to share rides and under what conditions? 3) How will new transportation services and innovations impact individual car ownership? 3) How can these transportation innovations provide more reliable, affordable, and convenient options for disadvantaged travelers? 4) What is the role of policy in steering these “revolutions” toward the public interest?

Electrification: Electrified cars, trucks, buses, and even planes create the potential to greatly reduce GHG emissions and local pollution. Key research questions include: 1) What policies are needed to accelerate the electrification of cars, related to charging infrastructure, incentives, automotive industry behavior, and consumer behavior? 2) How might these policies be modified to better serve lower income individuals? 3) What policies and strategies are needed to electrify trucks, especially those traveling through disadvantaged communities?

Transit: Despite major investments in public transportation, transit ridership is declining in California. The traditional model for providing transit must evolve quickly to be effective. Key research questions include: 1) What changes are needed to reverse the decrease in transit ridership? 2) What are new models for providing public transportation in ways that leverage new transportation technologies and services (such as partnering with ridehailing services for first/last mile access to transit stations)? 3) What changes in transportation finance are needed to support these changes, especially to serve low income riders? 4) How do we address bus electrification?

Land Use and Active Transportation: California's SB 375 provides the framework for integrating land use and transportation as a means of reducing GHG emissions. A range of policies and investments are needed to build on this framework. Key research questions include: 1) What infrastructure investments and policies are needed to induce more travelers to bike and walk, especially in disadvantaged communities? 2) What land use changes in urban, suburban, and rural contexts are most effective in supporting changes in mobility that reduce vehicle travel? 3) What changes in transportation finance are needed to support local and regional government initiatives and investments?

Goods Movement: Reducing environmental and health impacts related to freight activities is daunting in large part because the knowledge base for goods movement is far more limited relative to passenger transport. Key research questions include: 1) What policies and strategies are most effective at increasing freight efficiency, including reversing the dispersion of warehouses and distribution centers? 2) What policies and strategies are most effective at transitioning trucks to electric drive (i.e., batteries and hydrogen fuel cells)? 3) To what extent are trucks causing high pollution exposure in disadvantaged communities, and what are the most effective strategies for reducing this exposure?

The C-STACC has advanced the state of knowledge in the five key research areas described above through a bottom-up and top-down approach. The C-STACC research approach has included three regional "case study" initiatives that address specific concerns and opportunities in each region, and three statewide initiatives that incorporate regional case study findings and inform the design of state strategies and policies. The regional case studies are Southeast Los Angeles, the Inland Empire, and the Central Valley. The statewide initiatives include 1) Leveraging the Three Revolutions to Create Equitable and Sustainable Communities, 2) Accelerating the Transition to Zero-Emission Vehicles, and 3) a Statewide Transportation Modeling Initiative. This report addresses the case study in the Inland Empire.

1.2. Inland Empire Regional Initiative

This Inland Empire Regional Initiative of the C-STACC has been led by UC Riverside, consisting of researchers from both the Center for Environmental Research and Technology (CE-CERT) and the Center for Social Innovation (CSI). The research team has carried out a research and engagement effort (with participation from UCLA) that focused on developing transportation strategies and policies that address transportation and air quality challenges in Inland Southern California. This effort was divided into two main focus areas: 1) the deployment of shared mobility strategies in the City of Riverside, and 2) the development of techniques to reduce the impacts of trucks associated with local goods movement. The first research area is described in detail in Section 2 of this report; The second research area is described in detail in Section 3 of this report.

2. Shared Mobility in the City of Riverside

Like many cities in California, the City of Riverside is considering multiple options and strategies for personal mobility, with the idea of getting away from the personal-automobile ownership model that is common today. As part of this strategy, the City developed a “Smart City” transition plan, which included promoting vehicle electrification to the furthest extent possible, as well as take advantage of how vehicles are becoming increasingly connected and automated.

As part of their Smart City effort, the City of Riverside proposed in 2018 to move forward with revitalizing a major section of the city, designated as the *Innovation District* [Riverside, 2018]. Residents within the Innovation District experience exposure to particulate matter (PM), ozone, affordable housing, unemployment, low birth weight, cardiovascular disease, and poverty. The largest contributor to PM and ozone in this area is transportation emissions from the local traffic on arterial roadways as well as two freeways that cross the corridor.

In 2019, the City of Riverside applied for a Strategic Growth Council Transformative Climate Community (TCC) grant. In 2020, the City was awarded the TCC grant, with a focus to improve its Eastside neighborhood region [Riverside, 2021]. The goal of this TCC project is to provide a major boost to advancing integrated transit, urban greening, affordable housing and solar rooftops in Riverside. Our C-STACC Inland Empire effort dovetailed perfectly with this larger City of Riverside TCC project, focusing specifically on shared mobility in the Innovation District.

As part of the Innovation District effort, the City and UCR have partnered to create the *Innovation Corridor*, a six-mile section of University Avenue, a congested arterial roadway connecting the UCR campus and downtown, see Figure 2.1. Some of the research being conducted on the Innovation Corridor includes the development of vehicle monitoring techniques, traffic smoothing techniques through advanced signalization, and air quality sensing in highly trafficked areas [CE-CERT, 2021].

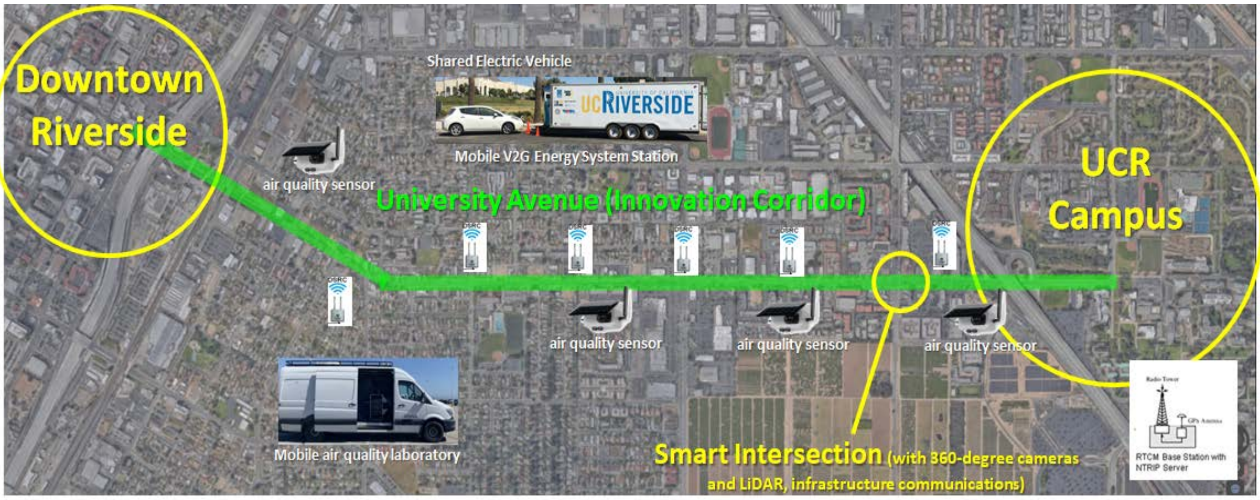


Figure 2.1: Riverside Innovation Corridor and Associated Research Components

Another major component of the City’s Innovation District activity, is the future deployment of shared mobility in the City. Many forms of shared mobility have been discussed, following the general shared mobility definition of shared use of a vehicle, bicycle, or other mode that enables users to have short-term access to transportation modes on an “as-needed” basis [Shaheen, 2019]. This included examining carsharing, personal vehicle sharing (PVS, including peer-to-peer (P2P) carsharing and fractional ownership), scooter sharing, bike-sharing, transportation network companies (TNCs, also known as ridesourcing or ridehailing such as Uber and Lyft), ridesharing (i.e., carpooling, vanpooling), microtransit, and courier network services as defined in [Shaheen, 2019].

2.1. Shared Mobility Planning and Community Outreach in Riverside

As part of this C-STACC project, UCR researchers engaged with the City to help develop a shared mobility plan for the City of Riverside. These activities included assisting with community outreach in evaluating what types of shared mobility might work in the city, and conducting extensive modeling of zero-carbon carsharing options within the City. The UCR team also worked closely with a local carsharing company called StratoShare [StratoShare, 2021]. This local company is an on-demand carsharing operator that exclusively rents low-carbon vehicles (e.g., EVs, hydrogen fuel cell electric vehicles) by the hour or day to the public, throughout Inland Southern California. Drivers download the StratosShare app, create accounts, select time of use as well as pickup/drop-off locations, and push to start. StratosShare was founded under the vision to provide a low-cost zero-emission shared-use transportation to Inland Southern California. StratosShare is already up and running, working with the California Energy Commission and Toyota in deploying 15 vehicles in disadvantaged communities throughout Riverside and San Bernardino Counties. These vehicles are strategically located at train stations, universities, airports, and downtown locations to provide a first/last-mile transportation solution. StratosShare is planning to expand their system with additional vehicles and additional locations, so they played a strong role in Riverside's shared mobility planning.

2.1.1. Joint Activities with City of Riverside TCC project

In parallel with this C-STACC effort, UCR researchers also were part of a separate (but related) SGC Transformative Climate Community (TCC) community engagement team, as described in the previous section. This TCC project was awarded to the City of Riverside in 2020, with a focus on advancing integrated transit, urban greening, affordable housing and solar rooftops in Riverside, with a particular focus on the Eastside neighborhood. The overall Riverside TCC community engagement team includes the City of Riverside, Riverside Community Health Foundation, Riverside Transit Agency, the Safe Routes to School Partnership, and the UCR research team. This overall effort began in 2019 with a series of events with Eastside Community Groups to better understand the needs of the community. Specific outreach events were held in 2019 and 2020, where twenty residents and 15 stakeholders were regularly engaged in the process. In all, twelve community meetings were hosted, with the Eastside HEAL Zone Collaborative serving as the advisory body when developing the planning and outreach meetings. With 10-30 attendees per meeting, each group participated in a climate action framework that educated participants on climate impacts for the Eastside neighborhood and included discussions on transportation needs.

The following community outreach methods were utilized for these community meetings:

- **Website/Social Media** - Establishment of a website (www.riversideca.gov/eastside) explaining the overall effort while also capturing potential projects from residents through an interactive mapping tool. The City also established a tccgrantideas@riversideca.gov email to solicit ideas.

- **Surveys** - Collected surveys soliciting input regarding potential projects. A total of 340 surveys were collected from community residents and partnering organizations. The Eastside HEAL Zone Collaborative Meetings included discussions on climate change impact and transportation needs.

- **Project Meetings** - The Residents of Eastside Active in Leadership, RCHF staff presented an educational seminar about the impacts of climate change. The group received monthly updates and helped reach out to more residents.

- **Design Charrettes** - A specific themed workshop, a Green N' Clean TCC Event, was held in late 2019, where projects leaders shared information with residents who then voted for their preferred project with over 100 participants giving unique input.

- **CBO Participation** – The City subcontracted with a community-based organization, the Safe Routes Partnership, to conduct outreach and information gathering. The participation of Safe Routes Partnership was critical in that they were able to program creative and interactive resident activities that merged expertise in pedestrian and traffic safety with critical thinking and input from residents that was primary to choosing many of the City's active transportation projects.

At the TCC Project Final Presentation Event, project leaders presented on projects and community questions and feedback was collected. Residents and stakeholders were engaged in the decision-making process by addressing concerns and providing feedback on projects and proposing new projects.

Based on community feedback, a number of transportation-related recommendations were made, providing transformational enhancements to non-motorized accessibility to local services and regional transportation within the Eastside neighborhood. Specific improvements were suggested in the area of the University and Chicago intersection, such as the University Avenue High Visibility Crosswalks & Accessible Pedestrian Signal Buttons, the Chicago at Entrada Pedestrian Signal, the University and Chicago Diagonal Crosswalk, and the Solar-Panel Shaded Walkway on Chicago from 7th to University. These recommendations are all focused on linking together residential zoning in that area, particularly various housing project, to commercial zones on University and Chicago. These improvements are also adjacent to transit stops at University & Chicago. The main recommendations were to make pedestrians feel safer walking and socializing with High Visibility Crosswalks, Edge-Lit LED Stop Signs, Pedestrian Lighting, Parklets, and Murals. In addition, there were recommendations for active transportation, including Class IV bike lanes from Iowa-Chicago and University at Iowa, including Advanced Signal Detection aimed at high traffic areas of the Eastside community where pedestrians and bicyclists will benefit most.

Other transportation recommendations were aimed towards improving transit, and potentially increased forms of shared mobility. One recommendation was to expand the Vine Street Mobility Hub to allow for additional bus bays and an improved design. In addition, to promote usage of this expanded hub, the Riverside TCC grant is funding the purchase of 4,356 CommuterLink general monthly passes.

2.1.2. Shared Mobility Survey

Building on the Riverside TCC project’s community outreach program, The UCR team worked with the City of Riverside and StratosShare to develop and carry out a targeted community survey on travel needs and shared mobility in the Innovation District. There were a number of survey questions that were directed at establishing existing travel patterns and needs. Next, several questions were aimed directly at the potential of a zero-emissions carsharing system. In total, there were approximately 350 active responses to this community survey. The questions and responses of this survey are summarized below.

An initial question focused on the frequency of trips in the Eastside Neighborhood. Based on the community response, 21.2% of the respondents live in Eastside, and 38.5% of the respondents come to Eastside daily. Approximately 19.4% for the respondents visit Eastside once or twice a week, and 11.5% for those who visit Eastside once or twice a month. The share of those who visit Eastside a few times a year is 4.1%. Among all the respondents, 4.7% visit Eastside for the first time.

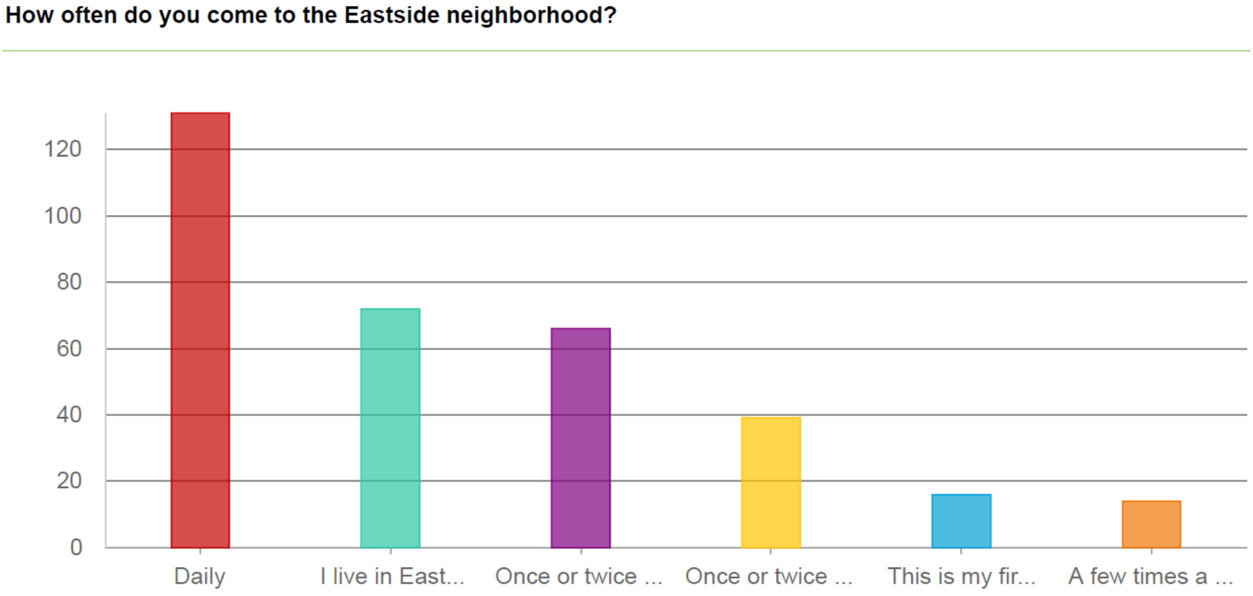


Figure 2.2. Travel Frequency Survey Results

The next question focused on existing travel means. It was found that the respondents have diverse means of transportation for their trips in the community. Family or personal vehicle is the major mode for travel, which accounted for 65.3% of the trips. Walking (34.4%) ranks second, followed with public transportation (18.5%) and biking (7.4%). The share of other modes, including ridesharing, skating, motorcycle and scooter, is less than 5%.

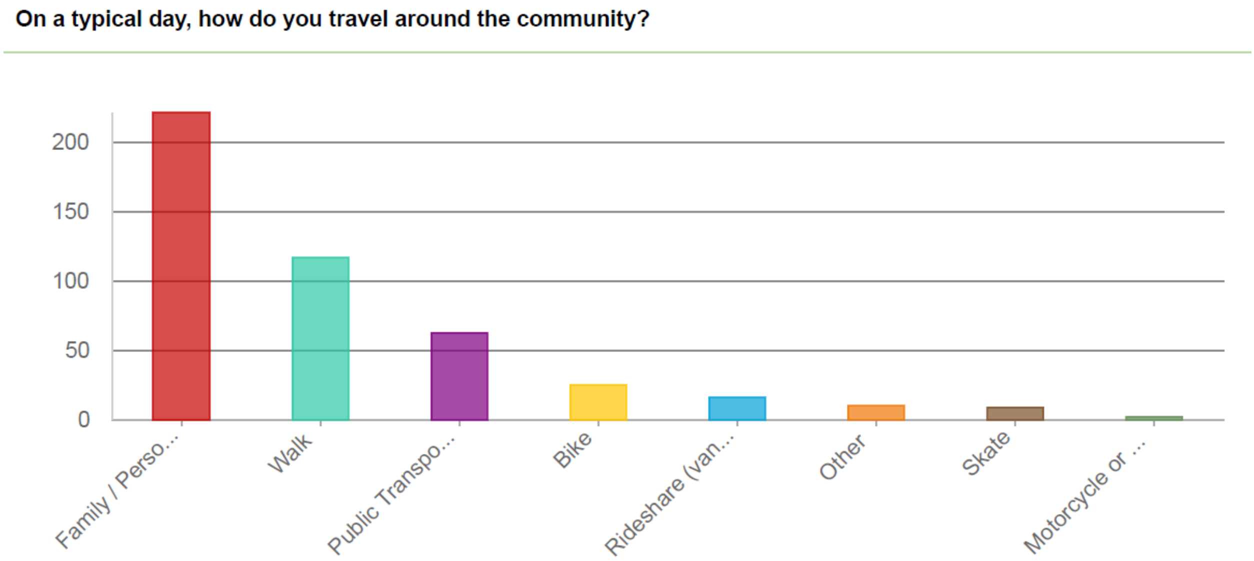

On a typical day, how do you travel around the community?

Figure 2.3. Travel Survey Results

The next question focused on biking in the community, and how biking could be improved upon. Approximately 47.35% of the respondents agree that more bike lanes should be introduced in the community. The percentage of respondents that are interested in better traffic enforcement, bike share stations, driver/bicyclist education, lower vehicle speeds, and social bike groups are 32.0%, 27.9%, 25.9%, 18.8% and 12.9 respectively.

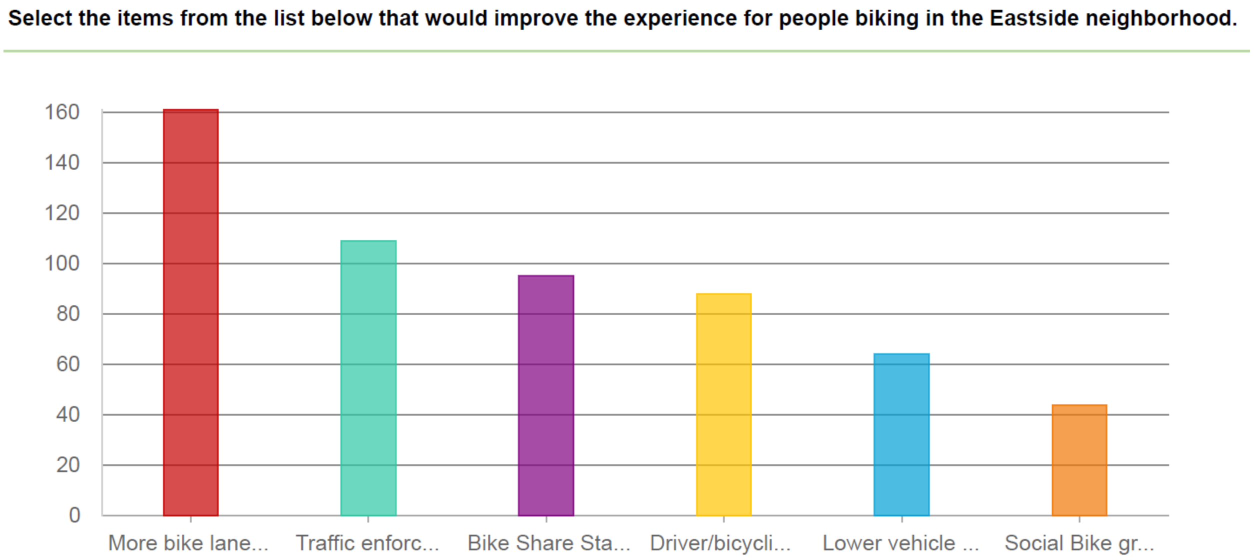

Select the items from the list below that would improve the experience for people biking in the Eastside neighborhood.

Figure 2.4. Biking Improvements Survey Results

The next question focused on transit use. Various suggestions were provided in terms of transit improvements. The option that ranked the highest was to plant additional plants and trees / shade near transit stops (52.9%). The respondents were also interesting in other approaches, including reducing waiting time, adding transit stops near work/school/shopping, and designing transit bus only lanes during rush hour.

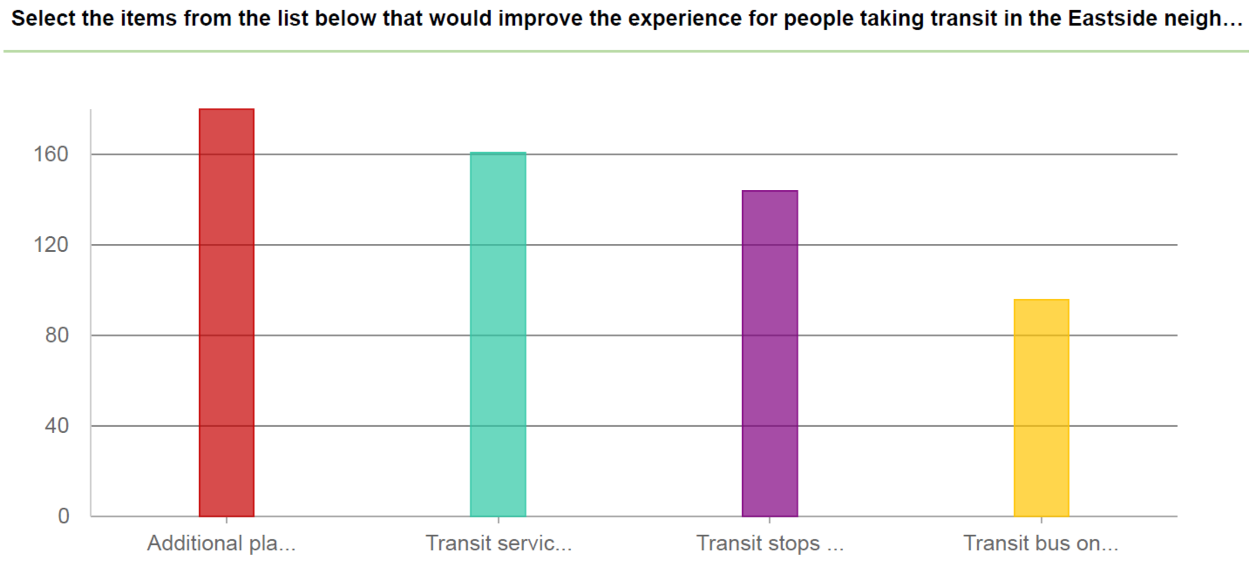


Figure 2.5. Transit Improvements Survey Results

The next question focused on how to improve the walking experience in the community. In this case, the highest-ranking option to improve the pedestrians' experience is to provide better lighting for sidewalks, which was selected by 58.8% of the respondents. Other options such as public space/street furniture, marked crosswalks, wider sidewalks, and social walk groups are ranked 2nd to 5th in the survey, as shown in Figure 2.6.

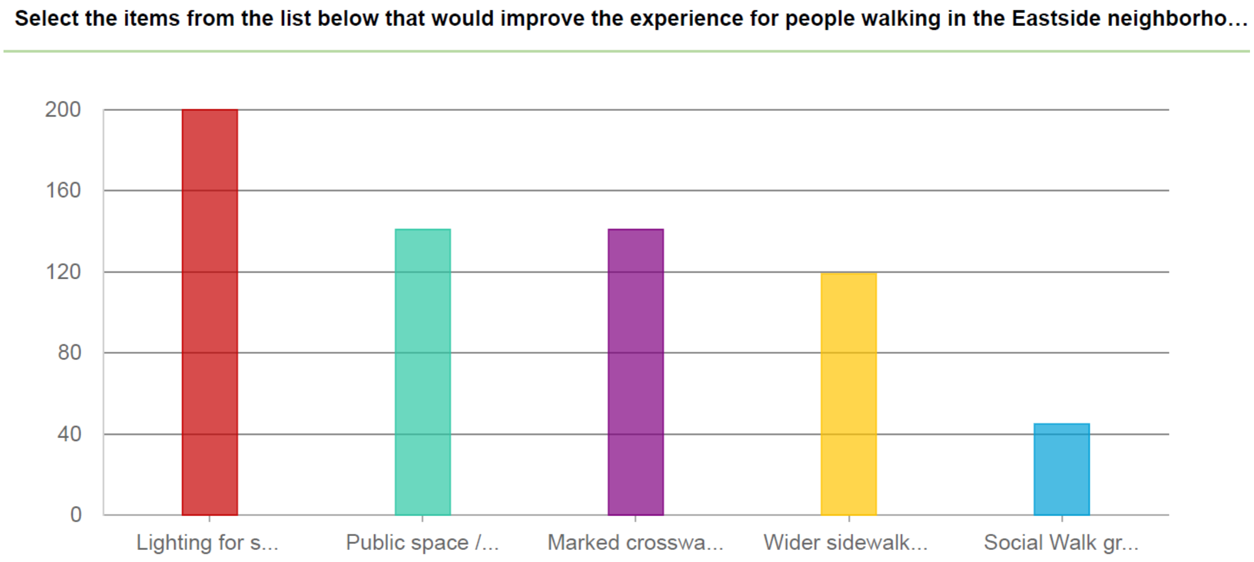


Figure 2.6. Walking Improvements Survey Results

Next, the survey focused on the importance of moving away from personal vehicle travel in the community. Most respondents (over 70%) stated that it is very important to prioritize active and public transportation, where 20% of the respondents answer “somewhat important”, and 4% answered “not important”.

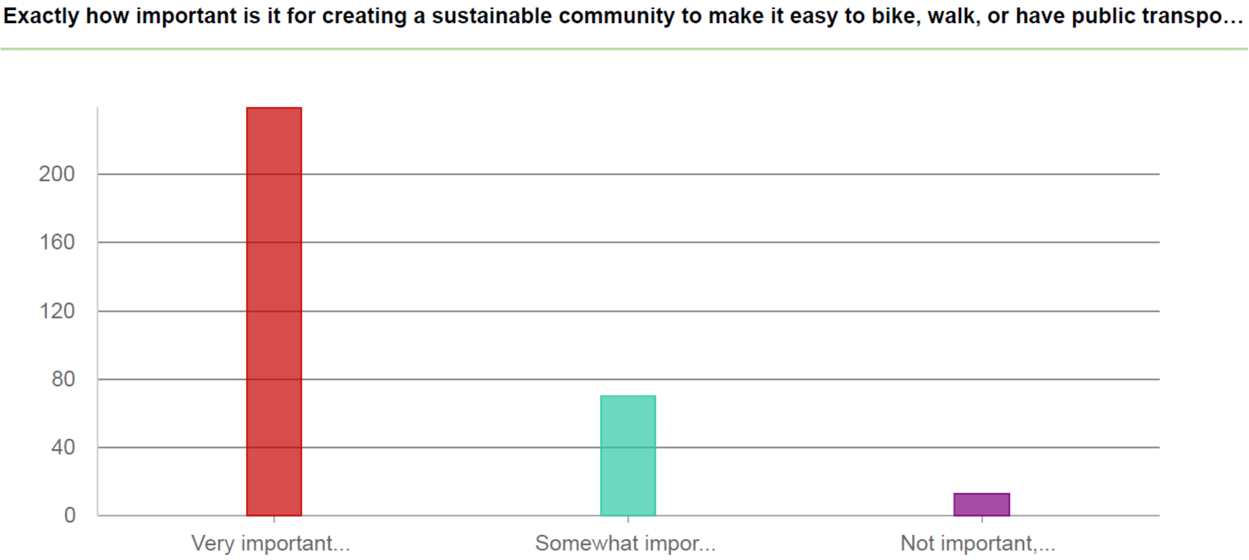

Exactly how important is it for creating a sustainable community to make it easy to bike, walk, or have public transpo…

Figure 2.7. Importance of moving away from personal vehicle travel.

For specific community improvements, a number of choices was provided to the community. Among all the options, “better safety within the park” ranks the first with a 56% approval rating. The ratings were between 36%-46% for other options, such as investments in native trees and plants, more parks/expansion of parks, cooling centers for hot days, better access to parks, more activities at the park, investment in community gardens, and more public art in parks.

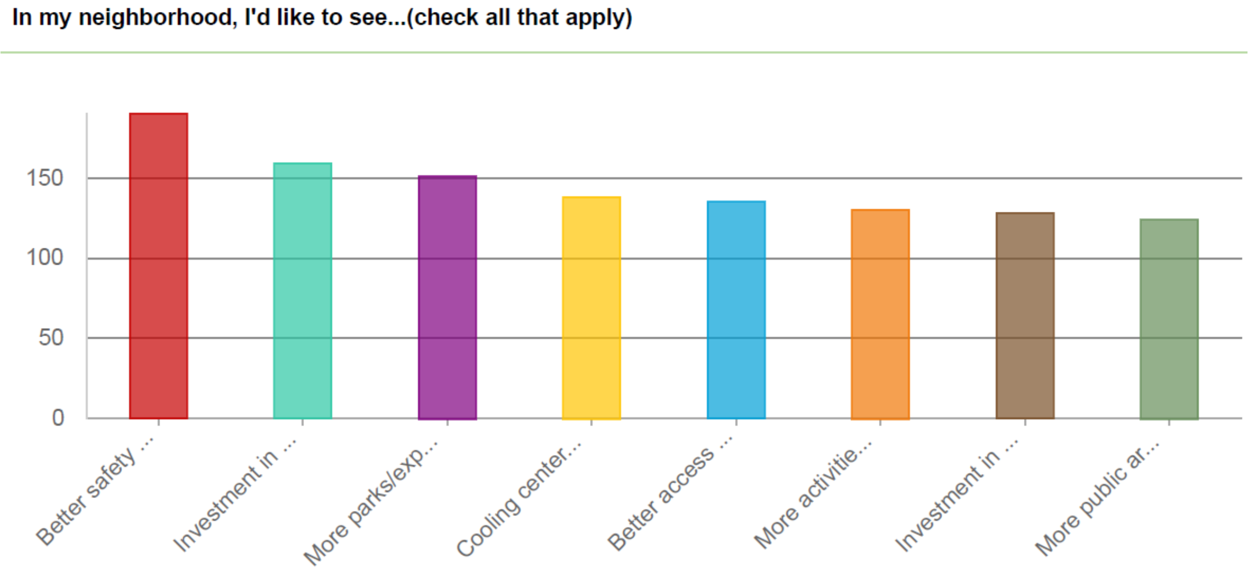

In my neighborhood, I'd like to see...(check all that apply)

Figure 2.8. Community Improvements.

Another question focused on the climate crisis, examining the community's largest concerns. The largest concern was on air quality (65%), followed by accessibility to green modes of transportation (38%), clean water (37%), and a number of other topics (fires, weather, natural disasters, education, and green job training).

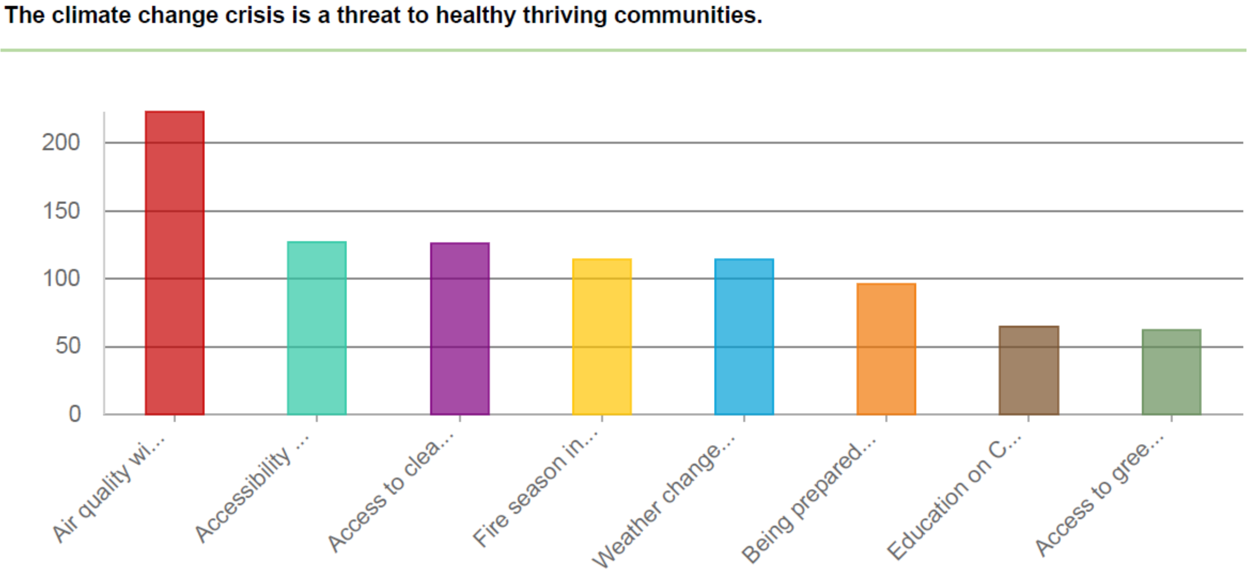


Figure 2.9. Climate Crisis Concerns.

Next, specific questions were targeted at electric vehicle carsharing. Figure 2.10 illustrates that approximately 60% of the respondents were interested in using electric vehicle carsharing services, with 40% not being interested.

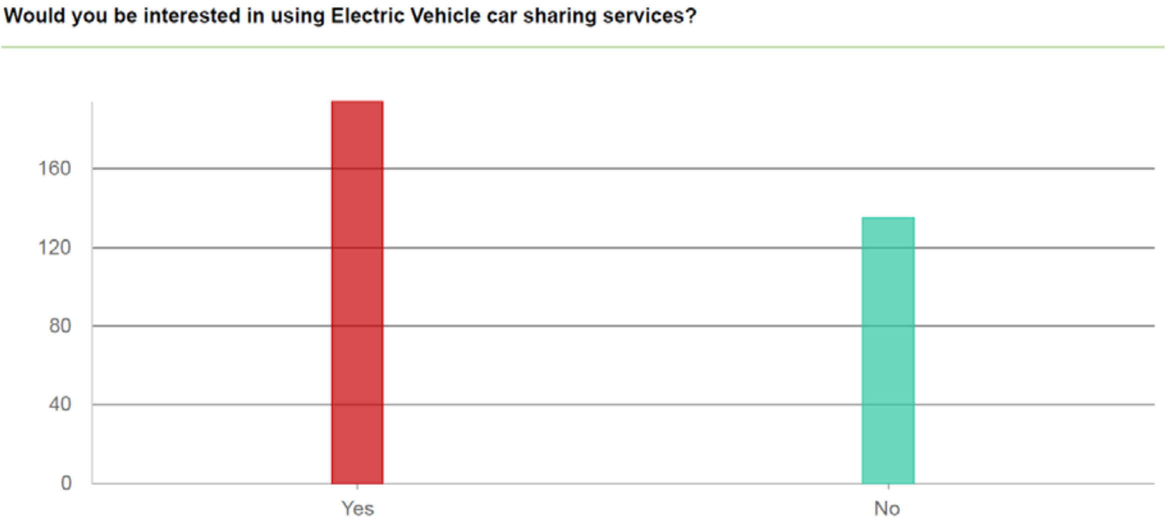


Figure 2.10. Community Interest in Electric Vehicle Carsharing Services.

Other questions were directed at possible locations within the community for zero-emissions carsharing locations. These data were used as input to the carsharing modeling that took place, described in the next section.

Lastly, there were general demographic questions, such as the survey respondent's age, as shown in Figure 2.11.

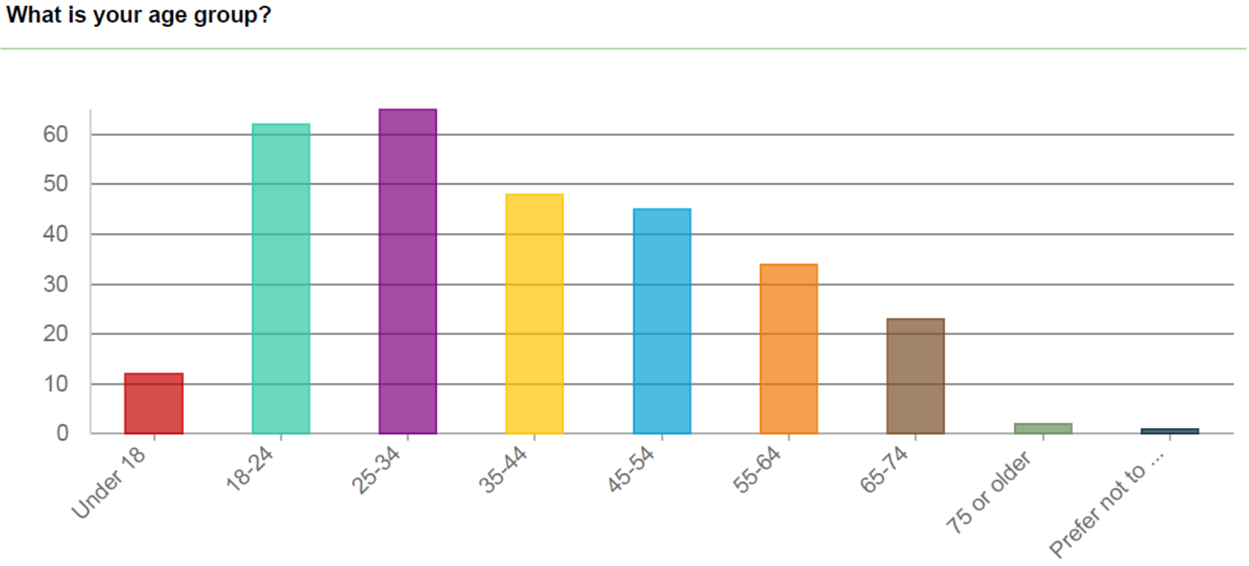


Figure 2.11. Respondent's age groups.

Another interesting response was on the words chosen to promote community improvements, with a focus on transportation. A word cloud was generated, illustrated in Figure 2.12.

Figure 2.12. Word Cloud of Riverside Community Improvements.

In summary, this Community Climate Collaborative Survey has generally good response. It was clear that the current residents utilize private vehicles for most of their travel, but the community in general was very much in favor of improving other modes such as walking, public transit, biking, and shared mobility. Most respondents agree that it is important to create a sustainable community, by making it easier and safer to use active and public transportation. The majority of respondents were in favor of zero-emissions carsharing.

2.2. Shared Mobility Modeling

In addition to the community survey on green transportation options and shared mobility, the research team did extensive shared mobility modeling, working with StratosShare and the City of Riverside. Specifically, the focus was on evaluating different scenarios for a carsharing system utilizing a zero-emissions fleet. From the literature, it is clear that carsharing systems show great potential in reducing vehicle ownership, achieving VMT and GHG reduction, encouraging alternative transportation modes, and increasing access and mobility of disadvantaged communities [Shaheen et al., 2019]. An aggregate-level study of 6,281 people in Canada and the U.S. documented that 33% of members sold a vehicle due to carsharing, and another 25% postponed a vehicle purchase due to roundtrip carsharing [Martin & Shaheen, 2011]. U.S. and Canadian aggregate data also reveal that each roundtrip carsharing vehicle removes between 6 and 23 cars on average from roads. Other studies and surveys also show that in Northern America, 23%-35% of members sold personal vehicles after joining roundtrip car sharing service, and 25%-71% of them postponed or entirely avoided a car purchase [Lane, 2005; Martin et al., 2010]. Fraiberger and Sundararajan [F&S, 2015] found that below-median income households are almost twice as likely to give up private vehicle ownership attributable to their greater propensity to avoid private vehicle ownership's fixed costs when a peer-to-peer carsharing alternative exists. Significant reduction of VMT (up to 80%) was also found according to the research on both roundtrip and one-way car sharing. For all of these reasons, Riverside wants to increase carsharing operations within the community.

Further, vehicle electrification and increased automation have the potential to reduce carsharing GHG emissions, along with reducing private vehicle ownership. A number of studies and pilots have demonstrated the efficacy of these carsharing systems. For example, in 1999, UC Riverside initiated a UCR IntelliShare research program, consisting of both modeling and deploying an automated shared-use electric vehicle system consisting of over 50 electric vehicles [Barth & Todd, 2003]. In 2015, the Zipcar's College Travel Study showed that college/university market respondents use public transportation and ride-sourcing services (e.g., Lyft or Uber) slightly less, and they also bike slightly less due to Zipcar [Stocker et al., 2016]. Car sharing also help to project a progressive, environmentally conscious image and reduce on-campus parking demand (see, e.g., [Zheng, 2009]).

It is important to note that most existing carsharing studies focus on analyzing the impact of the car sharing program *after* their real-world deployment. It is more challenging to predict the impact of car sharing *before* implementation due to the lack of behavioral data from the participants. Two methodologies have been applied in existing research. The first method is primarily survey-based. As an example, Shaheen designed a quasi-longitudinal survey to collect the attitudinal and belief data to investigate the process that travelers may follow to accept or adapt an innovative car sharing program named CarLinks [Shaheen, 1999]. As another example, a survey with 840 Beijing residents was conducted to collect data on transportation patterns, automobile ownership, environmental attitudes, and carsharing response; in this study, over 25% of the participants expressed a high level of interest in carsharing [Shaheen and Martin, 2010]. Further, Wang et al. conducted a survey to explore the potential response of Shanghai residents to carsharing, showing that people who are interested in carsharing were younger, more likely to be educated, had longer commute distance, and owned fewer cars [Wang, 2011].

Another mechanism for predicting carsharing success is based on discrete-choice modeling. For example, in a car sharing study for London, a Perceived Activity Set (PAS) model was created to build a conceptual framework of shared mobility, referring to a set of out-of-home activities that encompass their potential travel needs when making decisions that structurally affect their accessibility [Vine et al., 2013]. This modeling method focused on the long-term impact of carsharing, including the decision to purchase or sell a car or a bike, and the decision to subscribe the transit/carsharing membership. Another study in Rotterdam, Netherland developed a method in modeling the short-term impact of the car sharing using discrete choice model. The discrete choice model considers five conventional modes: car driver, car passenger, public transport, cycling, and walking. Carsharing was considered as a new mode that was introduced within the mode choice, meaning that a new utility function was required for the carsharing alternative, consisting of variables that are likely to explain carsharing demand.

In this research project, our goal was to predict the impact of potential deployment of zero-emission carsharing in the City of Riverside. A hybrid model was developed with three key components: survey data, discrete-choice model, and agent-based simulation. In our modeling effort, we first derived travel demand data and travelers' activity schedules, and then applied this to the BEAM model (Behavior, Energy, Autonomy, and Mobility), developed by Lawrence Berkeley National Laboratory [LBNL, 2021]. BEAM is a mesoscopic simulation model for urban transportation systems with particular support on shared mobility modeling, energy estimation and computation over large-scale networks. With proper travel demand and travelers' activity schedules, BEAM can evaluate traffic condition, energy consumption and air quality for the entire network, and predict the mode choice and routing decision for each individual agent.

The trips in BEAM are associated with the travelers' demographic information synthetized by PopGen and CEMDAP, other modeling components of the BEAM framework. A discrete choice model was applied to describe the model choice behavior with existing means of transportation, e.g., car driving, car passenger, public transit, cycling, and walk. The parameters for this model were adopted from literature, and then calibrated using data from Eastside Climate Collaborative Survey and other localized data. We then introduced carsharing service into this discrete choice model to study its impact on travel behavior and its benefit on fossil fuel savings and greenhouse gas reduction considering the mode shift from private cars to zero-emission carsharing vehicles.

2.2.1. BEAM Platform and Data Collection

In a discrete-choice model, typically there are three types of variables: 1) variables that represent the level-of-service data of a certain mode (e.g. travel time, cost); 2) dummy variables that represent the characteristics of a person (e.g. age, gender, income) or a household (e.g. number of cars, income); and 3) an alternative specific constant to represent variables that are not present in the utility function but still affect the mode choice. The traveler's daily trip activity data and the corresponding person/household attributes are critical to estimate the mode share for transportation. In our modeling efforts, we introduced a simulation-based data collection method using multiple tools such as BEAM, PopGen and CEMDAP, which provide calibrated level-of-service data and person/household data to support the discrete choice model, as illustrated in Figure 2.13.

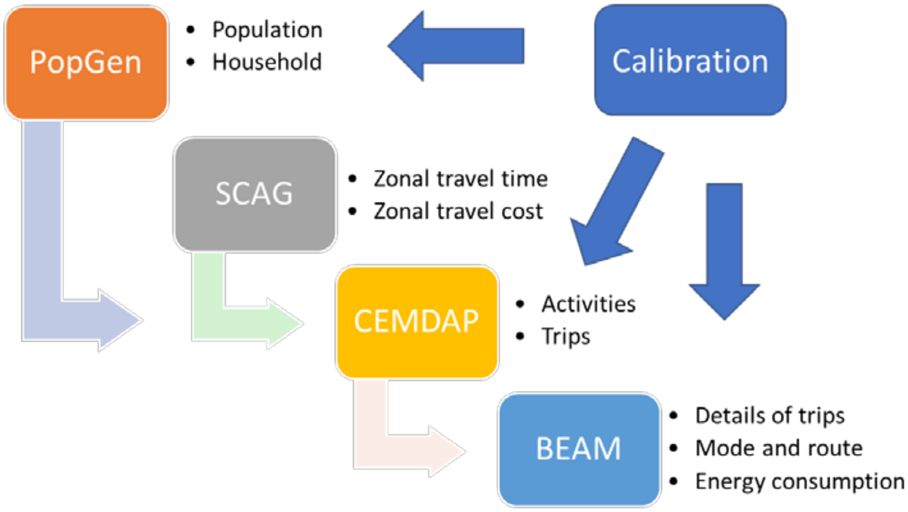


Figure 2.13. System diagram for data collection

To acquire personal and household information, we generated raw data using PopGen, and calibrated them using latest survey data from city-data.com. PopGen is a synthetic capable of producing synthetic data while controlling and matching household-level and person-level attribute distributions. It can be implemented easily and effectively for synthesizing populations while matching population controls in small geographies. PopGen has been applied and tested in several states, metropolitan planning organizations (MPOs), and research studies. PopGen generated 687,608 households and 1,776,827 persons in Riverside County using the 2012 American Community Survey (ACS) database, the largest household survey that the Census Bureau administers conducted to collect information ancestry, citizenship, employment, and income.

As PopGen takes 2012 ACS data for population generation, it is necessary to update the demographical information using an up-to-date data source. In this research, we utilized the survey data from city-data.com to calibrate the essential variables, such as population, age, income for each zone. As an example of this calibration, we took the income data around a potential carsharing station in Riverside. The median household income was $47,708 according to city-data.com (see Figure 2.14). We then used a normal distribution to generate new income distribution for those households. In the new calibrated data, the median and average household income become $47,634 and $47,733, respectively.

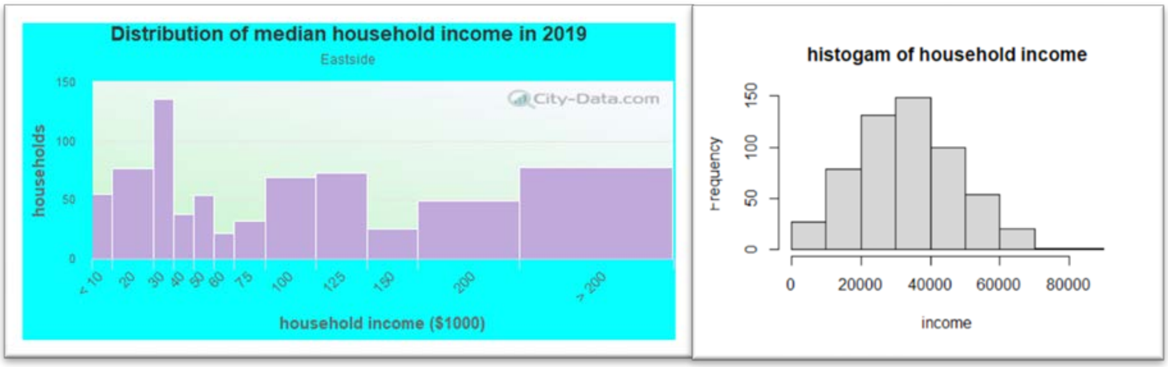
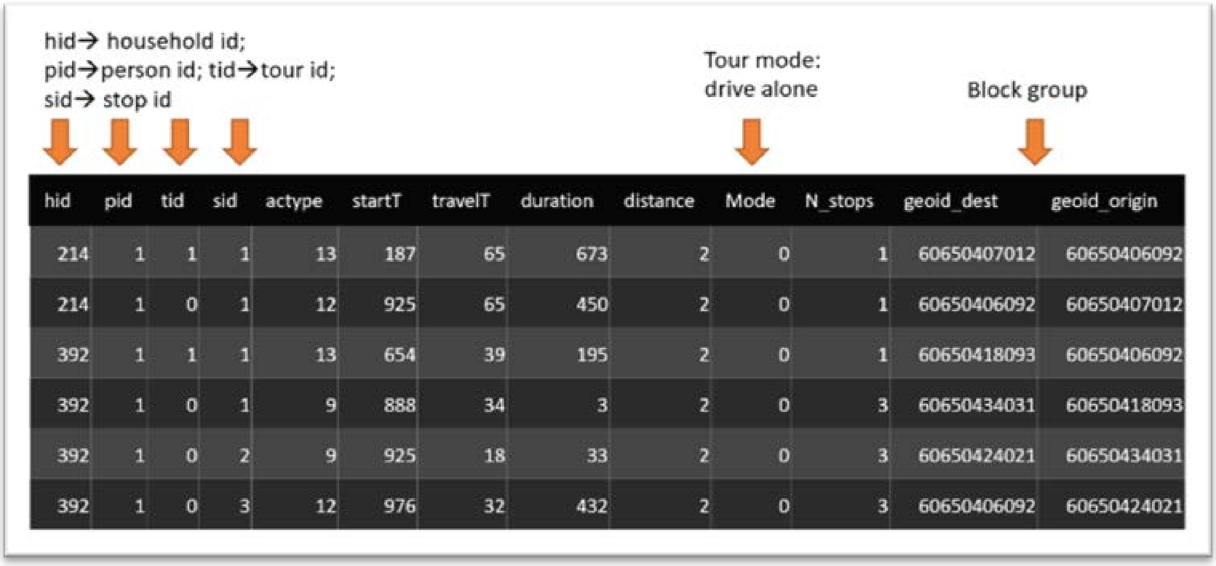


Figure 2.14. Example for income data calibration.

For further calibration, we utilized data from the Southern California Association of Governments (SCAG). The SCAG region encompasses six counties (Imperial, Los Angeles, Orange, Riverside, San Bernardino, and Ventura) and 191 cities in an area covering more than 38,000 square miles. SCAG develops long-range regional transportation plans including sustainable communities' strategy and growth forecast components, regional transportation improvement programs, regional housing needs allocations and a portion of the South Coast Air Quality management plans [Southern California Association of Governments, 2021]. Zone-based level-of-service travel data (LOS-data) from SCAG Model is necessary to analyze carsharing alternatives, indentifying travel time, travel cost, along access/egress time for public transit.

Next, we utilized the Comprehensive Econometric Micro-simulator for Daily Activity-travel Patterns (CEMDAP) software, representing a system of econometric models that represent the decision-making behavior of individuals [LBNL, 2021]. It is one of the first systems to comprehensively simulate the activity-travel patterns of workers as well as non-workers in a continuous time domain. Given various land-use, socio-demographic, activity system, and transportation level-of-service attributes as input, the system provides as output the complete daily activity-travel patterns for each individual in the household [Bhat, 2004]. With the data from PopGen and SCAG, CEMDAP creates daily activities for each person in the region of study (i.e., Riverside). As is shown in Figure 2.15, CEMDAP outputs household's ID, person's ID, start time of travel, travel time, mode of travel, original zone, and destination zone.



hid	pid	tid	sid	actype	startT	travelT	duration	distance	Mode	N_stops	geoid_dest	geoid_origin
214	1	1	1	13	187	65	673	2	0	1	60650407012	60650406092
214	1	0	1	12	925	65	450	2	0	1	60650406092	60650407012
392	1	1	1	13	654	39	195	2	0	1	60650418093	60650406092
392	1	0	1	9	888	34	3	2	0	3	60650434031	60650418093
392	1	0	2	9	925	18	33	2	0	3	60650424021	60650434031
392	1	0	3	12	976	32	432	2	0	3	60650406092	60650424021

Figure 2.15. Sample output from CEMDAP

The personal/household data from PopGen and trip data from CEMDAP were then loaded into BEAM to derive the mode-specific level-of-service data for all the travelers. In the research team's previous project funded by US Department of Energy, the BEAM model of the City of Riverside was already coded and calibrated using multiple data sources. It was applied to evaluate energy efficiency opportunities from large-scale deployments of Connected and Automated Vehicles (CAVs) coupled with shared mobility in California under a variety of scenarios. The Riverside BEAM model provides a powerful platform to evaluate the performance of the current shared mobility systems and predict the results of the future deployment, including link-by-link trajectories, mode and routing decision and energy consumption. Figure 2.16 shows the BEAM network with traffic in the City of Riverside model.

Figure 2.16. Riverside BEAM Network from Via, a BEAM visualizer

PopGen, CEMDAP and BEAM provide calibrated level-of-service data and person/household data to support the discrete choice model. In the next section, we describe the model and identify the coefficients, with a focus on the carsharing mode.

2.2.2. Model Development and Calibration

In this section, we describe the mode choice model for the City of Riverside considering the introduction of carsharing. The basic form of the model is adapted from the discrete choice model proposed in [Dorenbos, 2018]. Data from our city survey and city-data.com were utilized to calibrate the coefficients (e.g. beta values) in the model. Below are the utility functions with work as the tour purpose for all conventional modes, including a car driver, a car passenger, public transport, cycling, and walking. More details are provided in [Dorenbos, 2018].

Car driver:

$$u_{cd} = ASC_{cd} + \beta_{TT,cd} * TT_{cd} + \beta_{car0,cd} * D_{car0,cd} + \beta_{car1,cd} * D_{car1} + \beta_{age2544,cd} * D_{age2544} \\ + \beta_{inc4h,cd} * D_{inc4h}$$

Car passenger:

$$u_{cp} = ASC_{cp} + \beta_{TT,cp} * TT_{cp} + \beta_{fem,cp} * D_{fem} + \beta_{inc4h,cp} * D_{inc4h}$$

Public transport:

$$u_{pt} = ASC_{pt} + \beta_{TT,pt} * TT_{pt} + \beta_{car0,pt} * D_{car0,pt} + \beta_{age1829,cd} * D_{age1829}$$

Cycling:

$$u_{cy} = ASC_{cy} + \beta_{TT,cy} * TT_{cy} + \beta_{inc4h,cd} * D_{inc4h}$$

Walking:

$$u_{wk} = ASC_{wk} + \beta_{TT,wk} * TT_{wk}$$

For carsharing, since there are no observed data available for this alternative, beta values cannot be directly estimated. Based on literature, we assign beta values in following way. The level-of-service components of the utility function, including travel time, the cost over the distance or reservation time, and access/egress time component, are based on the variables used in the implementation of car-sharing in MATSim [Ciari et al., 2013]. For personal characteristic component and alternative specific constant, we use the lowest positive value of that variable in the utility functions of the conventional modes, or zero if there are no positive values. The utility function of car sharing mode is then formulated as follows:

$$u_{cs} = ASC_{cs} + \beta_{TT,cs} * TT_{cs} + \beta_{cost,cs} * cost_{cs} + \beta_{AET,cs} * AET_{cs} + \beta_{int,cs} * D_{int,cs} + \beta_{car0,cs} * D_{car0} + \beta_{car1,cs} * D_{car1} + \beta_{age2544,cs} * D_{age2544} + \beta_{hh2l,cs} * D_{hh2l} + \beta_{inc4h,cs} * D_{inc4h}$$

Table 2.1 list all the coefficients in the utility functions, with the definitions

Table 2.1. Definitions of Coefficients in the Utility Functions

Name	Definition	Name	Definition
ASC_{cd}	Constant for car driving	$\beta_{car0,\text{xx}}$	0 car in household
ASC_{cp}	Constant for car passenger	$\beta_{car1,\text{xx}}$	1 car in household
ASC_{pt}	Constant for transit	$\beta_{age0017,\text{xx}}$	Age: 0-17
ASC_{cy}	Constant for cycling	$\beta_{age1829,\text{xx}}$	Age: 18-29
ASC_{wk}	Constant for walking	$\beta_{age2544,\text{xx}}$	Age: 25-44
ASC_{cs}	Constant for car sharing	$\beta_{fem,\text{xx}}$	Gender: female
$\beta_{TT,cd}$	Travel time for car driving	$\beta_{inc4h,\text{xx}}$	Income: above median value
$\beta_{TT,cp}$	Travel time for car passenger	$\beta_{edu34,\text{xx}}$	Education: bachelor or higher
$\beta_{TT,pt}$	Travel time for transit	$\beta_{hh2l,\text{xx}}$	Household: 2 members or less
$\beta_{TT,\text{cy}}$	Travel time for cycling	$\beta_{int,\text{cs}}$	Personal interest in carsharing
$\beta_{TT,wk}$	Travel time for walking	$\beta_{cost,cs}$	Travel cost for car sharing
$\beta_{TT,\text{cs}}$	Travel time for car sharing	$\beta_{AET,cs}$	Access/egress time for carsharing

Note that a personal interest component $\beta_{int,cs} * D_{int,cs}$ was also introduced in the function to indicate the willingness of the traveler in using carsharing services if available. According to our community survey (Figure 2.10), 57% of participants answer “Yes”, 40% of participants answer “No” to the question of using a zero-emissions carsharing service. We integrated this result with the simulated person/household data by assigning random binary values $D_{int,cs}$ to indicate the personal interest in carsharing.

We further calibrated the beta-values using survey data from city-data.com. As shown in Figure 2.17, this website provides the mode share data for work-based trips in 2019. We associate the modes provide in the survey data with the 5 conventional modes in the discrete-choice model. Car driving mode corresponds to car alone in the survey. Car passenger mode corresponds to carpooled and taxi. Public transportation corresponds to bus, long-distance train, and subway. Cycling and walking are associated with bicycle and walked, respectively. We fixed the beta-values in the existing utility functions and fine-tuned the alternative specific constants to match the mode share from survey data. Table 2.2 shows the calibrated coefficients based on the survey data from Riverside.

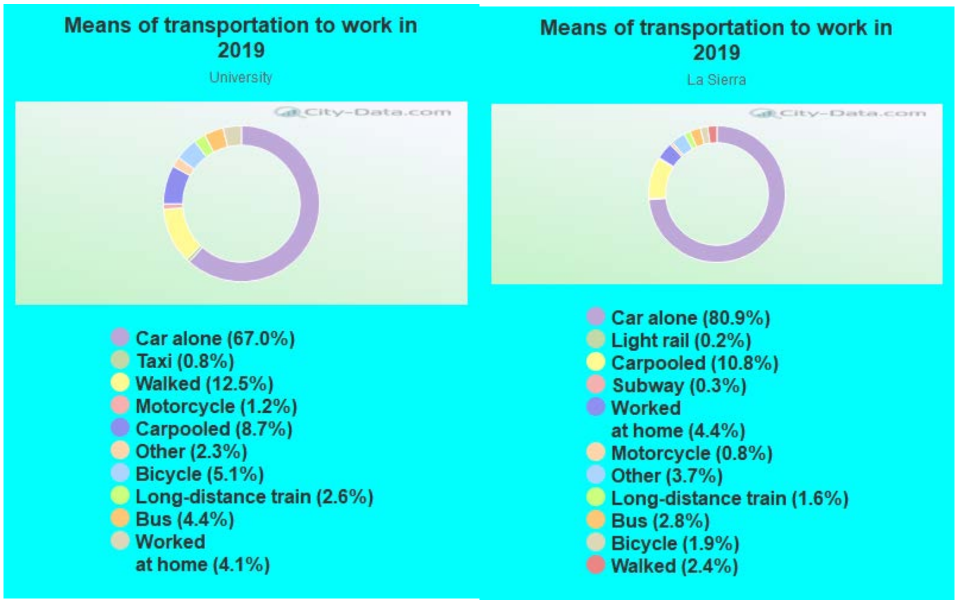


Figure 2.17. Ground-truth mode share data for work-based trips in city-data.com

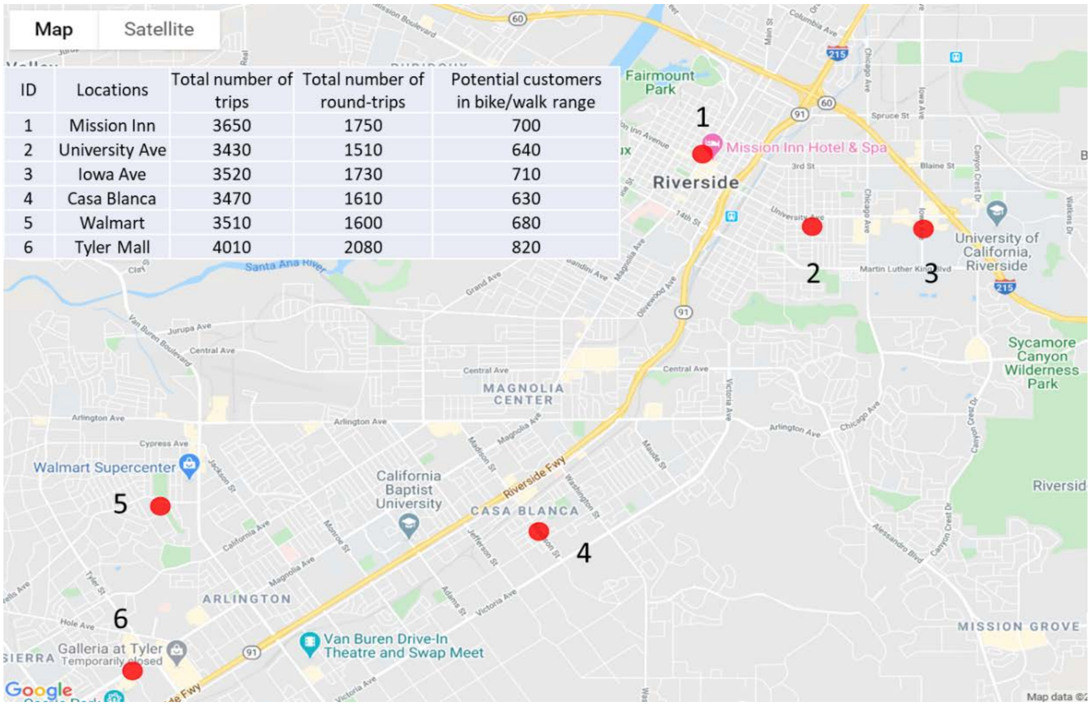
The personal and household data along with trip-based level-of-service information derived from BEAM and other models can then be applied to those calibrated utility functions to calculate the utility for each mode. Based on multinomial logit model assumption, the mode share of each mean of transportation before and after introducing carsharing, and the environmental impact of the mode shift can be estimated, described in the next section.

Table 2.2. Calibrated coefficients in the utility functions

Name	Value	Name	Value
ASC_{cd}	1.11	$\beta_{car0,\mathrm{cd}}$	-5.31
ASC_{cp}	-1.16	$\beta_{car0,\mathrm{pt}}$	0.443
ASC_{pt}	-1.54	$\beta_{car1,\mathrm{cd}}$	-1.05
ASC_{cy}	0.555	$\beta_{edu34,\mathrm{cp}}$	-0.56
ASC_{wk}	4.00	$\beta_{age0017,\mathrm{cd}}$	-3.45
ASC_{cs}	-1.69	$\beta_{age1829,\mathrm{pt}}$	1.06
$\beta_{TT,cd}$	-0.0967	$\beta_{fem,\mathrm{cd}}$	-0.311
$\beta_{TT,cp}$	-0.111	$\beta_{fem,\mathrm{cp}}$	0.765
$\beta_{TT,pt}$	-0.0479	$\beta_{inc4h,\mathrm{cd}}$	-0.749
$\beta_{TT,\mathrm{cy}}$	-0.0701	$\beta_{inc4h,\mathrm{cp}}$	-1.41
$\beta_{TT,wk}$	-0.0545	$\beta_{inc4h,\mathrm{cy}}$	-0.701
$\beta_{TT,\mathrm{cs}}$	-0.08	$\beta_{age2544,\mathrm{cs}}$	0.272
$\beta_{int,\mathrm{cs}}$	-5.00	$\beta_{car0,\mathrm{cs}}$	-0.167

2.2.3. Modeling Results

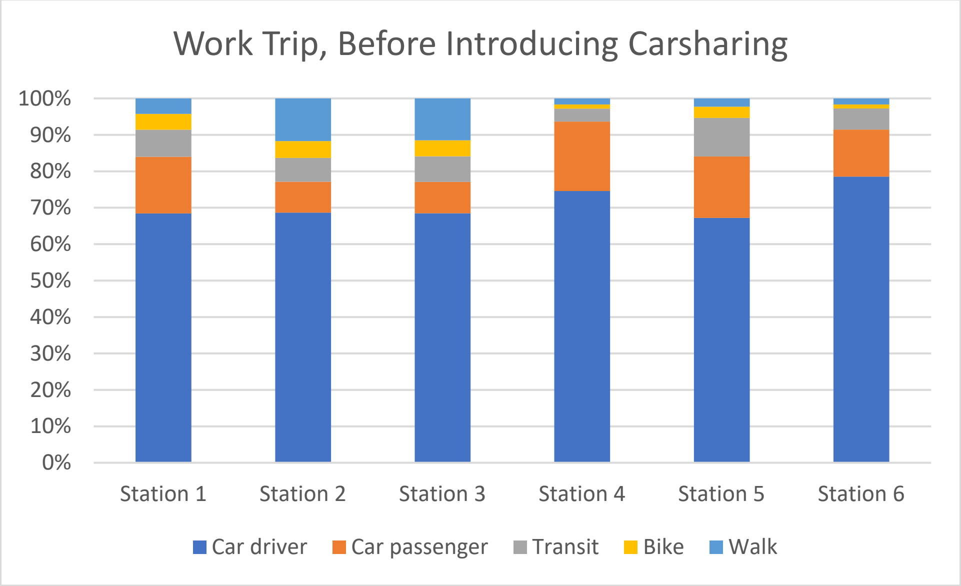
To evaluate the potential impact of zero-emissions carsharing in the City of Riverside, we first identified potential locations of carsharing stations and the demand around the station, based on community input data. Figure 2.18 shows six potential locations suggested by the community and the city. Station 1 is in Eastside neighborhood near Mission Inn. Station 2 and 3 are in University neighborhood near UCR campus. These three stations will be deployed along the Innovative Corridor, and the other three will be in the southern part of Riverside, one in Casa Blanca neighborhood, one in Airport neighborhood, and one in La Sierra neighborhood close to the shopping mall named Galleria at Tyler. Based on BEAM data, we identified the potential customers of the carsharing service at each station as the travelers who live, work or have other activities within walk/bike range of the station and plan to make roundtrips from that station. The table at the left-top corner of Figure 2.18 shows the number of potential customers and trips at each station.



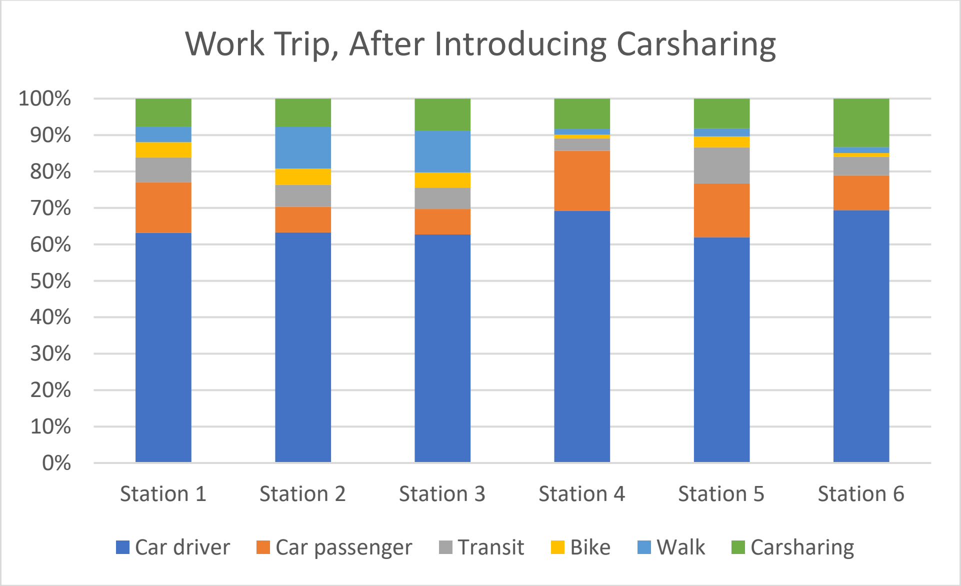
ID	Locations	Total number of trips	Total number of round-trips	Potential customers in bike/walk range
1	Mission Inn	3650	1750	700
2	University Ave	3430	1510	640
3	Iowa Ave	3520	1730	710
4	Casa Blanca	3470	1610	630
5	Walmart	3510	1600	680
6	Tyler Mall	4010	2080	820

Figure 2.18. Potential locations and travel demand of carsharing stations

Next, we applied the discrete choice model to estimate the mode share of those potential customers around each station. Figure 2.19 shows the mode share before and after introducing carsharing for the trips with a work-commute purpose. For the “before carsharing” scenario in Figure 2.19(a), the mode shares for all conventional modes are very close to the survey results from city-data.com, showing good performance in coefficient calibration. For the “after carsharing” scenario in Figure 2.19(b), the mode share for carsharing for work trips is between 8%-13%. About two thirds of the carsharing trips are shifted from car driving trips, and the rest are shifted from other modes including car passenger, public transit, cycling and walking. Due to the introduction of carsharing services, trips from single driver cars are reduced by 8-12%, trips as car passenger (including carpool and taxi) are reduced by 10-26%, and trips as transit passenger are reduced by 4-16%. Walking and bicycle trips are less impacted by carsharing, with 6% and 3% reduction, respectively.



(a) Before introducing carsharing



(b) After introducing carsharing

Figure 2.19. Mode shares for work trips before and after introducing carsharing

For the trips with education or other purpose, we can also estimate the mode share before and after introducing carsharing as shown in Figure 2.20. For education-based trips, the mode share of carsharing is less than 1%, which has little impact on conventional modes. For trips with other purposes, the mode share of carsharing is between 15%-23%. Among all the new carsharing trips, 39% of them are shifted from car driving trips. Note that for education-based or other trips, there is no observed data in the City of Riverside to indicate the ground-truth mode share for calibration, therefore those results from the uncalibrated model are not as significant as the results for work trips.

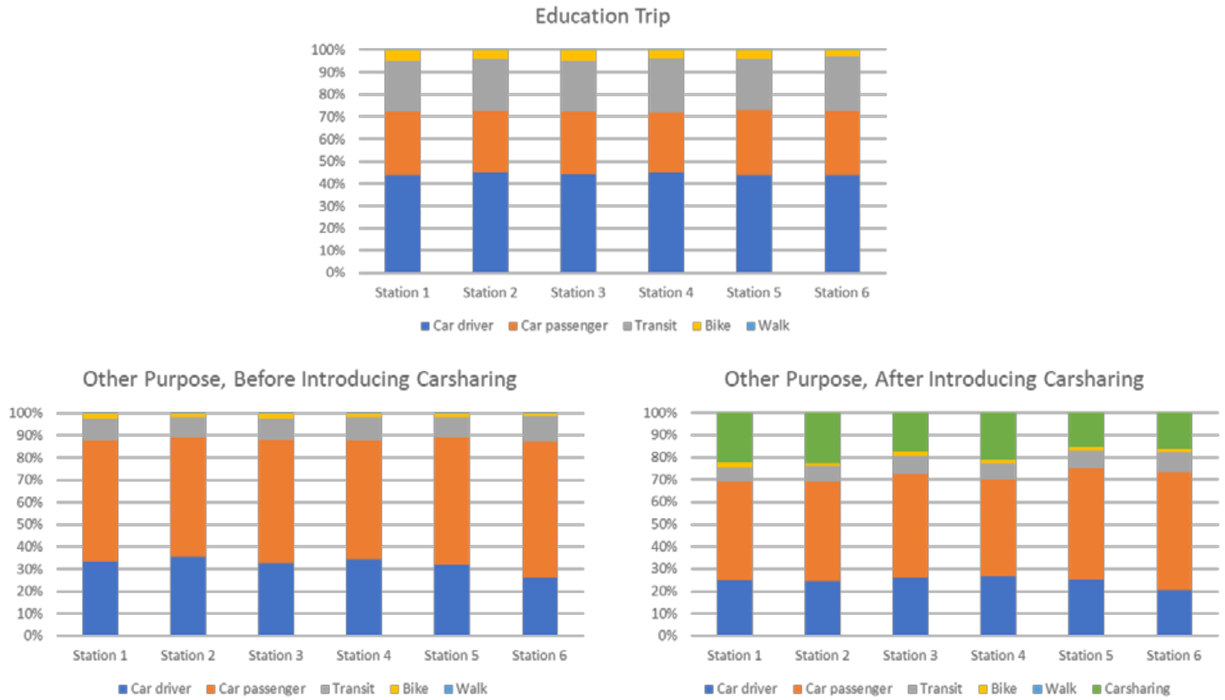


Figure 2.20. Mode shares for education and other trips

It is clear that the potential for carsharing services can enhance the accessibility of the local residents near the station, especially for the household that do not own a private car. According to the numerical results, for the people have zero cars in their family, the mode share of car sharing for work trip increases to 17%-40%. Considering the high correlation between income and car ownership, the carsharing program would significantly improve the accessibility of the disadvantaged communities.

When considering that the carsharing fleet would be zero-emissions (electric or fuel cell), the mode shift from gasoline private vehicles to electric carsharing vehicles would significantly reduce fuel consumption and greenhouse gas emissions. According to the results shown in Figure 2.19, it is expected that greenhouse gas emissions would go down by 10%, simply by reducing the use of the private gasoline-powered cars after introducing carsharing in the neighborhood. Beside the direct mode-shift impact shown in the proposed model, carsharing would serve as the last-mile solution for public transit and further reduce private car trips from this carsharing-transit synergy. In the long term, the reduction of car ownership will further decrease the travel demand and therefore reduce fuel consumption and greenhouse gas emissions. Those benefits are being explored in future research.

2.2.4. Key Conclusions and Recommendations

As shown in the previous section, a zero-emissions carsharing service is a promising approach to improve the accessibility and environmental sustainability of communities. To successfully implement the carsharing services, the following recommendations can be made to decision-makers:

1) The preferable locations of the carsharing stations should be in a community with high population density, and the residents of that community can quickly access to the station conveniently by walking or cycling.

2) According to previous analyses, people who have zero cars in their family will have higher use rates of carsharing services for their travel, so car ownership is a critical index in identifying the best locations for carsharing stations. For example, a disadvantaged area with lower car ownership may receive more significant benefit from introducing zero-emission carsharing.

3) Age is another key factor that impacts the acceptance of carsharing. Carsharing receives higher interest in a community with higher percentage of people aged 45 or below.

4) Reducing access/egress time can increase the popularity of carsharing. This can be achieved by easier parking and transaction at the carsharing station.

5) The Riverside community survey shows that 40% of the respondents are not that interested in zero-emissions carsharing services. It is clear that outreach activities will be required to further increase the acceptance of carsharing in the community.

3. Goods Movement in Inland Southern California

The future of the Inland Southern California is inextricably linked to the future of its goods movement logistics sector. Due to a variety of factors, Inland Southern California has grown to become one of the largest hubs of goods movement activity in the nation, with considerable infrastructure, employment, and economics connected to the logistics industry. This logistics industry will continue to grow as an important part of the economy, but it is critical that it be managed in a way that the quality of life in the communities is preserved, negative environmental impacts are minimized, and good-paying jobs are prevalent.

Currently, increasing imports throughout the nation are straining the current logistics supply chain, where more than 44% of the nation's goods pass through Inland Southern California on their way to their final destination—as such, the nation greatly depends on a properly functioning goods movement system in Inland Southern California. Nationwide imports continue to surge in terms of the activity through the ports of Los Angeles and Long Beach, sometimes causing unprecedented congestion with dwell times for over a quarter of the fleet averaging over five days for containers waiting at anchor as well as peak congestion once on the transition through the Inland Southern California freeways and throughout Southern California.

It is clear that goods movement logistics in Inland Southern California has grown substantially over the last few decades and there are a number of underlying *positive* elements:

- There is already a rich flow of goods through the region, contributing to California's wealth;
- There is the possibility of substantial employment growth in the region;
- There is the opportunity to transform goods movement in the region, with the goal of accomplishing the massive logistics necessary to keep up with the imports and exports for much of the US (mostly through the ports) and to serve the supply needs of Southern California.

In addition to these positive elements, there are also a number of *negative* elements:

- Air quality in the region is poor, notably due to the huge flow of diesel-fueled heavy vehicles (both trucks and locomotives), generating NOx, particle matter, and greenhouse gas emissions (i.e., CO_2); this has adversely affected the health and quality of life in the region (see Figure 3.1).

- Traffic congestion in the region is severe, across all roadway types (freeways, arterial roadways), negatively affecting the quality of life in the region. This leads to not only increased emissions, but also an economic loss due to time spent in traffic.

- The employment situation in the region is quite volatile, with the majority of the logistics related employment opportunities being part-time, temporary, low paying, and lacking upward career mobility. Employment is also under the threat of replacement by automation, and subject to pandemic-related and other negative health considerations.

- State-level Regulations have required high investments and operating costs on industry in order to achieve environmental goals; this has impacted the relationship between local logistics stakeholders and political leaders.

- Land use has been negatively affected, where greenery is being replaced by densely packed storage facilities, truck and trailer parking, and massive railyards; this has decreased the social and environmental attractiveness, and precluding implementation of facilities from higher value sectors such as high-tech, manufacturing, and R&D parks.

- Social equity has suffered, where the impacts of air pollution, congestion, and other measures is significantly higher on disadvantage communities in the region.

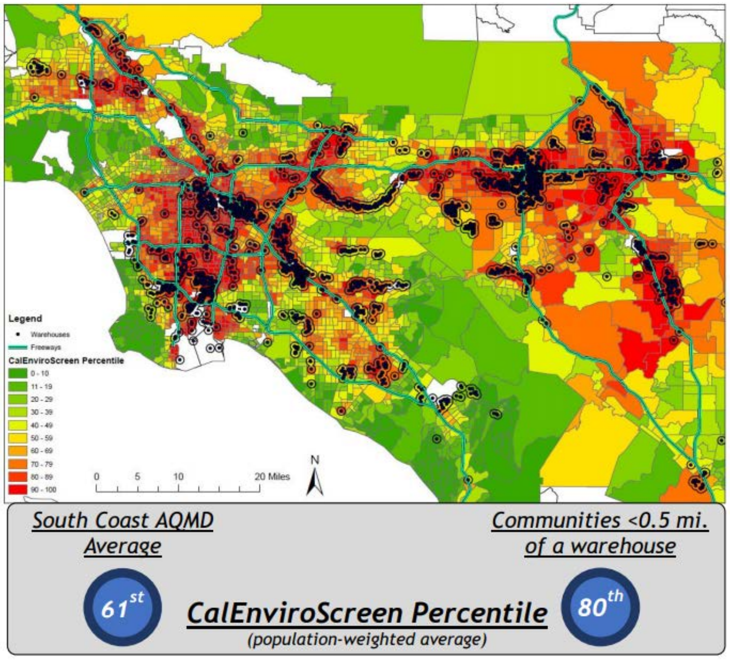


Figure 3.1. Environmental Burden on Communities living within a half mile of a warehouse in Southern California compared with other residents. (from the SCAQMD draft staff report on PR2305, page 17, posted January 2021).

outcomes have a number of interlaced (sometimes complex) *causes*, which need to be addressed:

- The poor air quality associated with goods movement is not due to warehouse operation itself, but instead is mostly due to its associated transportation activities. The internal operation of warehouses typically has a high degree of automation and are highly electrified, that can be accomplished cleanly with renewable electricity. Indeed, several warehouses have been awarded high green building certificates.
- The majority of the poor air quality is associated with the heavy-duty freight transportation sector, which includes diesel trucks and locomotives. This accounts for well over 90% of the emissions associated with warehouse operations. We currently rely on heavy-duty vehicles in high volume that travel significant distances in the region. This can be further broken down in to:
    - Goods received by sea at the ports are encapsulated in 20-foot or 40-foot transport containers, and these containers are sent directly to the logistic facilities all around Inland Empire;
    - Goods to be shipped by sea from the ports have to be encapsulated in 20-foot or 40-foot transport containers; these goods arrive by land to Inland Empire already

containerized or their containerization is done at logistic facilities all around Inland Empire;

- Similar to the seaward goods, shipped-by-land goods from/to Inland Empire logistics facilities to/from all over North America are mostly encapsulated in 20-foot or 40-foot regular or high-top intermodal containers, or in 53-foot semi-trailers.

This flow of heavy-duty vehicles all the way to/from most logistics facilities in Inland Southern California is also a major cause of congestion and road infrastructure deterioration on highways and roadways all over the region. Furthermore, these heavy vehicles are diesel-powered; nevertheless, there is currently a big push to transition these vehicles to zero emissions, based on battery or fuel cell technology.

The proliferation of facilities and heavy vehicles is also caused by the fact that most of the companies operating in the Inland Southern California logistic ecosystem are in many ways operating in silos:

- Warehouses are designed and planned to support the peak storage and throughput capacity requirements of their tenants, each independently. The sum of the company-specific peaks through the year is significantly higher than the peak of the overall storage and throughput requirements in the region. This leads to facilities whose capacity is much higher than their average required capacity to meet clients' demands; and to facilities with slow-moving items, expected to have a long duration-of-stay, to be located in often real-estate locations and in facilities not designed for such slow-moving items. This means that the space occupied by warehouses could support more flow than currently achievable, without spatial expansion, and that a smaller set could support the current flow, reducing the negative impacts of the logistics ecosystem.
- Warehouses are typically built in areas that have low land prices; this usually drives where warehouses are located. Instead, warehouses could be located in regions that are more strategic, minimizing travel and other negative externalities.
- In order to reduce transportation costs, companies aim to fill large containers or semi-trailers and transport them to targeted long-haul destinations, causing large demand for heavy-duty transportation with the implications discussed above. At the same time, they are diminishing their customer service capabilities, imposing long order-to-delivery lead times and low shipment frequency to customers, so as to avoid having to rely on less-filled containers or semi-trailers, smaller trucks, or higher-price less-than-truckload or express parcel transportation.

In addition, real-estate reality within Inland Southern California is hugely affected by two key factors:

- There is very limited land available in primary logistics corridors. Land prices are getting ever higher in such zones, which leads to expansion into a wider territory, pushing the geographical limits of the logistics zone.
- It is often the case that commercial zoning is adjacent to disadvantaged communities and freeways. There are many documented cases of these community unsuccessfully opposing the location of proposed warehouses in recent years. However, there is a large incentive for the cities and counties to acquire revenue from these transactions, and in the absence of other offers for commercial development, and potentially the lack of resources of the communities opposed to the development, it has become common that logistics warehouses constituting a majority portion of these neighborhoods. This places negative

impacts of air pollution, noise and congestion problem on these areas in comparison to a zoning pattern that would space the warehouse operations out throughout the region. Planning and zoning requirements between cities and counties also can vary greatly, often times leading to inefficiencies in the overall arrangement of the broader logistic operations.

- Regulations make it long and tedious for developers to get construction and renovation permits. The process often requires several years between request and approval, with significant costs and risk of refusal. This infuses a lot of inertia in the evolution of the logistics configuration and attracts logistics ecosystem partners to develop outside of the region, and even out of California toward less regulated states such as Arizona and Nevada. These moves may potentially create even greater congestion and pollution.

To address these goods movement issues in Inland Southern California, UC Riverside has a number of research programs in place, including IE-RISE (being led by the UCR CSI team) and the Sustainable Freight Research Initiative (being led by the UCR CE-CERT team). As part of these efforts, we describe the community outreach efforts carried out as part of this C-STACC project. This research has focused primarily on the community of San Bernardino where there are plans to increase goods movement with the introduction of a new Air Cargo Hub at the San Bernardino Airport. We conducted a number of listening sessions with a number of community partners, identifying four broad areas of concern, including: 1) air pollution and health; 2) traffic safety; 3) noise pollution and congestion; and 4) infrastructure damage and its effects on local traffic. The research team then closely examined the truck traffic in the surrounding community to the airport, and developed new “low-exposure” routing algorithms for trucks, based on knowing community demographics, sensitive receptors (schools, hospitals), truck travel patterns, and roadway exposure ratings.

3.1. Community Outreach

UC Riverside’s Center for Social Innovation (CSI) has a large program in community outreach in Inland Southern California. They have recently launched an Inland Empire Roadmap for an Inclusive and Sustainable Economy (IE RISE). *IE RISE* is an innovative project to develop a robust regional economic and institutional plan that: a) engages grass-roots, business, and government partners across its various sub-regions, b) supports youth voices to build the next generation of regional leadership, c) engages and builds research and policy capacity within the region, and d) provides a roadmap for a more inclusive, equitable and sustainable economy and society.

As part of this effort, the CSI team has reached out to institutional allies and local partners. The CSI team has convened a coalition of community based organizations, industry, public institutions and other stakeholders with the purpose of creating a unified vision for the Inland Empire. Recently, IE-RISE has continued to work with our coalition partners to continue these discussions around our core values of inclusion, sustainability, and equity. In addition to the steering committee, monthly meetings are held for each issue track including: access and equity in technology, arts and culture, disability, economic development, education, environmental justice, food systems, good governance, grassroots media and narrative, gender justice, health, homelessness, housing, immigrant justice, labor/workforce, LGBTQ+ equity, nonprofit equity, philanthropy, public safety, racial justice, transportation, and youth development and empowerment.

Specific to transportation, the group has held stakeholder discussions on opportunities presented by new projects such as the Redlands Rail project (low-emission diesel passenger rail, which will later be converted to hydrogen fuel cell), a “hyperloop project” connecting passengers from Rancho Cucamonga Metrolink to Ontario Airport, and high-speed rail from Las Vegas to Apple Valley, with a possible connector to Rancho Cucamonga. In addition, the group has discussed challenges associated with transportation projects such as California High Speed Rail’s Los Angeles to Anaheim segment, which will likely move freight traffic from coastal counties (LA and Orange) to inland areas (Colton and other locations in San Bernardino) that will adversely affect communities already ranking high on Cal EnviroScreen measures.

Central to goods movement and this C-STACC effort, a number of community outreach activities have taken place, as described below.

3.1.2. Community Engagement and Working Groups

UCR’s CSI researchers have reached out to a number of community partners in California’s Inland Empire. The Center for Community Action and Environmental Justice (CCAEJ) group initially emerged as a key research partner for this research, where they are engaged in a number of studies of local warehousing in different Inland Empire cities. Subsequent to internal organizational challenges at CCAEJ, including the abrupt departure of half of the organization’s staff, the research team continued to work with key personnel in their new organizational homes, including Warehouse Workers Resource Center (WWRC) and Inland Congregations United for Change (ICUC). We have also worked closely with these two organizations as part of the larger San Bernardino Airport Communities Coalition (SBACC). We have had regularly scheduled teleconferences with CCAEJ, WWRC, ICUC, and SBACC on the goods movement/warehousing issue. These groups are concerned with not only impacts of warehousing on the local workforce, but also on the local residents that are affected by truck traffic and emissions.

3.1.3. Community Listening Session - IE RISE - Transportation Track

As part of this program, CSI researchers carried out an online listening session on September 25th, 2020. CSI, along with several community partners, led this session that touched on key assets of transportation infrastructure in the Inland Empire, what is currently working well and what aspects need to be improved, and how the region can achieve equity within the next ten years. Participants flagged the key components of the transportation sector in the Inland Empire. This includes: logistics-from the ports to the warehouses, automobiles-how residents get to and from work, and transit. One key asset stakeholders identified is the region’s location and proximity to ports, freeways, rail lines, and ports of entry. Participants also flagged the strong infrastructure for airports and other air assets.

Ontario Airport was highlighted as a key Inland Empire asset that has had growing success, particularly before the COVID-19 crisis. Despite the pandemic, the airport’s cargo component and increased presence of major e-commerce players such as FedEx, UPS, and Amazon has allowed the airport to continue to thrive. San Bernardino airport is also trying to increase its cargo capacity. There are several older airports that have the infrastructure to support increased air cargo, and a diverse network of airport-type facilities that could allow the IE to expand its economic base.

While these industries are important assets, participants also flagged concerns with pollution and other increasing inequities. Areas that could be improved include the long commuting times (although that has changed during the pandemic), air pollution, and the types of jobs and labor that do not always pay a living wage. Additionally, participants lamented the concentration of transportation resources on the west side of the region, leaving other areas with a severe lack of affordable or accessible transportation options. There is also a live/work gap—where people can afford to live versus where the jobs are exacerbates inequalities. More focus on housing and incentivizing businesses to focus on where people live would help with this issue. Finally, there is a lack of integrated planning on housing and transportation.

Suggestions from the community coming out of this session included: including more diverse voices in decision-making processes, listening to community needs, and finding new leaders. These recommendations were all highlighted as important to achieve equity.

3.1.4. Community Listening Session - San Bernardino Coalition Community

A second community listening session was also conducted. CSI researchers led a listening session with the San Bernardino Coalition Community, with participation from CCAEJ, and a presentation from UCR's CE-CERT on the low exposure routing modeling project (described in Section 3.2). This session was conducted remotely on Tuesday, September 29th , 2020. The San Bernardino Airport was lifted up as a case study and participants were engaged in a discussion with guiding questions.

The session opened up with a welcome from CSI and CCAEJ. The facilitators talked about the importance of building community power, organizing, and having a seat at the decision-making table. Participants were reminded that their voice matters and that this community forum is a great tool for them to express their views to a larger audience.

Details were then provided on the San Bernardino Airport air cargo facility modeling study. It was demonstrated how different trucking routes and how they can have different types of impacts on health, infrastructure, and community well-being. The intent of the modeling study is to route trucks in a way that will minimize the expires of pollutants, especially in terms of vulnerable communities and places like hospitals and schools. Through the analysis, CE-CERT identified areas in San Bernardino that have high sensitivity to poor air quality. The goal of this listening session was to confirm these high sensitivity areas, and flag any areas or concerns that the data may have missed. After getting some initial reactions from the participants and answering some clarifying questions, we presented the six questions noted below to the group.

1) *How many of you have families employed in the warehouse or trucking industry?*
2) *How is your community currently experiencing truck traffic? In terms of schools, workplace...*
3) *What are the specific time of day issues that you experience?*
4) *If the trucks are all electrified, are there other issues of environmental concern?*
5) *From your perspective, what would an equitable transportation system look like?*
6) *Do you have specific areas of concern in your neighborhood where you want to see improvements made in terms of environmental justice?*

Participants living in the region noted that the increased truck traffic is affecting them and their families in a number of ways. With many of them either employed themselves or someone they know being employed in the warehousing transportation industry, they realize the economic benefit of the industry. At the same time, they are very concerned with the consequences.

A few examples include:

- Significant noise pollution from the freeways, airports, railways;

- Extreme road damage that is not repaired in a timely manner, or at all;
- Participants are seeing truck traffic on roads that normally do not have truck traffic. The current congestion is now clogging up residential streets/areas;
- There are more trucks on the streets near pedestrian areas like schools;
- There is constant truck traffic at all hours of the day/night, but the worst is around early morning hours (4am) and in the afternoon;
- Air quality is a serious concern, especially with the increasing impacts of climate change on the region; participants report more “smog” in the region.

Overall, community members flagged 4 broad areas of concern: (1) public health and safety, (2) noise pollution and congestion, (3) infrastructure damage and its effects, and (4) congestion issues being at all times of the day/night. Recommendations from this session were similar to the recommendations that came out of the first IE-RISE listening session. There was a specific emphasis on community voice and giving the community more power in the region. Participants also noted their support for clean technology and increased sustainability in the warehouse logistics sector.

3.1.5. Community Mapping Tool

To supplement the qualitative data, we have collected from the listening sessions, we also utilized a mapping tool for further analysis, shown in Figure 3.2. We developed the base “Story Map” and then allowed community members to note specifically on the map which locations they thought would be particularly sensitive to these truck routes. Community members were able to flag these specific locations. The location data on location sensitivity is collected through ArcGIS web map application. Residents from nearby areas could access the App and drop a pin on the map and answer the survey questions on location sensitivity (pedestrian safety, air safety, traffic safety, environmental safety).

Next, we created a data hub for this project and invited residents in the surrounding areas to report sensitivities in their neighborhood using key locations as reference points. We asked the public about their opinion on location sensitivity in vehicle safety, air safety, pedestrian safety and environmental safety. Residents can identify a new location by dropping a pin on the map. A smart editor tool guided them to fill out a short survey where they will report location name, their contact information, and four sensitivity items. They could also leave a message in the report. Additionally, the search bar in the mapping tool allows residents to navigate to a key location in the database using keyword search.

San Bernardino Airport is at the center of sensitive locations due to a “massive increase” in traffic according to staff members from the San Bernardino Airport Community Coalitions. On the south side of the San Bernardino Airport, there is a Mountain View Power Plant. Accordingly, this location already has pollution issues. Additional trucking routes would exacerbate air, environmental, vehicle, and pedestrian safety issues. Norton Science Academy is located in the southwest side of the airport. A staff member from the San Bernardino Airport Community Coalitions reported that this location is sensitive to vehicle and pedestrian safety issues and prone to environmental and air pollution. There are heightened concerns about pollution, and vehicle & pedestrian safety near W 5th street and San Bernardino Intermodal Facility. Similarly, areas on the far west side of the 215 freeway because there is a yard for trucks that serve J.B. Hunt. Seccombe Lake is located on the west side of the San Bernardino Airport. This area is reported for being sensitive to environmental and air pollution. On the northwest side of the airport, the sensitive area is near the 215 freeway on the path for trucks traveling from San Bernardino Airport to Amazon warehouses. There is also a travel center in Verdemont and a large stockpile of broken concrete left from the Oxbow project. On the north side of the airport, the sensitive area is near a community center, an Amazon Air Hub, and a truck trailer storage facility. Moving to the east side of the airport, there is Packinghouse Christian Academy and a dog park, where it is sensitive to pedestrian safety concerns. Additionally, the location on W 210 FWY right after the Baseline entrance is sensitive to pollution, and pedestrian & vehicle safety. Finally, there is freeway construction on 210 off 5th to baseline. This area is also sensitive to vehicle safety concerns. Overall, sensitive locations are located in all four corners of the airport. However, more residents reported location sensitivity issues on the west side of the airport. It is also the area where three different truck routes merge on 215 Freeway.

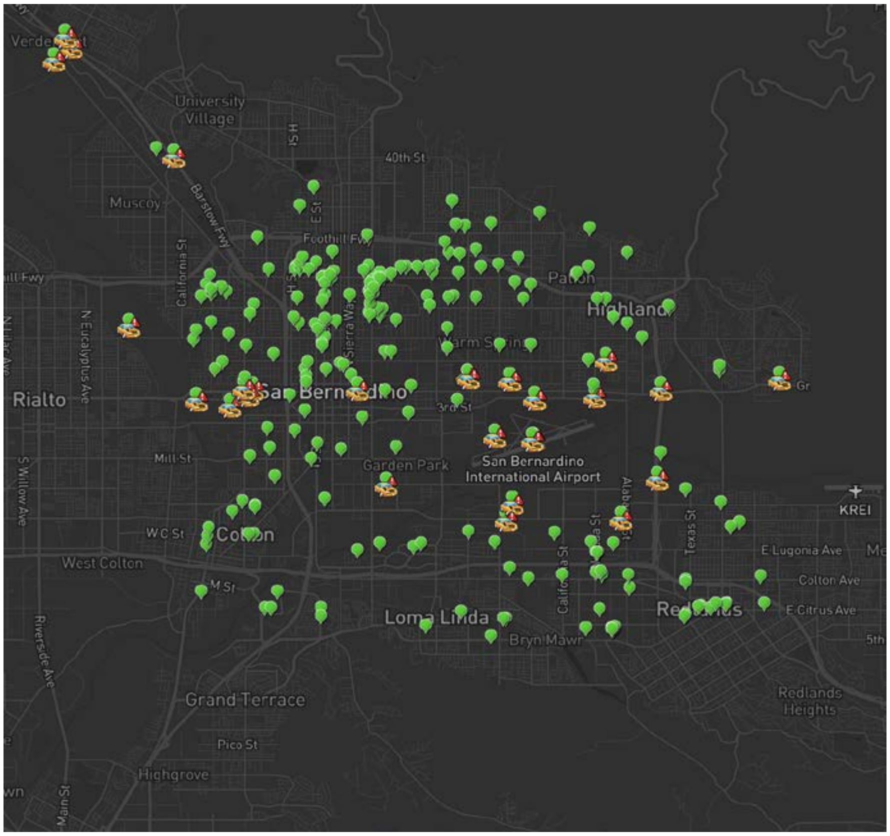


Figure 3.2. Community Mapping Tool

The final interactive report is available in this ArcGIS Story Map, located at:

https://storymaps.arcgis.com/stories/91d1d41f2e184537840f27aab4af260d

3.2. Routing to Reduce Human Inhalation of Traffic-Related Air Pollutants in San Bernardino Airport Area

Over the last several years, researchers at UCR's CE-CERT have developed a number of advanced fleet management tools to mitigate negative impacts of goods movement. These tools include Intelligent scheduling software tailored for electric trucks, dynamic time-of-day fleet scheduling software, geofencing strategies, and low pollutant exposure truck routing. These tools are coupled with CE-CERT's research in connected and automated vehicles, with a focus on heavy-duty vehicles.

As part of the C-STACC effort for the Inland Empire, we focused our efforts on introducing low-pollutant exposure routing techniques center around the San Bernardino Airport, which is being used as a major air cargo hub for Amazon, UPS, and FedEx. This section of the report describes this case in detail.

3.2.1. Background

San Bernardino International Airport is a public airport located two miles southeast of San Bernardino City in San Bernardino County, California. The airport mainly supports air cargo operations and it has recently been approved to undergo a major expansion as an Amazon regional air hub [SBDIA, 2021]. Local residents, communities, and organizations have been expressing concerns about future employment opportunities and environmental impacts [SBAC, 2021].

This community is largely part of the SB 535 Disadvantaged Communities (DAC) [OEHHA, 2021], and it is located east to Muscoy, which is one of the AB 617 communities designated in 2018. As a promising geofencing strategy, *exposure-based routing* can navigate a heavy-duty-diesel-truck (HDDT) through a DAC in a way that lowers the total exposure of community members to the pollutant emissions from the truck without significantly increasing travel time [Boriboonsomsin, 2020]. In this project, we evaluated the exposure-based routing in the San Bernardino Airport area, as shown in Figure 3.3. This area is bounded by Freeway I-215 in the west, I-10 in the south, and I-210 curving from south to north then connecting the east-west side. Corner one, two, three and four corresponds to the Northwest, Northeast, Southeast, and Southwest corners of the San Bernardino city area, respectively. The location of San Bernardino Airport west side is marked in the figure below, and we evaluated the potential HDDT trips from the four corners to and from the airport.

3.2.2. Methods and Assumptions

Figure 3.4 presents the methodological framework of exposure-based routing. It involves a modeling chain that starts from vehicle emission modeling to air dispersion modeling, human exposure assessment, and finally vehicle route calculation where the output from one step is used as an input for the next step. In addition, each step also requires other inputs. The inputs and assumptions associated with each modeling step are described below.

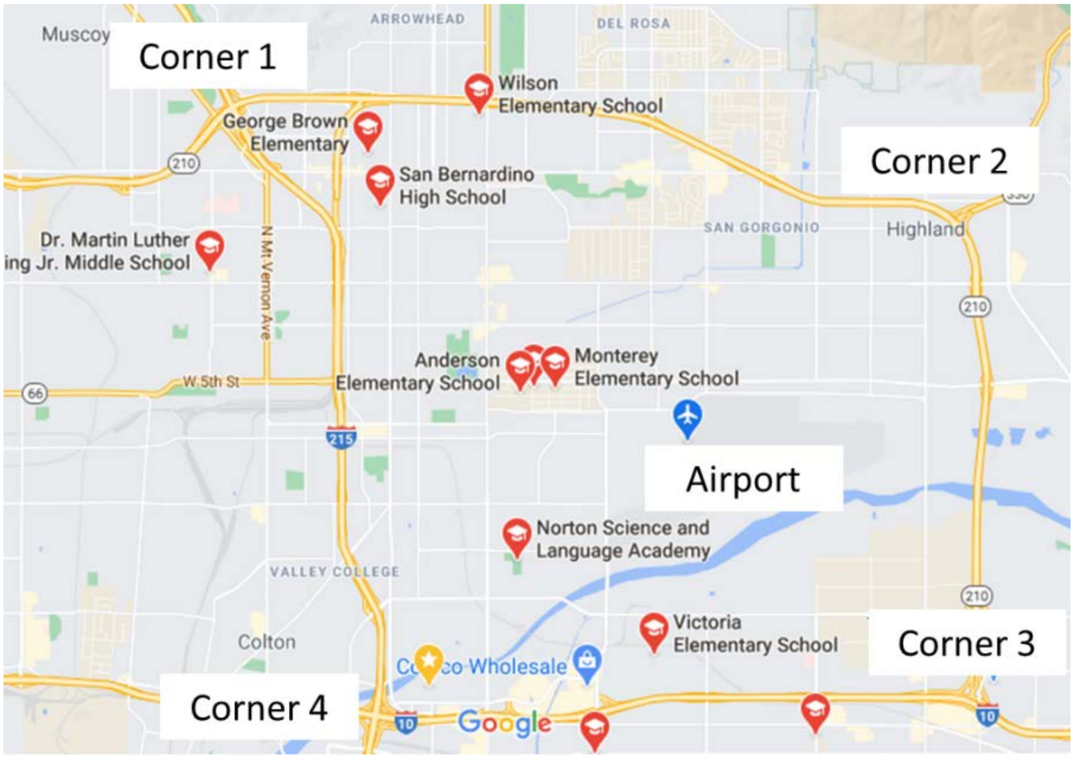


Figure 3.3. Map of study area

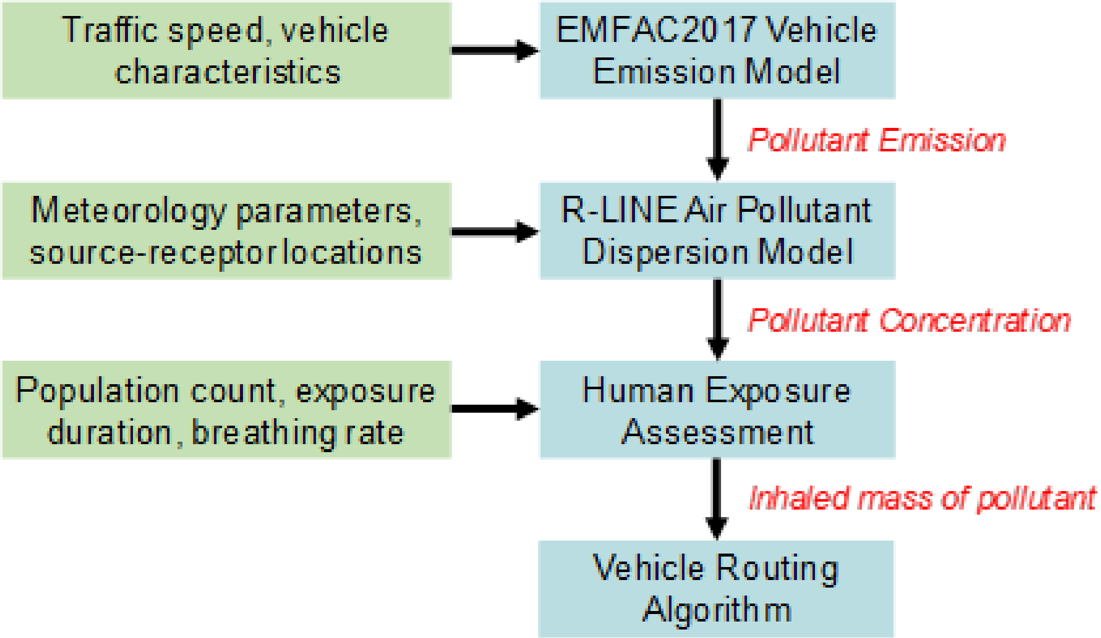


Figure 3.4. Methodological framework of exposure-based routing

3.2.3. Vehicle Emission Modeling

The calculation of emissions was focused on fine Particulate Matter ($PM_{2.5}$), Nitrogen Oxide (NO_x), and Carbon Dioxide (CO_2) emissions from HHDTs. They were calculated using Equation below:

$$E_{i,j} = V_{i,k} \times L_i \times EF_{j,k} \quad (1)$$

where $E_{i,j}$ is mass emission of pollutant j on link i; $V_{i,k}$ is HHDT volume on link i with link speed k; L_i is length of link i; and $EF_{j,k}$ is emission factor of pollutant j at speed k.

The emission factors for heavy-duty diesel trucks were obtained from CARB's EMFAC2017 emission model for the following model run specifications:

- *Source* – EMFAC2017 (v1.0.2) Emission Rates [CARB, 2017; CARB, 2021]
- *Region Type* – County
- *Region* – Los Angeles, assuming trucks come from LA County
- *Calendar Year* – 2018
- *Season* – Annual
- *Vehicle Classification* – EMFAC2011 Categories
- *Vehicle Model Year* – 2012

The calculation was done for a single heavy-duty diesel truck of model year 2012, but for all the roadway links in the modeling area. It was assumed that this truck would be traveling at the speed equal to the speed limit each roadway link. The data regarding speed limit on roadway links was obtained from a commercial digital roadway map. Emission factors of the truck were obtained from CARB's EMFAC2017 model [CARB, 2017; CARB, 2021], which is a regulatory model for estimating on-road mobile source emissions in California. Only running exhaust $PM_{2.5}$, NO_x and CO_2 emissions were calculated.

3.2.4. Air Dispersion Modeling

An atmospheric dispersion model was needed to estimate the concentration of air pollutants emitted from vehicular sources at specific receptor locations. In this study, R-LINE, a research grade dispersion model for near-roadway assessment was used [Snyder, 2013]. Micro-meteorology data inputs for R-LINE such as temperature, wind speed, wind direction, surface friction velocity, and Monin-Obukhov length were obtained for Redlands Station from South Coast Air Quality Management District website [SCAQMD, 2019]. The data for Monday May 9, 2016 were used. Source height was assumed to be 2.5 meters (~8.2 ft), which represents a typical height of exhaust stacks of heavy-duty diesel trucks. Receptor height was assumed to be 1 meter (~3.3 ft), which represents an average height of 5 year-old children.

3.2.5. Human Exposure Assessment

In this research, pollutant exposure is referred to the amount of pollutant inhaled by a group of subjects. Therefore, inhaled mass (IM) was used to represent the pollutant exposure, which was calculated as:

$$IM = C * Pop * t * BR \quad (2)$$

where C is pollutant concentration ($\mu g/m^3$) in a given microenvironment; Pop is number of subjects in the microenvironment; t is truck travel time on the road link (hour); and BR is breathing rate (m^3/hour/capita) of the subjects exposed to the pollutant.

Breathing rates of population in different age groups were based on the U.S. EPA's Exposure Factors Handbook [EPA, 2011]. In addition, the California Office of Environmental Health Hazard Assessment's Technical Support Document of Exposure Assessment and Stochastic Analysis included detailed breathing rate scenarios [COEHHA, 2012]. It is desirable to reduce population exposure to traffic-related air pollutants because tailpipe emissions, such as $PM_{2.5}$ and NO_x, are associated with health risks in young children, older adults, patients, and even healthy adults [Brunekreef, 1997; Gong, 2004; Weichenthal, 2012]. Thus, in this research both population-wide average breathing rate of 17 m^3/day and population-specific breathing rate were applied, and the results will be presented.

3.2.6. Vehicle Route Calculation

The Vehicle Routing Problem (VRP) is traditionally aimed at finding a travel route between a pair of O-D points that has the shortest distance or shortest travel time. However, in this research, the vehicle routing objective is to reduce inhaled mass of pollutant while limiting the increase in travel distance within a reasonable range for the trip. This is a multi-objective VRP studied by many researchers (e.g., [Grodzevich, 2006]). Several methods for solving multi-objective VRP are summarized in [Demir, 2014]. In previous studies, we used a weighting method that transformed the multi-objective VRP into a single-objective VRP. The specific methods can be found in [CARB, 2020]. In this study, due to limited number of Origin-Destination pairs, we simply selected freeway routes and compared them with manually selected alternative routes that have similar travel time.

3.2.7. Network Characterization

Figure 3.5 shows four entry/exit points located at four corners of the study area. The sensitive facilities or receptors used in this study are primarily used by individuals that are most susceptible to the effects of air pollution. Daycares, schools (elementary to high schools), assisted living homes, and public parks were chosen as the sensitive facilities. The population data were projected to calendar year 2018 at census block level based on 2010 Census and 2018 American Community Survey. Population at sensitive facilities were projected based on school enrollment data and census population. Population at residential blocks are estimated based on several sources including population by age groups [Suburbanstats, 2021], employment data [USBLS 2017; USBLS, 2021], and school enrollment rate [Slate, 2021; NCES, 2021].

To better understand how the R-LINE model parameters impact the output concentration values, sensitivity analysis of road width and freeway sound barrier options in R-LINE was tested. The results showed that for the current modeling scenario, the road width and sound barrier options only have minor effects on the modeled concentration results. On the other hand, the most impactful factors are traffic speeds, emission factors, meteorological conditions, and population distribution.

Influence of varying breathing rate was also examined. As mentioned above, three different breathing rate scenarios was applied: an averaged breathing rate of 15 m^3/day, an age-group specific breathing rates (in m3/day), and age-group specific breathing rates normalized by average body mass (in m3/day/kg) as shown in Table 3.1.

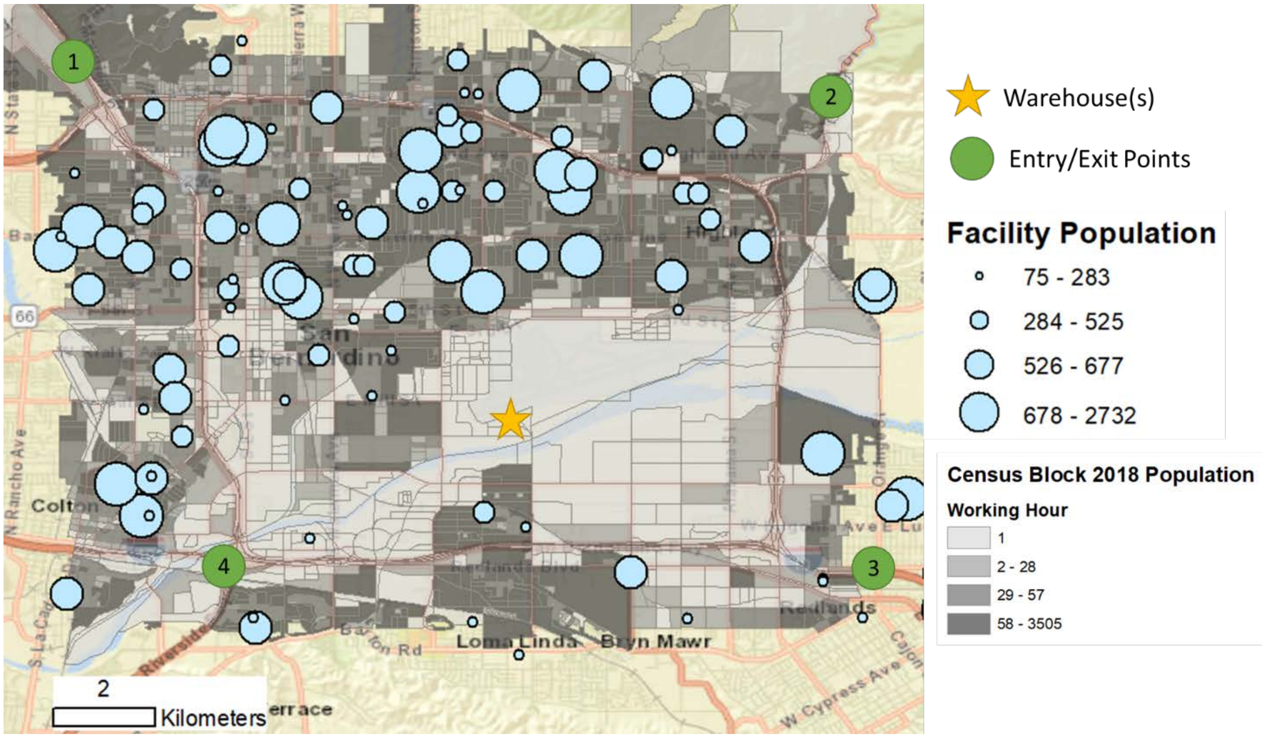


Figure 1.5. Map of population, sensitive facilities, and truck trip attractions in San Bernardino

Table 3.1. Recommended Mean Point Estimates for Long-Term Daily Breathing Rates

Age group	0-2	2-9	2-16	16-30	16-70
m3/day	6.2	10.7	13.3	15	13.9
m3/day/kg (body mass)	0.658	0.535	0.452	0.21	0.185

Figure 3.6 shows the colored map of modeled $PM_{2.5}$ *IM* values at sensitive facilities and census blocks based on the meteorological conditions at 10 A.M. on May 9, 2016, assuming a population-averaged breathing rate of 15 m^3/day. For instance, a $PM_{2.5}$ *IM* value of 0.23 µg/link means that there would be 0.23 µg of $PM_{2.5}$ inhaled by the nearby population after the truck traversed this roadway link in the given scenario. As air pollutants from one roadway link can reach multiple facilities/blocks within 1,500 meters, the *IM* values of roadway links are generally higher for those near large sensitive facilities and densely populated census blocks. Figure 3.6 also shows the wind direction, and it can be observed that roadway links upwind of large sensitive facilities and densely populated census blocks generally have higher *IM* values than those downwind. Figure 3.7 shows the aggregated $PM_{2.5}$ *IM* values from both sensitive facilities and census blocks based on the meteorological conditions at 10 A.M. and 3 P.M. on May 9, 2016, assuming a population-averaged breathing rate of 15 m^3/day. The aggregated $PM_{2.5}$ *IM* values are generally higher at 10 A.M., when compared to that of 3 P.M., due to the more turbulent condition in the afternoon contributes to faster dispersion of air pollutants. The comparison shows how the meteorological conditions can affect the *IM* values.

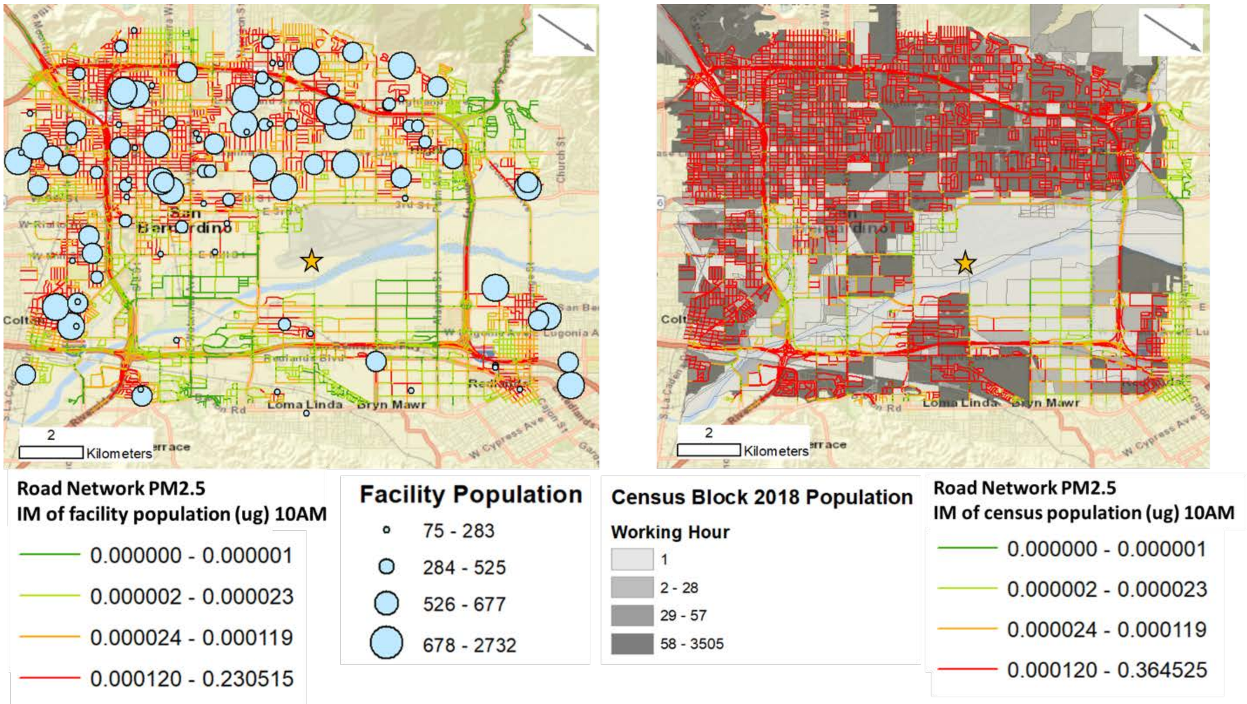


Figure 3.6. Inhaled mass of $PM_{2.5}$ (µg/link) at (left) sensitive facilities and (right) census blocks at 10 A.M. assuming a population-averaged breathing rate of 15 m^3/day

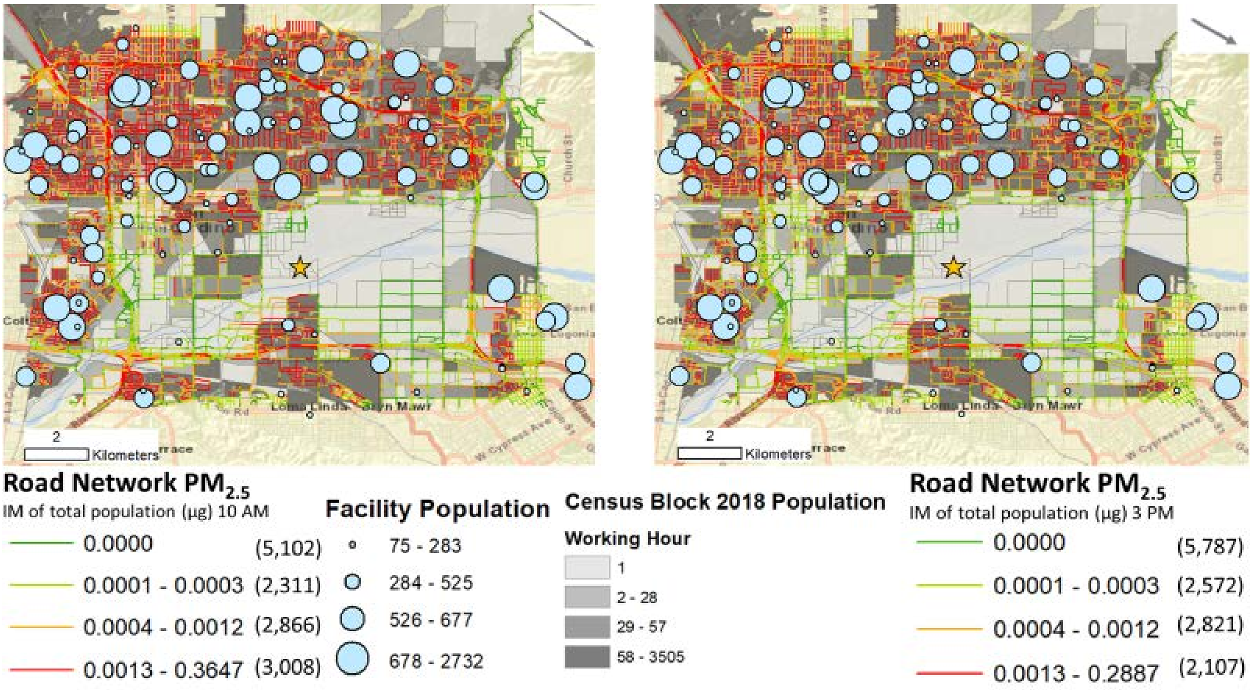


Figure 3.7. Total inhaled mass of $PM_{2.5}$ (µg/link) at 10 A.M. (left) and 3 P.M. (right) assuming a population-averaged breathing rate of 15 m^3/day

Figures 3.8 and 3.9 shows the modeled $PM_{2.5}$ *IM* based on the age-group specific breathing rate of m^3/day as shown in Table 3.1. These figures give a visual comparison of how the breathing rate can affect the *IM* values. When using age-group specific breathing rate, due to the lower rate of younger children, the overall *IM* values will be lower in Figures 3.8 and 3.9. It acts equivalently as reducing the weight factor for younger children when calculating *IM* values.

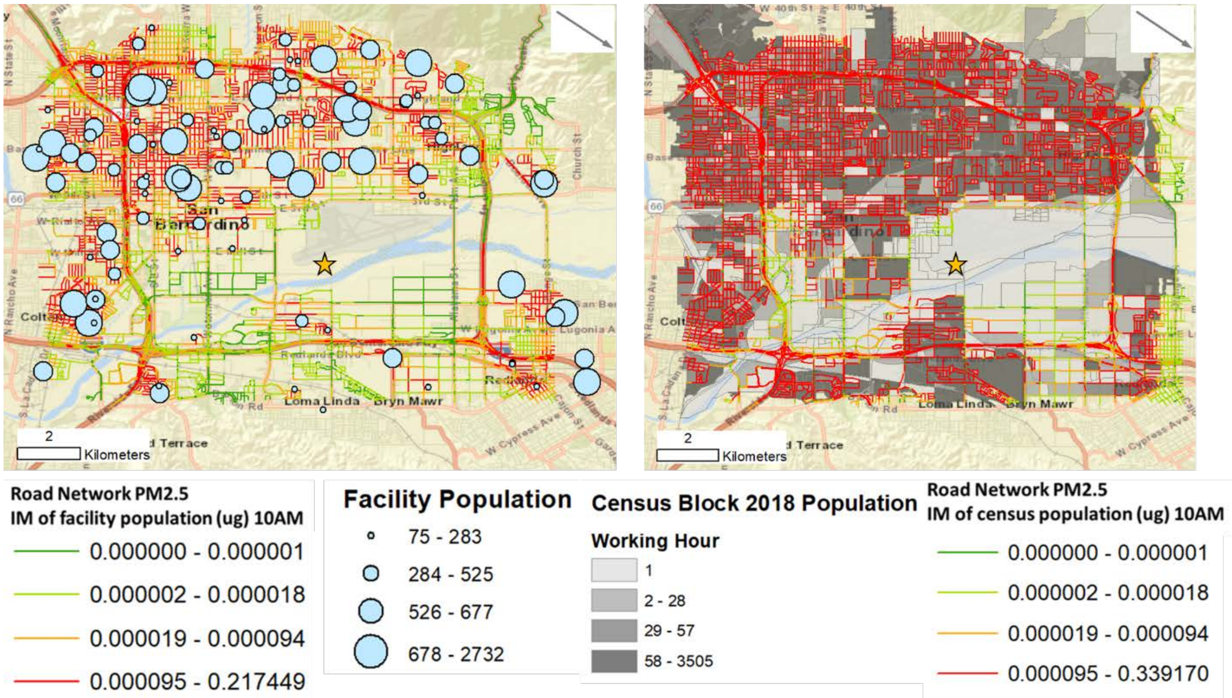


Figure 3.8. Inhaled mass of $PM_{2.5}$ (μg/link) at (left) sensitive facilities and (right) census blocks at 10 A.M. assuming age-group specific breathing rate of m^3/day.

3.2.8. Low Exposure Route Comparison

For trips that connect the four freeway corners and the air cargo hub, both a freeway route (FR) and a low exposure route (LER) were determined. The selection methods are based on freeway routes and local street routes that have similar travel time as described earlier.

Figure 3.10 illustrates three example trips. Originating from corner 1, the coral-colored route shows the freeway route (FR) and the green route shows LER-a that takes Mill Street (left) and LER-b which uses Orange Show Road (center) to the destination. Similarly, for corner 2 (right), the coral-colored route shows the freeway route (FR) and the green route shows LER that takes San Bernardino Ave to the warehouse area. The comparison of route attributes is summarized in Table 3.2, assuming a population-averaged breathing rate of 15 m^3/day. For corner 3 and corner 4, the destination is located close to freeway route (FR), therefore any shift to local streets will significantly increase the travel time. Considering the travel time trade-off, we decided that for corner 3 and corner 4, the freeway routes are the same as the low exposure routes.

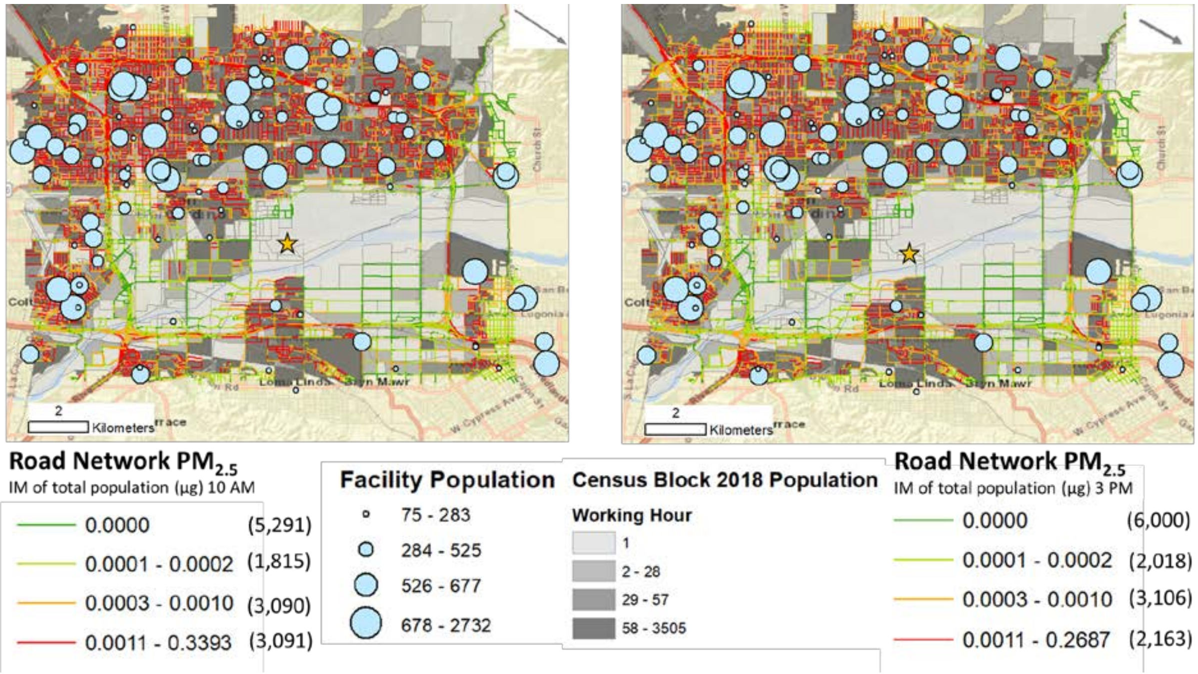


Figure 3.9. Total inhaled mass of $PM_{2.5}$ (μg/link) at 10 A.M. (left) and 3 P.M. (right), assuming age-group specific breathing rate of m^3/day.

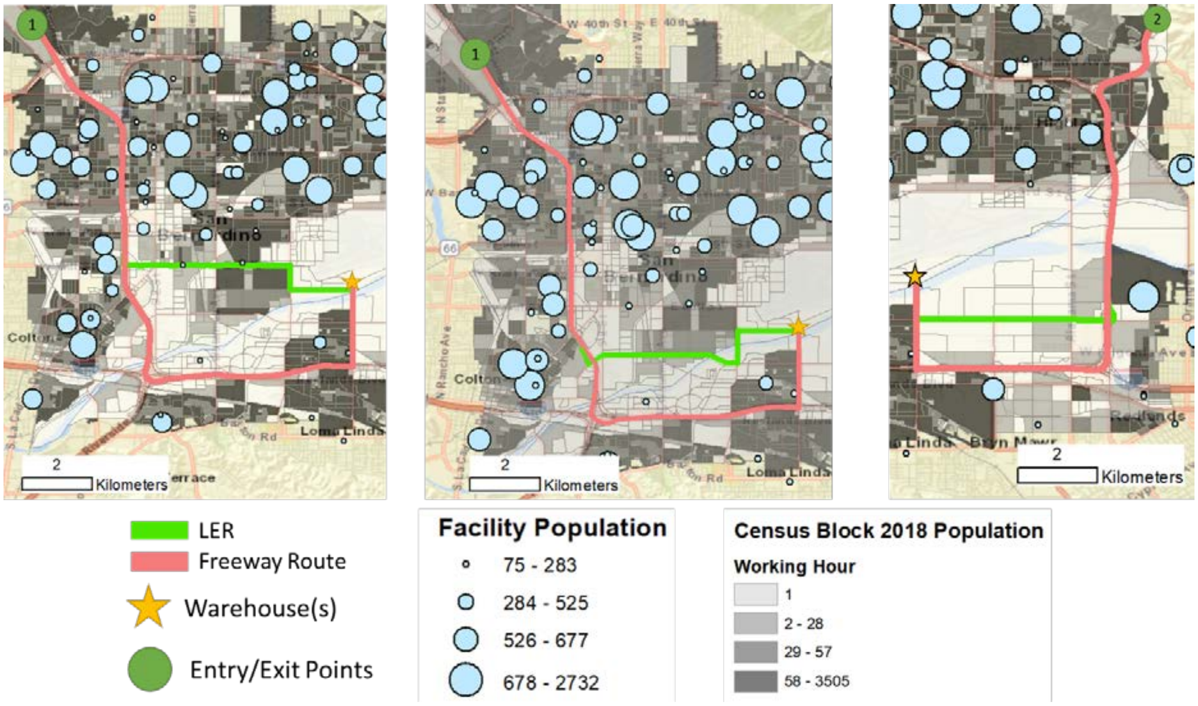


Figure 3.10. Example trips of FR and LER. Corner 1 LER-a, Mill Street, (left); Corner 1; LER-b, Orange Show Road (center); and Corner 2 (right)

Table 3.2. Comparison of route attributes for an example trip for Corner 1 and Corner 2, assuming a population-averaged breathing rate of 15 m^3/day

Scenario	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)
FR, Coral @ 10 A.M., Corner 1	11.45	12.99	0.22	21.27	18.65
LERa, Green @ 10 A.M., Corner 1	8.16	11.32	0.19	23.27	13.73
Change (%)	-29%	-13%	-14%	9%	-26%
FR, Coral @ 10 A.M., Corner 1	11.45	12.99	0.22	21.27	18.65
LERb, Green @ 10 A.M., Corner 1	9.19	13.59	0.17	16.69	16.08
Change (%)	-20%	5%	-19%	-22%	-14%
FR, Coral @ 10 A.M., Corner 2	9.36	13.00	0.09	10.14	14.31
LER, Green @ 10 A.M., Corner 2	7.99	13.30	0.06	7.34	12.81
Change (%)	-15%	2%	-29%	-28%	-10%

3.2.9. Truck Flow Analysis

The truck flow between each corner to/from the warehouse was estimated so that a truck flow weighted comparison of the route attributes between the freeway route and low exposure route can be analyzed.

To estimate the number of trucks entering and exiting from the four corners, we chose the following locations to reflect truck volume. Looking at Figure 3.11, corner one incoming truck flow is reflected at I-215 S at point IN 1, corner four is both I-10E and I-215N at points IN 2 and IN 3; corner two is reflected at I-210 S at point IN 6; and finally corner three at I-10 W at point IN 7. Since the warehouse is next to an airport and airplanes bring in goods as well, to determine the number of trucks leaving from corner 1, outgoing truck flow is reflected at I-215 N at point OUT 5, and corner four is both I-215 S and I-10 W at points OUT 6 and OUT 7, all of these outgoing points are reflected in Figure 9. Table 3.3 shows the number of trucks entering and exiting for all four corners, label in Figure 3.11.

The truck flow data was obtained from the Caltrans PeMS truck flow at mainline loop detector stations (LDS) [PEMS 2020a, 2020b, 2020c, 2020d]. Truck flow on the ramps was not available so it was assumed that the lower bound of the truck flow leaving I-10E and heading to the warehouse was estimate by IN 5 – OUT 2, assuming IN 10 is equal to zero. Another assumption is that all trucks that exit at the Mt. View Ave exit are going to the warehouse(s). Point IN 4 and IN 8 are only for references and we compared our estimation with the two points. Sources of uncertainty include the trucks exiting/entering the freeways at off/on ramps and the PeMS estimation.

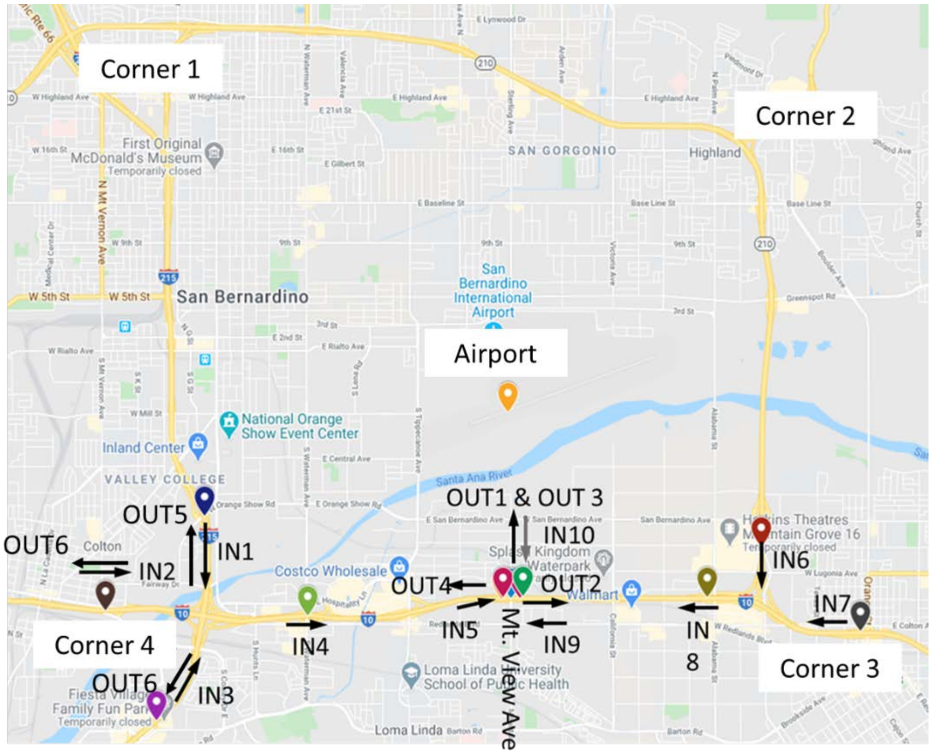


Figure 3.11. Truck Flow IN and OUT for all four corners

Table 3.3. Truck flow in study area at 10 A.M.

Hour	IN 1	OUT 5	IN 2	OUT 6	IN 3	OUT 7	Sum (IN 1, 2 & 3)	IN 4	Difference (IN 4 vs Sum)	IN 5
10 A.M.	179	30	453	151	137	590	769	537	-0.43	509

Hour	OUT 1	OUT 2	IN 6	IN 7	Sum (IN 6 & 7)	IN 8	Difference (IN 8 vs Sum)	IN 9	OUT 3	OUT 4
10 A.M.	242	267	13	158	171	385	0.56	349	-144	493

Using the truck flow from Table 3.3 the truck flow for each corner was calculated using the following equations:

Trucks going to warehouse from Corner 1 = $\frac{IN1}{IN1+IN2+IN3} \times OUT1$

Trucks going to Corner 1 from warehouse = $\frac{OUT5}{OUT5+OUT6+OU7} \times OUT4$

Trucks going to warehouse from Corner 2 = $\frac{IN6}{IN6+IN7} \times OUT3$

Trucks going to warehouse from Corner 3 = $\frac{IN7}{IN6+IN7} \times OUT3$

Trucks going to warehouse from Corner 4 = $\frac{IN2+IN3}{IN1+IN2+IN3} \times OUT1$

Trucks going to Corner 4 from warehouse = $\frac{OUT6+OUT7}{OUT5+OUT6+OU7} \times OUT4$

The lower limit of the truck flow heading to the warehouse from I-10 at Mt. View, was found to be 56 and 186 (truck/hour) coming from corners 1 and 4, respectively. Whereas the lower limit of the truck flow leaving the warehouse and heading towards corner 2 and 3 was found to be 11 and 133 (truck/hour) heading towards corners two and three, respectively. The truck flow exiting (going to warehouses) and entering (leaving warehouses) I-10 at Mt. View can be seen in Figure 3.12.

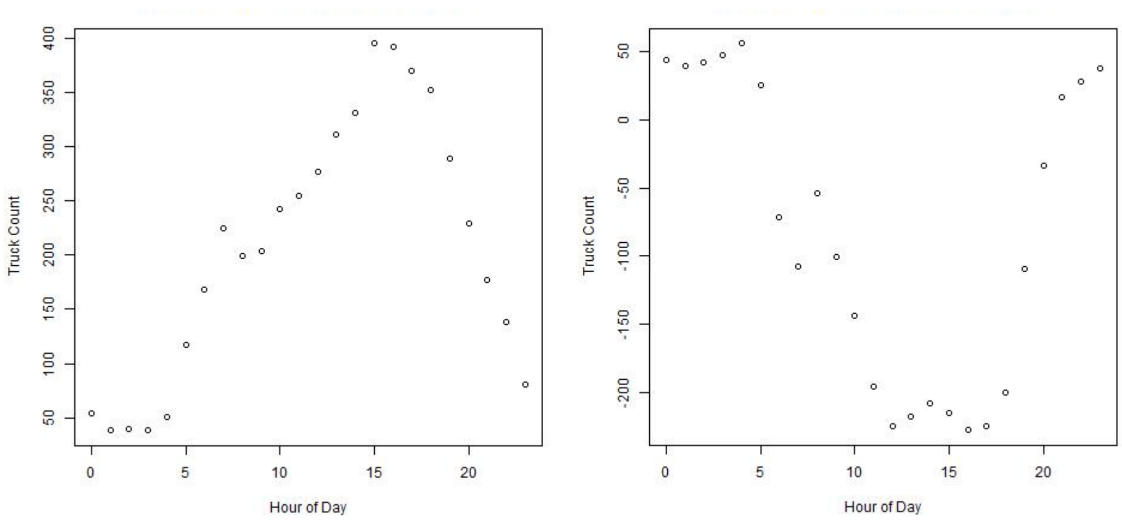


Figure 3.12. Trucks exiting to Mt. View (left) and trucks entering to Mt. View (right)

3.2.10. Weighting Results based on Truck Flow Analysis

Morning 10 A.M. Scenario

Tables 3.4 through 3.6 shows the weighted change of the LER for all four corners at 10 A.M., including the trucks heading outbound from the warehouse to corners one and four, and only showing corner one LERa the Mill Street route. Table 4 used the assumed population-averaged breathing rate of 15 m^3/day to show the weight change of the LER. Table 4 the overall, as compared with the FR, the LER would be 14% longer in travel time and increase NO_x inhalation by 67%, but would reduce distance by 3%, $PM_{2.5}$ inhalation by 15%, and CO_2 by 1%.

Table 3.4. Summary of route attributes based on truck flow at 10 A.M., assuming an averaged breathing rate of 15 m^3/day

MY 2012 10am		Freeway Route					Low Exposure Route					Difference (v.s. Freeway Route)				
Corner #	No. of Trucks	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)
1a Inbound	56	641.34	727.51	12.14	1191.23	1044.42	456.90	633.66	10.48	1303.18	769.03	-184.44	-93.86	-1.66	111.95	-275.39
1a Outbound	19	202.16	233.29	4.38	430.55	330.89	143.80	203.47	3.97	478.26	242.90	-58.36	-29.82	-0.41	47.71	-87.99
2	11	102.92	143.00	0.97	111.56	157.36	87.87	146.35	0.69	80.75	140.91	-15.05	3.36	-0.28	-30.81	-16.45
3	133	629.92	966.51	7.10	894.94	1107.58	659.26	1268.47	3.73	512.20	1144.03	29.34	301.96	-3.37	-382.74	36.45
4 Inbound	186	1064.18	1511.84	8.76	1218.59	1851.44	1073.84	1731.38	7.84	2586.51	1897.50	9.66	219.54	-0.92	1367.92	46.07
4 Outbound	474	2528.72	3387.33	20.56	2909.19	4328.83	2603.30	3972.84	19.30	6304.61	4513.54	74.58	585.51	-1.25	3395.42	184.71
Total	879	5169	6969	54	6756	8821	5025	7956	46	11266	8708	-144.27	986.69	-7.89	4509.45	-112.61
												-3%	14%	-15%	67%	-1%

Table 3.5. Summary of route attributes based on truck flow at 10 A.M., assuming age group specific breathing rate in m^3/day

MY 2012 10am		Freeway Route					Low Exposure Route					Difference (v.s. Freeway Route)				
Corner #	No. of Trucks	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)
1a Inbound	56	641.34	727.51	10.60	1036.71	1044.42	456.90	633.66	8.95	1065.39	769.03	-184.44	-93.86	-1.65	28.67	-275.39
1a Outbound	19	202.16	233.29	3.82	374.03	330.89	143.80	203.47	3.40	392.71	242.90	-58.36	-29.82	-0.42	18.68	-87.99
2	11	102.92	143.00	0.86	98.07	157.36	87.87	146.35	0.62	73.01	140.91	-15.05	3.36	-0.24	-25.06	-16.45
3	133	629.92	966.51	6.37	784.67	1107.58	659.26	1268.47	3.46	470.67	1144.03	29.34	301.96	-2.91	-313.99	36.45
4 Inbound	186	1064.18	1511.84	7.83	1069.10	1851.44	1073.84	1731.38	7.02	2317.91	1897.50	9.66	219.54	-0.81	1248.81	46.07
4 Outbound	474	2528.72	3387.33	18.33	2546.90	4328.83	2603.30	3972.84	17.30	5659.43	4513.54	74.58	585.51	-1.04	3112.53	184.71
Total	879	5169	6969	48	5909	8821	5025	7956	41	9979	8708	-144.27	986.69	-7.06	4069.64	-112.61
												-3%	14%	-15%	69%	-1%

Table 3.6 shows the weighted change of the LER for all four corners, assuming a weight-based age-group specific breathing rate of m^3/day/kg. Table 3.6 the overall, as compared with the FR, the LER would be 14% longer in travel time and 59% increase in NO_x inhalation, but would reduce distance by 3%, $PM_{2.5}$ inhalation by 13%, and CO_2 by 1%.

Table 3.6. Summary of route attributes based on truck flow at 10 A.M., assuming a weight based age-group specific breathing rate in m^3/day/kg

MY 2012 10am		Freeway Route					Low Exposure Route					Difference (v.s. Freeway Route)				
Corner #	No. of Trucks	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)
1a Inbound	56	641.34	727.51	0.22	21.45	1044.42	456.90	633.66	0.21	31.21	769.03	-184.44	-93.86	-0.01	9.76	-275.39
1a Outbound	19	202.16	233.29	0.08	7.83	330.89	143.80	203.47	0.08	11.26	242.90	-58.36	-29.82	0.00	3.44	-87.99
2	11	102.92	143.00	0.02	1.89	157.36	87.87	146.35	0.01	1.25	140.91	-15.05	3.36	-0.01	-0.64	-16.45
3	133	629.92	966.51	0.14	17.66	1107.58	659.26	1268.47	0.07	9.51	1144.03	29.34	301.96	-0.07	-8.15	36.45
4 Inbound	186	1064.18	1511.84	0.13	19.69	1851.44	1073.84	1731.38	0.12	38.43	1897.50	9.66	219.54	-0.02	18.74	46.07
4 Outbound	474	2528.72	3387.33	0.32	47.49	4328.83	2603.30	3972.84	0.29	93.35	4513.54	74.58	585.51	-0.03	45.87	184.71
Total	879	5169	6969	1	116	8821	5025	7956	1	185	8708	-144.27	986.69	-0.12	69.01	-112.61
												-3%	14%	-13%	59%	-1%

Overall, the results show that for all three breathing rate assumptions at 10 A.M. that the LER decrease the $PM_{2.5}$ inhalation when compared to the FR; however, the NO_x inhalation increases for all three LER when compared to the FR. There is a slightly higher reduction in $PM_{2.5}$ inhalation and increase in NO_x inhalation when assuming a m^3/day breathing rates (Tables 3.4 and 3.5) when compared to the age-specific breathing rate of m^3/day/kg (Table 3.6).

Afternoon 3 P.M. Scenario

Tables 3.7 through 3.9 shows the weighted change of the LER for all four corners at 3 P.M., Table 3.7 used the averaged breathing rate of 15 m^3/day. Table 3.8 used age-group specific breathing rate in m^3/day. And Table 3.9 used age-group specific breathing rate normalized by average body mass in m^3/day/kg body mass.

Overall, the results show that for all three breathing rate assumptions at 3 P.M., the LER have decreased $PM_{2.5}$ inhalation when compared to the FR; however, the NO_x inhalation increases for all three LER when compared to the FR. The $PM_{2.5}$ inhalation is not significantly affected by the assumed breathing rate. However, the total NO_x inhalation significantly changed with applying different set of breathing rates. The weight-based age-specific (m^3/day/kg body mass) had the lowest NO_x inhalation increase, followed by the population-averaged and then the age-specific (m^3/day) having the highest increase of 65%, 77% and 81%, respectively.

When comparing the 10 A.M. (Tables 3.4, 3.5, 3.6) to 3 P.M. (Tables 3.7, 3.8, 3.9) for all scenarios, the 10 A.M. scenarios had a greater $PM_{2.5}$ inhalation reduction for all three assumed breathing rates. The higher reduction in $PM_{2.5}$ inhalation at 10 A.M. could be due to the atmosphere being more static in the morning allowing for a higher pollutant build-up (Figure 3.7 and 3.9), therefore a bigger impact on the reduction, when compared to 3 P.M.. This time-of-day effect can also be applied to reduce population inhalation as fleet operations and geofencing strategies.

Table 3.7. Summary of route attributes based on truck flow at 3 P.M. (assuming an Averaged breathing rate of 15 m^3/day)

MY 2012 3pm		Freeway Route					Low Exposure Route					Difference (v.s. Freeway Route)				
Corner #	No. of Trucks	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)
1a	69	790.22	896.40	9.93	963.31	1286.88	562.97	780.76	8.88	1128.24	947.55	-227.26	-115.65	-1.05	164.93	-339.32
1a Outbound	9	95.76	110.51	1.39	135.33	156.74	68.11	96.38	1.29	158.80	115.06	-27.65	-14.12	-0.10	23.47	-41.68
2	16	149.70	208.00	0.90	103.48	228.89	127.81	212.88	0.67	78.01	204.97	-21.89	4.88	-0.23	-25.47	-23.93
3	193	914.10	1402.53	5.71	747.39	1607.24	956.67	1840.71	2.98	422.55	1660.14	42.57	438.18	-2.73	-324.84	52.90
4	263	1504.72	2137.71	7.35	1022.47	2617.89	1518.38	2448.14	6.93	2379.59	2683.03	13.66	310.43	-0.42	1357.12	65.14
4 Outbound	508	2710.10	3630.31	13.27	1883.63	4639.34	2790.04	4257.81	13.09	4440.67	4837.29	79.93	627.50	-0.18	2557.04	197.96
Total	1058	6164.61	8385.46	38.55	4855.60	10536.98	6023.98	9636.68	33.84	8607.87	10448.04	-140.63	1251.22	-4.72	3752.26	-88.94
												-2%	15%	-12%	77%	-1%

Table 3.8. Weighted comparison of route attributes between freeway route and low exposure routes in San Bernardino City for all four corners based on truck flow at 3 P.M., assuming age-group specific breathing rate of m^3/day

MY 2012 3pm		Freeway Route					Low Exposure Route					Difference (v.s. Freeway Route)				
Corner #	No. of Trucks	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)
1a Inbound	69	790.22	896.40	8.66	836.25	1286.88	562.97	780.76	7.56	916.84	947.55	-227.26	-115.65	-1.10	80.59	-339.32
1a Outbound	9	95.76	110.51	1.21	117.34	156.74	68.11	96.38	1.10	129.66	115.06	-27.65	-14.12	-0.11	12.33	-41.68
2	16	149.70	208.00	0.80	90.84	228.89	127.81	212.88	0.60	70.57	204.97	-21.89	4.88	-0.20	-20.27	-23.93
3	193	914.10	1402.53	5.11	648.76	1607.24	956.67	1840.71	2.76	386.53	1660.14	42.57	438.18	-2.35	-262.23	52.90
4 Inbound	263	1504.72	2137.71	6.56	890.82	2617.89	1518.38	2448.14	6.21	2134.72	2683.03	13.66	310.43	-0.35	1243.90	65.14
4 Outbound	508	2710.10	3630.31	11.82	1638.39	4639.34	2790.04	4257.81	11.74	3990.08	4837.29	79.93	627.50	-0.08	2351.70	197.96
Total	1058	6164.61	8385.46	34.16	4222.39	10536.98	6023.98	9636.68	29.98	7628.41	10448.04	-140.63	1251.22	-4.18	3406.01	-88.94
												-2%	15%	-12%	81%	-1%

Table 3.9. Weighted comparison of route attributes between freeway route and low exposure routes in San Bernardino City for all four corners based on truck flow at 3 P.M., assuming a weight-based age-group specific breathing rate of m^3/day/kg

MY 2012 3pm		Freeway Route					Low Exposure Route					Difference (v.s. Freeway Route)				
Corner #	No. of Trucks	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)	Driving Distance (miles)	Driving duration (min)	$PM_{2.5}$ IM (ug)	NOx IM (ug)	CO_2 (kg)
1a Inbound	69	790.22	896.40	0.18	17.57	1286.88	562.97	780.76	0.18	27.61	947.55	-227.26	-115.65	0.00	10.04	-339.32
1a Outbound	9	95.76	110.51	0.03	2.48	156.74	68.11	96.38	0.03	3.82	115.06	-27.65	-14.12	0.00	1.33	-41.68
2	16	149.70	208.00	0.02	1.76	228.89	127.81	212.88	0.01	1.22	204.97	-21.89	4.88	0.00	-0.54	-23.93
3	193	914.10	1402.53	0.11	14.96	1607.24	956.67	1840.71	0.06	7.85	1660.14	42.57	438.18	-0.05	-7.11	52.90
4 Inbound	263	1504.72	2137.71	0.11	16.91	2617.89	1518.38	2448.14	0.10	35.08	2683.03	13.66	310.43	-0.01	18.16	65.14
4 Outbound	508	2710.10	3630.31	0.20	31.45	4639.34	2790.04	4257.81	0.19	65.25	4837.29	79.93	627.50	-0.01	33.80	197.96
Total	1058	6164.61	8385.46	0.65	85.14	10536.98	6023.98	9636.68	0.57	140.82	10448.04	-140.63	1251.22	-0.08	55.69	-88.94
												-2%	15%	-12%	65%	-1%

3.2.11. *Street Safety Concern*

When redirecting heavy duty trucks to other streets, safety concerns always arise if it will increase the number of accidents on the streets. We have collected the historical collision data [TIMP, 2021] on Mill St and Orange Show Rd from 2008 to 2019 as shown in Figure 3.13.

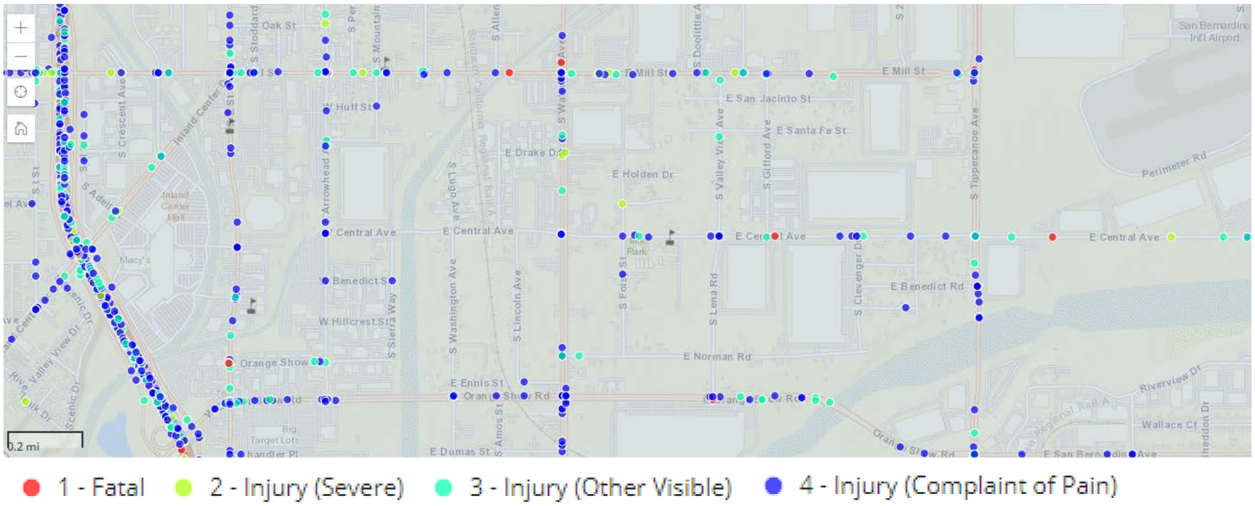


Figure 3.13 Historical vehicle collision map in the area of Corner 1 LER

Also we summarized the number of collisions by involved party type in Table 3.10. From the table we can see that after 2013 and 2014, the number of total collisions on both streets increased significantly and the trend continued to 2019.

Table 3.10 Summary the number of collisions by involved party type: Mill St. (left), Orange Show Rd. (right)

Year	Total	Bicycle	Pedestrian	Motorcycle	Truck	Vehicle Only
2009	4	0	0	0	2	4
2010	6	1	0	0	1	5
2011	7	0	1	1	0	6
2012	5	0	0	2	1	5
2013	7	0	0	2	2	7
2014	16	0	3	5	2	13
2015	16	0	1	2	1	15
2016	16	1	3	1	1	12
2017	15	0	0	1	2	15
2018	10	0	0	2	1	10
2019	18	0	1	3	0	17
Sum	**120**	**2**	**9**	**19**	**13**	**109**

Year	Total	Bicycle	Pedestrian	Motorcycle	Truck	Vehicle Only
2009	2	0	0	0	0	2
2010	8	3	0	0	0	5
2011	6	0	0	1	1	6
2012	5	0	0	0	0	5
2013	13	1	0	2	2	12
2014	8	0	1	0	2	7
2015	13	0	1	1	0	12
2016	20	1	0	3	0	19
2017	17	0	2	4	0	15
2018	17	2	2	0	2	13
2019	23	1	3	1	1	19
Sum	**132**	**8**	**9**	**12**	**8**	**115**

4. Policy Priorities and Future Work

This Inland Empire Regional Initiative of the C-STACC effort focused on developing transportation strategies and policies that address transportation and air quality challenges in Inland Southern California. This effort was divided into two main focus areas: 1) the deployment of shared mobility strategies in the City of Riverside, and 2) the development of techniques to reduce the impacts of trucks associated with local goods movement.

4.1. Policy Priorities for Deploying Zero-Emission Carsharing

Based on our community outreach and the carsharing modeling, it was found that a zero-emission carsharing operation would have the largest impact for an Inland Southern California city such as Riverside, with the potential to shift work-based travel modes by approximate 8%, resulting in greenhouse gas reductions due to the increased use of zero-emission vehicles and a reduction in overall vehicle miles traveled. It was found that the location of the carsharing stations made a big difference, especially for households that do not own private vehicles. Based on the modeling results, for residents without personal vehicles, the mode share of car sharing for work trips increases to 17%-40%, significantly improving the accessibility in disadvantaged communities.

For this portion of the project, the key policy priorities are:

1. When deploying zero-emission carsharing systems, chose station locations in neighborhoods with high population densities, allowing the residents of that community to quickly access to the station conveniently by walking or cycling;
2. It is important to analyze the resident demographics when deploying carsharing, since younger residents are more likely to embrace zero-emission carsharing operations;
3. It is also important to reduce access/egress time for the zero-emission carsharing vehicles through convenient parking and simple transactions.
4. Overall, only 40% of the city's residents were interested in zero-emission carsharing, so further outreach and promotional activities are critical to further increase the acceptance of carsharing in the community.

4.2. Policy Priorities for Low Pollutant Exposure Truck Routing

The research team closely examined the truck traffic in a region that has a high density of warehouses and truck traffic. To help mitigate the impacts on the community, the research team developed new "low-exposure" routing algorithms for trucks, based on knowing community demographics, sensitive receptors (schools, hospitals), truck travel patterns, and roadway exposure ratings. New low-pollution exposure routes were generated and compared to current truck traffic patterns, resulting in a 10% - 40% reduction in pollutant exposure to the community, reducing fleet fuel consumption by 3% - 5%, however at a cost of increasing fleet travel time by 10% to 30%.

For this portion of the project, the key policy priorities are:

1. Have local cities utilize their authority to designate truck routes through their communities, choosing routes that have the least air pollution impact on their residents;
2. Encourage voluntary actions by goods movement companies to use emerging routing technologies to divert heavy-duty truck traffic to low-impact routes, accepting a tradeoff between slightly increased delivery time/distance for reducing inhalant exposure of PM 2.5 and NOx to residents and sensitive receptors such as schools and hospitals; as an added incentive, there would be a slight reduction in fleet average fuel consumption.

3. It would be beneficial to conduct a pilot program for low-exposure routing, documenting the actual benefits to the community and analyzing the impact to fleet(s).

4.3. Future Work

For our zero-emission carsharing analysis for the City of Riverside, the city has recently applied for and received a Clean Mobility Option grant to deploy zero-emission vehicles in a carsharing system, working with a local carsharing company (StratosShare). UCR is involved in carsharing station selection and then conducting the impact analysis. If the initial zero-emission carsharing deployment is successful, the system will likely be expanded.

For the goods movement strategy development, we are currently discussing with Amazon plans to conduct a pilot study on low-exposure routing, utilizing a subset of their fleet. It is expected that Amazon may adopt a variety of our truck management strategies.

5. References

[Barth, 2003] Barth, M., & Todd, M. (2003). UCR IntelliShare: an intelligent shared electric vehicle testbed at the University of California, Riverside. In Journal of IATSS Research, Vol. 27, No. 1.

[Bhat, 2004] Bhat, C. (2004). CEMDAP. https://www.caee.utexas.edu/prof/bhat/CEMDAP.htm Accessed on Feb, 2021.

[Bierlaire, 2003] Bierlaire, M. (2003). A free package for the estimation of discrete choice models. the 3rd Swiss Transportation Research Conference. Ascona: Switzerland.

[Boriboonsomsin, 2020] Boriboonsomsin, K. (2020). California Air Resources Board Project. Geofencing as a Strategy to Lower Emissions in Disadvantaged Communities, see https://ww3.arb.ca.gov/research/single-project.php?row_id=68793

[Brunekreef, 1997] Brunekreef, B., N. A. Janssen, J. de Hartog, H. Harssema, M. Knape, and P. van Vliet. (1997). Air pollution from truck traffic and lung function in children living near motorways. Epidemiology, 298-303.

[Caltrans, 2020] California Department of Transportation. Caltrans Performance Measurement System (PeMS). I-10W Truck Flow (2020). http://pems.dot.ca.gov/?report_form=1&dow_0=on&dow_1=on&dow_2=on&dow_3=on&dow_4=on&dow_5=on&dow_6=on&tod=all&tod_from=0&tod_to=0&holidays=on&agg=on&s_time_id=1590969600&e_time_id=1593561540&dnode=Freeway&fwy=10&dir=W

[CARB, 2017] California Air Resource Board. EMFAC2017 Web Database, see https://arb.ca.gov/emfac/2017/

[CARB, 2020] CARB, 2020 Report, see https://ww3.arb.ca.gov/research/singleproject.php?row_id=68793

[CARB, 2021] California Air Resource Board. MSEI - Modeling Tools - EMFAC Software and Technical Support Documentation, see https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-modeling-tools-emfac

[COEHHA, 2012] California Office of Environmental Health Hazard Assessment (2012). Technical Support Document for Exposure Assessment and Stochastic Analysis. August 27, see https://oehha.ca.gov/air/crnr/notice-adoption-technical-support-document-exposure-assessment-and-stochastic-analysis-aug.

[Demir, 2014] Demir, E., Bektaş, T., and Laporte, G. (2014). The bi-objective pollution-routing problem. European Journal of Operations Research, 232(3), 464-478.

[Dorenbos, 2018] Dorenbos, G. (2018). Car-Sharing in Activity-Based Models. Thesis in Delft University of Technology.

[EPA, 2011] U.S. Environmental Protection Agency (2011). Exposure Factors Handbook: 2011 Edition, September.

[Fraiberger, 2015] Fraiberger, S., & Sundararajan, A. (2015). Peer-to-peer rental markets in the sharing economy. In: NYU Stern School of Business Research Paper. Available at: http://ssrn.com/abstract=2574337.

[Gong, 2004] Gong Jr., H., W. S. Linn, S. L. Terrell, K. R. Anderson, K. W. Clark, C. Sioutas, W. E. Cascio, N. Alexis, and R. B. Devlin (2004). Exposures of elderly volunteers with and without chronic obstructive pulmonary disease (COPD) to concentrated ambient fine particulate pollution. Inhalation Toxicology, 16(11-12), 731-744.

[Grodzevich, 2006] Grodzevich, O. and Romanko, O. (2006). Normalization and other topics in multi-objective optimization. in Proc. of the Fields MITACS Industrial Problems Workshop, Toronto, 89-101.

[Lane, 2005] Lane, C. (2005). PhillyCarShare: first-year social and mobility impacts of carsharing in Philadelphia, Pennsylvania. Transp. Res. Rec. 1927, 158–166

[Martin 2010] Martin, E., Shaheen, S., & Lidicker, J. (2010). Impact of carsharing on household vehicle holdings. Transp. Res. Rec. 2143, 150–158.

[Martin, 2011] Martin, E., & Shaheen, S. (2011). Greenhouse gas emission impacts of carsharing in North America. IEEE Trans. on Intell. Transp. Syst. 12 (4), 1074–1086.

[NCES, 2021] National Center for Education Statistics. Child Care. See, https://nces.ed.gov/fastfacts/display.asp?id=4

[OEHHA, 2021] OEHHA ArcGIS Online. SB 535 Disadvantaged Communities, see https://oehha.maps.arcgis.com/apps/View/index.html?appid=c3e4e4e1d115468390cf61d9db83efc4

[PEMS, 2020a] California Department of Transportation. Caltrans Performance Measurement System (PeMS). I-10E Truck Flow (2020). http://pems.dot.ca.gov/?report_form=1&dow_0=on&dow_1=on&dow_2=on&dow_3=on&dow_4=on&dow_5=on&dow_6=on&tod=all&tod_from=0&tod_to=0&holidays=on&agg=on&s_time_id=1590969600&e_time_id=1593561540&fwy=10&dir=E&dnode=Freeway&content=elv

[PEMS, 2020b] California Department of Transportation. Caltrans Performance Measurement System (PeMS). I-215N Truck Flow (2020). http://pems.dot.ca.gov/?report_form=1&dow_0=on&dow_1=on&dow_2=on&dow_3=on&dow_4=on&dow_5=on&dow_6=on&tod=all&tod_from=0&tod_to=0&holidays=on&agg=on&s_time_id=1590969600&e_time_id=1593561540&dnode=Freeway&fwy=215&dir=N

[PEMS, 2020c] California Department of Transportation. Caltrans Performance Measurement System (PeMS). I-215S Truck Flow (2020). http://pems.dot.ca.gov/?report_form=1&dow_0=on&dow_1=on&dow_2=on&dow_3=on&dow_4=on&dow_5=on&dow_6=on&tod=all&tod_from=0&tod_to=0&holidays=on&agg=on&s_time_id=1590969600&e_time_id=1593561540&dnode=Freeway&fwy=215&dir=S

[PEMS, 2020d] California Department of Transportation. Caltrans Performance Measurement System (PeMS). I-210ETruck Flow (2020).

http://pems.dot.ca.gov/?report_form=1&dow_0=on&dow_1=on&dow_2=on&dow_3=on&dow_4=on&dow_5=on&dow_6=on&tod=all&tod_from=0&tod_to=0&holidays=on&agg=on&s_time_id=1590969600&e_time_id=1593561540&dnode=Freeway&fwy=210&dir=E

[SBAC, 2021] San Bernardino Airport Communities, see https://sbairportcommunities.org/home

[SBDIA, 2021] Amazon Air Regional Air Hub. Air Cargo Development at SBD International Airport, see https://www.sbdairport.com/facilities-amenities/amazon-air-regional-air-hub/

[SCAG, 2021] Southern California Association of Governments. (2021). Retrieved from Southern California Association of Governments: https://scag.ca.gov/

[SCAQMD, 2019] South Coast Air Quality Management District (2019). Meteorological Data for AERMOD, see http://www.aqmd.gov/home/air-quality/meteorological-data/data-for-aermod .

[Shaheen 2010] Shaheen, S. A, & Martin, E. (2010). Demand for Carsharing Systems in Beijing, China: An Exploratory Study. International Journal of Sustainable Transportation, 4(1), 41-55.

[Shaheen 2019] Shaheen, S., Cohen, A., & Farrar, E. (2019). Carsharing's Impact and Future. Retrieved from https://escholarship.org/uc/item/2f5896tp

[Shaheen, 1999] Shaheen, S. (1999). Dynamics in Behavioral Adaptation to a Transportation Innovation: A Case Study of Carlink–A Smart Carsharing System. California PATH Research Report, UCB-ITS-PRR-99-41.

[Slate, 2013] Slate. The Day Care Dilemma (2013), see https://slate.com/human-interest/2013/08/day-care-in-the-united-states-is-it-good-or-bad-for-kids.html

[Snyder, 2013] Snyder, M. G. and Heist, D. K. (2013). User's Guide for R-LINE Model Version 1.2, see https://www.cmascenter.org/r-line/documentation/1.2/RLINE_UserGuide_11-13-2013.pdf .

[Stocker, 2016] Stocker, A., Lazarus, J., Becker, S., & Shaheen, S. (2016). North American College/University Market Carsharing Impacts: Results from Zipcar's College Travel Study 2015. Transportation Sustainability Research Center, Berkeley.

[Suburbanstats, 2021] Population Demographics for California 2020, see https://suburbanstats.org/population/how-many-people-live-in-california .

[TIMP, 2021] Transportation Injury Mapping System, see https://tims.berkeley.edu/.

[USBLS, 2017] U.S. Bureau of Labor Statistics. Older Workers: Labor force trends and career options, see https://www.bls.gov/careeroutlook/2017/article/older-workers.htm.

[USBLS, 2021] U.S. Bureau of Labor Statistics. Monthly Labor Review, see https://www.bls.gov/opub/mlr/2017/article/occupational-choices-of-the-elderly.htm.

[Vine, 2013]	Vine, S. L., Lee-Gosselin, A. S., & Polak, J. (2013). A new concept of accessibility to personal activities: Development of theory and application to an empirical study of mobility resource holdings. Transport Geography.
[Wang, 2012]	Wang, M., Martin, E., Shaheen, S. (2012). Carsharing in Shanghai, China. Transportation Research Record: Journal of the Transportation Research Board. 2319. 86-95.
[Weichenthal, 2012]	Weichenthal, S., R. Kulka, P. Bélisle, L. Joseph, A. Dubeau, C. Martin, D. Wang, and R. Dales (2012). Personal exposure to specific volatile organic compounds and acute changes in lung function and heart rate variability among urban cyclists. Environmental Research, 118, 118-123.
[Zheng, 2009]	Zheng, J. M. (2009). Carsharing in a University Community: Assessing Demand and Distinct Market Characteristics. Transportation Research Record, 2110, pp., 18-26.