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FUTURE OF MOBILITY WHITE PAPER

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- Southern California Association of Governments (SCAG),
- Sacramento Association of Governments,
- Tahoe Regional Planning Agency,
- California Transportation Commission (CTC),
- California Energy Commission (CEC),
- California Air Resources Board (CARB),
- California High Speed Rail Authority (HSRA), and
- Bay Area Rapid Transit (BART).

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Further, we are grateful for the written feedback we received from 13 representatives from the following organizations: HSRA; California Trucking Association; and representatives of four Caltrans divisions: Sustainable Freight Branch, Chief Office of Freight Planning, Office of System Planning, and Office of State Planning.

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Introduction

Purpose and Goals of the Future of Mobility White Paper

Transportation is undergoing a transformative revolution. Trending technologies and competitive markets are accelerating innovation in the field at faster rates than previously predicted. As such, California is required to renew its long-range comprehensive transportation plan, called the California Transportation Plan (CTP), every five years. This Future of Mobility White Paper is intended to inform and guide policymakers and modelers developing the next iteration of the CTP – CTP 2050 – by presenting updated descriptions and analyses of developments impacting California's transportation system.

This revision is especially pertinent. In the past five years, ridesourcing or transportation network companies (TNCs), like Lyft and Uber; carsharing services, like Getaround and car2go; and bikesharing services, like Spin and Ford GoBike, have continued to grow their market shares. Automated vehicles (AVs) may come to market as soon as 2018, and more Californians are registering more electric vehicles than ever before. Drones, 3D printing, and automation could impact goods movement in California.

On the policy side, transportation agencies are reconsidering existing funding mechanisms, which may become unreliable if people use public transit less. At the same time, High Speed Rail (HSR) is under construction in the state, and recent legislation reiterates California's commitment to pedestrian- and bicycle-friendly policy, evidenced by the first-ever California Statewide Bicycle and Pedestrian Plan published in 2017.

Methodology

Not surprisingly, trends in transportation technology, innovative business models, renewable energy, machine learning, and user behavior will continue to converge, impacting transportation systems and mobility options. Over the last year, we reviewed literature, news articles, and reports on the future of mobility – often reflecting varying levels of detail, predictions, and impacts. We also conducted six expert interviews in Spring 2017 on the future of mobility. Finally, we developed a framework, described below, which organizes and describes the status, predictions, and impacts of numerous current and future trends. The white paper covers the following topics:

Overarching Topics	**Current and Emerging Transportation-Specific Topics**		
• Climate Change and Sustainability • Demographics • Economics • Transportation Equity and Public Health	• Connected and Automated Vehicles • Zero Emission Vehicles • Carsharing • Bikesharing	• Ridesourcing/ TNCs • Alternative Transit Services • Shared Mobility Public-Private Partnerships and Data Sharing	• Information and Communications Technology • Freight and Goods Movement • California's Passenger Rail System

These topics were selected by the Caltrans project management team representing the Division of Planning and the Division of Research, Innovation and System Information. Additionally, throughout the project's evolution since Winter 2017, questions about a number of topics that could impact transportation in the long run were raised. These topics are debated in terms of their significance and viability. They are also hardly mentioned in published peer-reviewed literature. These topics include:

- Cybersecurity Risk;
- Blockchain;
- 3D Printing;
- Drones and Unmanned Aerial Vehicles (UAVs);
- On-demand Trucking/"Uber for Freight," and;
- Hyperloop.

As such, we were tasked with presenting the state of knowledge on each of these topics. We consulted and referenced literature that quantified existing impacts and extended predictions through 2050, where possible. We created and employed a framework for presenting each topic. This framework, described below, presents the level of understanding and uncertainty we found when reviewing each topic.

Additional studies, papers, and data can be used to supplement the contents of this white paper, many of which have been studied in depth by Caltrans. Where relevant, we also point to existing studies, white papers, and governmental documents that readers can use to gain additional insight. It is important to note that additional worthy literature exists beyond the sources cited. Our research depicts a snapshot of the state of the knowledge to date, but it is not exhaustive. We also note that the pace of technology and innovative developments continues to evolve, along with the research.

In May 2017, as part of the California Transportation Planning Conference panel "Drivers of Change," panelists asked the audience for their opinions on emerging transportation trends. The audience, which included representatives from state and local agencies, indicated their opinions on which transportation trends are most important, where regional agencies should focus their efforts, and how automated vehicles and private mobility services are affecting the transportation sector. About 46 percent of respondents noted that they felt a mix of hope and concern about the prospects and long-term effects of automated vehicles. Roughly 30 percent of respondents said they felt excited and hopeful. Questions also gauged their opinions of the effectiveness of different measures, such as high occupancy toll (HOT) lanes and transportation demand management (TDM) strategies. The majority of respondents indicated that regional agencies should focus on increasing the resiliency of infrastructure, taking advantage of innovative technologies, and helping local jurisdictions implement climate goals.

In addition to reviewing materials and conducting interviews, as discussed previously, we consulted a Technical Advisory Committee (TAC) of over 50 participants from local and state transportation agencies to inform our lists of research questions, topics to explore, and literature to consult. The TAC included representatives from the Caltrans

Transportation Economics Branch, Transportation Planning Branch, Modeling Group, Multi-Modal System Planning Office, and planners from Districts 3, 4, 10, and 11. Advisors from the Southern California Association of Governments (SCAG), Sacramento Association of Governments (SACG), California Transportation Commission (CTC), California Energy Commission (CEC), California Air Resources Board, California High Speed Rail Authority (HSRA), and Bay Area Rapid Transit (BART), among other organizations, participated in webinars and provided feedback that is reflected in the white paper.

We presented project developments during two webinars, guiding the TAC through the project's evolution. We received feedback on areas of confusion, sources to consult, how to present topics, and how to format and organize the paper. We also incorporated written feedback from 13 representatives of: SACG, HSRA, California Trucking Association, and four Caltrans divisions: the Sustainable Freight Branch, Chief Office of Freight Planning, Office of System Planning, and Office of State Planning.

Finally, once an initial draft of the white paper was complete, we presented our findings to a panel of eight additional experts to review our work. Experts represented the CTC, California State Transportation Agency, Governor's Office of Planning and Research, California Trucking Association, HSRA, Intelligent Transportation Systems Joint Programs Office, LA Metro, Southern California Association of Governments (SCAG), the Native Indian Justice Center, and Caltrans' Sustainability and Planning and Modal Programs divisions. They provided valuable feedback that contributed to the final white paper.

Future of Mobility White Paper Framework

We developed this Future of Mobility white paper as a primer for planners and modelers responsible for developing the CTP 2050. Due to the uncertainty and the rate of development of many emerging technologies and trends, we were unable to capture each at the same level of detail, including key metrics. Nevertheless, awareness of these developments could influence scenario analysis and modeling outcomes in the future. Policymakers and practitioners may find the descriptions, tables, and figures in this document useful in future planning.

This document organizes recent information on each topic, reflecting the state of the knowledge (where possible). As noted earlier, the level of depth varies based on the topic. We compare each topic based on the following criteria (see Table 1.1 below for categories, ratings, and descriptions):

1. **Research Coverage (extensive, existing, or limited):** Extent to which robust metrics (e.g., vehicle miles traveled (VMT), greenhouse gas (GHG) emissions, modal impacts, auto ownership and use impacts); predictions (e.g., size of market today and up to 2050); and/or on-the-ground studies exist about each topic;
2. **State of Development (current, emerging, or future):** The state of development of a trend or technology affecting transportation; and
3. **Degree of Variance (low, medium, or high):** The degree of variance (how wide the range) in predictions about each topic.

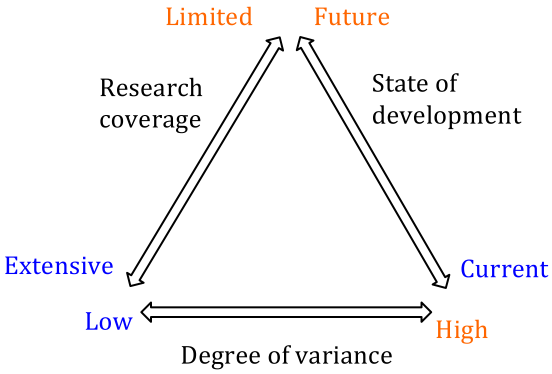
Using these three factors, we organized topics by those that are relatively well studied and, in contrast, those that have sparse analysis, at present.

TABLE 1.1: Descriptions of Category Ratings for Transportation Topics

Category	Rating	Description
Research Coverage	**Limited**	• Published, peer-reviewed studies and policy recommendations on the topic may not exist • Information is primarily available through news and media sources
	Existing	• Models may predict how to improve efficiency of systems and/or services • White papers and grey literature may assert suggestions • Peer-reviewed studies exist but questions and debates remain; not many studies include empirical data and/or metrics
	Extensive	• Research coverage is abundant and grounded in empirical data • Multiple organizations have published analyses and recommendations in grey literature
State of Development	**Future**	• Technology is being conceptualized and patented but has not yet come to market • Impact analyses, if they exist, are primarily hypothetical
	Emerging	• Technology is in the process of coming to market, or will do so soon • Early adopters are aware of and beginning to use innovative technology and methods • Variations on the technology from different firms exist, and firms are in competition
	Current	• Technologies have come to market and are in notable use • Market analyses exist and are backed with substantial evidence of market size
Degree of Variance	**High**	• Future impacts on transportation are very uncertain • Future impacts are dependent on other changing trends and technologies • Predictions vary relatively widely in terms of overall direction and rate of growth/shrinkage and/or absolute market size
	Medium	• Future impacts are proposed and becoming clearer and more well understood • Predictions vary among experts, but assumptions are generally well understood
	Low	• General consensus on magnitude and rate of change and resulting impacts • If predictions vary, they vary slightly

Figure 1.1 shows how each category of ratings can be mapped visually, capturing the status of knowledge and understanding of each topic in the White Paper. Each section includes this figure to frame the information we present, enabling the reader to compare the extent of what we know.

FIGURE 1.1: 3-Axis Graph for Mapping Topics



To further clarify the purpose of each section, we indicate whether the metrics included in the content of that section could be possible model inputs. Not surprisingly, many sections do not include modeling inputs due to a lack of research and uncertainty. The discussions, nevertheless, are valuable. Some sections compare future projections, and some list current impact understanding. These sections provide useful context to increase awareness for modelers and policymakers, although additional sources may be necessary to find specific model inputs. We also provide suggestions on how to use each section's written content and highlight key findings from our research on the topics covered.

We present the state of knowledge of each topic and whether there are direct model inputs, projections, and/or impacts in each section, as shown for the Demographics section as an example in Figure 1.2.

FIGURE 1.2: State of Knowledge and Metrics Table Example

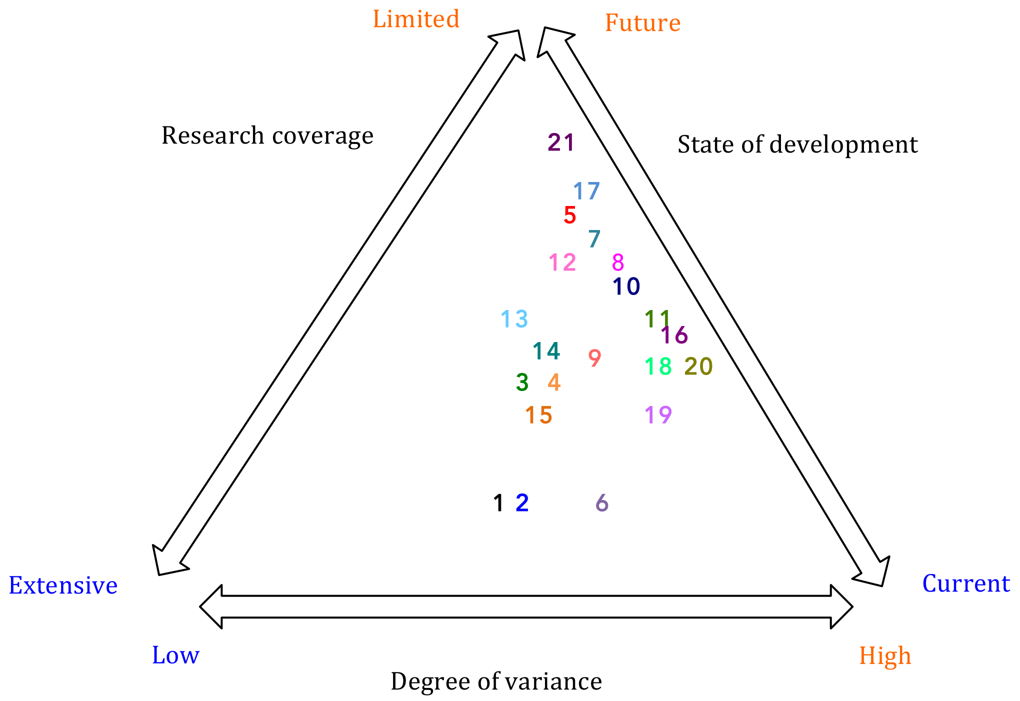
Topic: Demographics	
State of Knowledge	
Research Coverage	Existing
State of Development	Current
Degree of Variance	Medium
Metrics in this Section	
Direct model inputs	Yes
Projections	Yes
Impacts to date	No

At the beginning of the Future of Mobility White Paper, we present overarching descriptions of widespread trends influencing California's transportation landscape. These trends – Demographics, Economics, Climate Change and Sustainability, and Transportation Equity and Public Health – and their predicted impacts on transportation through 2050 are complex. These sections should thus be used to provide context through a subset of existing data and analyses.

Next, for transportation-specific topics, we identify and describe the state of the market, current understanding of impacts, and future projections, where relevant. We also note key considerations related to equity, public-private partnerships, and data sharing for shared mobility including: carsharing, bikesharing, and ridesourcing companies/TNCs. The state of knowledge and available metrics vary for these topics, which we indicate by employing the triangle infographic and table in each section.

Finally, we discuss several technologies and services that may impact transportation leading up to 2050. However, their impacts are highly uncertain. These topics were pursued as a result of feedback we received from the TAC and outside experts (e.g., hyperloop, drones, blockchain). Specific data, projections, and analyses on many of these topics are still limited. In such cases, we provide high-level descriptions and note areas where these technologies and services could be applied.

Topic Map



1 Demographics
2 Economics
3 Climate Change and Sustainability
4 Transportation Equity and Public Health
5 Connected and Automated Vehicles
6 Zero Emission Vehicles (ZEVs)
7 Carsharing
8 Bikesharing
9 Ridesourcing/Transportation Network Companies (TNCs)
10 Equity Considerations: Carsharing, Bikesharing, and Ridesourcing/TNCs
11 Alternative Transit Services
12 Shared Mobility Public-Private Partnerships (PPPs) and Data Sharing
13 Information and Communications Technology
14 Freight and Goods Movement
15 California's Passenger Rail System
16 Cybersecurity Risk
17 Blockchain
18 3D Printing
19 Drones and Unmanned Aerial Vehicles (UAVs)
20 On-demand Trucking/"Uber for Freight"
21 Hyperloop

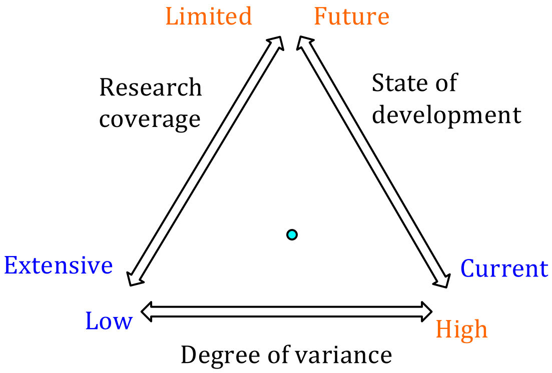
Demographics

Changes in demographics and generational preferences may have a significant impact on transportation networks and travel patterns. In this section, we explore California's projected growth over the coming decades and discuss research on shifting travel preferences of younger and older populations.

Use this section to:

1. **Review projections of population growth** produced by California state agencies, and
2. **Understand generational travel behavior trends** based on existing research of Generation Z, Millennial, Generation X, and Baby Boomer cohorts.

Topic: Demographics	
State of Knowledge	
Research Coverage	Existing
State of Development	Current
Degree of Variance	Medium
Metrics in this Section	
Direct model inputs	Yes
Projections	Yes
Impacts to date	No



Key Findings:

- California's population on July 1, 2016 was 39.4 million. Between 2016 and 2060, the state is projected to grow from 39.4 million to 51.1 million people, a rate of 0.6 percent annually. The Central Valley, San Francisco Bay Area, Inland Empire, and greater Sacramento regions are all expected to grow faster than the statewide average.
- Although there is little existing travel behavior research about Generation Z (those born 1998 to 2010), one study that surveyed U.S. Generation Z members found that 92 percent of respondents own or plan to own a vehicle in the future. It also found that 72 percent of respondents would give up social media for a year to have a car.
- One study of American Millennial travel behavior found that youth travel behavior deviates remarkably little from adults, especially when considering more important predictors, such as economic factors like employment status and income.
- Although trends in vehicle ownership and driving among Millennials are indeed shifting downward, it is not clear as to whether this will be a permanent shift or simply a delayed process due to economic circumstances and the postponement of certain lifestyle decisions (e.g., home ownership, children).
- Some studies suggest that Baby Boomers moving toward retirement age may decrease their car use as they retire. However, the advent of automated vehicles

could expand transportation options and increase travel among aging and retired populations.

Statewide Population Projections

California expects steady population growth over the coming decades. According to the California Department of Finance, between 2016 and 2060 the state is projected to grow from 39.4 million to 51.1 million, a rate of 0.6 percent annually, as shown in Table 2.1 (California Department of Finance, 2017).

TABLE 2.1: California State Population Projections

Year	Projected Population
2016	39.4 million (as of July 1, 2016)
2018	40 million
2035	45 million
2055	50 million
2060	51.1 million

Source: California Department of Finance, 2017

The Millennial generation (born between 1981 to 1997) was the largest generation in California as of 2016, with 9.4 million or 24 percent of the state's population. Generation X (born 1965 to 1980) is projected to overtake the Baby Boomer (born 1946 to 1964) generation in total size by 2019, when both become about 20 percent of the population in California.

From 2016 to 2036, the share of the population age 65 and older is projected to grow from 14 to 23 percent. Counties in the greater Los Angeles region will add the most people from 2016 to 2060, with Los Angeles, Riverside, and San Bernardino counties each projected to grow by over one million. The Central Valley, San Francisco Bay Area, Inland Empire, and greater Sacramento regions are all expected to grow faster than the statewide average between 2016 and 2060, increasing their share of the population by one to two percent each (California Department of Finance, 2017).

In expert interviews, most experts predicted that urban areas will become more dense as people migrate toward city centers. Although one expert disagreed with this assumption, the majority of others said that this may result in increased urban sprawl. This trend could push economically disadvantaged people farther from job markets, creating a high-density, high-income space in the urban middle.

Generational Travel Behavior

Potentially shifting travel behavior among generational groups is important to consider when hypothesizing about future travel demand. Below we summarize projected travel preference changes among the Generation Z, Millennial, and Baby Boomer cohorts.

Generation Z (Born 1998 to 2010)[1]

There is little existing travel behavior research about Generation Z (those born in the mid-1990s to 2010). One study that surveyed U.S. Generation Z members found that 92 percent of respondents own or plan to own a vehicle in the future. It also found that 72 percent of respondents would give up social media for a year to have a car. Only eight percent of respondents claimed that they wanted shared mobility services as a replacement for car ownership (Autotrader and Kelley Blue Book, 2016).

Millennials (Born 1981 to 1997)[2]

In addition to being the largest generational group in California, Millennials also comprise the largest portion of the U.S. population (McDonald, 2015). Thus, their travel decisions will strongly influence the structure and function of urban areas for decades to come. Millennials in the U.S. are earning drivers licenses and purchasing vehicles at a lower rate than past generations at the same age. A study from the University of Michigan showed that the number of 19-year olds licensed to drive in the U.S. has decreased by 18 percent from 1983 to 2014 (Schoettle and Sivak, 2016). Another study found that Millennials are 29 percent less likely to purchase a vehicle than Generation X at the same age (Cortright, 2015).

However, studies that investigate the reasons for declines in vehicle ownership and driving have mixed findings. One study of American travel behavior between 1995 and 2009 found that lifestyle-related demographic shifts explain ten to 25 percent of the decrease in driving, while Millennial-specific factors, such as changing attitudes, explain 35 to 50 percent of the drop in driving. A general dampening of miles traveled across all age groups, including but not exclusive to Millenials, accounts for 40 percent of the decrease (McDonald, 2015). A 2016 study of Millennial travel behavior in California found that Millennials report driving 18 percent fewer miles by car, on average, than members of the previous Generation X. This driving behavior pattern is confirmed among residents of both urban and suburban areas of California (Circella et al., 2016). Another study found that factors like employment status and household income are the strongest influencers on travel behavior for both youth and adults. This study found that youth travel behavior deviates remarkably little from that of adults, especially when considering more important predictors, such as employment status and income (Blumenberg et al., 2012).

Although trends in vehicle ownership and driving among Millennials are indeed shifting downward, it is not entirely clear as to whether this will be a permanent shift or simply a delayed process due to economic circumstances and the postponement of certain lifestyle decisions. A study of California Millennials found that independent Millennials living in urban areas own fewer cars per driver than other groups, on average. However, the study

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[1] Approximately 74 million people in the U.S., making up 23 percent of the total population (U.S. Population by Age and Generation, 2016).

[2] Approximately 79 million people in the U.S., making up 24 percent of the total population (U.S. Population by Age and Generation, 2016).

found that many older Millennials who live in urban areas reported that they plan to purchase a new vehicle in the near future (Circella et al., 2017). In addition, most national-level Millennial travel behavior studies use the National Household Travel Survey (NHTS) as a main data source, the last of which was conducted in 2009. Future studies that use updated data sources collected after the Great Recession period (such as the upcoming 2018 NHTS) may be able to more accurately assess the changing travel behavior of Millennials in the U.S.

Generation X (Born 1965 to 1980)[3]

There is little existing research that focuses specifically on future travel preferences of Generation X, the generational cohort preceding Millennials and following the Baby Boomers. Some research suggests that members of Generation X drove less between 2007 and 2013. In Portland, Honolulu and Philadelphia, members of Generation X drove fewer miles in 2013 than they did in 2007 at a rate of 3 percent or more, depending on the city. However, markets like Cleveland, Pittsburgh, and Seattle saw higher driving rates by Generation X members during these years (Kane and Tomer, 2008). Generation X members in California drive more than Millennial Californians in both urban and suburban neighborhoods. However, a number of reasons may be associated with this trend, such as differences in life stage, the presence of children, and the impact of personal attitudes (Circella et al., 2016). Similar to other generational travel behavior studies, it is unclear how much these observed travel behavior changes are due to generational preferences or due to economic effects during the Great Recession.

Baby Boomers (Born 1946 to 1964)[4]

The Baby Boomer Generation will soon comprise a significant proportion of the older population, as many are reaching retirement age. A study focused on travel behavior changes of retiring Baby Boomers found that retirement is a transition point associated with decreasing car use. However, prolonged careers, women changing professional roles, and informal care-giving may make the transition to retirement different than observed in previous cohorts (Siren and Haustein, 2015). In addition, the development of automated vehicles may have a large impact on the travel behavior of retired individuals and those who are no longer able to drive themselves. These people may have access to a much wider range of affordable mobility options, which could in turn increase the amount that they travel (Shergold et al., 2016). Differences between lifestyles of Boomer generation members may also exist, especially as they age. However, very little research exists, to date, about the travel behavior differences between more and less active Boomers.

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[3] Approximately 66 million people in the U.S., making up 20 percent of the total population (U.S. Population by Age and Generation, 2016).

[4] Approximately 76 million people in the U.S., making up 23 percent of the total population (U.S. Population by Age and Generation, 2016).

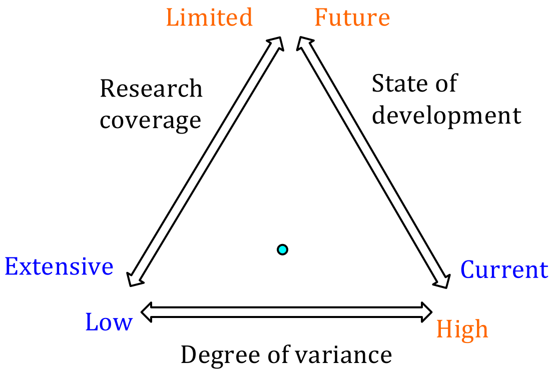
Economics

Changes in employment and income across the state can have a large impact on the travel behavior of Californians and the demands placed on the state's transportation network. In this section, we discuss projected growth in California's employment sector and other economic metrics. We also explore the role that a road user charge could have on microeconomic factors and we discuss the effect that emerging trends, like telecommuting and online shopping, could have on future travel behavior.

Use this section to:

1. **Review projections of state economic growth** by job sector and geographic region;
2. **Gauge tradeoffs between road user charges and gasoline taxes** from economic, equity, and administrative perspectives; and
3. **Explore the potential travel impacts of telecommuting and online shopping** and the factors that may lead to increased or decreased travel demand.

Topic: Economics	
State of Knowledge	
Research Coverage	Extensive
State of Development	Current
Degree of Variance	Medium
Metrics in this Section	
Direct model inputs	Yes
Projections	Yes
Impacts to date	No



Key Findings:

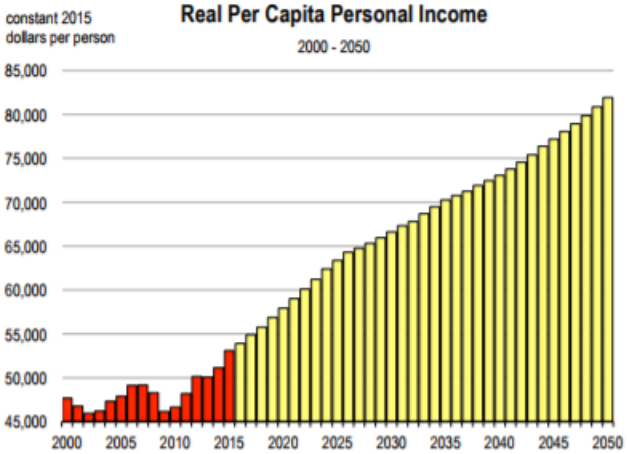
- In California, total employment is projected to increase one percent per year on average between 2016 and 2021. Within the same time frame, per capita income is expected to rise by 1.8 percent per year, on average, and is expected to increase to $80,000 by 2050 (in 2015 dollars).
- The Sacramento Valley and the Bay Area are expected to lead the state in job growth, followed by inland counties in Southern California. Income gains will be the highest in the Bay Area and Southern California due to job generation in high-paying sectors, like technology and business services.
- Mileage-based road user charges (RUCs) are an innovative way for states to raise transportation funds. RUCs can benefit rural and low-income users because even though they may pay more due to having longer commute distances, there are less taxes levied on their often less fuel-efficient vehicles.
- Thirty-seven percent of U.S. workers telecommuted in 2015, an increase of seven percent since 2008. On average, U.S. workers telecommuted from home about two days per month.

- Seventy-nine percent of Americans who shop are also online shoppers, which equates to an increase of almost 60 percent since 2000.
- Impacts on travel are difficult to assess from telecommuting and online shopping. It is possible that both could lead to increased or decreased travel. In the future, drone delivery could impact road traffic, and telecommuting could change the types of trips made rather than simply replace them. It is unclear if an overall increase or decrease of trips or mileage would result.

California Statewide Economic Projections

California makes up 12 percent of the U.S. population and 11.6 percent of the nation's non-farm job employment. In 2015, the per capita income in California was $53,224, and the average salary per worker was $70,022. Total employment is expected to increase one percent per year on average between 2016 and 2021. Within the same time frame, per capita income is projected to rise by an average of 1.8 percent per year (Schniepp, 2016). By 2050, real per capita income is expected to increase to over $80,000 (in 2015 dollars), as shown in Figure 3.1 below.

FIGURE 3.1: Real Per Capita Personal Income Projections



Source: Schniepp, 2016

Between 2016 and 2021, the largest gains in job creation will occur in professional and business services, education and healthcare, leisure and hospitality, wholesale and retail trade, and government. Together, these sectors will account for 74 percent of net job creation in California. The Sacramento Valley and San Francisco Bay Area are expected to lead the state in job growth, followed by inland areas in Southern California, like Imperial, Riverside, and San Bernardino counties. Income gains will be rapid in the Bay Area and Southern California due to job generation in high-paying sectors, like business services and technology (Schniepp, 2016).

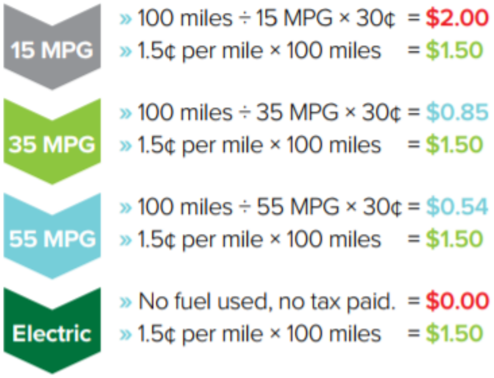
Microeconomic Implications: Road User Charges

With the Federal gasoline tax remaining at the same rate since 1993 and newer vehicle models becoming more fuel efficient (Povich, 2017), a few states, including California, have been experimenting with innovative ways such as road user charges (RUCs) to help fund infrastructure and maintenance costs. RUCs charge users for their incremental use of transportation infrastructure, typically by charging a per-mile tax.

RUC User Costs and Benefits

Costs and benefits of a RUC are directly related to the gas mileage of one's personal vehicle. All else equal, those with lower gas mileage see a benefit and lower costs, while those with better gas mileage experience higher costs. Figure 3.2 below illustrates how drivers of less fuel efficient vehicles pay more under a gas tax scenario and less under a RUC scenario (ODOT, 2017).

FIGURE 3.2: Fuel Efficiency and Gas Taxes versus Road User Charges



» 100 miles ÷ 15 MPG × 30¢ = $2.00
» 1.5¢ per mile × 100 miles = $1.50

» 100 miles ÷ 35 MPG × 30¢ = $0.85
» 1.5¢ per mile × 100 miles = $1.50

» 100 miles ÷ 55 MPG × 30¢ = $0.54
» 1.5¢ per mile × 100 miles = $1.50

» No fuel used, no tax paid. = $0.00
» 1.5¢ per mile × 100 miles = $1.50

Source: ODOT, 2017

RUC Urban versus Rural Implications

There are urban versus rural issues that arise when considering mileage-based taxation, especially when accounting for the longer distances often needed for travel in more rural areas of the state. Rural vehicle owners typically have longer commute distances than urban residents, but they also often own more fuel inefficient vehicles. Thus, even though switching to a mileage-based system penalizes these individuals because of their longer commute distances it also benefits them because it no longer accounts for their lower gas mileage (Weatherford, 2011). Some studies have shown that RUCs can be more equitable than the gasoline tax, and income-based VMT fees can better protect low-income households while generating additional revenue (Yang et al., 2016).

Other RUC Considerations

Other considerations when implementing RUCs include administrative and legal issues. The cost of administering individually-based fee programs is much higher than that of the gas tax, which is only levied on a handful of oil producers and distributors. In addition, it is illegal at present (per the California Streets and Highways code) to raise a fee for an existing piece of infrastructure in California (SFCTA, 2010). Nonetheless, a RUC could be an innovative and equitable way to raise state transportation funds in the future.

Emerging Trends: Telecommuting and Online Shopping

Two broad trends that could have notable impacts on travel behavior are telecommuting and online shopping. Telecommuting is a work arrangement in which an employee works from outside of an office, often their home or a location near their home. Thirty-seven percent of U.S. workers telecommuted in 2015, marking an increase of seven percent since 2008. U.S. workers telecommuted from home about two days per month, on average. Nine percent of workers claimed to telecommute more than 10 days per month, at least half of all workdays, in a typical month. However, while the percentage of U.S. workers who have telecommuted is growing, telecommuting remains more the exception than the norm (Jones, 2015).

Online shopping has grown in popularity over the last couple of decades with the growth of online retailers, like Amazon, who makes up nearly 70 percent of all e-commerce (Zaczkiewicz, 2017). At present, 79 percent of Americans who shop are also online shoppers, which equates to an increase of almost 60 percent since 2000. Fifteen percent of online shoppers do so weekly, and 28 percent shop online a few times per month. However, 64 percent of Americans claim they prefer buying from a physical store, all things being equal. Prices are often lower when shopping online than in brick-and-mortar stores, and cost savings is the main factor for shoppers when choosing to shop online (Mobile Fact Sheet, 2017). If trends in telecommuting and online shopping continue to grow, the travel behavior of certain segments of the state's population could decrease for both commuting and shopping trips in some instances. However, it is important to note that increases in online shopping can also result in more freight traffic, and other trips could replace work trips (e.g., lunch, errands, etc.) (Martin et al., 2016).

Augmented Reality (AR) also has the potential to reduce commuting trips, since it can create a virtual workplace for teams. The number of trips to healthcare and education locations may also be reduced, since consulting medical practitioners and educators via a virtual platform may become more common (SDAG, 2018).

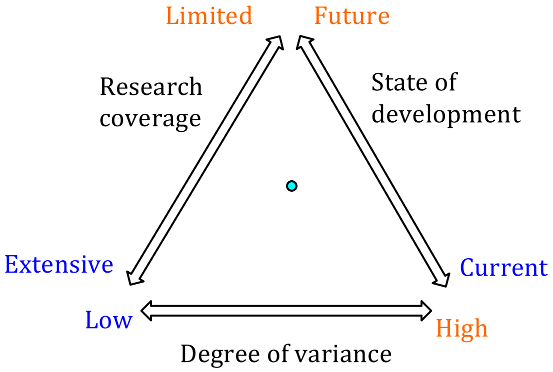
Climate Change and Sustainability

Although California has made significant strides to improve climate change mitigation efforts, there is room for improvement – including in the transportation sector – to meet greenhouse gas (GHG) reduction targets. In this section, we present expected changes due to climate change and their potential impacts on California's transportation infrastructure through 2050.

Use this section to:

1. **Complement existing work** on sustainability strategy and project implementation, including from Caltrans' Department of Sustainability;
2. **Review climate change impacts** on the transportation system, generally; and
3. **Refer to tools and models** that have more granular data and analysis of climate change impacts.

Topic: Climate Change and Sustainability	
State of Knowledge	
Research Coverage	Extensive
State of Development	Current
Degree of Variance	Medium
Metrics in this Section	
Direct model inputs	No
Projections	Yes
Impacts to date	No



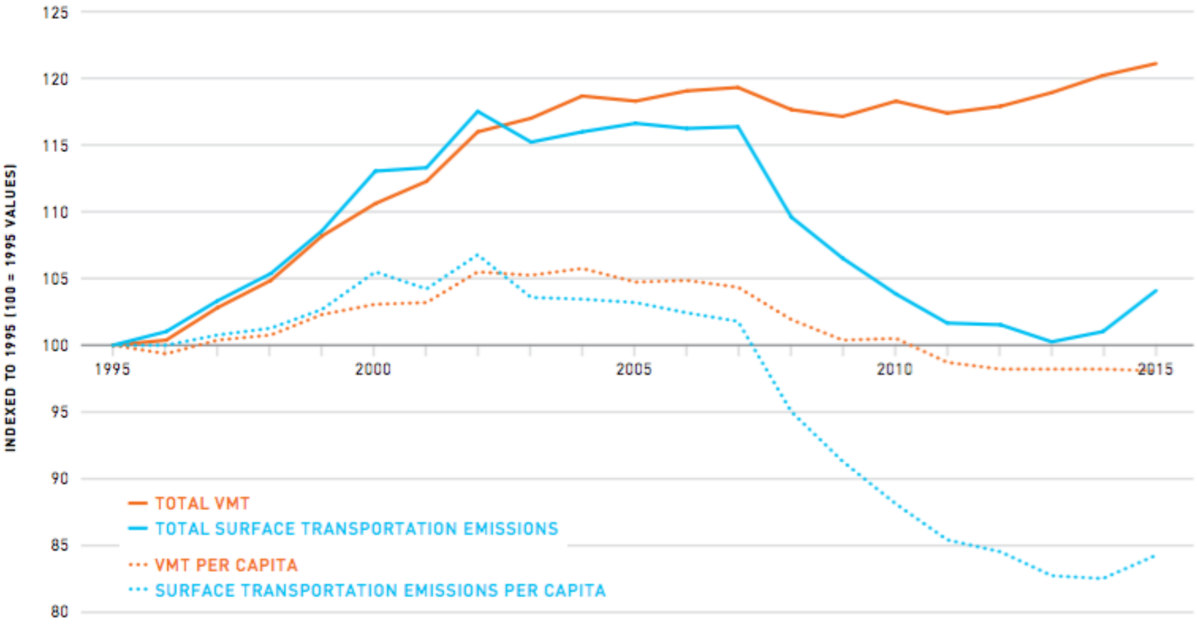
Key Findings:

- In California, although per capita GHG emissions have decreased by 12 percent since 2006, transportation-specific emissions increased by 2.7 percent from 2014 to 2015.
- According to models of projected emissions, scenarios that reflected early implementation of mitigation strategies resulted in larger emissions reductions than scenarios with later implementation of mitigation strategies.
- Predictions of specific changes in weather patterns include increased rainfall, temperatures, and drought, depending on geographic location, and sea level rise is expected to impact California's coastline. For further information on projections for specific California regions, please see: Cal-Adapt Climate Tools online resource.
- Increased frequencies of landslides, flooding, heat waves, and wildfire risk could tangibly impact California's transportation infrastructure.

Climate Change Predictions

In California, since the passage of AB 32 in 2006, per capita GHG emissions have dropped by 12 percent.[5] The California Air Resources Board predicts that fossil fuel demand will decrease by 35 percent by 2030 (California Air Resources Board, 2017). However, transportation-specific emissions increased 2.7 percent from 2014 to 2015, as shown in Figure 8.1 below (Next 10, 2017).

FIGURE 4.1: Vehicle Miles Traveled and GHG Emissions from Surface Transportation



Source: Next 10, 2017

Climate models typically compare a deep reduction scenario (e.g., cutting GHG emissions by 75 to 80 percent in California by 2050 compared to 1990 levels) to a business-as-usual scenario, although specific assumptions differ across models. These models display varying projections of GHG emissions through 2050 (Morrison et al., 2015). See Figure 8.2 below. According to Morrison et al. (2015), scenarios that favor early implementation of mitigation strategies result in larger overall emission reductions when compared to mitigations strategies that are implemented later.

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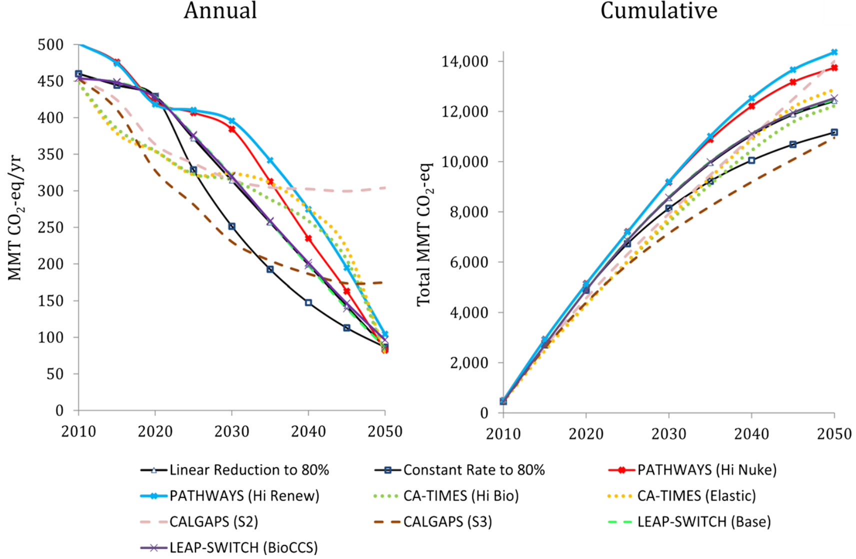
[5] AB 32, the California Global Warmings Solutions Act, can be found on the California state legislation information website.

FIGURE 4.2: GHG Emission Projections Across Selected Models

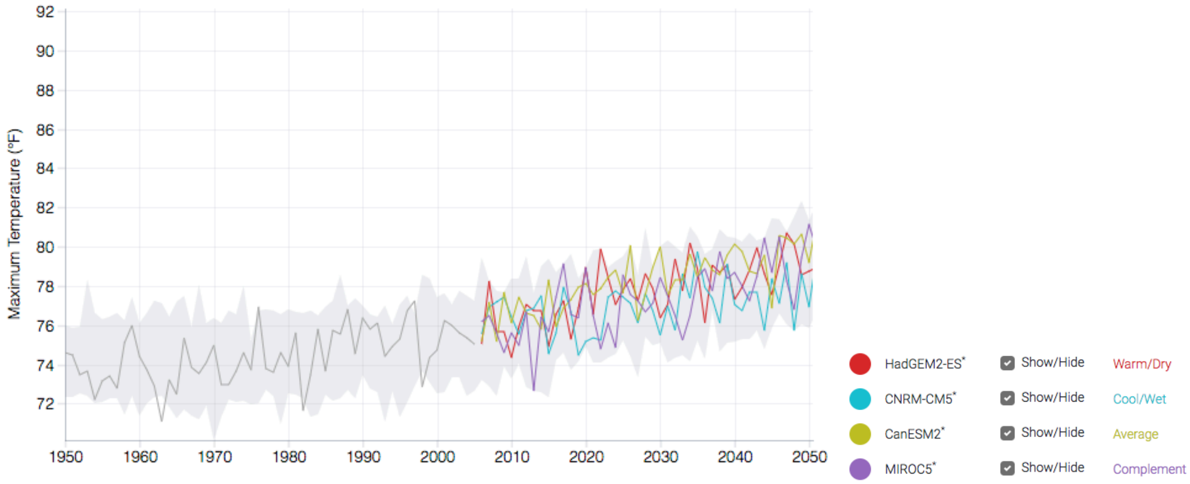

Annual

Cumulative

Source: Morrison et al., 2015

Predictions of specific changes in weather patterns include increased rainfall, temperatures, and drought, depending on geographic location. Furthermore, sea level rise is expected to occur along California's coastline. The number of days with temperatures over 95°F will likely double or triple by 2100 and will continue to increase regardless of mitigation scenarios (California Natural Resources Agency, 2016; Cal-Adapt, 2017). Yearly maximum temperatures will also increase over time, even if emissions peak in 2040, as shown in Figure 4.3 below.

FIGURE 4.3: Annual Maximum Temperature Projections



Source: Cal-Adapt, 2017

Tropical Pacific Ocean temperatures are expected to warm even as GHG mitigation strategies are implemented. A recent study found that California may experience an El Niño-like state with more precipitation, especially in December, January, and February (Allen and Luptowitz, 2017).

Further information on projections for specific California regions can be found at Cal-Adapt Climate Tools online resource, which is provided by the California Energy Commission (Cal-Adapt, 2017).

Climate Change Impacts

The significant impacts that climate change is predicted to have on transportation infrastructure are summarized in Table 4.1 below. Local and regional plans for climate change mitigation and adaptation reflect varying priorities, depending on the geographic and infrastructure in consideration.

TABLE 4.1: Highlighted Climate Change Impacts

Change	**Cause**	**Impact(s)**	**Transportation-Specific Impact(s)**
More frequent, heavier rainfall; extreme winter storms	Changing weather patterns	Increased landslides, flooding	Railroad, road, and bridge closures
Heat trapping in urban areas, more extreme heat days, more heat waves	Increasing temperatures	Reduced incentive for active transportation, increased wildfire risk	Road surface expansion, pavement buckling Stress on railroad tracks, bridge joints
Sea level rise, extreme coastal storms, storm surges	Rising ocean temperatures, melting of land-based ice sheets, coastal land uplift	Flooding	Oil refineries for fuel at risk of saltwater intrusion

Sources: Cal-Adapt, 2017; California Natural Resources Agency, 2016

Transportation Equity and Public Health

Equity touches every aspect of the transportation system. Regulatory agencies have attempted to measure access to transportation services across socio-demographic groups (Dumas, 2015; Wired, 2011). With new data sources and analytic techniques, the transportation sector has a pivotal opportunity to paint a more accurate portrait of transportation equity. New methodologies also enable equity analysis on a finer scale. This is especially pertinent as innovative modes come to market, which have the potential to further expand access or constrict it.

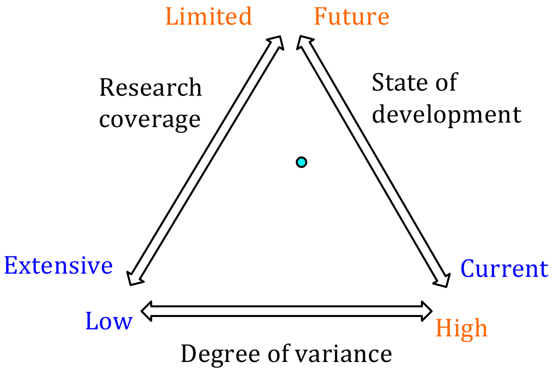
Equitable access can be considered in terms of proximity to opportunities, goods, and services, and the ease of getting to all three. These factors include: employment, education, healthcare, food and groceries, and housing (Blackwell, 2017; Cohen and Cabansagan, 2017; Shaheen et al., 2017; Kambitsis, 2011). Increasingly, as transportation networks rely on wireless services and technologies, equitable mobility will depend on access to broadband Internet, smartphones, and bank accounts (Shaheen et al.,2016; Blackwell, 2017). Acknowledging these barriers and adjusting transportation networks, as needed, requires creative solutions involving public and private sector players in conjunction with community members. It also requires analyzing how programs and interventions target and ultimately benefit populations across time and space.

This section highlights the roles of transportation services and land use in equitable access to goods and services. We describe key issues that have traditionally restricted access to transportation modes. Since public health and equity are interdependent, we present some of the key issues related to public health, transportation, and equity in this section. Finally, we provide an overview of factors to consider when analyzing mobility and accessibility.

Use this section to:

1. **Explore key issues** facing populations with limited transportation access;
2. **Explain transportation as a social determinant of health**, and;
3. **Frame projects and policies** in terms of which populations they benefit.

Topic: Transportation Equity and Public Health	
State of Knowledge	
Research Coverage	Existing
State of Development	Current
Degree of Variance	Medium
Metrics in this Section	
Direct model inputs	No
Projections	No
Impacts to date	Yes



Key Findings:

- Among U.S. urban residents, 34 percent of blacks and 27 percent of Hispanics report taking public transit daily, almost daily, or weekly, compared to 14 percent of whites. Differences in public transit use among individuals of different races are not clearly documented in rural areas, however.
- The increased travel time associated with some public transit networks and lack of vehicle access for minority and low-income populations puts certain job opportunities out of reach.
- There is disproportionate suffering from the negative externalities of pollution and congestion among lower-income groups and people of color. In California, five of the smoggiest cities are also locations with the highest projections of ozone increases associated with climate change.
- Creating interdisciplinary teams that can prioritize community involvement among low-income communities can support decision making amidst complex environments.
- New methodological tools that analyze electronic origin-destination data can support equity analyses on a more granular level (when data are de-identified for personally identifiable information). Tracking public transit use according to ridership characteristics can more accurately identify inequities in existing public transit networks.

Key Issues Associated with Restricted Transportation Access

Title IV of the Civil Rights Act stipulated that the provision of transportation services receiving federal funding must not be restricted on the basis of race, color, or origin (Dumas, 2015). This legislation, however, required that one must prove the *intent* to discriminate in order to reverse unjust transportation service decisions. Therefore, transportation decisions often continued to result in discriminatory *effects* on certain groups of people, especially poor people and people of color (Dumas, 2017). Many advocates argue that transportation continues to be a prominent civil rights issue.

Among U.S. urban residents, 34 percent of blacks and 27 percent of Hispanics report taking public transit daily, almost daily, or weekly, compared to 14 percent of whites (Anderson, 2016). Blackwell (2017) notes that most people using public transit in some California cities, like Los Angeles, are people of color without easy job access. In some cases, the increased travel time associated with some public transit networks puts certain job opportunities out of reach.

Low-income populations are also more likely to use public transportation on a regular basis across the U.S. (Anderson, 2016). Very low-income families spend, on average, 30 percent of their income on transportation (Cohen and Cabansagan, 2017). According to Grengs et al. (2013), about 40 percent of buses and 25 percent of rail transit around the U.S. are in poor condition. Infrastructure improvements to update these networks can create jobs in manufacturing and construction (Blackwell, 2017). Although public transit reliability, congestion, and economic growth are closely related, there are disparate viewpoints on whether projects that spur new development (e.g., creating construction jobs) or projects that improve the efficiency of existing infrastructure (e.g., greater service reliability), increase economic opportunity more significantly (Shaheen et al., 2016).

Traditionally, vehicle ownership has also predicted access to employment opportunities. African-Americans and Hispanics are still less likely to have access to a private vehicle (Anderson, 2016). In Shaheen et al.'s (2016) work, the authors note that the Mineta National Transit Research Consortium studied a cohort of people for 15 years and concluded that increased automobile access is associated with a smaller chance of being unemployed in the future and greater income gains. However, the cost of car ownership and maintenance may be greater than the income gains associated with car ownership. Shared mobility may compensate for these increased costs, especially in conjunction with automated and electric technologies. Please note that we provide a discussion of transportation equity and shared modes in a later section of this white paper, titled "Equity Considerations: Carsharing, Bikesharing, and Ridesourcing/TNCs."

Public Health

As mobility and access to transportation are increasingly considered social determinants of health, many experts cite transportation's critical role in enabling self-sufficiency and full societal participation (Scribner et al., 2017; Grengs et al., 2013). Public health issues, in relation to transportation, range from safety to pollution. We briefly cover these topics below.

Regarding transportation safety, motor vehicle deaths in the U.S. increased eight percent between 2014 and 2015 with increases continuing into the first half of 2016, even when accounting for a change in vehicle miles traveled (National Safety Council, 2017). According to the National Highway Traffic Safety Administration, approximately 94 percent of traffic accidents are due to human error (Roberts, 2017). In addition to preventing motorized vehicle crashes, designing systems to protect non-motorized modes (i.e., pedestrians and bicyclists) remains a priority for California. The state's plan: "Toward an Active California" (2017) emphasizes bicycle- and pedestrian-friendly development, citing California's goal to double walking, triple bicycling, and double public transit use between 2010 to 2020, while reducing bicycle and pedestrian casualties by ten percent per year (Caltrans, 2017).

Climate change's health effects disproportionately burden certain demographic groups. For example, heat waves increase the number of cardiovascular deaths, with people older than 65 and African Americans at greater risk. Since individuals older than age 65 and African Americans, Latinos, and Asians are less likely to have vehicle access, these groups are less able to relocate to cooler areas during extreme heat events. Inner-city communities are more likely to experience the heat-island effect: in many inner-city communities, there is less tree cover to offset trapped heat in impoverished communities (Morello-Frosch et al., n.d.). There is also disproportionate suffering from the negative externalities of pollution and congestion (Cairns et al., 2003). In California, five of the smoggiest cities are also locations with the highest projections for ozone increases due to climate change (Morello-Frosch et al., n.d.). Pollution increases the incidence of disease, particularly asthma and skin irritation, and airborne chemicals can alter hormonal processes. The technologies and business models discussed throughout this white paper can expand access to mobility options, and increased electrification has the potential to reduce transportation-specific emissions.

Populations with Less Accessibility

A significant challenge in tackling transportation inequities is that efforts to prioritize access for socio-demographic groups may conflict with one another. For example, increasing mobility access with vehicles may increase vehicle miles traveled (VMT), if vehicles are not shared and/or not electric. This, in turn, increases the burden of pollution bared by populations in congestion-heavy zones. Creating interdisciplinary teams that prioritize community involvement can support decision making in complex policy environments. When communities are not involved, services that could improve access could be divisive. For example, some residents of San Francisco's Mission District met Ford GoBike's expansion with hostility, stating that the company had not considered community needs in their planning efforts (Levin, 2017). Without direct community input, services could also fail to result in increased access for the communities they are attempting to target.

Whether populations can access transportation modes depends on service schedules, costs, and proximity to pick-up and drop-off locations. The latter is partially a result of land use patterns. Although, transportation services have traditionally attempted to maximize travel speed, compact development and job opportunities close to home can maximize access. Compact development can simultaneously reduce travel demand, lower VMT, promote mobility, the environment, and equity (Grengs et al., 2013).

Different programs and policies may increase transportation equity for different groups of people. It is important to consider the following factors when examining traditionally disadvantaged groups, as shown in Table 5.1 below, to understand which demographics may benefit from a certain program or policy. For example, some programs aim to increase access for an older population, while others try to increase access for a particular region.

TABLE 5.1: Socio-demographic Factors for Equity Analysis

Factor	Examples
Demographics	Age, household type, race, ethnicity
Income Class	Quintiles, poverty line, percent income spent on transportation
Physical Mobility	Physiological ability
Geography	Jurisdictions, neighborhoods, density

Sources: Shaheen et al., 2016; Litman, 2015

The degree to which target groups gain access to mobility may change, depending on the region considered. Definitions of environmental justice in relation to transportation also differ contextually, based on which issues are affecting distinct people and places. (Cairns et al., 2003). Acknowledging distinctions across geographies can encourage use of more relevant data sources and metrics (e.g., CitiLab's *Sugar Access*, which quantifies travel time and cost to work and non-work locations through an integrated geographic information software platform) to monitor how projects affect distinct groups (Shaheen et al., 2016). The data sources and metrics to use may then change depending on the project or region in consideration.

In addition, new methodologies to analyze electronic origin-destination (OD) data can support equity analyses on a more granular level (when data are de-identified for personally identifiable information). State regulations have not kept pace with advances in modeling, computation, and data collection capabilities. Although transportation agencies are required to complete Title IV Service Monitoring Reports, Dumas (2015) found that only reports from the Massachusetts Bay Transportation Authority and Bay Area Rapid Transit were publicly available, for example. Tracking public transit use according to actual ridership characteristics can more accurately identify inequities in existing public transit networks. This is especially important because census data are not published as frequently and may not be collected at accurate scales.

Connected and Automated Vehicles

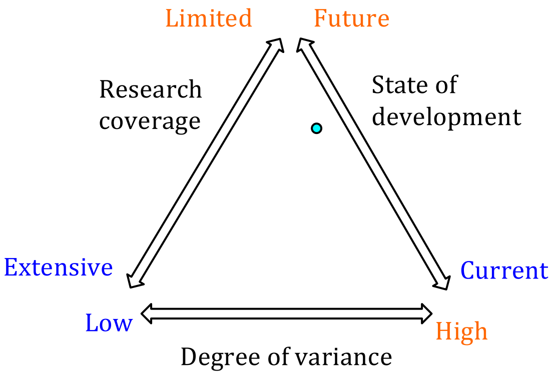
Connected and automated vehicle (CV/AV) technology is developing rapidly and could become common in vehicles on the road within decades. These innovations could be some of the most disruptive transportation technologies since the introduction of the automobile and could have dramatic effects on future travel behavior and urban design.

While there are many companies developing AV technology, there exist few public deployments serving passengers, at present. However, this is expected to change as the technology matures and companies begin selling vehicles with more automated and connected features and begin offering AV passenger services. The timeline of when AVs and CVs will be introduced and will gain market share is uncertain, as are the impacts these vehicles will have on the transportation system. In this section, we provide a brief explanation of the current state of the AV/CV market and outline key trends, developments, and technology diffusion projections.

Use this section to:

1. **Familiarize reader with the current state of the industry** of AVs and CVs, including announcements and rollout projections;
2. **Review the range of potential impacts** that AV and CV technology could have on travel behavior, the environment, and the transportation system; and
3. **Determine areas of planning that will likely be affected** by AVs and CVs.

Topic: Connected and Automated Vehicles	
State of Knowledge	
Research Coverage	Limited
State of Development	Emerging
Degree of Variance	High
Metrics in this Section	
Direct model inputs	No
Projections	Yes
Impacts to date	No



Key Findings:

- Model results that predict the change in travel demand or energy use due to AVs depend significantly assumptions about future rates of adoption of shared AVs vs. privately owned AVs.
- CV technology, if integrated into today's vehicles or future AVs, could offer important safety and transportation network performance benefits.
- According to different studies, anywhere from 20 percent to 95 percent of miles traveled on U.S. roads could be in AVs by 2030. Fully automated taxi fleets could become a reality between 2023 and 2030, according to a report by Bloomberg.

- Over 40 companies worldwide are developing AV technology. Over the last three years, $80 billion worth of AV-related investments, partnerships, and acquisitions have been made.
- AVs will affect the following urban policies: traffic safety, mobility, sustainability, jobs and the economy, human services, public finance, and land use.

Current State of the Industry – Automated Vehicles

There is a lot of interest among private sector players to develop AV technology. As of May 2017, over 40 companies around the world were developing AV technology (CB Insights, 2017), including most major auto manufacturers and many technology companies. Between August 2014 and June 2017, there were more than 160 separate AV-related investments, partnerships, and acquisitions. The estimated value of these deals approached $80 billion dollars (Kerry and Karsten, 2017). Most auto manufacturers that have announced plans for AVs already offer or plan to release vehicles with some automated features by 2017. The Society of Automotive Engineers (SAE) have defined five levels of automation, with Level 1 referring to vehicles that automate one primary control function (e.g., adaptive cruise control or self-parking) and Level 5 referring to full self-driving in all driving environments without human controls (USDOT, 2016). See Table A1 in the Appendix for definitions of all levels of automation.

Many AV developers are targeting Level 4 automation, where a human driver does not need to intervene as long as the vehicle is operating in a suitable environment for its capabilities. AV companies have become increasingly skeptical about Level 3 (partially automated) technology, as they deem it may be unsafe, if a human operator is required to take over at high speeds. At present, AV testing efforts are being conducted around the world. However, there are very few serving passengers using AVs on public roads currently. In October 2017, Waymo announced it was hoping to transition its passenger testing operations in the Phoenix, AZ area to a full shared AV commercial service by as early as late-2017 (Lee, 2017). In December 2017, Lyft and NuTonomy partnered to offer rides in a Boston neighborhood in NuTonomy's AVs hailed through the Lyft platform (Hawkins, 2017). General Motors announced in November 2017 that they plan to launch and operate a fleet of shared AVs in several big cities in 2019 (Jenkins, 2017).

As of November 2017, 21 states have enacted legislation related to AVs. California has had testing regulations in place since September 2014, and as of November 2017, 43 companies were registered with the California Department of Motor Vehicles (DMV) to be able to test on public roads in the state (DMV, 2017). In October 2017, the California DMV released its revised deployment regulations, which would allow AVs without human drivers to be tested on state public roads sometime in 2018.

Current State of the Industry – Connected Vehicles

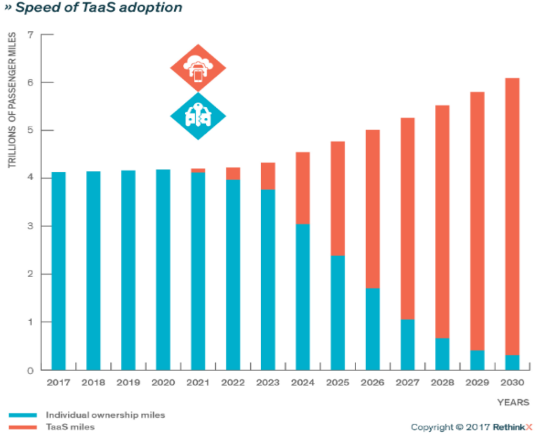
Connected vehicle (CV) technology is important for ensuring the efficient and safe operations of roadway vehicles, and it is especially important to integrate with AV technology. CV technology allows vehicles to communicate with each other and the world around them to ensure greater safety and efficiency benefits. CV technology can enable transportation agencies to access vehicle data related to speed, location, and trajectory, which could allow for better management of traffic flow in real time (Murtha, 2015). The United States Department of Transportation (USDOT) issued a Notice of Proposed Rulemaking (NPRM) in late-2016 that would standardize vehicle-to-vehicle (V2V) communication technology using Dedicated Short Range Communication (or DSRCs) in all new light-duty vehicles (NHTSA, 2016). However, these efforts at the federal level have been slow to materialize.

Future Developments and Projections

Eighty percent of the top 10 global automakers announced to have an SAE Level 4 or Level 5 vehicle by 2021 or earlier, with some declaring that the vehicles will be on public roads at that time (Business Insider, 2016). However, as of late-2017, some automakers have been scaling back these predictions. Ford's new CEO Jim Hackett claims that AVs that can drive in any circumstance will not be ready by 2021 (Fortune, 2017).

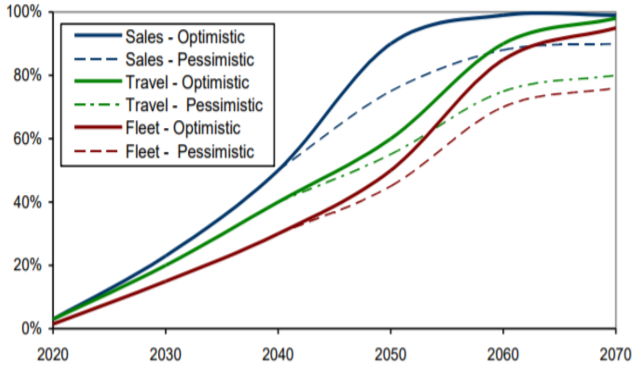
A report by Bloomberg compiled multiple expert predictions and found that fully automated taxi fleets could become a reality between 2023 and 2030. One of the more bullish projections on AV diffusion, by RethinkX, predicts that by 2030, 95 percent of US passenger miles traveled will be served by on-demand automated electric vehicles owned by fleets, not individuals. They refer to this business model as Transportation as a Service (TaaS), which has a similar meaning to Mobility on Demand (MOD); see Figure 6.1 below (Arbib and Sebab, 2017). Nevertheless, expert predictions on the timeline and rollout of AVs vary greatly. Some experts believe that technical challenges may be more difficult to solve than currently expected, and Level 4 or higher AVs may not become commercially available until the 2030s or 2040s (Litman, 2017). If AV implementation follows a similar uptake pattern of other vehicle technologies, like air bags or automatic transmissions, it could take one to three decades to dominate vehicle sales, plus one or two more decades to dominate vehicle travel, as shown in Figure 6.2 below.

FIGURE 6.1: On-Demand AV Passenger Mile Share Projections



Source: Airbib and Sebab, 2017

FIGURE 6.2: Optimistic and Pessimistic AV Sales, Travel, and Fleet Penetration Levels



Source: Litman, 2017

Potential Impacts of AV/CVs

The range of benefits and risks of cheap, automated mobility are yet to be fully understood. The impact that AVs and shared AV services may have on congestion, VMT, and GHG emissions is uncertain at present, with some studies predicting that roadway capacity may be freed up due to more efficient operations and right-sizing of vehicles. Other studies predict increased vehicle travel as a result of more convenient and cheaper automated transportation options (Stocker and Shaheen, 2016). In addition, impacts may vary depending on the land-use context (urban, suburban, or rural areas) and the availability of AV services or penetration of personal AV ownership. The range of predicted impacts depends heavily on assumptions of automated mobility costs, rates of personal AV ownership, shared AV market share, travel behavior changes, and future policy decisions. Factors that contribute to increased or decreased VMT are outlined in Figure 6.3 below:

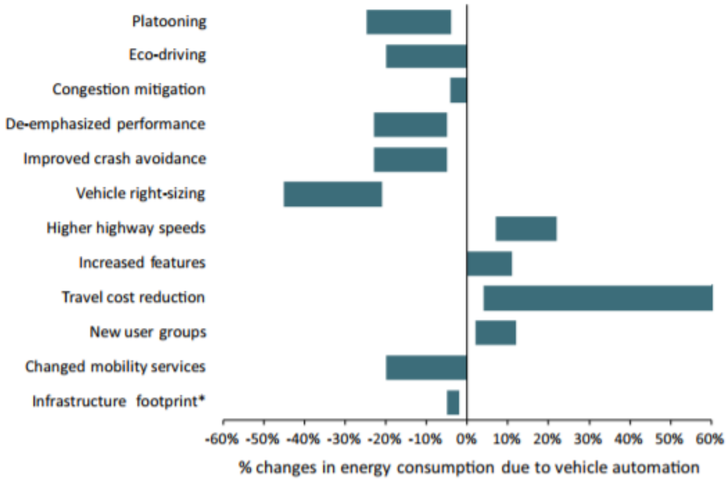
FIGURE 6.3: AV Factors Expected to Increase, Decrease Vehicle Miles Traveled (VMT)

Increases Vehicle Miles Traveled	**Decreases Vehicle Miles Traveled**
• Reduced per-mile costs induces demand for travel	• Reduction in personal vehicle ownership due to uptake of shared AV services
• More convenient and productive travel (can work or sleep in vehicle) increases miles traveled	• Automated transit vehicles improve cost, quality, and desirability of public transportation services
• Provides convenient vehicle travel to non-drivers (e.g., youth, elderly, disabled populations)	• Some reduced vehicle travel, such as looking for parking spaces
• AV services increase amount of deadheading (0-occupancy) VMT	• Makes dense urban living more attractive due to reduced parking demand and pedestrian risks
• Increases urban sprawl due to increased travel convenience	

Source: Litman, 2017

Scenario-based studies show a range of AV impacts on VMT and energy consumption from different factors. One study found that automation might plausibly reduce transportation-related GHG emissions and energy use by nearly half or could nearly double them, depending on which effects come to dominate (Wadud et. al, 2016). Energy impacts depend on a number of different factors, with some decreasing energy consumption and others increasing it, as shown in Figure 6.4 below.

FIGURE 6.4: Estimated Ranges of Energy Impacts due to AVs



Source: Wadud et al., 2016

We found the greatest range of uncertainty was associated with AV travel cost impacts on energy consumption. For instance, total automobile travel and fuel consumption could increase significantly, if AVs reduce the cost of drivers' time. Nevertheless, energy and emission reductions may be enabled by greater vehicle connectivity and vehicle pooling, even without full automation.

The integration of CV capabilities with AV technology, often referred to as connected and automated vehicles (CAVs), is important for optimizing overall transportation network performance. Analyses by researchers at the UC Riverside Center for Environmental Research and Technology found that many network-wide factors could affect the performance of a specific CAV application. They found that the penetration rate of CAV technologies is an important factor when evaluating the traffic flow impacts and overall performance measures, especially when there is growing trend toward mixed traffic within the next decade (Tian et al., 2017). CV technology is an especially important tool moving forward to ensure the safe and sustainable operations of increasingly automated vehicles.

Seven areas of urban policy and planning will likely be shaped by AVs and will need special attention by policymakers in the coming decades:

- Traffic safety,
- Mobility,
- Sustainability,

- Jobs and the economy,
- Human services,
- Public finance, and
- Land use.

In order to maximize positive benefits and mitigate negative effects, cities will need to employ many sources of expertise both inside and outside of government (Bloomberg Philanthropies and The Aspen Institute, 2017).

Zero Emission Vehicles (ZEVs)

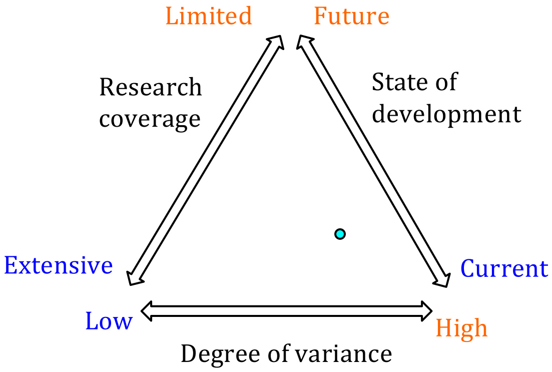
California's Zero Emission Vehicle (ZEV) Mandate was recently adapted to hasten the state's transition to an EV future, increasing the number of ZEVs on the road to 1.5 million by 2025 (ZEV Action Plan, 2016). EV sales are indeed increasing across the country, especially in California. In Q1 of 2017, EV sales rose to 2.7 percent of all vehicle sales, the largest share to date.

However, charging infrastructure remains a barrier to feasible widespread EV adoption. A combination of factors affects projections of how much charging infrastructure will be necessary to sustain that number of EVs. User behavior, shared mobility, battery prices, concerns over grid load, and technology development influence EV proliferation. Most current analyses also fail to account for emerging technologies like wireless (or inductive) charging systems, and how these factors will intersect as the transportation sector changes. In this section, we provide a brief explanation of the current state of the EV market, explain factors affecting EV deployment, and synthesize existing projections and uncertainties for EV charging infrastructure.

Use this section to:

1. **Compare projections** of EV adoption rates under different assumptions, and
2. **Provide context on limitations** due to California's charging infrastructure gap.

Topic: Zero Emission Vehicles	
State of Knowledge	
Research Coverage	Existing
State of Development	Emerging–Current
Degree of Variance	High
Metrics in this Section	
Direct model inputs	No
Projections	Yes
Impacts to date	Yes



Key Findings:

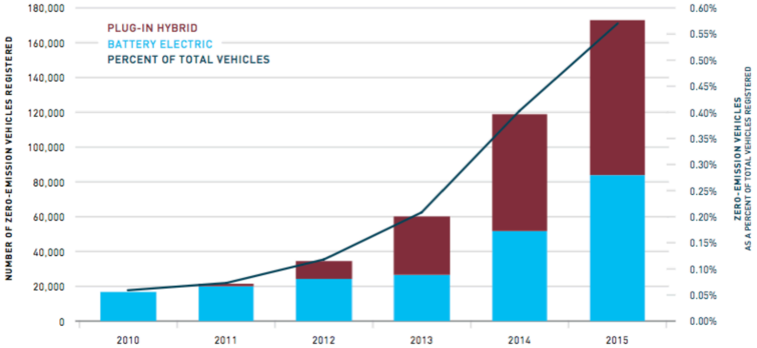
- Projections of EV adoption rates vary widely based on differing assumptions about shared vehicle growth and automation. One scenario predicts that 95 percent of VMT will occur in shared, electric AVs by 2030. Another scenario predicts that 80 percent of shared AVs will be electric by 2040. Under a slow adoption scenario, if the rates of personal ownership stay constant, 37 percent of U.S. vehicles will by electric by 2042.
- Personal EV sales have grown at increasing rates since 2013.
- California has a significant charging infrastructure gap: there are 27 EVs per Level 2 charger and 196 EVs per DC Fast Charger.

- To achieve California ZEV goals, one million chargers should be installed by 2020. Utility companies have installed or have submitted proposals to install about 102,850 chargers. Tesla aims to install 10,000 Tesla Superchargers, which require an adapter for models other than Teslas, by 2018.

Current State of the Market

Over 20 plug-in electric models are available today, many of which are more lightweight with longer ranges (ZEV Action Plan, 2016; Erriquez et al., 2017). EV market share has grown increasingly over the past four years, as seen Figure 7.1 below. Lithium battery prices have fallen more rapidly than expected, with average prices dropping 77 percent since 2010 (Bloomberg New Energy Finance, 2017).

FIGURE 7.1: EV Registrations, 2010-2015



Source: Next 10, 2017

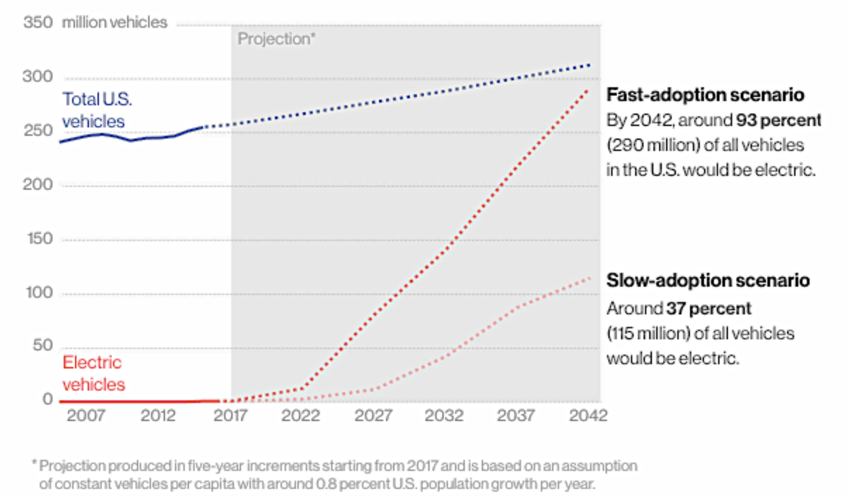
Shared Electric Vehicles

Mobility on Demand (MOD) and shared mobility services (e.g., Zipcar, Lyft) may affect the rate and sheer number of EVs on the road. See Table 7.2 below for a summary of the latest projections of future EV deployment, which vary widely by source, and Figure 7.3 for fast- versus slow- private EV ownership adoption scenarios.

TABLE 7.2: Variable Zero Emission Vehicle Adoption Dates

Description	**Projected Date**	**Source**
2.9 million ZEVs on U.S. roads	2022	Rocky Mountain Institute, 2017
1.5 million ZEVs on California roads	2025	ZEV Action Plan, 2016
EVs price competitive without subsidies	2025	Bloomberg New Energy Finance, 2017
95 percent of VMT will occur in shared EVs	2030	Airbib and Sebab, 2017
Pure EV sales overtake plug-in hybrid sales	2030	Bloomberg New Energy Finance, 2017
80 percent of shared AVs are electric	2040	Bloomberg New Energy Finance, 2017

FIGURE 7.3: EV Vehicle Adoption with Constant Car Ownership



Fast-adoption scenario
By 2042, around **93 percent** (290 million) of all vehicles in the U.S. would be electric.

Slow-adoption scenario
Around **37 percent** (115 million) of all vehicles would be electric.

* Projection produced in five-year increments starting from 2017 and is based on an assumption of constant vehicles per capita with around 0.8 percent U.S. population growth per year.

Source: Leahy, 2017

Shared systems reduce the cost of operating an EV, as shown in Figure A1 in the Appendix, increasing the technology's economic viability (Shaheen et al., 2016; Arbib and Sebab, 2017; Knupfer et al., 2017). Although the price of lithium ion batteries is decreasing substantially, thus spurring EV sales, the battery requirements for shared EVs may differ. For examples, the cost of a more expensive battery that takes less time to charge may be distributed over a shared system. Additionally, neighborhood electric vehicles (NEVs) are smaller vehicles that have capped speeds in urban areas that could be used as non-emitting localized modes. See Table A2 in the Appendix for a description of behavioral factors influencing EV adoption.

Charging and Infrastructure: Limitations and Developments

Experts highlighted EVs, ICT, and AV/CV as disruptive mobility technologies. As EVs are deployed, cities will need to adapt by installing more charging stations, one expert said. Across California, there are 27 EVs per Level 2 charger (i.e., 240 Volts), which can supply 80 miles of range in six to 350 minutes. There are 196 EVs per DC Fast Charger, which can supply an 80-mile charge in two to 24 minutes (Next 10, 2017).

Due to California's overall lack of charging infrastructure, there is not enough research to date on where and how to best distribute new infrastructure. Wireless charging technology, which would remove the need for a cord connection between an EV and charger, is under development and may affect charging network distributions if implemented.

EVs could also increase energy storage, since EV batteries could balance the grid load (Kammen and Sunter, 2016). Use of EVs as an energy storage system is being studied by researchers, and one expert noted that renewable energy and grid distribution will provide additional power sources for transportation. To make this a reality, standards and regulations will need to cross vehicle, grid, and building industries, since vehicle-to-grid technology will be instrumental for EV grid integration (Markel et al., 2015; van der Kam and van Sark, 2015).

According to the most recently updated California's 2016 Zero Emission Vehicle Action Plan, one million charging stations will be necessary by 2020 to achieve ZEV goals. California governments and major utilities companies (i.e., Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric (SDG&E)) are responding to this challenge through proposals for installing chargers, see Table A3 in the Appendix. Across the three major utility companies proposing SB 350 projects, PG&E claims that it will be able to provide charging coverage to 40 percent of the 1.5 million future EVs. SDG&E estimates that it will be able to serve 10 percent, leaving 50 percent up to SCE and state public and municipal utilities.

Carsharing

Carsharing, which began in the U.S. in 1994, is one of the most mature forms of shared mobility (Martin et al., 2016; Jerram, 2017). In this section, we define the following carsharing business models[6] and describe the impacts of these systems:

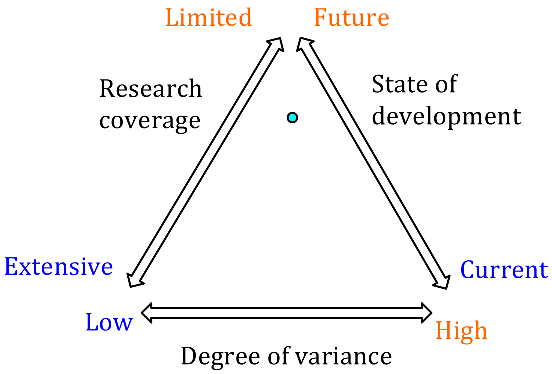
- **Peer-to-Peer (P2P) Carsharing**, where members rent out privately owned vehicles in a peer network.
- **Business-to-Consumer (B2C) Carsharing**, where an entity maintains a vehicle fleet.

Limited projections for market growth over time exist, which vary based on assumptions. The rate of carsharing's projected growth depends on a variety of factors including competition from other shared modes, such as ridesourcing (e.g., Lyft/Uber), and how quickly developing technologies are implemented. Automation and electrification will likely affect B2C models more directly, since automated vehicles (AVs) may be more quickly integrated as fleet vehicles. However, new business models that do not yet exist may also come to fruition.

Use this section to:

1. **Assess the current state of the national carsharing market** and existing business models**,**
2. **Learn carsharing's impacts to date** and potential for future expansion,
3. **Hypothesize how carsharing and automation** may converge, and
4. **Compare predictions** for shared vehicle adoption rates.

Topic: Carsharing	
State of Knowledge	
Research Coverage	Limited-Existing
State of Development	Emerging
Degree of Variance	Medium–High
Metrics in this Section	
Direct model inputs	Yes
Projections	Yes
Impacts to date	Yes



Key Findings:

- The U.S. carsharing market currently amounts to $23 billion. As of 2016, there were two million carsharing members in Northern California.
- Predictions for how carsharing business models will manifest in the future, especially when taking automated technologies into consideration, is highly uncertain.

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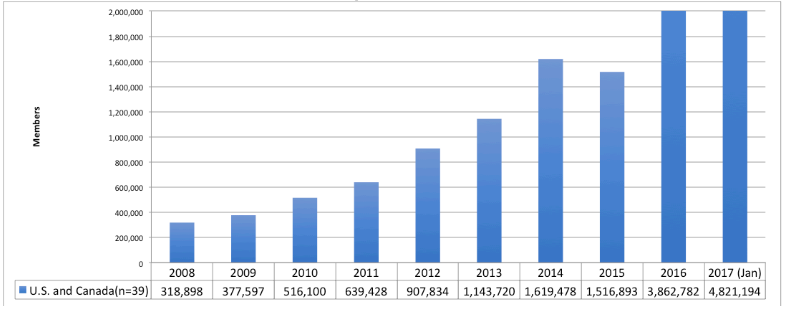
[6] We discuss market growth and impacts of Transportation Network Companies (TNCs) in another section.

- However, carsharing is expected to grow in market share. Existing carsharing members state that they expect to use their memberships more frequently in the next two years.
- Shared, automated fleets may be operated by private or public entities. AVs may also exist in a P2P marketplace.
- A key recent roundtrip carsharing study found that, on average, members reduced VMT by 27 percent. Roundtrip carsharing members increased their use of public transit, carpooling, and non-motorized modes, including biking and walking. However, in some cases, carsharing members decreased their use of public transit.
- In a study that analyzed the impacts of car2go, each car2go vehicle removed seven to ten privately owned vehicles from city streets, a result of vehicles sold and purchases avoided. The miles taken off the road from sold and foregone vehicle purchases accounts for any additional miles driven in a car2go vehicle.
- For the majority of one-way carsharing users in a car2go-focused study, public transit and active transportation use did not change. However, a greater proportion of users decreased their public transit use than increased.
- Although 27 percent of P2P carsharing members stated that they were driving more as a result of their membership, 46 percent of members did not have a vehicle beforehand. 20 percent of members were driving less.
- More research is needed on carsharing impacts to reflect a broader range of land use and built environments, for instance.

Current State of the Market

Histograms of total membership reflect steady rapid growth up to 2015, as shown in Figure 8.1. The U.S. carsharing market currently amounts to $23 billion (Grosse-Ophoff et al., 2017). As of 2016, there were two million carsharing members in North America (Jerram, 2017). Not all members who have memberships use them, however. For instance, over 55 percent of P2P surveyed carsharing members used their carsharing membership at least once (Shaheen et al., 2017).

FIGURE 8.1: Total Active Carsharing Membership Growth in U.S. and Canada



Source: TSRC, 2017

Carsharing services can be either one-way or roundtrip; descriptions for these models are shown in Table 8.1 below. Figure A2 in the Appendix presents the number carsharing memberships by type, signaling significant growth of the P2P market from 2016 to 2017.

TABLE 8.1: Carsharing Business Models

Roundtrip, Station-Based	Vehicles must be returned and parked in the same space as they were retrieved from
One-Way, Free-Floating or Station-Based	Vehicles can be dropped off: • Anywhere within a specified geographic zone (free-floating) or • At a station that differs from the retrieval station.

One projection estimates that personal vehicle sales will slow due to shared mobility, reducing private auto sale growth by one-third from previously expected projections (Grosse-Ophoff et al., 2017). Many automakers have entered the carsharing market to ensure a role in mobility management and auto sales, including Daimler, GM, and BMW through their services car2go, Maven, and ReachNow, respectively. Daimler and BMW's one-way carsharing services have millions of members globally (Jerram, 2017). Turo, a P2P service, has tripled its revenue year over year (Marshall, 2016).

The broader public may first be introduced to AVs through a shared-fleet service model instead of through privately-owned AVs (The Economist, 2016). In October 2017, Waymo, Google's AV subsidiary, tested a shuttle service using fleet SAVs in Phoenix, Arizona. They are prepared to launch the service to riders for free (Gibbs, 2017). Shortly after, the French company Navya announced an electric, automated shuttle vehicle geared primarily for fleet deployment (Williams, 2017).

Impacts to Date

In this section, we cover impacts to date according to studies on Roundtrip Carsharing, One-Way Carsharing, Peer-to-Peer Carsharing, Casual Carpooling, and Shared Automated Vehicles (SAVs).

Roundtrip Carsharing

Table A4 in the Appendix summarizes results of carsharing impact studies, to date, in North America. The variations in total vehicle miles traveled (VMT)/vehicle kilometers traveled (VKT) reductions are likely due to methodological differences. The most comprehensive of these studies found that, on average, roundtrip carsharing members reduced their VMT by 27 percent (Martin and Shaheen, 2011).[7] About the same amount of roundtrip carsharing members increased their use of public transit as decreased it, suggesting that carsharing does not substitute for public transit for a majority of users. Carsharing members also exhibited a statistically significant increase in the amount of biking, walking, and carpooling (Martin and Shaheen, 2011).

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[7] VMT reduction calculations include vehicles sold and postponed vehicle purchases.

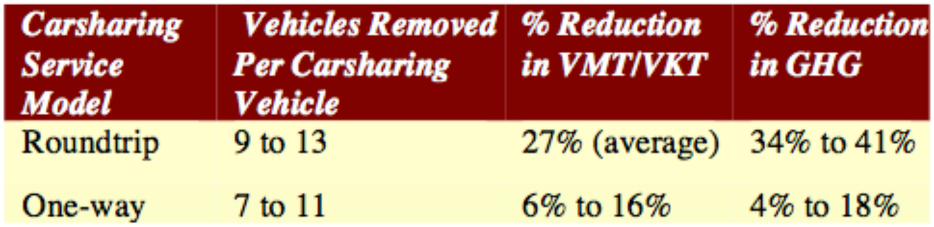
Vehicles used for roundtrip carsharing services are in use 12 to 15 percent of the time, significantly exceeding the four percent usage rate of privately owned vehicles (Thomas, 2017). On college/university campuses, 43 percent of Zipcar college members sold a vehicle, and 40 percent stated that they were less likely to buy a car as a result of their membership (Stocker et al., 2016).

One-Way Carsharing

Current analysis of one-way carsharing impacts is limited. Vehicles in one-way carsharing are in use 15 to 18 percent of the time (Thomas, 2017). One five-city study in North America quantified the impacts of car2go's one-way service. This study found that members reduced their VMT six to 16 percent per year, depending on the city (Martin and Shaheen, 2016). Focusing on San Diego, because it is the only California location in the study, car2go reduced VMT by up to 20 million miles in that location. Eleven percent of San Diego users increased their rail use, and 20 percent decreased. Active transportation modes seemed to complement this service, and 34 percent of users reported walking more due to carsharing. For the majority of users, public transit and active transportation use did not change.

We summarize the impacts of roundtrip and one-way carsharing from two key studies in North America in Table 8.2 below.

TABLE 8.2: Impacts of roundtrip and one-way carsharing



Carsharing Service Model	Vehicles Removed Per Carsharing Vehicle	% Reduction in VMT/VKT	% Reduction in GHG
Roundtrip	9 to 13	27% (average)	34% to 41%
One-way	7 to 11	6% to 16%	4% to 18%

Source: Lazarus et al., 2017

Peer-to-Peer Carsharing

As shown in Figure A3, the number of vehicles that are part of P2P network has grown over the past two years. A survey of 1,151 members of three U.S. P2P carsharing organizations showed mixed impacts on public transit use. Users reported a net decline in ridesourcing/TNC use and a net increase in the number of shared rides (i.e., making fewer trips alone). Although 27 percent of members stated that they were driving more since joining, 46 percent did not have a vehicle beforehand. Twenty percent of members stated that they were driving less. Thirty-two percent also noted that if their P2P carsharing service disappeared, they would likely need to acquire a vehicle (Shaheen et al., 2017).

Casual Carpooling

Casual carpooling, which is entirely and informally user-organized, has existed for over 30 years. As of 2014, 75 percent of San Francisco Bay Area casual carpool users were previously public transit riders, and 10 percent drove alone (Shaheen et al., 2016).

Shared Automated Vehicles (SAVs)

Pilots of SAV services have been small-scale, recent, and limited to specific geographic areas, inhibiting studies on their impacts (Stocker and Shaheen, 2017). However, various reports and reviews have described potential future scenarios that include SAV impacts. We present future scenarios and projections in the section below.

Future Projections

Services in existence today are expected to grow in market share. Responses to McKinsey's 2017 consumer survey showed that the majority of existing carsharing members expect to increase their usage rates in the next two years (Grosse-Ophoff et al., 2017). In this study, 67 percent of respondents predicted that they will increase their use of carsharing memberships over the next two years. This reflects a slightly greater proportion than the 63 percent of surveyed ridesourcing/TNC members who predicted an increase in their use of ridesourcing/TNC services.

Innovative business models are also expanding carsharing services. In October 2017, Zipcar announced a subscription model geared toward weekday commuters. In exchange for a monthly fee, subscribers will receive unlimited access to Zipcar vehicles Monday through Friday (Hawkins, 2017). Insurance companies are also bridging previous divides in the industry. In April 2017, AAA launched GIG Car Share, a one-way carsharing system, in the Bay Area (A3 Mobility LLC, 2017). Models like these prioritize flexibility and user need, suggesting that services will differ across geographic regions (Shaheen et al., 2015; Jerram, 2017). In preparing carsharing growth projections, emerging and future business models should be analyzed in addition to those in existence today.

Automation technology is also predicted to impact the shared vehicle market through SAV services. The Department of Energy released its 2017 mobility scenarios report, describing a shared automated future where automation and shared mobility trends converge (U.S. Department of Energy, 2017). Tesla also envisions a P2P marketplace where a privately owned AV could provide rides for a fee when not in use by the owner (Musk, 2016). Public sector entities may also own and operate SAVs in the future (Stocker and Shaheen, 2016). In Table 8.3, we summarize the latest projections of SAV market penetration, which differ by source, due to variable assumptions.

TABLE 8.3: Variable Shared Vehicle Adoption Dates

Description	Projected Date	Source
Near-end of private car ownership in major U.S. cities	2025	Zimmer, 2016
25 percent of miles driven in U.S. could be in shared, automated EVs	2030	Boston Consulting Group, 2017
Majority of shared cars on the road will have utilization rates of 50 percent	2030	Fujitsu America, Inc., 2017
1 out of 10 vehicles sold is shared	2030	McKinsey&Company, 2016
95 percent of VMT will occur in shared EVs	2030	Airbib and Sebab, 2017
SAVs reach 35 percent market penetration	2040	Cambridge Systematics, Inc., 2016

Bikesharing

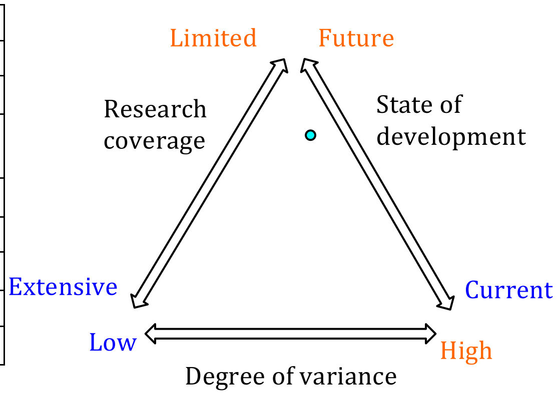
Since the launch of the first public bikesharing system in the US in 2010, bikesharing ridership and program development have grown steadily (NACTO, 2016). At present, 171 bikesharing programs are operating in North America (Meddin, 2017). Sixty cities are running public bikesharing programs. With this growth in ridership, bikesharing is becoming integral to transportation ecosystems across California.

This section explains the recent growth of the bikesharing market, introduces bikesharing business models in existence today, presents bikesharing systems functioning across California, and discusses measured impacts, to date. Due to the recent development of the service, projections of market growth are limited. Generalizable studies on bikesharing system impacts are not widely available in the literature.

Use this section to:

1. **Assess the current national bikesharing market,** including recent growth and business models to date; and
2. **Review station-based bikesharing's documented impact,** to date.

Topic: Bikesharing	
State of Knowledge	
Research Coverage	Limited –Existing
State of Development	Emerging
Degree of Variance	Medium–High
Metrics in this Section	
Direct model inputs	No
Projections	Yes
Impacts to date	Yes



Key Findings:

- Current bikesharing market metrics and immediate projections are summarized in the table below:

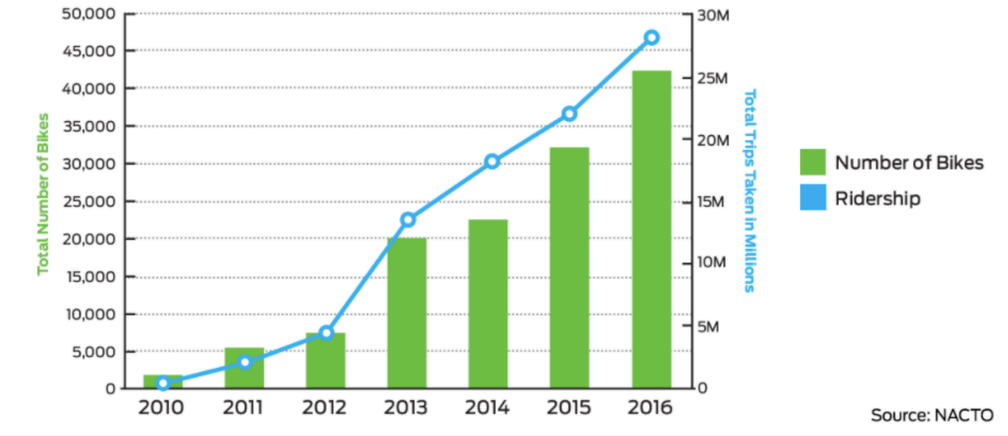
Date	Metric	Count
2016	Number of rides taken with bikesharing service across the U.S.	28 million
2017	Number of bikesharing services across California	15
2017	Number of bikesharing services with explicit equity programs	3
2020	Projected size of U.S. bikesharing market	$6.3 billion

- Benefits of bikesharing systems include: increased mobility, increased flexibility, cost savings from modal shifts, low implementation and operational costs, reduced traffic congestion, reduced fuel use, increased use of public transit and alternative modes, increased health benefits, greater environmental awareness, and economic development.
- Bikesharing can be integrated into existing transportation systems to encourage multimodal mobility. For example, stations can be located in public transit hubs and payment systems can be integrated.
- Bikesharing may replace rail trips and personal vehicle trips, or may complement public transit, depending on urban density and bicycle-friendly infrastructure.

Current State of the Market

In the bikesharing market, ridership and bicycle supply have grown since its inception in 2010, as shown in Figure 9.1 below. Projections from 2015 predict that the bikesharing market could be a US$6.3 billion by 2020.

FIGURE 9.1: Bikesharing Growth in the U.S.



Source: NACTO, 2016

Although none of the largest nationwide bikesharing systems are in California, companies are increasingly competing for business in the Silicon Valley, and programs are in use or pilot phases in California's northern and southern urban areas (Malouff, 2017; Meddin, 2017; Kendall, 2017).

Bikesharing business models existing at present are shown in Figure A3 in the Appendix (Shaheen and Cohen, 2016). In Northern California, there are currently 8,175 shared bikes in operation. There are about 4,705 shared bikes in Southern California. These numbers include station-based and dockless systems, and bikesharing services operating on college campuses, though the majority of services are station-based. This may be due to city regulations and permitting processes, which could be more restrictive of free-floating systems. See Table A4 in the Appendix for a list of all current bikesharing programs in California by location and each service's infrastructure distribution.

The largest dockless bikesharing systems are in China. At present, many of the companies are experiencing issues with bikes being abandoned (Fortune, 2017). However, an increasing number of pilot programs are exploring dockless system feasibility, especially in the Silicon Valley (Kendall, 2017).

Electric bicycle sales are also on the rise, with 190,000 electric bicycles sold in 2014 (Statista, 2017). In France, Velib upgraded its citywide fleet to include electric bicycles (e-bikes), and Social Bicycle's JUMP launched pilot projects with cities across California this year (RFI, 2017; Meddin, 2017). JUMP recently received a permit to operate a fleet of dockless e-bikes in San Francisco (Dickey, 2018). Integrating electric bicycles with traditional bicycles may pose on-road planning challenges, since e-bikes can travel at much faster speeds, despite potentially needing to share bike lanes.

Impacts to Date

Benefits of bikesharing systems include: increased mobility, increased flexibility, cost savings from modal shifts, low implementation and operational costs, reduced traffic congestion, reduced fuel use, increased use of public transit and alternative modes, increased health benefits, greater environmental awareness, and economic development (Shaheen et al., 2010; Shaheen and Cohen, 2016).

Studies have found that the availability of bikesharing increases its use. Notably, if there are more bikes available in an urban area, and more distinct *services* available, ridership increases until the market becomes saturated (Shaheen and Cohen, 2016; Zhang et al., 2016).

Impacts on Public Transit Use

Similar to public transit systems, bikesharing systems require a relatively dense population to function well (Faghih-Imani et al., 2014; Tsay et al. 2016). Across a variety of studies, researchers find that bikesharing infrastructure visibility and availability contribute significantly to roundtrip bikesharing system use (Faghih-Imani et al., 2014). If docking stations are located near restaurants, public transit hubs, and parks, their usage frequency increases (Wang et al., 2015). UC Berkeley researchers found that in dense urban areas, bikesharing use is correlated with reduced rail use, as shown in Figure 9.2 below (Shaheen and Chan, 2015).

FIGURE 9.2: Bikesharing Impacts on Rail

Bikesharing members in larger cities rode the bus less, attributable to reduced cost and faster travel associated with bikesharing.

Across all cities surveyed, increased bus use was attributed to bikesharing improving access to/from a bus line.

Rail usage increased in small cities (Minneapolis-St. Paul) and decreased in larger cities (Mexico City, Montreal, and Washington, DC) - all larger regions with denser rail networks. Shifts away from public transit in urban areas are often attributed to faster travel times and cost savings from bikesharing use.

5.5% sold or postponed a vehicle purchase

58% Increased cycling

50% of bikesharing members reduced personal auto usage

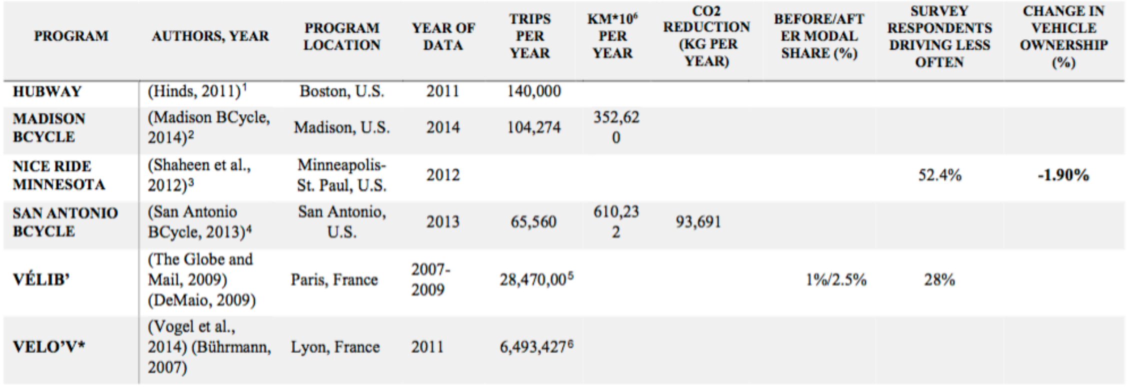
Source: Shaheen and Chan, 2015

Buck et al. (2012) found that for short-term users (i.e., non-members), 35 percent of bikesharing trips substituted public transit trips, and 53 percent substituted walking trips. For annual members, 45 percent substituted public transit trips, and 31 percent substituted walking trips (Buck et al., 2012). In contrast, in smaller cities, bikesharing increases public transit use likely due to a less robust public transit network.

Impacts on Car Use

Shaheen and Chan (2015) also found that bikesharing did not increase the amount that users drive, and reduced the amount that 15 to 50 percent drive, depending on location. Bicycles may be viewed as viable substitutes for cars, in dense areas especially, because of their speed and ability to use road infrastructure (Zhang et al., 2016). Table 9.1 below summarizes results of other bikesharing impact studies.

TABLE 9.1: Bikesharing Impacts on CO_2 Reduction and Driving



PROGRAM	AUTHORS, YEAR	PROGRAM LOCATION	YEAR OF DATA	TRIPS PER YEAR	KM*10^6 PER YEAR	CO2 REDUCTION (KG PER YEAR)	BEFORE/AFTER MODAL SHARE (%)	SURVEY RESPONDENTS DRIVING LESS OFTEN	CHANGE IN VEHICLE OWNERSHIP (%)
HUBWAY	(Hinds, 2011)[1]	Boston, U.S.	2011	140,000					
MADISON BCYCLE	(Madison BCycle, 2014)[2]	Madison, U.S.	2014	104,274	352,620				
NICE RIDE MINNESOTA	(Shaheen et al., 2012)[3]	Minneapolis-St. Paul, U.S.	2012					52.4%	**-1.90%**
SAN ANTONIO BCYCLE	(San Antonio BCycle, 2013)[4]	San Antonio, U.S.	2013	65,560	610,232	93,691			
VÉLIB'	(The Globe and Mail, 2009) (DeMaio, 2009)	Paris, France	2007-2009	28,470,00[5]			1%/2.5%	28%	
VELO'V*	(Vogel et al., 2014) (Bührmann, 2007)	Lyon, France	2011	6,493,427[6]					

Source: Shaheen and Cohen, 2016

Ridesourcing/Transportation Network Companies (TNCs)

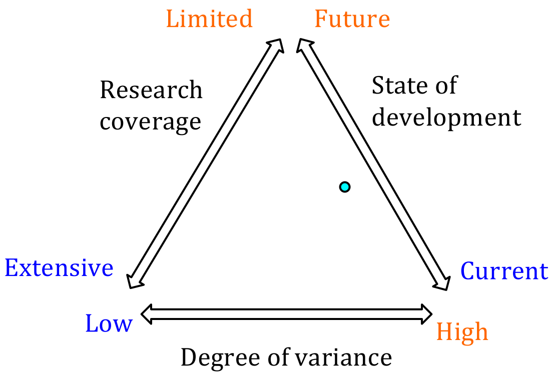
Ridesourcing services (also known as transportation network companies or TNCs) are services that offer on-demand rides by connecting drivers using their personal vehicles with passengers hailing a ride, typically via smartphone. Ridesourcing/TNC services have grown rapidly since the launch of Uber (black cars only) in 2010 and the subsequent launch of Sidecar (June 2012), Lyft (June 2012), and UberX (July 2012) in San Francisco, California with a peer-to-peer service.

In this section, we summarize the current market size of the ridesourcing industry and present findings from various studies on the travel behavior change, vehicle miles traveled (VMT) impacts, and the trip-making characteristics of ridesourcing.

Use this section to:

1. **Understand the current measured impacts** of ridesourcing/TNC services on travel behavior and VMT in select cities that have existing studies,
2. **Review various methodologies** of major studies that assess ridesourcing/TNC impacts at present and refer to sources for more in-depth information, and
3. **Quantify the current market size** of ridesourcing/TNC services in California and around the world.

Topic: Ridesourcing/TNCs	
State of Knowledge	
Research Coverage	Existing
State of Development	Current
Degree of Variance	Medium–High
Metrics in this Section	
Direct model inputs	No
Projections	Yes
Impacts to date	Yes



Key Findings:

- Ridesourcing services (peer-to-peer on-demand ride services) have grown rapidly around the world since their introduction in San Francisco in Summer 2012. In California, Uber operates in over 172 urban areas, and Lyft serves 92 cities.
- Based on findings across different studies, a notable portion of users making trips with ridesourcing would have otherwise driven in an area where driving is more prevalent (33 percent in Colorado) but taken a taxi or public transit where these modes are more common (36 percent and 30 percent, respectively, in San Francisco).
- In three out of four studies, more than a third of surveyed respondents would have taken public transit, biked, or walked in place of ridesourcing, had the services been unavailable.

- Per two recent studies, ridesourcing services make up a non-trivial portion of VMT in San Francisco and New York City, constituting about 20 percent of average weekday intra-San Francisco VMT and seven percent of total New York City VMT in 2016.
- The 2017 SFMTA study in San Francisco found that 20 percent of total ridesourcing VMT are out-of-service miles. However, this is lower than the more than 40 percent of taxi VMT that are out-of-service miles.

Ridesourcing/TNC Market Size

At present, Lyft operates in more than 300 cities in the U.S. and completes more than 18.7 million rides per month (Meyer, 2017; Bensigner, 2017). Uber is active in over 700 cities across more than 80 countries around the world (Zook, 2017). Other ridesourcing companies around the world have a significant market presence, as well. Didi operates in over 400 cities in China with over 400 million users (it.people, 2017). Grab serves over 30 cities in six counties in Southeast Asia and has over 1 million users (Grab, 2017), and Ola has over 600,000 vehicles across 110 cities, mainly in India (BusinessWire, 2017).

Ridesourcing services have grown rapidly in California (their birthplace state), as well. In May 2013, Uber served 17 urban areas, the majority of which were urban areas with populations of over 30,000. In May 2017, Uber grew to serve 172 areas, 102 of which had populations under 30,000 (Wang, 2017). As of November 2017, Lyft served 92 cities in California (Lyft, 2017). Although ridesourcing is most heavily used in large metropolitan areas, they are gaining in popularity in smaller cities and less dense suburban or rural areas throughout the state.

Both Lyft Line and UberPOOL launched in August 2014. As of December 2017, 905 million UberPOOL and Lyft Line trips (combined) had been taken since the services launched (Paige Tsai and Peter Gigante, personal communication). In December 2017, UberPOOL was available in 36 cities globally. This includes over 14 US cities, Toronto (Canada), Latin America (seven cities), and Europe (London and Paris). Twenty percent of Uber trips are pooled in those cities (Paige Tsai, personal communication). As of December 2017, Lyft Line was available in 16 U.S. markets, and it accounts for 40 percent of Lyft rides in those locations (Peter Gigante, personal communication; Shaheen and Cohen, 2018, Forthcoming).

Impacts Understanding

Some studies have documented the travel behavior and VMT impacts due to ridesourcing services, although research on this topic is preliminary in nature due to a lack of reliable operator data and other information. This section covers ridesourcing studies and their findings related to impacts on modal shift, VMT, trip-making characteristics, and auto ownership.

Modal Shift Impacts

Users of ridesourcing services are either replacing a trip previously made with another form of transportation with ridesourcing or they are making an entirely new trip they otherwise would not have, if these services were not available (i.e., induced demand). Across multiple studies in different cities, researchers find that modal shift impacts due to ridesourcing are city- or region-dependent. Further, their impacts may be changing over time. While some studies conclude that ridesourcing is largely not substituting for public transit trips, several other studies (described below) suggest that ridesourcing can compete with public transit and active modes (cycling and walking).

Table 13.1 shows survey results regarding mode replacement of ridesourcing trips. The studies in the first four columns show what transportation mode respondents would have used had ridesourcing not been available. Note that the studies by Clewlow and Mishra (2017) and Feigon and Murphy (2016) both use different methodologies than the Rayle et al. (2016) and Henao (2016) studies. Clewlow and Mishra (2017) ask which transportation modes respondents would have used in general for the trips that they make using ridesourcing services, while the Rayle et al. (2016) and Henao (2016) studies ask what mode respondents would have used in place of their most recent ridesourcing trip. The former approach does not allow for a representative snapshot of ridesourcing mode replacement, since it relies on a generalization from the survey respondent as opposed to a recollection of a discrete and recent trip event. The surprisingly low taxi mode replacement share in the Clewlow and Mishra (2017) study (one percent) compared with the other two studies points to these differences in survey question design and weighting methodologies. In addition, the results in this study were aggregated across seven U.S. cities, which may blur notable impact differences between cities. The Feigon and Murphy (2016) study aggregates results across the same seven cities and includes only those respondents who use ridesourcing the most often compared to other shared modes (bus, train, carsharing, and bikesharing). This methodology represents only a specific subset of very frequent ridesourcing users and therefore is not a balanced reflection of modal replacement among all ridesourcing users. The Hampshire et al. (2017) study is unique from the others in that it assesses behavioral change due to the service suspension of Uber and Lyft in Austin, Texas in mid-2016. Their survey used Uber and Lyft historical trip data to allow respondents to select their last Uber or Lyft trip taken in the Austin area and asked how they now make this “pre-suspension” reference trip. These various methodological differences should be noted when comparing results in Table 10.1.

TABLE 10.1: Ridesourcing Modal Shift Impacts

Study Authors **Location** **Survey Year** **Mode**	Rayle et al.* San Francisco, CA 2014	Henao* Denver and Boulder, CO 2016	Clewlow and Mishra** Seven U.S. Cities***** Two Phases (2014 – 2016)	Feigon and Murphy*** Seven U.S. Cities***** 2016	Hampshire et al.**** Austin, TX 2016
Drive (%)	7	33	39	34	45
Public Transit (%)	30	22	15	14	3
Taxi (%)	36	10	1	8	2
Bike or Walk (%)	9	12	23	17	2
Would not have made trip (%)	8	12	22	1	-
Carsharing / Car Rental (%)	-	4	-	24	4
Other / Other ridesourcing (%)	10	7	-	-	42 (another TNC) 2 (other)

*Survey question: "How would you have made ***your last trip,*** if ridesourcing services were not available?"

Survey question: "If ridesourcing services were unavailable, ***which transportation alternatives would you use for the trips* that you make using ridesourcing services?"

Survey crosstab and question: For respondents that use ridesourcing most often compared to other shared modes: "How would you make ***your most frequent (ridesourcing) trip if ridesourcing was not available?"

****Survey question: "How do you currently make the last trip you took with Uber or Lyft, now that these companies no longer operate in Austin?"

*****The impacts in both of these studies were aggregated across: Austin, Boston, Chicago, Los Angeles, San Francisco, Seattle and Washington, DC.

The study by Rayle et al. (2016) shows that if ridesourcing were unavailable, 36 percent of respondents in 2014 would have taken a taxi. In contrast, Henao (2016) found only 10 percent would have used a taxi in Denver and Boulder, CO. In addition, the portion of users who would have driven a vehicle, if ridesourcing were not available is much higher in the Colorado, Austin, and two seven-city studies (33, 45, 39, and 34 percent, respectively) than in the San Francisco study (7 percent). Ridesourcing services are drawing a portion of users from public transit services as well (up to 30 percent, depending on the city and study), which is a topic of much interest to public agencies and policymakers. These findings suggest that ridesourcing could draw from driving in cities where driving is more prevalent but also from other modes like taxis and public transit in cities where these forms of transportation are more common. The study in Austin has a high proportion (42 percent) of users who claim they now make their last Uber or Lyft trip with another ridesourcing service. This study differs from the others in that it focused specifically on the departure of Uber and Lyft, rather than on the departure of ridesourcing more broadly from the city of Austin. It is important to note that these impact differences could change over time as ridesourcing gains a larger and more diverse set of users.

Rayle et al. (2016) also found that half of the ridesourcing trips had more than one passenger (i.e., not including the driver) with an average occupancy of 2.1 passengers. A key limitation of this study, however, is that responses were based only on user surveys in the San Francisco Bay Area and did not include an analysis of actual travel behavior. It is important to note that this and the other studies did not include ridesplitting services, such as Lyft Line and UberPOOL, which blends for-hire ridesourcing services with pooling by pairing individuals with similar origins and destinations to offer ridesourcing-type services with the increased occupancy of pooled rides.

VMT Impacts and Trip Characteristics

At present, only a couple of studies assess the VMT and trip-making impacts of ridesourcing services. The most comprehensive of which are studies in New York City (Schaller, 2017) and San Francisco (SFCTA, 2017). Table 10.2 below summarizes some of the key findings and metrics from these studies.

TABLE 10.2: Ridesourcing Key Trip and VMT Metrics

City *Study Author* Data Time Period	**Key Trip Metrics**	**Key Mileage Metrics**	**Average Trip Lengths**
San Francisco, CA *SFCTA* 1 month, late-2016	*Ridesourcing trips comprise…* • **15% of vehicle trips** (intra-SF, avg. weekday) • **9% of person trips** (intra-SF, avg. weekday)	*Ridesourcing mileage comprises...* • **20% of intra-SF VMT** (avg. weekday) • **6.5% of total VMT** (avg. weekday) • **10% of total VMT** (avg. Saturday)	*Intra-SF ridesourcing trips are on average...* • **3.3 miles/trip** (avg. weekday) • **3.2 miles/trip** (avg. Saturday) • **3.7 miles/trip** (avg. Sunday)
New York City, NY *Schaller Consulting* Full year, 2016	*Ridesourcing trips comprise…* • **80 million vehicle-trips** (in 2016) • **133 million person-trips** (in 2016)	*Ridesourcing mileage comprises…* • **7% of total VMT** (in 2016) *TNC mileage equates to an <u>estimated increase of…</u>* • **3.5% citywide VMT** (in 2016) • **7% VMT in Manhattan, western Queens, and western Brooklyn** (in 2016)	*Ridesourcing trips are on average…* • **5.4 miles/trip**

Both studies use slightly different methodologies and datasets, but each illustrates ridesourcing trip totals and share of VMT in their respective cities. SFCTA (2017) does not attempt to predict change in VMT due to ridesourcing services, but Schaller (2017) offers a preliminary calculation. Schaller's study found that ridesourcing services contributed to a 3.5 percent increase in citywide VMT and a seven percent increase in VMT in Manhattan, western Queens, and western Brooklyn in 2016. This calculation is preliminary, however, and uses various sources as proxies to estimate modal shift from other transportation modes like public transit and driving.

Both studies in San Francisco and New York City include in-service and out-of-service miles in their VMT measurement. Deadheading (or out-of-service) miles are an important metric of these services and represent miles driven by ridesourcing drivers, while waiting for a passenger request and driving to the passenger pickup point. Neither the New York or San Francisco studies account for vehicle occupancy levels (e.g., due to UberPOOL, Lyft Line). Henao (2017) estimates in his study that 1.6 miles were expended for every passenger-mile traveled. This equates to 100 miles to complete 60.8 passenger-miles. This study is based on data collected by one driver, which impacts its generalizability and may reflect survey response bias due to passenger-driver interactions. The SFCTA (2017) finds that approximately 20 percent of total ridesourcing VMT are out-of-service miles. This is lower than the more than 40 percent of taxi VMT that are deadheading miles. The SFCTA study is restricted to the city of San Francisco and does not reflect regional travel patterns, as noted in the study limitations. The greater efficiency of ridesourcing to taxis in this case is likely due both a higher number of ridesourcing vehicles and more efficient hailing technology.

Given the current understanding that exists in the literature, it is difficult to estimate the exact VMT percentage change due to the entry of ridesourcing services in cities. The lack of data shared by ridesourcing companies, paired with under-researched and potentially changing modal shift implications makes VMT change hard to measure, at present. It is important to note that ridesourcing services have only existed since Summer 2012. Nevertheless, these services have gained a notable share of total miles in New York and San Francisco in a relatively short time period. These studies suggest that there may be an increase in VMT in these cities due to ridesourcing services, although the exact magnitude is still unknown.

Auto Ownership Impacts

More research is needed to document the vehicle ownership impacts of ridesourcing services. These impacts include the proportion of users that sell or forego purchasing a personally owned vehicle due to their use of ridesourcing. The Clewlow and Mishra (2017) study notes that nine percent of respondents disposed of one or more household vehicles due to ridesourcing, but this study does not measure vehicles that would have been purchased, if ridesourcing services did not exist (i.e., suppressed vehicles). The Hampshire et al. (2017) study of Uber and Lyft's service suspension in Austin queried respondents about the impact the suspension had on personal vehicle acquisitions. Their survey found that while 83 percent of respondents did not consider acquiring a vehicle as a result of the service suspension, the remainder of respondents at least considered acquiring a personal vehicle. Nine percent of respondents did acquire a personal vehicle due to the suspension of Uber and Lyft in Austin. The service suspension in Austin is unique in that it offers an opportunity to measure vehicle suppression with revealed preference data. However, the study does not assess vehicles sold due to the presence of ridesourcing services prior to the suspension. In addition, ridesourcing services other than Uber and Lyft continued to operate in Austin after the service suspension (e.g., Ride Austin, Fasten, Fare, and others), so a larger proportion of respondents might have reported vehicle suppression effects, had all ridesourcing services been suspended in the Austin area.

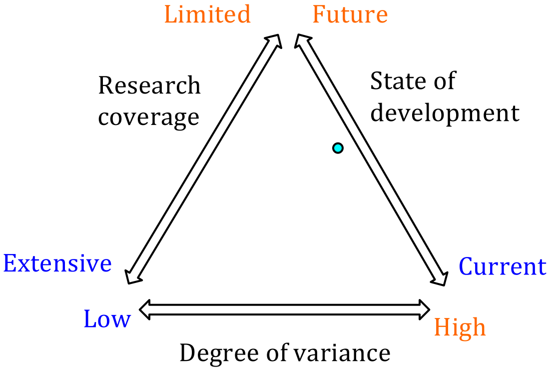
Equity Considerations:
Carsharing, Bikesharing, and Ridesourcing/TNCs

Transportation agencies across the country are experimenting with initiatives to broaden access to shared modes, especially for disadvantaged populations. However, limited research exists on how successful these pilots are at increasing access for a sustained time period. Anderson et al. (2017) define transportation equity as the ability of people to reach destinations efficiently in terms of their travel time and out-of-pocket costs, regardless of geographic location, socioeconomic status, and race. In this section, we cover transportation equity issues in shared mobility. We also explain how the future technologies and trends as covered in this paper can be analyzed with an equity framework as they emerge.

Use this section to:

1. **Review shared mobility equity pilot examples**,
2. **Examine findings of two** recent shared mobility equity studies, and
3. **Explore tools** for equity analysis moving forward.

Topic: Equity Considerations for Shared Mobility	
State of Knowledge	
Research Coverage	Limited
State of Development	Emerging
Degree of Variance	High
Metrics in this Section	
Direct model inputs	No
Projections	No
Impacts to date	Yes



Key Findings:

- Despite the launch of pilots aimed toward broadening access to shared systems, actual usage of bikesharing, carsharing, and ridesourcing/TNC systems by low-income individuals has been minimal. There are, at present, limited studies examining potentially discriminatory effects of ridesourcing/TNC services.
- Equity and resiliency are difficult to measure, but their measurement is key to understanding change and articulating improvement over time. Frameworks and tools can suggest methodology to isolate factors to measure.
- Frameworks from Shaheen et al. (2017) and Anderson et al. (2017) are two examples of methodologies that can be used in assessing barriers to transportation access and siting mobility hubs, respectively. Mobility hubs are defined as a space where infrastructure for innovative modes are integrated with existing public transit routes.

Shared Mobility Equity Pilots

Shared modes have the potential to increase equitable access to transportation, particularly due to their reduced cost, flexibility, and potential to reach underserved areas. An October 2017 pilot in Pittsburgh, Pennsylvania is offering bikesharing services to public transit pass holders for free. The transit pass is a refillable, $1 card that can be purchased with cash, eliminating the need for a debit card or bank account to use the system (Peters, 2017). In Los Angeles, the city used funds from the California Air Resources Board to provide 100 electric vehicles (EVs) to low-income communities, and Sacramento made shared EVs available at three public housing complexes (Shaheen et al., 2017). One expert also expert labeled the relationship between affordable housing and transportation as an important equity factor.

Despite the launch of pilots aimed toward broadening access to shared systems, actual usage of bikesharing, carsharing, and ridesourcing/TNC systems by low-income individuals has been minimal (Bergman, 2013; DDOT, 2007; Golub, 2007). Although about 24 percent of US bikesharing systems offer income-based subsidies for memberships, 73 percent of bikesharing services do not explicitly address equity through income-based subsidies (NACTO, 2016). High upfront, annual membership costs can dissuade low-income individuals from joining shared systems. Subsidized carsharing membership fees may also expire after as little as one year.

Inequities in Ridesourcing/TNC Services

There are limited studies examining potentially discriminatory effects of ridesourcing/TNC services. However, one recent study analyzed ridesourcing/TNC wait time disparities by sending passengers on controlled routes. The authors discovered a pattern of discrimination, correlating up to 35 percent longer wait times for African Americans, and drivers cancelled more frequently when those requesting rides had African American-sounding names (Ge et al., 2016). A different study assessed the spatial variability of ridesourcing/TNC wait times, finding that the effects of population and employment density are associated with longer wait times after the morning and evening rush hour, respectively. The authors explain that this is likely due to declines in driver supply during peak commuting times. Such patterns could negatively affect those with off-peak employment hours more heavily. The authors also conducted a spatial analysis; however, this did not indicate an association between areas with higher a percentage of minorities and longer wait times (Hughes and MacKenzie, 2016).

Tools for Health and Equity Analysis

Prioritizing equity may require extra attention as technologies rapidly come to market. Analyzing transportation networks with a systems lens is generally the responsibility of the public sector (Walker, 2017). The public sector has an opportunity to leverage public rights-of-way, regulating the private sector so rides for low-income individuals become subsidized through permit fees (Shaheen and Cohen, 2016; Tsay et al., 2016). For dense urban areas, requirements to locate bikesharing and carsharing in poorly served neighborhoods as a condition of approval could support equity efforts. However, this stipulation alone is not a guarantee that vehicles will be accessible to disadvantaged communities. Public transit agencies should also note that cutting late night public transit service disproportionately affects low-income neighborhoods (Shaheen et al., 2017). The San Francisco Bay Area Planning Urban Research (SPUR) Association recommends funding subsidies and other equity-promoting programs with mobility operator permit fees (Fleisher, 2017).

Shared modes have the potential to bridge equity gaps in the near-term, creating opportunities for action as policy is implemented in the long run (Shaheen et al., 2017). Shaheen et al. (2017) proposed a framework to assess spatial, temporal, economic, physiological, and social barriers to transportation access. Anderson et al. (2017) also present a methodology to frame transportation equity when siting mobility hubs, which are defined as spaces where infrastructure for innovative modes are integrated with existing public transit routes. These frameworks, summarized in Table A5 in the Appendix, are particularly relevant and useful when incorporating shared modes into transportation systems. Table A6 in the Appendix lists resources to assist with health impact assessments. Qualitative aspects, such as equity and resiliency, are particularly difficult to measure, but their measurement is key to understanding change and, ideally, improvement over time. Frameworks and tools can provide a guide for partitioning factors, making the elements of socioeconomic qualifiers easier to quantify.

Alternative Transit Services

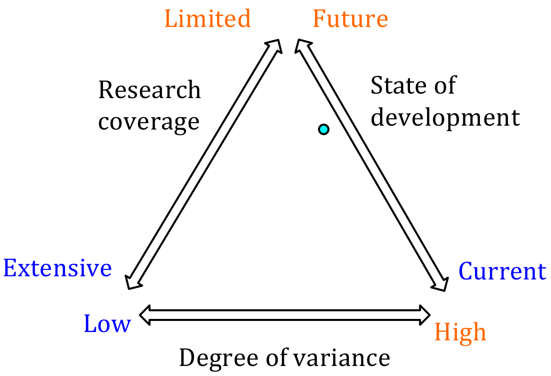
While public transit routes remain fixed, other innovative services are implementing technology to increase the flexibility of their operations. Alternative transit services, which include paratransit, employer shuttles, and microtransit, have the potential to supplement/compete with existing bus and rail routes (Shaheen and Cohen, 2016). These services can incorporate flexible routing, flexible scheduling, or both (Shaheen et al., 2015).

Research on alternative transit services is limited, at present. This is, at least in part, due to the more recent launch of services. For instance, Chariot, an app-based commuter shuttle service, launched in San Francisco in 2014 (Tchir, 2017). Although city transit authorities have experimented with partnerships with private microtransit providers, some pilots have failed due to lack of ridership and funds. In this section, we provide an overview of alternative transit services and their impacts to date.

Use this section to:

1. **Review definitions of and opportunities for** microtransit and paratransit, and
2. **Learn of the state of the market** for alternative transit services.

Topic: Alternative Transport Services	
State of Knowledge	
Research Coverage	Limited
State of Development	Current
Degree of Variance	Medium
Metrics in this Section	
Direct model inputs	No
Projections	No
Impacts to date	Yes



Key Findings:

- Microtransit services can be fixed-route with fixed-schedule or flexible-route with on-demand scheduling.
- There is limited research on alternative transit services market growth and impacts, at present.
- Microtransit may increase or decrease public transit ridership. A few recent news articles have questioned microtransit's economic viability and ridership potential.
- Paratransit partnerships have decreased user wait times and increased paratransit service use in some recent pilot projects. These partnerships can also decrease public transport agency subsidy costs for paratransit rides.

State of the Microtransit Market

Two forms of microtransit have emerged, defined as:

1. Fixed-route with fixed-schedule services, and
2. Flexible-route with on-demand scheduling (Shaheen and Cohen, 2016).

Two notable microtransit services currently in operation are Chariot, owned by Ford Motor Company, and Via, which is based in New York City (Berrebi, 2017). We discuss their operational distinctions in Table 11.1 below.

TABLE 11.1: Operating Microtransit Services

Service Name	**Route Type**	**Service Description**	**Fare Range**
Chariot	Fixed route	15-seater vans operate on predetermined routes, but users can request additional stops	$3 to $6/ride Accepts pre-tax commuter benefits
Via	Flexible routes and scheduling	Users request rides in real time, and they are picked up by a Via van in minutes	$5 to $7/ride Accepts pre-tax commuter benefits

Sources: Shaheen et al., 2015; de Looper, 2015

Microtransit services may be able to add capacity and fill gaps in public transit networks. At present, many public transit authorities are experimenting with microtransit services through public-private partnerships (Shaheen and Cohen, 2016; Bliss, 2017). In October 2017, the Los Angeles Metropolitan Transit Authority released a request for proposals to the private sector to pilot an on-demand microtransit system (LA Metro, 2017). TransLoc, a technology firm with expertise in microtransit operations, plans to launch microtransit services in Orange County, Central Costa County, and the San Joaquin Valley through partnerships with local transit agencies in 2018 (Sisson, 2017). At present, it is unclear whether microtransit increases or decreases congestion, and riders may choose to use microtransit services instead of public transit (Berrebi, 2017).

A few microtransit initiatives have struggled in recent years due to budget constraints and insufficient ridership. Recent news articles question the economic viability and durability of the service (Tchir, 2017; Sisson, 2017; Bliss, 2017). Due to their high operating costs, microtransit services may require heavy ridership, significant subsidies and/or investments, or taxpayer support to survive financially (Bliss, 2017). A recent analysis of the RideKC: Bridj pilot found that only nine percent of riders took over ten trips during the pilot. Only six percent of survey respondents used RideKC: Bridj as their main commute mode (Shaheen et al., 2016). After six months, the RideKC: Bridj service had provided fewer than 600 rides, and the pilot was discontinued (Bliss, 2017).

State of the Paratransit Market

Ridesourcing/transportation network companies (TNCs) are increasingly becoming involved in paratransit operations. In 2016, Lyft partnered with CareMore, a California-based medical group focused on seniors, to provide non-emergency transportation to patients. Riders experienced 30 percent shorter wait times as a result of the partnership

(Grenoble, 2017). Lyft also partnered with Trapeze Group in October 2017 to lower paratransit costs[8] (Trapeze Group, 2017).

Uber and Lyft partnered with the Massachusetts Bay Transportation Authority (MBTA) in 2016. MBTA subsidized paratransit rides at $13 per ride, allowing paratransit users to pay $2 per ride (Urban, 2017). The partnership enabled MBTA to save $16 per paratransit ride, and users increased the number of their trips by 28 percent (Roman, 2017).

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[8] On average, paratransit services require about eight to ten percent of public transit agency operating budgets and provide about two to three percent of overall ridership, according to the Trapeze Group.

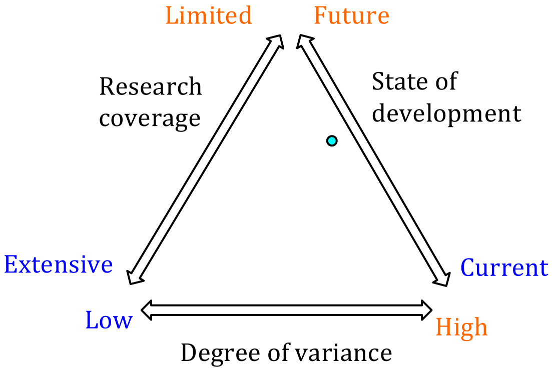
Shared Mobility Public-Private Partnerships (PPPs) and Data Sharing

Shared mobility public-private partnerships (PPPs) involve a public entity, such as a public transit agency or a city, and a private mobility provider entering into a partnership or agreement to operate a mobility service. They are becoming an increasingly popular option for public agencies to potentially lower costs, expand the reach of impacts, or improve the service quality of public transportation services. In this section, we discuss different types of shared mobility PPPs and emerging best practices around project implementation and data sharing.

Use this section to:

1. **Categorize different types of partnerships** that are emerging among shared mobility providers and public entities, and
2. **Determine emerging best practices** in the fields of shared mobility PPPs and data sharing.

Topic: Shared Mobility Public-Private Partnerships (PPPs) and Data	
State of Knowledge	
Research Coverage	Limited
State of Development	Emerging
Degree of Variance	Medium-High
Metrics in this Section	
Direct model inputs	No
Projections	Yes
Impacts to date	No



Key Findings:

- Shared mobility PPPs are becoming an increasingly popular option for public agencies to partner with private mobility providers and potentially lower costs or improve the service quality of public transportation services.
- PPPs could dramatically impact modal split, VMT, GHG emissions, and assumptions about the availability of public transport services throughout California, particularly in planning/modeling for CTP 2050.
- Best practices and types of shared mobility partnerships are constantly evolving, so it is important for public agencies to conduct sufficient background research and experiment with pilot projects that include performance-based evaluations (e.g., target metrics) and the flexibility to make changes, if needed.
- Data sharing between the public and private sectors is a critical part of PPPs and is useful in helping aid agencies in their planning processes (e.g., CTP 2050). Agencies can leverage public assets like parking spaces or street rights-of-way when negotiating for data access. Data sharing best practices include the use of APIs and data standardization.

Types of Shared Mobility PPPs

Four distinct types of shared mobility PPPs have emerged and can be classified as:

- First- and last-mile to public transit (i.e., complementing existing routes/lines);
- Existing public transit overlay (e.g., peak shaving of existing routes) or substitution (e.g., replacement of existing or discontinued services);
- Services for disadvantaged populations; and
- Other mobility services.

Some cities have entered first-mile/last-mile partnerships with ridesourcing/TNC companies to provide trips to and from public transit stations. One example of this is in Centennial, CO where the city partnered with Lyft to provide fully subsidized Lyft Line rides to the city's local light rail station. The pilot ran for six months, but it did not gain enough ridership to continue past the pilot phase (Centennial Innovation Team and Fehr & Peers, 2017). According to experts, the relationship between public transit and shared mobility services could be regulated, and transportation investments could be backed with data, through PPPs. Existing public transit overlay or substitution partnerships involve the full or partial outsourcing of public transportation services to a third party. These services are typically available for trips that originate and/or end in a given geographic area. An example of this type of partnership is in Innisfil, Canada, where the city decided to partially subsidize Uber rides for its residents instead of implementing a more costly bus service (Smith, 2017).

According to one expert, public agencies can have a tangible impact on equity by focusing on low-cost, low-risk options in partnerships. However, two experts expressed that because procurement rules move slowly, and policies are generally restrictive and inflexible, the government is not suited to accommodate rapid technological change. Cities have partnered with shared mobility companies to offer services for disadvanged populations that can target disabled, elderly, or lower income persons. This includes on-demand paratransit services in which a public agency outsources services to a shared mobility provider in an effort to reduce costs and improve service levels. The Massachusetts Bay Transportation Authority (MBTA) also partnered with Uber and Lyft to offer subsidized paratransit services starting in March 2017 (Mass.gov, 2017). Other mobility partnership opportunities exist, such as late-night services after public transit has stopped running or partnerships that accommodate increased travel demand during special events (e.g., a sporting event).

Shared Mobility PPP Best Practices

Although shared mobility PPPs are becoming more common, they are difficult to implement and often do not progress past pilot phase. Marketing and outreach are very important when launching these pilot programs and multiple studies of now-defunct shared mobility PPPs cite this as a major reason for low ridership (Shaheen et al., 2016;

Centennial Innovation Team and Fehr & Peers, 2017). Best practices for public entities when partnering with mobility providers include (TransitCenter, 2016):

- Reinforcing public transit's strengths,
- Leveraging agency-controlled assets,
- Planning for a streamlined user experience, and
- Being open to innovative ways of providing transportation.

Data Sharing

It is critical for local and regional governments to develop data standards and balance data sharing and privacy among individuals, companies, and public entities to improve system operations and aid in planning processes. When entering partnerships with mobility providers, it is important to also establish data metrics to be shared and best practices in transmitting these data. Shared mobility operators typically track many metrics of interest to public-sector entities, such as:

- The origin and destination of shared services,
- Travel time, and
- Trip duration.

Best practices in implementing data sharing include the use of application programming interfaces (APIs) and data standardization. APIs can allow for third-party app integration with other services, and data standardization is crucial in ensuring interoperability across an open data standard. Industry-wide data standards could aid in the development of consistent data formats, data sharing protocols, and privacy protections to ensure open data, interoperability, and comparability across platforms (Shaheen et al., 2016)

Information and Communications Technology

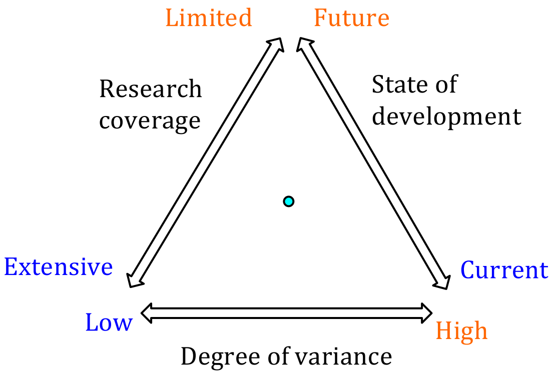
In this section, we provide a brief explanation of Information and Communications Technology (ICT), including current U.S. technology penetration levels and ICT's role in enabling shared mobility and automated vehicles.

ICT encompasses Internet-connected devices, such as computers and smartphones, and underlying communications infrastructure like cellular networks that allow for mobile communication and Internet access. ICT plays an instrumental role in allowing shared mobility services to operate and often helps facilitate vehicle or bicycle rental transactions. Experts believe that the proliferation of smartphones and access to mobile data have enabled many shared mobility services to gain the adoption levels of the present day (Mehndiratta, 2014). In interviews, one expert said that cities will rely on emerging technologies to optimize routes. Existing infrastructure could also be improved with ICT to prioritize biking and walking, as highways are replaced with high speed rail (HSR), according to two experts.

Use this section to:

1. **Review the timeline and projections** of ICT technology, including smartphone penetration and upcoming cellular network upgrades; and
2. **Examine the growing role of ICT in transportation systems** and review examples of these applications for transportation management and automated vehicles.

Topic: Information and Communications Technology	
State of Knowledge	
Research Coverage	Existing
State of Development	Emerging
Degree of Variance	Medium
Metrics in this Section	
Direct model inputs	No
Projections	Yes
Impacts to date	Yes



Key Findings:

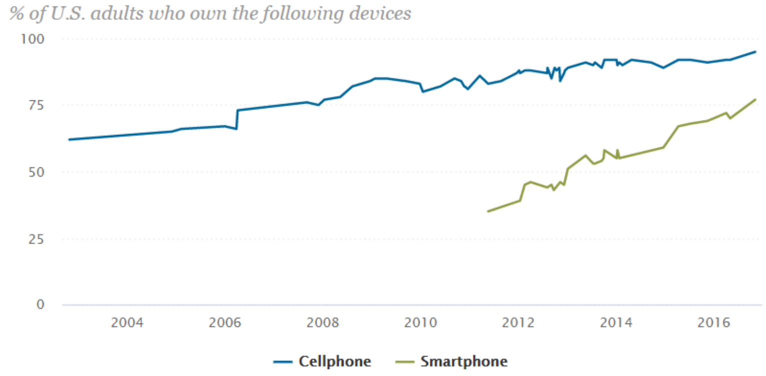
- The proliferation of smartphones and access to mobile data have been a major factor that allowed many shared mobility services to gain the adoption levels of the present day.
- As of late-2016, 95 percent of American adults own a cellphone and 77 percent own a smartphone.
- More than 98 percent of Americans have access to 4G LTE service, and 5G is expected to be available for large-scale deployment in 2019.

- Data generated from mobile phone and vehicle sensing technology is allowing both public and private transportation providers to operate their fleets and provide information to users in a more efficient manner.
- 5G mobile and software networks could be used to dramatically increase the accuracy and flexibility of automated vehicle sensing technology.

Mobile Networks and Devices

The use of Global Positioning System (GPS) applications, especially on mobile devices with access to mobile Internet services, has revolutionized real-time and on-demand transportation services. Accurate and fast GPS services used on mobile devices often rely on the quality of cellular networks. As of 2015, more than 98 percent of Americans have access to 4G LTE service (D'Orazio, 2015). As of late-2016, Pew found that 95 percent of American adults own a cellphone, and 77 percent own a smartphone (Pew, 2017). See Figure 12.1 below.

FIGURE 12.1: Percent of U.S. Adults who own a Cellphone and Smartphone



Source: Pew, 2017

The next generation of wireless cellular networks, known as 5G, is expected to be available for large-scale deployment in 2019, according to an announcement by nearly two dozen communications companies in early-2017. 5G technology is expected to be 100 times faster than current 4G LTE wireless technology and 10 times faster than Google Fiber home Internet services (Tibken, 2017). This faster connection could allow for a myriad of uses, including virtual reality, Internet of Things applications, and AVs.

The Role of ICT in Transportation Operations and Management

Recent advances in mobile phone sensing and cloud computing technology are giving rise to innovative ways to manage user demand and vehicle fleets. Transportation System Management and Operations (TSMO) is a concept that integrates ICT and big data analytics to better manage demand for the entire transportation system, TSMO could aide planners by providing more accurate and streamlined travel metrics related to including mode choice, route choice, and trip cost (SCAG, 2018). Big data analytics could also be used to detect the need for early maintenance of infrastructure. Services have emerged that offer mobile and online platforms to help vehicle fleet managers with scheduling, fleet allocation, vehicle maintenance, and many other critical functions.

Ridecell is an example of one such company that helps manage private vehicle fleets and offers analytics into fleet use and travel patterns to improve operations and routing algorithms (Ridecell, 2017). Public transportation agencies are taking advantage of these ICT innovations, as well. Predictive modeling is improving due to a greater wealth of passenger data being generated as a result of increased penetration and smartphone use. This is allowing for greater precision in predicting demand for both fixed- and flexible-route public transit. TransLoc is using big data predictive modeling to simulate rider demand for flexible-route microtransit solutions and is also helping cities and agencies pilot these new offerings (TransLoc, 2017). San Francisco-based Swiftly also harnesses passenger and real-time vehicle tracking data to improve the service quality, efficiency, and reliability of public transit operations (Swiftly, 2017). ICT and data generated from mobile sensing technology is allowing transportation providers to operate their fleets in a more efficient manner. Many operators, both public and private, are taking advantage of these types of solutions.

Cellular Network Technology and Automated Vehicles

5G mobile and software networks could be used to increase the accuracy and flexibility of AV sensing technology. Researchers exploring AV systems and network connections assert that the automated driving system must be extended to the network level instead of a standalone solution to provide a secondary layer of safety and to access the full technology benefits. From the network perspective, 5G architecture needs to provide high flexibility, low latency load balancing for data routing, and high-capacity nodes to allow for rapid data transmission with very low latency requirements (Dhawankar et al., 2017). Low latency describes computing networks that are optimized to process a high volume of data messages with minimal delay. The public sector will have to understand 5G technology and interact with providers to manage the cellular infrastructure that may be required for safe AV deployment. Establishing a reliable link between vehicles and intelligent infrastructure and traffic control systems will help to ensure maximum benefit from future smart infrastructure investments.

Freight and Goods Movement

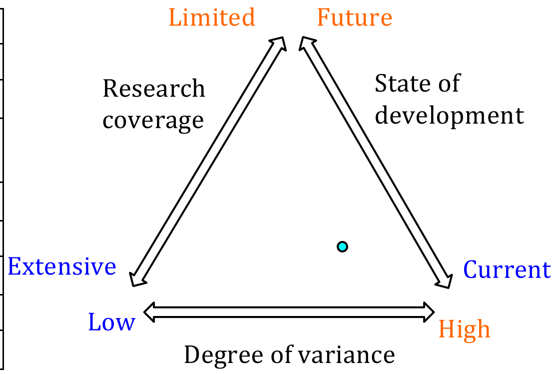
Freight is responsible for almost a third of California's GDP (California Sustainable Freight Action Plan, 2016). The Oakland, Los Angeles, and Long Beach ports are three of the ten largest in the country. Despite the economic benefits of California's freight sector, it currently contributes to local air pollution, traffic congestion, and infrastructure strain, especially in urban areas near freight highways and ports. Freight contributes to 45 percent of nitrogen dioxide emissions and 50 percent of diesel particulate matter emissions in California (California Sustainable Freight Action Plan, 2016). In addition to localized criteria air pollutants, freight is responsible for six percent of California's greenhouse gas (GHG) emissions, although this share could increase as freight demand grows.

In 2017, the Port of Los Angeles and Port of Long Beach handled around 5.197 million twenty-foot equivalent units (TEUs) of cargo per year combined (Port of Los Angeles, 2017; Port of Long Beach, 2017). This number is expected to reach 43 million TEUs per year by 2035 (California Cleaner Freight Coalition, 2016). According to the 2016 Freight Action Plan, California aims to improve the value of goods and services per mass of GHG production by 25 percent and deploy over 100,000 freight vehicles capable of zero emission technology by 2030 (California Sustainable Freight Action Plan, 2016). This section provides an overview of notable technologies and policies that are predicted to affect California's freight system.

Use this section to:

1. **Provide an overview of** the state of California's freight system,
2. **Review definitions and impacts to date** of some viable future freight technologies, and
3. **Compare port efficiency strategies.**

Topic: Freight and Goods Movement	
State of Knowledge	
Research Coverage	Existing
State of Development	Current
Degree of Variance	Medium
Metrics in this Section	
Direct model inputs	No
Projections	Yes
Impacts to date	Yes



Key Findings:

- In 2011, the Port of LA and Port of Long Beach handled around 5.197 million twenty-foot equivalent units (TEUs) of cargo per year combined (Port of Los Angeles, 2017; Port of Long Beach, 2017). This number is expected to reach 43 million TEUs per year by 2035.

- California aims to improve the value of goods and services produced per mass of GHG production by 25 percent and deploy over 100,000 freight vehicles capable of zero emission technology by 2030.
- Within five to ten years, trucking costs are predicted to decrease from $.12 per ton-mile to $.03 per ton-mile due to electrification and automation.
- Fifty percent of the total near-dock miles traveled in the port of LA and Long Beach are predicted to come from ZEVs in 2035. The adoption of ZEVs in freight is predicted to cause a four percent reduction in GHGs and a three percent reduction in nitrous oxide emissions.
- By 2040, approximately 93 percent of goods will be carried on trucks in the Central Valley, with only seven percent carried by rail, according to one source.

Platooning

Platooning allows trucks to drive closer together, relying on vehicle-to-vehicle (V2V) communication technology, as shown in Figure A4 in the Appendix. Truck platooning could be implemented within 18 months (Hsu, 2017). Enabling trucks to drive closer together increases fuel efficiency by reducing air drag. This methodology also decreases road congestion by increasing breaking and acceleration times, ultimately reducing local air pollution and GHG emissions. According to conservative estimates, widespread adoption of platooning can reduce energy use by 4.2 percent (Hsu, 2017). Since it currently relies on Level 1 automation, platooning requires a driver to be present in the vehicle. Barriers to adoption include concerns about the reliability and cost of V2V technology.

Parking

Truckers are limited to driving for, at most, 11 hours during a 14-hour shift, and 14-hour shifts can only be taken after ten consecutive off-duty hours. During this time, truckers must park to rest. One hundred percent of all public rest stops and 88 percent of all private truck stops cannot accommodate all of the trucks in their areas. Due to the lack of available truck parking, truckers are often forced to spend more time on the road searching for parking, sometimes illegally parking on city streets for their off-duty hours. This increases local diesel pollution and congestion (Shaheen et al., 2010).

Restriping (i.e., redrawing) parking spots to use space more efficiently, adopting new parking duration rules, strengthening parking rule enforcement, and using real-time information systems to broadcast the number of available parking spots in a location to truckers could reduce navigational fuel waste by 25 percent (Shaheen et al., 2010).

Freight Automation

Port Automation

Researchers are investigating freight-specific applications for automation technology. Port automation has already been implemented in some highly polluted and congested areas, including the Port of Long Beach[9]. At the Port of Long Beach, automation has demonstrated that it can increase efficiency and decrease local air emissions. However, port automation will likely displace workers. Depending on the level of automation in a given port, a single cybersecurity attack could affect entire ports and highways, which given the size of California's port network, has the potential for global impacts. The availability of cheaper, lower-risk strategies to increase efficiency and reduce pollution, as listed in Table 13.1 below, could be adopted instead of, or in addition to, port automation technologies. These strategies require lower capital investments, are less controversial, and could yield similar improvements when compared to automation. Most strategies have already been implemented or will be implemented in the near future (Jaller et al., 2016).

TABLE 13.1: Port Efficiency Strategies

Strategy Name	**Description**	**Impact**
Off-hour delivery services	Unloading/loading of cargo during off hours	Alleviate peak demand
Receiver-led cargo consolidation	Reorganizing of cargo in trucks	Package larger amount of goods in the same truck
Advanced appointment/reservation systems	Makes it possible for trucks to distribute their loading/unloading times	Less congestion within the port

In addition to automation technologies implemented at ports, automation can also be integrated into freight vehicles themselves. In the Netherlands, Dutch company Port-Liner introduced a fully electric, automated canal ship in January 2018. According to a Futurism article, each ship has the potential to replace 23,000 freight trucks in the region. The company aims to launch the vessels to transport goods among the Rotterdam, Amsterdam, and Antwerp ports in 2018 (Caughill, 2018).

Truck Automation

Most federal regulations support truck automation (Department of Motor Vehicles, 2017). Truck automation could increase operational efficiency along highway routes, benefitting commercial and non-commercial drivers. Similar to port automation, trucking automation has been met with resistance from trucking labor unions. Some forecasts predict that truck automation could double the ton-mile capacity of trucks in the long term, replacing some rail services and creating $100 billion in additional revenue. Trucking costs are predicted to decrease from $.12 per ton-mile to $.03 per ton-mile within the next five to ten years, if trucks are electrified and automated (Keeny, 2017). Port automation and platooning will likely increase the rate of adoption of automated trucks, since these two technologies are more compatible with AVs.

Electronic Data Loggers

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[9] Long Beach has implemented automated cranes, AVs to stage cargo for loading/unloading, and a central operating system to coordinate vehicle movements. This automation, combined with electrification of cranes/stacking vehicles, greater rail use, and electronic tracking of moving trucks and containers, all combine to double the cargo-handling capacity of the port. Local air emissions were also cut in half, and 14,000 new jobs were created (Port of Long Beach Middle Harbor Development).

Electronic data loggers (ELDs) automate the process of recording trucker service hours. This helps ensure that truckers have had enough rest so that they are not driving while fatigued. Although cost per ELD is predicted to be around $100 to $1000 per unit, depending on the age and size of the truck, all truckers were mandated to use ELDs in 2015. A net gain of $800 million in decreased accident rates is predicted to come from the widespread use of ELDs. However, concerns over truckers' privacy still remain (Department of Transportation, 2015).

Alternative Fuels

Using alternative fuels can decrease the pollution caused by California's freight vehicles. In addition to electric vehicle (EV) deployment, electrification of port operations can also lead to significant pollution reductions. Electrification from drayage truck regulation is expected to save $8.7 billion in health costs. Indeed, there was a 93 percent decrease in particulate matter from 2005 to 2013 due to diesel regulations (Ambros et al., 2015).

While zero emission vehicles (ZEVs) cost almost twice as much as conventional vehicles today, they can be pivotal in reducing the air pollution burden in areas with heavy traffic. The widespread adoption of these vehicles is limited by the development of their technologies, however. Currently, zero emission electric drayage trucks have ranges of around 75 to 200 miles, with a 90-minute charging time. Hydrogen fuel cell trucks produce around the same output and can have a much lower time required to refill a tank. It is unclear how expensive hydrogen fuel cell vehicles will be after development. Despite high capital and infrastructure costs, 50 percent of the total near-dock miles traveled in the port of LA and Long Beach are predicted to come from ZEVs in 2035. The adoption of EVs in freight is predicted to cause a four percent reduction in GHGs and a three percent reduction in nitrous oxide emissions (Ambros et al., 2015).

California state agencies are also collaborating on freight pilot projects to accelerate the transition to a zero-emission freight system. Three pilot projects are underway, in accord with the Sustainable Freight Action Plan, namely:

1. The Dairy Biomethane Pilot Project
2. Advanced Technology Corridors at Border, and
3. Advanced Technology for Truck Corridors (California Sustainable Freight Action Plan, 2016).

The first would require processing dairy biogas into biomethane for freight (Dairy Biomethane for Freight Vehicles, 2017). The second focuses on reducing congestion at border facilities, particularly along the California and Mexico border, and the third explores the potential for intelligent transportation systems, connected technologies, collaborative logistics, and incentives for zero-emission trucks on highways (Advanced Technology Corridors at Border Ports of Entry, 2017; Advanced Technology for Truck Corridors, 2017).

Marine Corridors

Marine corridors, also known as marine highways, are shipping routes that run parallel land highways. These could be used for freight transport in lieu of land transport by rail or truck. Marine highways are typically named with M, followed by the highway number that they run parallel to (e.g., a highway running parallel to I-5 will be called M-5). Marine highways are a national network, and they will ultimately run through major rivers, deltas, and coastlines across the country (Maritime Administration, n.d.).

On a per-ton, per-mile basis, shipping typically emits less GHGs and PM than most land transport modes (Nahlik, 2015). Shipping freight could reduce road congestion in major highways, mitigating air pollution near urban areas. Although marine highways are not widely used, a 14-month pilot project implemented a marine highway from Stockton to Oakland, running parallel to I-580 in 2013 (Robinson and O'Connor, 2015). Longer transport time suggests that marine highways would likely be used for non-time sensitive cargo. This pilot project highlighted some concerns that could impact the adoption rate of marine highways. Marine freight transport is generally slower than land transport. Barges that wait until enough cargo is on board to make trips profitable can cause delays. While it is relatively certain that there would be enough demand to make the M-580 route economically feasible, if implemented as a full-scale project, feasibility is harder to predict on routes spanning larger distances. Economic feasibility for other projects could be determined by how congested the corresponding land highway is and how many commercial vehicles are using land highways.

Another barrier is the potential increase in congestion on drayage routes and at ports due to increased shipping. This problem could be somewhat addressed by using small freight ships, which do not require cranes to load and unload containers. Ocean pollution and air pollution are also potential problems, although pollution from barges could be less harmful to humans than truck pollution since barge pollution would occur away from populated areas (Long Term Implementation of the M-580 Marine Highway, 2015).

California's Passenger Rail System

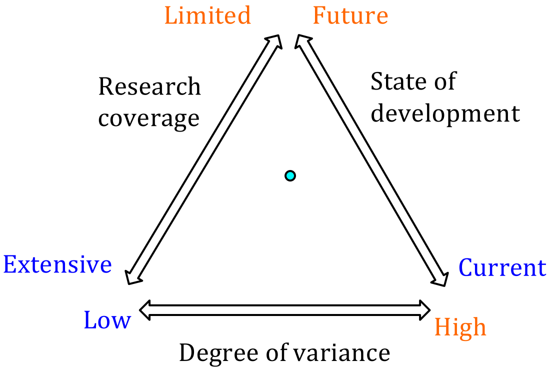
California's rail system is integral for movement of people and goods. In accord with the CTP 2040, the California Rail Plan is updated every four years to reflect the state of California's rail system. The Rail Plan also presents robust analysis and strategies to realize the statewide vision for the system. The future of rail in California will reflect updates to local, regional, and statewide rail systems. On local and regional levels, programs and pilots are currently updating rail networks. For example, the Bay Area Rapid Transit (BART) District in Northern California is expanding service into east Contra Costa County, using diesel-powered units for its cars (bart.gov, 2017). Integration of technologies, including electrification and light rail, will likely complement heavy rail implementation to expand rail access across California.

In this section, we briefly describe the role of rail in statewide transportation, highlight key challenges of fully integrating California's rail system, and present regional ridership projections. Although other technologies, such as 3D printing and hyperloop, may affect rail service through 2050, this section focuses primarily on the vision articulated in California's Rail Plan (2018) (Wilner, 2013). For information on 3D printing and hyperloop, please refer to the later sections in this white paper.

Use this section to review:

- **Some regional ridership projections**,
- **The vision** for the statewide rail system through 2040, and
- **A key challenge** in integrating the statewide rail system.

Topic: California's Passenger Rail System	
State of Knowledge	
Research Coverage	Limited-Existing
State of Development	Current-Emerging
Degree of Variance	Medium
Metrics in this Section	
Direct model inputs	No
Projections	Yes
Impacts to date	No



Key Findings:

- As described in the 2018 California Rail Plan, the 2040 vision for statewide rail is to increase the share of miles traveled via rail by 6.8 percentage points. Compared to today's share of 0.34 percent of passenger miles, this change would increase the number of passenger miles traveled via rail to 92 million.
- California aims to provide an integrated rail system through more frequent service and convenient transfers between rail and other transportation modes. Timed

transfers will be coordinated to happen in "pulses" or on a predictable schedule where riders can expect a train every half hour or hour, depending on demand.

- To achieve a fully integrated system, existing public and private rail and transit service providers must cooperate to implement plans cohesively, synthesize payment options, and coordinate timed transfers.
- The California rail system is working toward wide-scale electrification of intercity lines, particularly in the San Jose-Oakland-Sacramento corridor, the Central Valley from Merced to Sacramento, and Los Angeles to San Bernardino and Riverside then on to Coachella Valley.

Regional Ridership Projections

At present, California's rail system accounts for 0.34 percent of passenger miles. Current daily intercity ridership is approximately 115,000 trips per day. This reflects increases in ridership for some of the state's rail lines, two of which are shown in Table 14.1 below. The 2040 vision, as described in the 2018 Rail Plan, increases this share of passenger miles by 6.8 percent, an overall increase of 92 million passenger miles. In this case, 88 million passenger miles would be diverted to rail from the highway, approximately 1.3 million daily trips (Caltrans, 2018). Researchers also estimate that the number of rail trips made by California's older adult population (age 65 and older) will increase 71 percentage points by 2040 as compared to 2015, due to demographic shifts (UCB ITS, 2017). On a local level, rail technologies, such as light rail and diesel rail, have the potential to increase access to transportation in areas where heavy rail is not cost effective. Integrating the local, regional, and national rail systems may increase ridership beyond these projections through the network effect, which occurs when an alteration to one area of the system affects the system's use in another area, which may be located near or far to the original change (Landex, 2012).

TABLE 14.1: Rail Ridership Trip Characteristics for Two Systems[10]

	Region	**Ridership and Trip Characteristics**
Example 1: Caltrain Ridership	Northern California	• Ridership has doubled over the past ten years • Caltrain riders have shorter travel times than drivers at peak commute hours
Example 2: San Luis Obispo Rail Corridor (LOSSAN)	Southern California	• Steadier ridership during off-peak hours

Source: UCB ITS, 2017

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[10] The purpose of this table is to highlight recent increases in trip demand for two key California rail lines. It is not intended to cover ridership changes over time across all rail lines in the state.

Statewide Rail Vision

California has the opportunity to increase rail system efficiency by connecting and updating existing rail systems. As California's high speed rail (HSR) planning and implementation continues, some existing rail services will connect to it.

Overall, California aims to provide an integrated rail system through more frequent service and convenient transfers among rail and other transportation modes. This includes expanding the mix and scale of services to meet growing demand. Timed transfers will be coordinated to happen in "pulses" or on a predictable schedule where riders can expect a train every half hour or hour, depending on demand. California's HSR will impact California's rail system in the long run, offering a competitive option to driving and air travel as described below.

Projects to improve existing rail lines by 2020 are already underway. The California Rail Plan (2018) details such projects, their funding sources, and projected completion date in Section 6.2 of the document. The California rail system is also working toward wide-scale electrification of intercity lines, particularly in the San Jose-Oakland-Sacramento corridor, the Central Valley from Merced to Sacramento, and Los Angeles to San Bernardino and Riverside then on to Coachella Valley. Specific projects to accomplish this electrification goal are included in the Rail Plan (2018).

Description and Predicted Impacts of HSR

The final HSR route will run from Sacramento to San Diego with 24 intermediate stations. According to the 2016 HSR Business Plan, the rail service is expected to serve passengers beginning in 2025, with service in all of Phase 1 by 2029. See Figure A4 in the Appendix for a map of the entire project.

HSR has the potential to boost the economies of intermediate station cities: Gilroy, Merced, Fresno, Bakersfield, Madera, and Kings/Tulare. Stations built in or near downtown areas are most likely to spur development. However, weak market forces may restrict the degree of growth in intermediate cities, even if financial incentives encourage compact transit-oriented development (SPUR, 2017).

HSR routes will also connect those living farther from cities to jobs in urban centers and will connect coastal and central communities. This has the potential to encourage sprawl, if coastal workers move central for more affordable housing (SPUR, 2017). HSR is also expected to contribute to job growth around stations for maintenance and operations. See Table 14.2 below for the expected number of new jobs per region.

TABLE 14.2: Predicted Number of HSR Maintenance Jobs

Region	**Number of Jobs**
Northern California	900 to 1,100
Central Valley	1,000 to 1,200
Southern California	1,300 to 1,500

Key Challenge: Coordination for Transfers and Payment

Coordination among private and public actors is essential to realizing the state's rail vision. This is particularly challenging, however, since the government does not own the rail system in its entirety. The Rail Plan (2018) describes 22 regional plans that must be synthesized, which is not an exhaustive list. To achieve a fully integrated system, these and other existing rail and public transit service providers must cooperate to implement plans cohesively. At present, multiple payment systems in use create additional burdens for users, which an integrated payment system could reduce. Cohesion can also minimize risk of transfer delays and enable physical integration of systems through transit hubs (Caltrans, 2018). Although this is not the only challenge facing an integrated California rail system, integrating for seamless transfers and unified payment systems will positively impact ridership.

Cybersecurity Risk

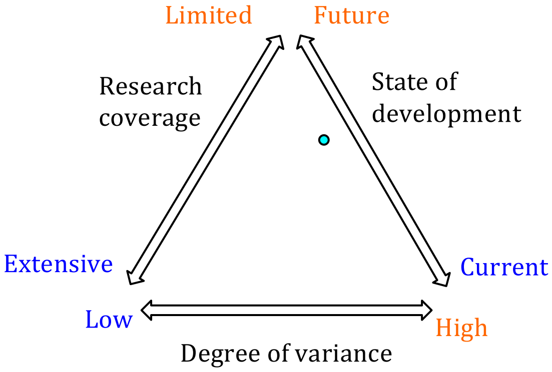
Cybersecurity is a growing concern for increasing technology-enabled vehicles and AVs. The benefits of Internet-connected vehicles include enhanced engine controls, automatic safety alerts, and remote control features. However, this connectivity can present potential downsides, if the systems are not secure and can be manipulated by malicious actors.

In this section, we provide a brief explanation of the current state of vehicle cybersecurity and outline potential risk cases and related research.

Use this section to:

1. **Learn about the field of vehicle cybersecurity** and the current state of the industry and connected vehicle technology, and
2. **Determine the key risks of increased vehicle connectivity** and cybersecurity implications for transportation and most notably public rights-of-way.

Topic: Cybersecurity Risk	
State of Knowledge	
Research Coverage	Existing–Limited
State of Development	Emerging
Degree of Variance	High
Metrics in this Section	
Direct model inputs	No
Projections	Yes
Impacts to date	No



Key Findings:

- The increased connectivity and reliance on software in automobiles presents many of the same cybersecurity risks as computers, but with potentially more life threatening consequences for passengers in fast moving vehicles.
- On top of the hacking risk to automobile software, researchers are learning that it is possible to affect AI systems by altering the environment they see in ways invisible to the human eye. Thus, this could create an additional security risk. It is important for public-sector decision makers to be aware of these potential risks when considering AV-related infrastructure investments.

Current State of Vehicle Cybersecurity

There are approximately 23 million vehicles worldwide with some type of Internet connection (McCarthy, 2015). The number of Internet-connected vehicles is expected to grow rapidly. A forecast by Gartner (2015) expects about one in five vehicles on the road worldwide will have some form of wireless network connection by 2020, amounting to more than 250 million vehicles. These vehicles can provide users with many benefits such as: enhanced engine controls, automatic safety alerts, and remote control features. The challenge of keeping the operations of these Internet-connected vehicles secure is already proving a difficult task for automakers and suppliers. In 2015, two computer programmers famously hacked into a Wired reporter's 2014 Jeep Cherokee and wirelessly disabled the transmission, forcing the driver to pull over to the side of the highway. This incident led to the recall of 1.4 million vehicles by Fiat Chrysler in July 2015 (Greenberg, 2017). This incident is just one example of the cybersecurity risks surrounding Internet-connected vehicles. The increased connectivity and reliance on software in automobiles presents many of the same cybersecurity risks as computers, but with potentially more life-threatening consequences for passengers in fast moving vehicles. The United Kingdom issued a set of cybersecurity guidelines for automakers in August 2017 (GOV.UK, 2017), although there has been little public-sector legislation on this topic, thus far.

Research and Risk Cases

As the amount of code in each vehicle continues to grow exponentially as automakers develop more applications, every line of code is an opportunity for hackers to exploit. Some examples of potential vehicle attacks include:

- Triggering airbags to deploy when vehicles reach high speeds,
- Using ransomware on a drivetrain to force owners to pay for their vehicles to work again, and
- Infecting vehicles with malware transmitted through V2V communications.

Problems also exist in keeping patches up to date to protect against cyberattacks. Dwindling vendor support for aging systems, ensuring updates of consumer-owned vehicles, and low-cost processors that do not properly address security issues, all make it difficult to keep patches up to date (Prowell, 2017).

On top of the hacking risk to automobile software, researchers are discovering that it is possible to affect artificial intelligence (AI) systems by altering the environment they see in ways invisible to the human eye. AI software used in AVs cannot yet consistently ignore or distinguish inanimate objects and numerical signals – like speed limits and highway numbers – since their perception of these objects can change based on distance and angle, among other factors. AI researchers at Google, Pennsylvania State University, OpenAI, and the University of Illinois at Urbana Champaign conducted a number of different studies that draw varying conclusions on whether their software could be susceptible to "hacks" of real-world objects, invisible to the human eye but potentially readable by machines (Gershgorn, 2017). This suggests a concerning opportunity for hackers to trick AI systems in AVs by altering the physical environment as opposed to hacking the vehicle systems themselves.

Vehicle cybersecurity is increasingly important for public-sector actors to be aware of and meet with appropriate regulations and guidelines for developers and automakers. These potential security threats should be considered when developing infrastructure and maintenance requirements for connected and automated vehicles.

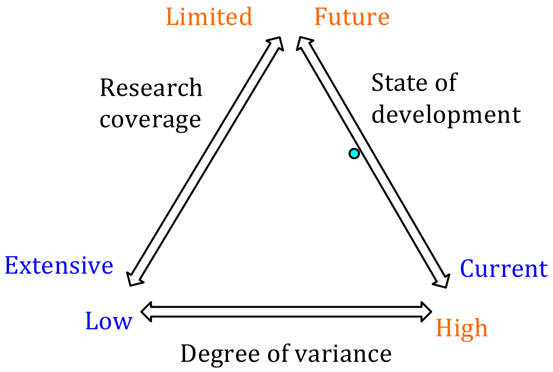
Blockchain

This section provides a brief explanation of blockchain technology in general and its potential applications to mobility and transportation technology. Though blockchain-based mobility efforts are in their infancy, there are some efforts that are researching and exploring these concepts.

Use this section to:

1. **Define and introduce blockchain,** and
2. **Explore the connection** between blockchain and mobility.

Topic: Blockchain	
State of Knowledge	
Research Coverage	Limited
State of Development	Emerging
Degree of Variance	High
Metrics in this Section	
Direct model inputs	No
Projections	No
Impacts to date	No



Key Findings:

- Blockchain is the underlying structure behind cryptocurrencies like Bitcoin, and enables a decentralized ledger that allows for financial transactions and smart contracts to be executed without intermediaries.
- Research groups are assessing applications of blockchain technology to data sharing, P2P transactions, and usage-based insurance.

Introduction to the Blockchain

Blockchain, the underlying structure behind cryptocurrencies like Bitcoin, is a decentralized ledger that allows for financial transactions and smart contracts to be executed without intermediaries. Blockchain works by using cryptography, multiple network nodes, and processing incentives to create a mutually agreed-upon record of transactions between all participants in a system, in an immutable and automated fashion. Although the technology has been used thus far mainly for currencies and financial transactions, some experts are speculating that the technology could be used for various mobility service transactions.

Blockchain Mobility Efforts

Toyota Research Institute's (TRI) recently formed working group is one of the most notable blockchain-related mobility efforts to date (Schiller, 2017). The working group brings together four other companies specializing in blockchain or mobility technologies, and their effort aims to provide an open blockchain platform across three verticals:

- Data sharing,
- P2P transactions, and
- Usage-based insurance.

Mobility data sharing via a blockchain could allow companies and individuals to share and monetize their own data with very low transaction costs in a secure marketplace. A blockchain-based carsharing network could allow for owners to rent their cars on a short-term basis at a potentially lower transaction cost than current peer-to-peer carsharing companies, and a blockchain would execute smart contracts and store information about users and vehicles. Blockchain technology could also enable usage-based insurance where the amount paid is based on distance driven and driver safety ratings. Although blockchain-based mobility services are at very early stages, it is important to address this technology, since decentralized technologies will likely be a unique challenge for public sector entities to regulate.

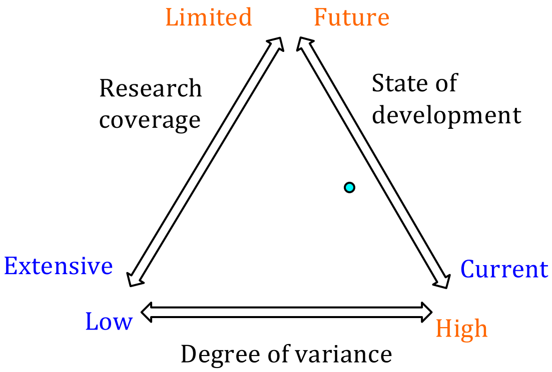
3D Printing

This section provides a brief explanation of 3D printing technology and its applications and potential impacts on goods movement and vehicle manufacturing.

Use this section to:

1. **Explore 3D printing technology,** and
2. **Consider its impact** on supply chains, manufacturing, and infrastructure.

Topic: 3D Printing	
State of Knowledge	
Research Coverage	Limited
State of Development	Emerging
Degree of Variance	High
Metrics in this Section	
Direct model inputs	No
Projections	No
Impacts to date	No



Key Findings:

- 3D printing technologies are in development, and the rate of their implementation could affect last-mile goods movement by shortening supply chains.
- 3D printing could begin to have a larger impact on certain aspects of the vehicle manufacturing process, and some companies are already manufacturing vehicles with 3D printed materials.
- 3D printing is a trend that could potentially lead to shorter delivery distances of finished products to their final destination.
- 3D printing technology could be used to lower the cost and speed up the process of construction and maintenance for various types of capital infrastructure.

3D Printing and Transportation Applications

The growth of 3D printing, or additive manufacturing, could have an impact on the transportation industry. Over the past few years, the number of patents on additive manufacturing processes and materials has grown exponentially (Ben-Ner and Siemsen, 2017). The photo below shows titanium additive manufaturing process in action. 3D printing shortens supply chains, since goods can be manufactured closer to the end consumer. Global transportation needs could therefore be more focused on raw materials and less on moving parts and finished goods. When finished goods must be transported to their final destination, these distances could be much shorter; therefore, it is important to consider 3D printing as a trend that could potentially shorten delivery distances of products. 3D printing is even affecting some areas of vehicle manufacturing. Local Motors is a company focused on low-volume manufacturing of open-source motor vehicle designs

Source: Sciaky, 2017

using multiple microfactories. They recently unveiled the world's first 3D printed car, named Strati (Local Motors Labs, 2017). There are also potential applications of 3D printing in construction and infrastructure maintenance. 3D printing may be able to reduce infrastructure expenditures in a number of ways. Rail cars are frequently custom-built for the tracks they operate on, which can vary depending on the standards in which the system was built. 3D printing is one way that public agencies may be able to rehab these systems at a reduced cost by lowering the costs of building and maintaining custom rail cars (Goulding, 2017). The technology may also be used for roadway paving and repair. 3D pavers are being developed that use sensors to scan a road and automatically make a digital mat, which can then be 3D printed in asphalt with variably layered material. These machines could dramatically lower the time and cost of roadway pavement compared to traditional methods (Millsaps, 2015). It is important to keep in mind that regulatory agencies may have to inspect and approve 3D printing designs, materials, and manufacturing sites separately.

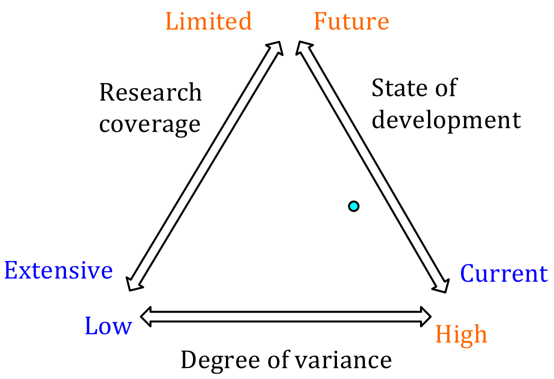
Drones and Unmanned Aerial Vehicles (UAVs)

Drones and Unmanned Aerial Vehicles (UAVs) have the potential to solve the last-mile problem in freight. Due to the increase in online shopping, companies are exploring using drone and automated robot delivery to get products quicker to consumers, who expect door-to-door delivery experiences. In this section, we briefly describe drone's potential impact on goods movement in California.

Use this section to:

1. **Review** the potential for drones and UAVs to impact goods movement, and
2. **Gain an understanding** of drone use to date.

Topic: Drones and UAVs	
State of Knowledge	
Research Coverage	Limited
State of Development	Emerging
Degree of Variance	High
Metrics in this Section	
Direct model inputs	No
Projections	No
Impacts to date	No



Key Findings:

- The last-mile portion of a delivery trip typically is responsible for a significant amount of local pollution and congestion. Drones could lessen pollution and congestion during this part of the trip.
- An estimated 20 drone trips may be necessary to replace one conventional delivery van trip, depending on the goods being delivered and delivery distance.

Potential Impacts of Drones and UAVs

The last mile problem refers to the inefficient transport that occurs at the last phase of freight movement when goods are delivered to homes and factories. The last-mile portion of a delivery trip typically is responsible for a significant amount of local pollution and local congestion. This is because the area that a given last-mile vehicle travels can be large due to delivery targets being spread out. Drones could lessen pollution and congestion due to last-mile transport (Mckinnon, 2016).

As of October 2017, an estimated 50 to 77 percent of the nation's households included an Amazon Prime member, signaling notable growth in demand for on-demand delivery (Weise, 2017). Companies, such as Amazon, have already adopted drones to deliver small orders within the drone's current flying range, which is about 10 miles (Soper, 2015). The United Parcel Service is experimenting with integrating drones and trucks to increase last-mile efficiency, especially in rural areas (Shaheen and Cohen, 2017). Companies, such as

Starship and Marble, have also developed prototypes for on-the-ground automated robot goods delivery (SCAG, 2018). Widespread use of drones might be limited due to their current limited carrying capacity and governmental regulations, and about 20 drone trips are estimated as necessary to replace one conventional delivery van trip (Weise, 2017).

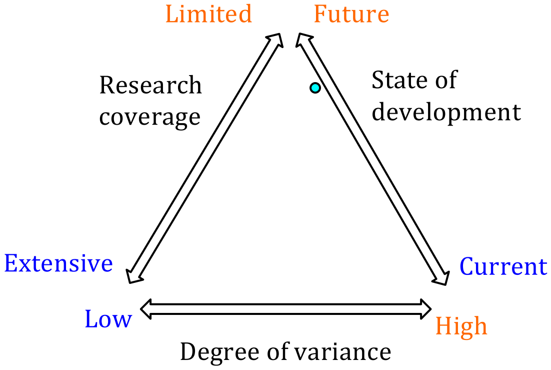
On-demand Trucking/"Uber for Freight"

As the ridesourcing company/TNC business model has proliferated across the world, other industries are becoming interested in applying that technology to their operations. An example of this transition is the launch of various on-demand trucking services. There is very limited research on this to date, and opinions on whether its adoption will be widespread are inconclusive. In this section, we define on-demand trucking and name services that exist at present.

Use this section to:

1. **Review the definition** of on-demand trucking, and
2. **Consider investments,** to date, in this business model.

Topic: On-demand Trucking	
State of Knowledge	
Research Coverage	Limited
State of Development	Emerging
Degree of Variance	High
Metrics in this Section	
Direct model inputs	No
Projections	No
Impacts to date	No

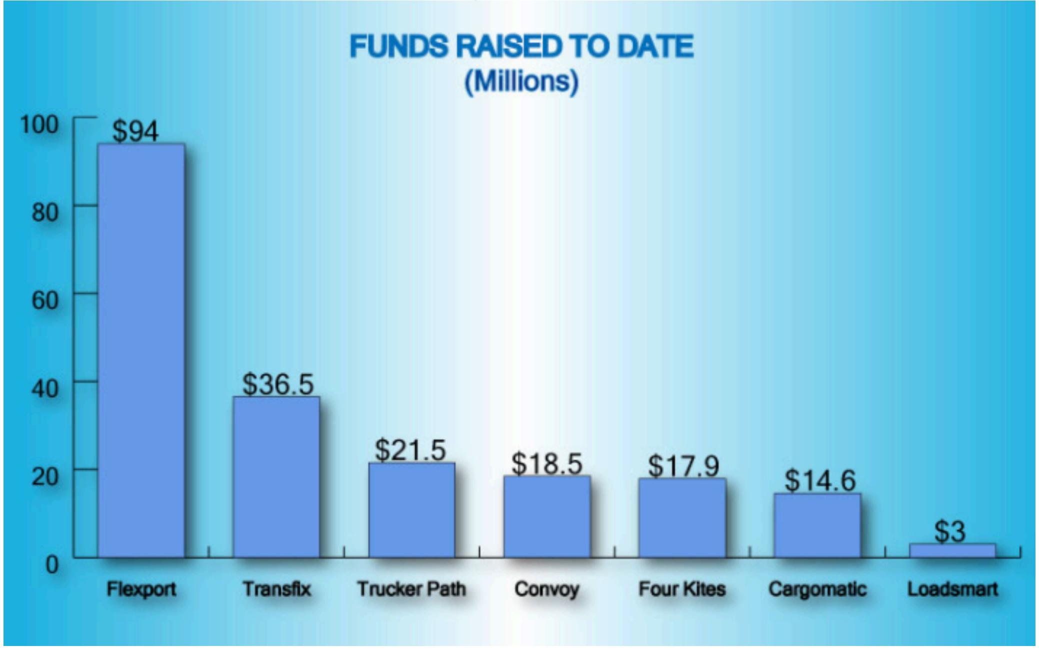


Key Findings:

- Often, shippers and truckers have to pay a large portion – around 45 percent of the total revenue – to brokers to connect truckers with goods. "Uber for freight" can cut down on trip price and delivery time by connecting truckers to shippers on-demand to optimize routing.

Some ridesourcing companies are launching on-demand trucking, sometimes referred to as "Uber for trucks." Often, shippers and truckers have to pay a large portion – around 45 percent of the total revenue – to brokers to connect truckers with goods. Brokers often conduct business over the phone, which slows the process, reducing its efficiency. "Uber for trucks" can cut down on trip price and delivery time by connecting truckers to shippers on-demand to optimize routing. For example, a truck might be able to double the revenue from a trip, if it can coordinate an additional haul that will lead back to where it started (Banham, 2016). Two hundred six million dollars have been invested in "Uber for freight" startups, to date, as shown in Figure 15.1 below (Rafter, 2017). Currently, Uber, Convoy, and Cargomatic are offering on-demand freight services.

FIGURE 15.1: Freight Disruptor Investment



Source: Rafter, 2017

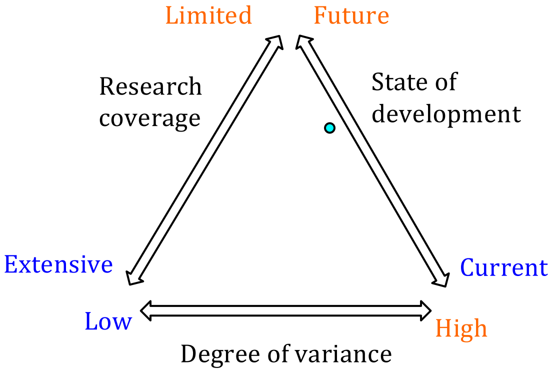
Hyperloop

Hyperloop, a high-speed rail train technology that relies on magnets to carry pods in a vacuum tube, is being proposed for freight and passenger travel, as shown in Figure A6 in the Appendix.

Even though conventional rail transport is cheaper by mile, logistics limitations and long transport times limit conventional rail use. Hyperloop routes are also being considered for passenger travel. Although hyperloop could greatly decrease travel time for long-distance trips, many are skeptical about the technology due to its cost and safety concerns (SDAG, 2018).

Use this document to:
1. **Consider possible applications** of hyperloop technology to goods movement and passenger travel in California.

Topic: Hyperloop for Freight	
State of Knowledge	
Research Coverage	Limited
State of Development	Emerging
Degree of Variance	High
Metrics in this Section	
Direct model inputs	No
Projections	No
Impacts to date	No



Key Findings:

- Hyperloop, a high-speed rail that operates in a vacuum tube, could replace some conventional rail transport. Hyperloop is also under development for passenger transport.
- According to one source, hyperloop for freight could decrease required inventory sizes by 20 percent, and would apply to delivery of lighter, time-sensitive goods.
- Most projections place the cost of building a hyperloop corridor at $60 million per mile of loop. Even if implemented, it is unclear how much hyperloop would decrease the travel time of goods.

Hyperloop routes are also under consideration in the state, including one route from San Diego to Los Angeles that could reduce the travel time between the cities to 13-minutes (SDAG, 2018). If successfully implemented, hyperloop for freight could drastically reduce transport times. Since hyperloop will likely be built with cleaner technologies, it may also reduce pollution. Hyperloop for freight could decrease required inventory sizes by 20 percent and would likely move lighter, time-sensitive goods (Dalagan, 2017). Since hyperloop will likely be built with cleaner technologies, it may also reduce pollution.

Most projections place the cost of building a hyperloop corridor at $60 million per mile of loop. Even if implemented, it is unclear how much hyperloop would decrease travel times for goods. Delivery speed might be more limited by last-mile logistics (i.e., transporting goods directly to people's homes and factories) than by the rest of the trip (i.e., getting the deliveries in the general region using hyperloop). As with most disruptive technologies, the likelihood of adoption depends mostly on whether hyperloop can provide a service, which is not offered by other forms of freight infrastructure. If enough demand for time-sensitive goods is realized in the future, hyperloop for freight will become significantly more feasible (Hsu, 2017).

Conclusion

Transportation influences most industries in California, and is affected by overarching trends across the state. Discussions of the future of transportation should include trends that are emerging now, despite, at times, a lack of research, data, and quantitative analyses. Although it is impossible to predict what the transportation ecosystem will look like in 2050, considering the technologies and services that are covered in this document will support more thorough analysis and planning. Understanding the rate at and degree to which technologies and services will proliferate is challenging, which justifies the need for additional research. Synthesizing projections across existing literature and considering the opinions of experts across specialties can encourage thoughtful interdisciplinary conversations when planning and modeling Californian transportation policy in the future.

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Appendix

TABLE A1: Levels of Automation

Automation level	Description
Level 0	No automation
Level 1	Automation of one primary control function, e.g., adaptive cruise control, self-parking, lane-keep assist or autonomous braking
Level 2	Automation of two or more primary control functions “designed to work in unison to relieve the driver of control of those functions”
Level 3	Limited self-driving; driver may “cede full control of all safety critical functions under certain traffic or environmental conditions,” but it is “expected to be available for occasional control” with adequate warning
Level 4	Full self-driving without human controls within a well-defined Operational Design Domain, with operations capability even if a human driver does not respond appropriately to a request to intervene
Level 5	Full self-driving without human controls in all driving environments that can be managed by a human driver

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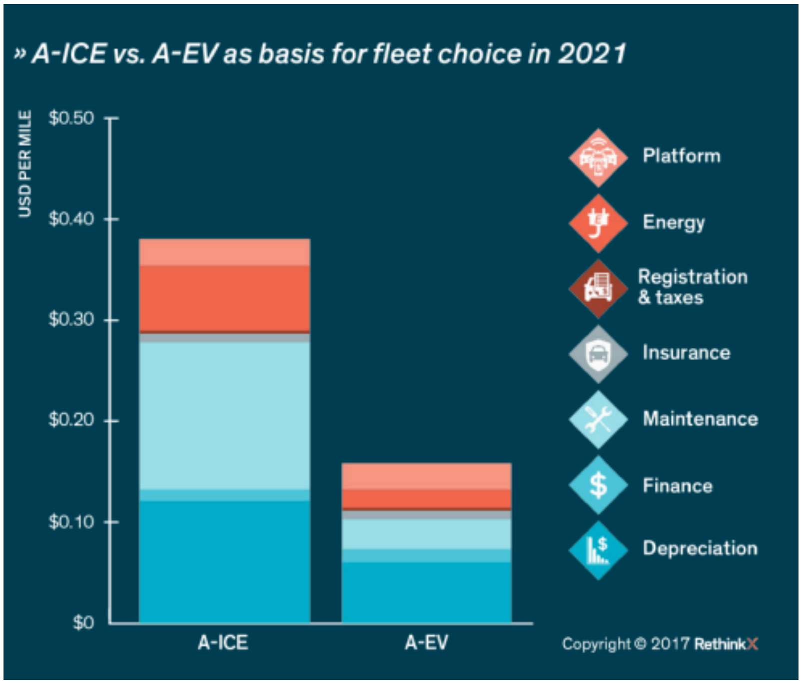
FIGURE A1: Projected Costs of ICE vs. EV Fleets



Source: Arbib and Sebab 2017

TABLE A2: Behavioral Factors Affecting EV Adoption

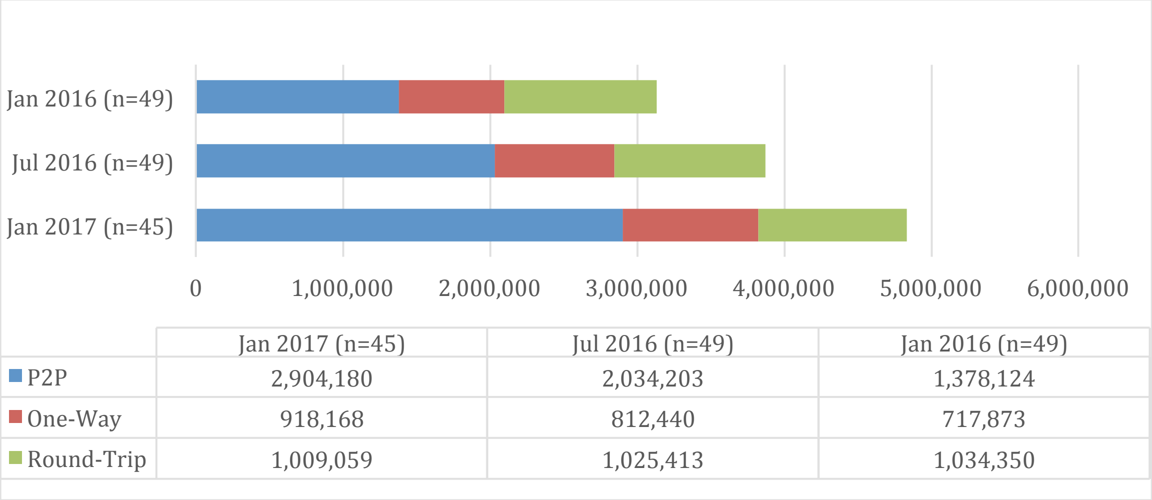
Environmental Attitudes	Information On-Demand
Shifts in environmental attitudes have influenced the scale of hybrid and EV adoption, forcing its acceleration (Shaheen et al., 2016). Still, many consumers are wary of EVs. According to a recent report that surveyed approximately 3,500 people across the US, Norway, and Germany, about 50 percent of respondents did not understand EV technology (Knupfer et al. 2017). Shared mobility services can serve as a testing ground for EVs, enabling people to experience them without making their own investments (Firnkorn and Müller 2012, Fairley 2013, He et al. 2017).	Technology is also breaking through behavioral barriers, as it is with many facets of the transportation sector. Access to public charging stations can lessen range anxiety (Yilmaz and Krein 2013; Chen, Kockelman, and Hanna 2016). People are now accustomed to information on demand, and presentation of charging infrastructure locations can reduce the knowledge gap.

TABLE A3: California's Current and Proposed EV Charging Infrastructure Projects

Name	Institution	Status	Outcome
Power Your Drive	SDG&E	Implemented	Authorizes 3,500 charging stations at 350 workplaces and homes
Charge Ready	SCE	Implemented	Authorizes 1,500 chargers at 150 workplaces, multi-unit dwellings, fleet stations, destinations
EV Charge Network	PG&E	Implementation in progress	Up to 7,500 charging stations will be installed at apartment, condos, workplaces starting in 2018
SB 350	PG&E	Proposed	Installation of up to 234 DC Fast chargers
SB 350	SDG&E	Proposed	Build 90,000 residential chargers, 45 chargers at San Diego airport, 2 DC Fast Chargers and 20 Level 2 chargers at each of the four park-and-ride locations in or near disadvantaged communities, five DC Fast Chargers along frequent taxi/shuttle/ridesourcing or TNC routes
Settlement for cheating on emissions tests	Electrify America, Volkswagon	Implementation in progress	350 Level 2 chargers across California urban areas by 2020
N/A	Tesla	Implementation in progress	Install 10,000 Tesla Superchargers by 2018

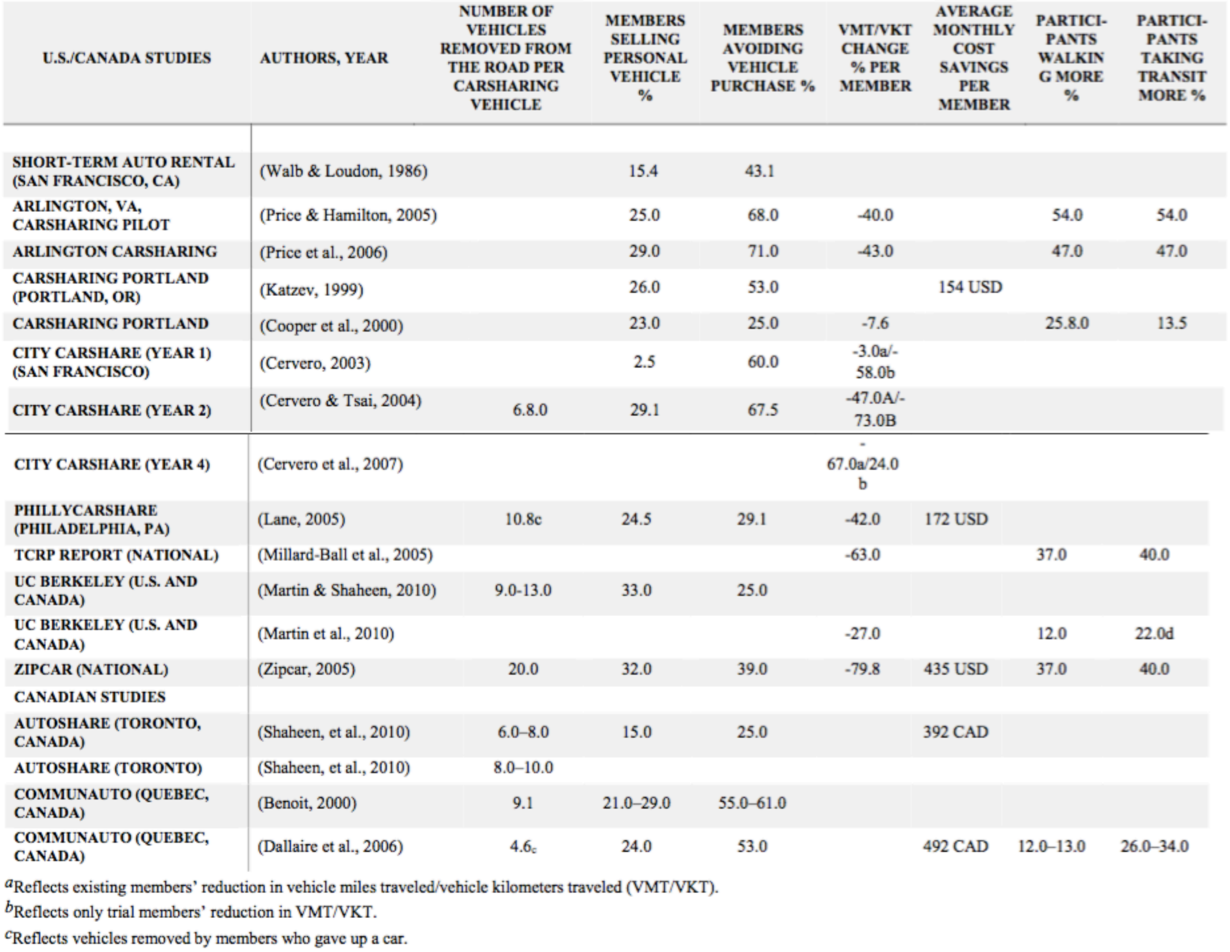
Sources: Taub 2017; Travish 2017; Marshall 2017; California PUC 2017

FIGURE A2: North American Carsharing Memberships by Business Model



	Jan 2017 (n=45)	Jul 2016 (n=49)	Jan 2016 (n=49)
🟦 P2P	2,904,180	2,034,203	1,378,124
🟥 One-Way	918,168	812,440	717,873
🟩 Round-Trip	1,009,059	1,025,413	1,034,350

TABLE A4: Impacts of North American Roundtrip Carsharing



U.S./CANADA STUDIES	AUTHORS, YEAR	NUMBER OF VEHICLES REMOVED FROM THE ROAD PER CARSHARING VEHICLE	MEMBERS SELLING PERSONAL VEHICLE %	MEMBERS AVOIDING VEHICLE PURCHASE %	VMT/VKT CHANGE % PER MEMBER	AVERAGE MONTHLY COST SAVINGS PER MEMBER	PARTICI-PANTS WALKING MORE %	PARTICI-PANTS TAKING TRANSIT MORE %
SHORT-TERM AUTO RENTAL (SAN FRANCISCO, CA)	(Walb & Loudon, 1986)		15.4	43.1				
ARLINGTON, VA, CARSHARING PILOT	(Price & Hamilton, 2005)		25.0	68.0	-40.0		54.0	54.0
ARLINGTON CARSHARING	(Price et al., 2006)		29.0	71.0	-43.0		47.0	47.0
CARSHARING PORTLAND (PORTLAND, OR)	(Katzev, 1999)		26.0	53.0		154 USD		
CARSHARING PORTLAND	(Cooper et al., 2000)		23.0	25.0	-7.6		25.8.0	13.5
CITY CARSHARE (YEAR 1) (SAN FRANCISCO)	(Cervero, 2003)		2.5	60.0	-3.0a/-58.0b			
CITY CARSHARE (YEAR 2)	(Cervero & Tsai, 2004)	6.8.0	29.1	67.5	-47.0A/-73.0B			
CITY CARSHARE (YEAR 4)	(Cervero et al., 2007)				-67.0a/24.0b			
PHILLYCARSHARE (PHILADELPHIA, PA)	(Lane, 2005)	10.8c	24.5	29.1	-42.0	172 USD		
TCRP REPORT (NATIONAL)	(Millard-Ball et al., 2005)				-63.0		37.0	40.0
UC BERKELEY (U.S. AND CANADA)	(Martin & Shaheen, 2010)	9.0-13.0	33.0	25.0				
UC BERKELEY (U.S. AND CANADA)	(Martin et al., 2010)				-27.0		12.0	22.0d
ZIPCAR (NATIONAL)	(Zipcar, 2005)	20.0	32.0	39.0	-79.8	435 USD	37.0	40.0
CANADIAN STUDIES								
AUTOSHARE (TORONTO, CANADA)	(Shaheen, et al., 2010)	6.0–8.0	15.0	25.0		392 CAD		
AUTOSHARE (TORONTO)	(Shaheen, et al., 2010)	8.0–10.0						
COMMUNAUTO (QUEBEC, CANADA)	(Benoit, 2000)	9.1	21.0–29.0	55.0–61.0				
COMMUNAUTO (QUEBEC, CANADA)	(Dallaire et al., 2006)	4.6c	24.0	53.0		492 CAD	12.0–13.0	26.0–34.0

[a] Reflects existing members' reduction in vehicle miles traveled/vehicle kilometers traveled (VMT/VKT).

[b] Reflects only trial members' reduction in VMT/VKT.

[c] Reflects vehicles removed by members who gave up a car.

Source: TSRC 2017

FIGURE A3: Bikesharing Business Models

Business-to-Consumer (B2C)
Private and/or public actors, or a public-private partnership, maintain(s) a fleet of a fixed number of bicycles that users access on an as-needed basis

Station-based
Users must park and lock bikes at a designated station or "hub"

One-way
Starting and ending stations are different

Roundtrip
Starting and ending stations are the same

Dockless
Users can park and lock bikes anywhere within a designated geographic region

Peer-to-Peer (P2P)
Community members allow others to use their bikes through a transaction facilitated by a third party

TABLE A4: Bikesharing Services Across California

Name	Location	Size	Company	Model
Ford GoBike	San Francisco, Oakland, Emeryville, Berkeley, San Jose	7000 bikes in 125 stations	Motivate	Station-based
N/a	Alameda	300 dockless bikes	Limebike	Dockless
N/a	South San Francisco	LimeBike = 300 Spin = 125 (plans to increase to 500)*	Limebike, Spin	Dockless
Bike Share for Arcata & Humbolt State University	Arcata	10 bikes on Arcata & Humbolt State University campus	Zagster	Station-based
Beverly Hills Bikeshare	Beverly Hills	50 bikes in 7 locations	Social Bicycles	Station-based; $2 fee to lock to a public bike rack
	Imperial Beach	250 bikes*	LimeBike	Dockless
Zot Wheels	UC Irvine	25 bikes at 4 stations in UC Irvine	Ecotrip by Collegiate Bicycle Company	Station-based
Long Beach Bike Share	Long Beach	400 bikes in 60 stations	Social Bicycles	Station-based
Los Angeles Bike Share	Downtown LA, Pasadena, Port of LA, Venice	1400 bikes in 125 stations	Bicycle Transit Systems	Station-based
Bruin Bike Share	UCLA	130 bikes in 18 hubs	Social Bicycles	Station-based
San Diego	San Diego	1800 bikes in 180 stations	Decobike	Station-based
San Mateo Bike Share	San Mateo	50 bikes in 11 stations*	Social Bicycle	Station-based
Santa Monica Bike Share	Santa Monica	500 bikes in 85 stations	Social Bicycles	Station-based
South Lake Tahoe	South Lake Tahoe	400 dockless bikes*	Limebike	Dockless
WEHOpedals	West Hollywood, CA	150 bikes in 20 stations	Social Bicycles	Station-based

*Pilot program

Source: Meddin 2017

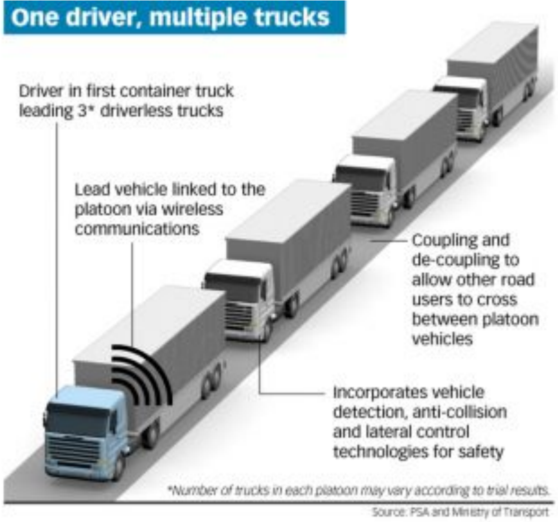
TABLE A5: Equity Frameworks

Purpose	Elements to Consider	Source
Identify barriers to equity	• Spatial barriers • Temporal barriers • Economic barriers • Physiological barriers • Social barriers	Shaheen et al., 2017
Siting mobility hubs	• Low automobility • Disadvantaged populations • Resiliency (to extreme climate events) • New service viability • Future growth potential • Transportation connectivity • Land use intensity	Anderson et al., 2017

TABLE A6: Public Health Resources

Name	Source	Use
Transportation Health Impact Assessment Toolkit	Centers for Disease Control and Prevention (CDC)	Identifies indicators for health impact assessments
Transportation and Health Tool	U.S. Department of Transportation, CDC	Provides indicator data for health impact analysis

FIGURE A4: Truck Platooning Diagram

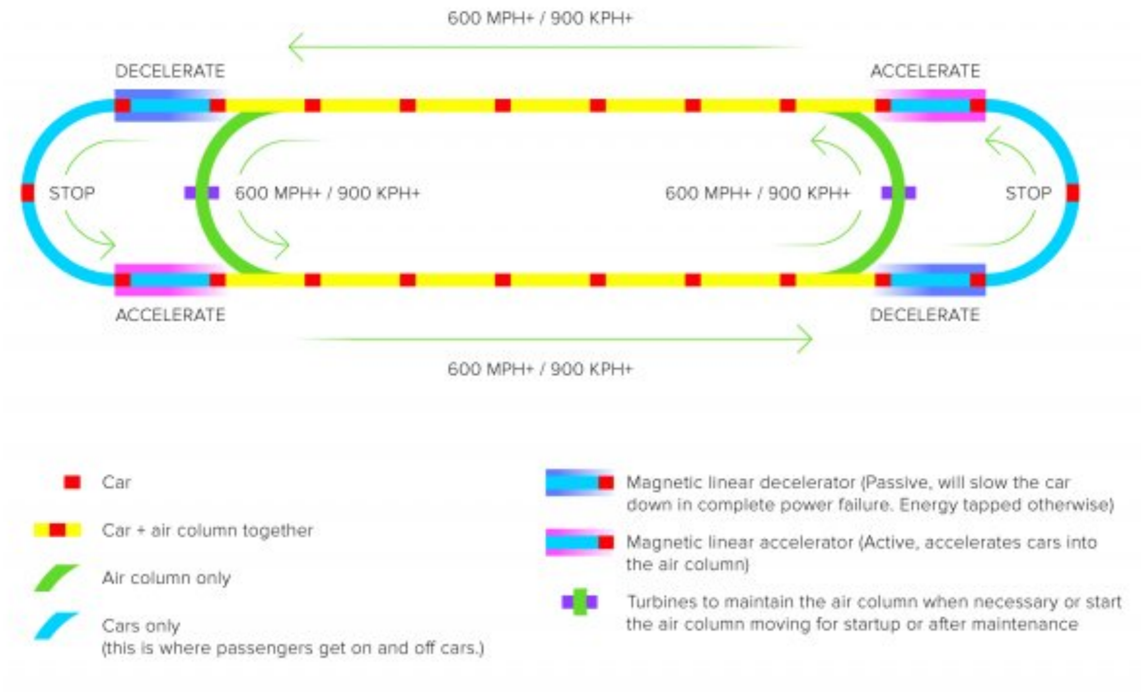


Source: Hwee, 2017

FIGURE A5: High Speed Rail System

Source: California High Speed Rail Authority, 2016

Figure A6: Hyperloop Diagram



Source: Yarow, 2013