Assessment of Options for Quantifying Reduction in Vehicle Miles Traveled (VMT) from Mitigation Measures

December 2024 (Updated June 2025)

A Research Report from the Pacific Southwest Region University Transportation Center

Susan L. Handy, University of California, Davis

Jamey M. B. Volker, University of California, Davis

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. PSR-23-21-02	2. Government Accession No. N/A	3. Recipient's Catalog No. N/A
4. Title and Subtitle Assessment of Options for Quantifying Reduction in Vehicle Miles Traveled (VMT) from Mitigation Measures		5. Report Date December 2024 (Updated June 2025) 6. Performing Organization Code N/A
7. Author(s) Susan L. Handy, Ph.D., https://orcid.org/0000-0002-4141-1290 Jamey M. B. Volker, Ph.D., https://orcid.org/0000-0002-4559-6165		8. Performing Organization Report No. UCD-ITS-RR-24-94
9. Performing Organization Name and Address University of California, Davis Institute of Transportation Studies 1605 Tilia Street, Suite 100 Davis, CA 95616		10. Work Unit No. N/A 11. Contract or Grant No. USDOT Grant 69A3551747109 Caltrans 65A0940 Task 3.2
12. Sponsoring Agency Name and Address U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology 1200 New Jersey Avenue, SE, Washington, DC 20590 California Department of Transportation Division of Research, Innovation and System Information, MS-83 1727 30th Street, Sacramento, CA 95816		13. Type of Report and Period Covered Final Report (April 2022 – September 2024) 14. Sponsoring Agency Code USDOT OST-R Caltrans DRISI
15. Supplementary Notes https://metrans.org/research/methods-for-assessing-the-effectiveness-of-potential-vehicle-miles-traveled-vmt-mitigation-measures		
16. Abstract Guidelines for the California Environmental Quality Act require the mitigation of projected increases in vehicle miles traveled (VMT) stemming from highway expansion projects. Quantifying the likely effects of proposed mitigation measures enables an assessment of the degree to which the mitigation program offsets the estimated increase in VMT for a project. The purpose of this report is to provide an overview of possible estimation methods for 45 mitigation strategies and recommendations on the most appropriate method for estimating the reduction in the number of miles of vehicle travel that could be expected to result from the implementation of a specific measure. The methods take into account the extent of the measure but may not account for the specific context. In general, two types of methods are available: travel demand forecasting models, and effect-size approaches. For several measures, this report concludes that the reduction in VMT cannot be estimated based on the available evidence. The Evidence Assessment Report provides as assessment of the strength of the evidence for each of the measures (Handy et al., 2024).		

17. Key Words Vehicle miles traveled; mitigation strategies; effect size; quantification		18. Distribution Statement No restrictions.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 49	22. Price N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Contents

List of Tables

Pacific Southwest Region UTC
University Transportation Center

About the Pacific Southwest Region University Transportation Center

The Pacific Southwest Region University Transportation Center (UTC) is the Region 9 University Transportation Center funded under the US Department of Transportation's University Transportation Centers Program. Established in 2016, the Pacific Southwest Region UTC (PSR) is led by the University of Southern California and includes seven partners: Long Beach State University; University of California, Davis; University of California, Irvine; University of California, Los Angeles; University of Hawaii; Northern Arizona University; Pima Community College.

The Pacific Southwest Region UTC conducts an integrated, multidisciplinary program of research, education and technology transfer aimed at *improving the mobility of people and goods throughout the region.* Our program is organized around four themes: 1) technology to address transportation problems and improve mobility; 2) improving mobility for vulnerable populations; 3) Improving resilience and protecting the environment; and 4) managing mobility in high growth areas.

California Department of Transportation (CALTRANS) Disclaimer

Disclosure

Susan L. Handy, Jamey M. B. Volker, and Reyhane Hosseinzade conducted this research titled, "Methods for Assessing the Effectiveness of Potential Vehicle-Miles-Traveled (VMT) Mitigation Measures" at the University of California, Davis. The research took place from April 2022 to September 2024, and was funded by contract 65A0940 from the California Department of Transportation (Caltrans) in the amount of $599,594.00. The research was conducted as part of the Pacific Southwest Region University Transportation Center research program.

Acknowledgements

Caltrans staff reviewed drafts of this report and provided valuable feedback.

Abstract

Guidelines for the California Environmental Quality Act require the mitigation of projected increases in vehicle miles traveled (VMT) stemming from highway expansion projects. Quantifying the likely effects of proposed mitigation measures enables an assessment of the degree to which the mitigation program offsets the estimated increase in VMT for a project. The purpose of this report is to provide an overview of possible estimation methods for 45 mitigation strategies and recommendations on the most appropriate method for estimating the reduction in the number of miles of vehicle travel that could be expected to result from the implementation of a specific measure. The methods take into account the extent of the measure but may not account for the specific context. In general, two types of methods are available: travel demand forecasting models, and effect-size approaches. For several measures, this report concludes that the reduction in VMT cannot be estimated based on the available evidence. The Evidence Assessment Report provides as assessment of the strength of the evidence for each of the measures (Handy et al., 2024).

Assessment of Options for Quantifying Reductions in Vehicle Miles Traveled (VMT) from Mitigation Measures

Executive Summary

Guidelines for the California Environmental Quality Act require the mitigation of projected increases in vehicle miles traveled (VMT) stemming from highway expansion projects. Quantifying the likely effects of proposed mitigation measures enables an assessment of the degree to which the mitigation program offsets the estimated increase in VMT for a project. The purpose of this report is to provide an overview of possible estimation methods for 45 mitigation strategies and recommendations on the most appropriate method for each (Table 1). This report pairs with a companion "Evidence Assessment Report" that reviews the empirical evidence on the effectiveness of the same 42 VMT mitigation strategies (Handy et al., 2024).

The recommended methods will produce estimates of VMT reductions with a high degree of uncertainty. The estimates will generally reflect a typical or average effect, rather than one that reflects the specific local context in which it is implemented. The evidence on which the methods are based predates the COVID-19 pandemic and thus might not be representative of post-pandemic effects. If multiple complimentary measures are implemented simultaneously, the total effects could be more than the sum of the effects of individual measures, though it is possible that the total effects will be less than the sum, particularly if reductions "top out" at some level. Mitigation measures are by definition implemented in conjunction with highway expansion projects, which are likely to lessen the effect of the measures relative to what the evidence might suggest. In addition, it is possible that backfilling could ultimately reduce the total VMT-reducing effect of the mitigation measures—if enough vehicles are removed from roadways to make it faster, safer, more enjoyable, or otherwise easier to drive, that could have a rebound effect of inducing more driving and VMT.

This review provides recommendations for methods for estimating the reduction in the number of miles of vehicle travel that could be expected to result from the implementation of a specific measure. The methods take into account the extent of the measure but may not account for the specific context. In general, two types of methods are available:

- Travel demand forecasting models: Such models are available for most metropolitan planning organizations (MPOs). Depending on the nature of the model, it may be usable for estimating the effects of many of the land use and transit measures reviewed in this report. A benefit of using such models is that they reflect many aspects of the local context, but they have a high degree of uncertainty especially for relatively small areas within the region. This report provides guidance on measures and situations for which models might be an appropriate method but does not discuss the details of how the models would be used to this end.

- Effect-size approaches: These methods employ estimates of effect sizes derived from empirical research, that is, real-world studies of the effect of the measure. Effect sizes are reported either as a number change in the outcome associated with a number change in the measure or as a percent change in the outcome associated with a percent change in the measure; the latter ratio is an "elasticity." This report provides guidance on what effect size is appropriate for a given measure and how it can be applied to estimate the possible reductions in VMT for that measure. Three sources provide guidance on the appropriate effect size for many of the measures: University of California, Davis assessment (Handy et al., 2024), the California Air Resources

Board (CARB) Senate Bill (SB) 375 Research Briefs, and the California Air Pollution Control Officers Association (CAPCOA) Handbook. When the available studies indicate a range of effect sizes, a mid-point effect size is recommended, though in some cases more weight is given to the more recent and more robust studies. For some measures, the available evidence focuses on aspects of travel behavior that are indirectly related to VMT.

For several measures, this report concludes that the reduction in VMT cannot be estimated based on the available evidence. This does not mean that the measures will not reduce VMT or should not be incorporated into a mitigation program. Even when the evidence is insufficient for quantifying the effect of a measure, it may be sufficient to be confident that the measure will reduce VMT some amount. The Evidence Assessment Report provides as assessment of the strength of the evidence for each of the measures (Handy et al., 2024).

1. Introduction

Guidelines for the California Environmental Quality Act require the mitigation of projected increases in vehicle miles traveled (VMT) stemming from highway expansion projects. Quantifying the likely effects of proposed mitigation measures enables an assessment of the degree to which the mitigation program offsets the estimated increase in VMT for a project. The purpose of this report is to provide an overview of possible estimation methods for 45 mitigation strategies and recommendations on the most appropriate method for each (Table 1). This report pairs with a companion “Evidence Assessment Report” that reviews the empirical evidence on the effectiveness of the same 42 VMT mitigation strategies (Handy et al., 2024).

The recommended methods will produce estimates of VMT reductions with a high degree of uncertainty. The estimates will generally reflect a typical or average effect, rather than one that reflects the specific local context in which it is implemented. The evidence on which the methods are based predates the COVID-19 pandemic and thus might not be representative of post-pandemic effects. If multiple complimentary measures are implemented simultaneously, the total effects could be more than the sum of the effects of individual measures, though it is possible that the total effects will be less than the sum, particularly if reductions “top out” at some level. Mitigation measures are by definition implemented in conjunction with highway expansion projects, which are likely to lessen the effect of the measures relative to what the evidence might suggest. In addition, it is possible that backfilling could ultimately reduce the total VMT-reducing effect of the mitigation measures—if enough vehicles are removed from roadways to make it faster, safer, more enjoyable, or otherwise easier to drive, that could have a rebound effect of inducing more driving and VMT.

This review provides recommendations for methods for estimating the reduction in the number of miles of vehicle travel that could be expected to result from the implementation of a specific measure. The methods take into account the extent of the measure but may not account for the specific context. In general, two types of methods are available:

- Travel demand forecasting models: Such models are available for most metropolitan planning organizations (MPOs). Calibrated based on travel survey data, they consist of a mathematical representation of the region’s transportation system (include land use patterns) and provide a means of estimating the effects of changes to that system. Depending on the nature of the model, it may be usable for estimating the effects of many of the land use and transit measures reviewed in this report. A benefit of using such models is that they reflect many aspects of the local context, but they have a high degree of uncertainty especially for relatively small areas within the region. They are generally do not fully incorporate the effects of active travel projects and parking management measures, and are thus unable to produce accurate estimates of the VMT effects of those projects. This report provides guidance on measures and situations for which models might be an appropriate method but does not discuss the details of how the models would be used to this end.

- Effect-size approaches: These methods employ estimates of effect sizes derived from empirical research, that is, real-world studies of the effect of the measure. Effect sizes are reported either as a number change in the outcome associated with a number change in the measure or as a percent change in the outcome associated with a percent change in the measure; the latter ratio is an "elasticity." Longitudinal studies of changes that occur in given places when the measure is implemented provide stronger evidence of the effect than cross-sectional studies, which compare VMT (or other aspects of travel, see below) in places with versus places without the measure (usually while controlling for other differences). This report provides guidance on what effect size is appropriate for a given measure and how it can be applied to estimate the possible reductions in VMT for that measure. Three sources provide guidance on the appropriate effect size for many of the measures:
    - University of California, Davis (UC Davis) assessment: As summarized in the Evidence Assessment Report (Handy et al., 2024), the UC Davis team reviewed the available evidence (focusing on peer-reviewed academic studies) for each of the measures and provided an assessment of the sufficiency of the evidence for quantifying their effects.
    - The California Air Resources Board (CARB) Senate Bill (SB) 375 Research Briefs: These briefs were originally produced by a team of researchers from UC Davis and the University of Southern California (USC) in the 2012-2014 timeframe. The team updated many of the briefs in 2025, and several new topics were added. This report cites the 2025 brief for the measures for which they are available and the 2014 briefs for topics for which updates were not made; for some measures, no brief was prepared in either 2014 or 2025. The briefs, available on the CARB website[1] (CARB, n.d.), provide guidance on the range of possible effect sizes based on the available empirical research.
    - The California Air Pollution Control Officers Association (CAPCOA) Handbook: The CAPCOA Handbook also employed the available empirical evidence in developing methods for estimating percentage reductions in greenhouse gas (GHG) emissions for various emissions-reduction measures for proposed development projects. The assumptions for each measure, including measures to reduce emissions from transportation but also other sources, are presented in the Handbook. For many but not all of the transportation measures, the assumptions are consistent with the guidance in the CARB briefs. For many measures, the method includes an estimate of percent reductions in VMT if that measure were to be implemented for a given development project. The methods impose caps on the maximum reductions for individual measures and combinations of measures. Because the methods estimate percent reductions in VMT for the development project itself, rather absolute reductions for an area, they are not always directly usable for estimating the effects of mitigation measures for highway projects. However, the assumptions built into the tool are be relevant for some measures.

  When the available studies indicate a range of effect sizes, a mid-point effect size is recommended, though in some cases more weight is given to the more recent and more robust studies.

  For some measures, the available evidence focuses on aspects of travel behavior that are indirectly related to VMT. For most transit measures, the available studies quantify the effect of

[1] https://ww2.arb.ca.gov/our-work/programs/sustainable-communities-program/research-effects-transportation-and-land-use

the measure on transit ridership rather than VMT; for most bicycle and pedestrian measures, the available studies quantify the effect of the measure on walking and bicycling rather than VMT. In these cases, the effects can be converted to an estimated effect on VMT, but the conversion is not one-to-one for three reasons: 1) Not all new transit, walking, or bicycling trips replace driving trips; 2) For trips that do replace driving trips, the trip distance may be different; and 3) Auto occupancy is often greater than one, meaning that one additional transit, walking, or bicycling trip may replace less than one driving trip. The additional assumptions needed to convert the estimated effect on transit, walking, or bicycling into an effect on VMT adds to the uncertainty of the estimate. Other indirect evidence of a reduction in VMT comes from studies showing a decrease in car ownership and/or a decrease in trip distances associated with the measure.

For several measures, this report concludes that the reduction in VMT cannot be estimated based on the available evidence. This does not mean that the measures will not reduce VMT or should not be incorporated into a mitigation program. Even when the evidence is insufficient for quantifying the effect of a measure, it may be sufficient to be confident that the measure will reduce VMT some amount. The Evidence Assessment Report provides as assessment of the strength of the evidence for each of the measures (Handy et al., 2024).

Table 1. Summary of Recommendations for Quantifying Mitigation Measures

	Quantification Recommendation
Public transportation measures	
Transit service headways/frequency	Use effect size estimate or travel demand model
First/last mile connectivity	Do not quantify
Transit service coverage	Use effect-size approach or travel demand model
Transit-supportive roadway design	Do not quantify or use travel demand model
Transit fares	Use effect-size approach or travel demand model
Transit reliability	Do not quantify
Mobility hubs	Do not quantify
TNC/transit partnership	Do not quantify
Transit stop amenities	Do not quantify
Transit vehicle amenities	Use effect-size approach
Park-and-ride lots	Do not quantify
Marketing transit	Do not quantify
On-demand transit	Use effect-size approach
Commuter/regional rail	Use effect-size approach or travel demand model
Travel demand management measures	
Telecommuting	Use effect-size approach
Employer-based Commute Trip Reduction programs	Use effect-size approach
Transit pass subsidies	Use effect-size approach

	Quantification Recommendation
Ridesharing Programs	Use effect-size approach
Car-sharing programs	Do not quantify
Community-based travel planning	Use effect-size approach
Safe Routes to School and other school-based programs	Do not quantify
Broadband improvements	Do not quantify
Land use measures	
Transit-Oriented Development (TOD)	Use effect-size approach or travel demand model
Residential density	Use effect-size approach or travel demand model
Employment density	Use travel demand model or do not quantify
Affordable housing	Use effect-size approach
Land preservation as growth management	Use travel demand model or do not quantify
Land-use mix	Use travel demand model or do not quantify
Delivery Hubs	Do not quantify
Jobs/housing balance	Use travel demand model or do not quantify
Road management measures	
Congestion pricing	Use effect-size approach or travel demand model
Road diets/ complete streets	Do not quantify
Local network connectivity	Use effect-size approach or travel demand model
Traffic calming	Do not quantify
Curb management	Do not quantify
Active transportation measures	
Bicycle facilities	Use effect-size approach
Pedestrian facilities	Use CAPCOA approach
E-bike incentive programs	Use effect-size approach
Bike share and scooter share	Use effect-size approach
Parking management measures	
Parking workplace pricing	Use effect-size approach
Parking cash-out programs	Use effect-size approach
Pricing on-street parking	Use effect-size approach
Adaptive parking pricing	Do not quantify
Residential parking restrictions	Use effect-size approach
Unbundling parking costs	Do not quantify

2. Public Transit Measures

For the transit measures for which sufficient evidence is available (see Table 2), VMT reductions can be estimated using an effect-size approach. For many of the public transit measures, studies have quantified the effect of the measure on transit ridership rather than VMT. In this case, the elasticity is the percent change in ridership given a one percent (or in some cases, a one unit) change in the measure. The results of these studies (as summarized in the CARB briefs and in the Evidence Assessment Report (Handy et al., 2024)) can be used to estimate the change in transit ridership that the measure could produce. Translating the estimated change in ridership into an estimated change in VMT requires assumptions about the share of new transit trips that replace driving trips, average vehicle occupancy, and the average length of those driving trips. In general, the change in VMT can be estimated in two steps as follows:

> Change in number of transit trips = (elasticity x % change in measure) x current transit trips in the area affected by the measure
>
> Change in VMT = Change in number of transit trips x share of transit trips that replace driving trips x 1/average vehicle occupancy x average length of driving trips

When the effect size is in the form of an elasticity, the percent change in the measure is used. The extent of the measure, e.g., the share of the transit system to which it applies, should be taken into account in determining the current number of transit trips to which to apply the effect size. Recommended elasticities are presented in the following subsections. Recommendations for the conversion of change in transit trips to change in VMT are as follows.

Share of new transit trips replace driving trips: Two approaches are recommended. One approach is to use the mode share for the region. This approach assumes that the share of new transit trips that replace driving trips is equal to the share of trips in the region that are driving trips. This approach most likely overstates the reduction in driving trips, as transit riders are less likely to own a vehicle than the general population. Research shows that new trips for a given are sometimes entirely new trips rather than trips shifted from another mode to the new mode (Piatkowski et al., 2015). The second approach is to use survey data on mode substitution, collected using a hypothetical "what would you have done" question. For example, a survey of riders by the Atlanta Regional Commission found that, if transit service had not been available, 31.4% of respondents would have used "Uber, Lyft, etc." to make their trip, 24.6% would have driven alone, and 20.4% would have driven with someone else, while 12% of respondents said they would not have made a trip. If a similar question has been asked in a local transportation survey, the results can be used in calculating the number of driving trips reduced. A third option is to use the model developed by Greenwald (2003) to predict the substitution rate for transit versus driving. The model takes into account many characteristics of the local context but is based on data that is now over two decades old.

Average vehicle occupancy: Transit trips are not directly equivalent to vehicle trips, in that each transit trip represents one person while each vehicle trips reflects more than one person trip on average. Each new transit trip that replaces driving replaces less than one vehicle trip. Data on average vehicle occupancy is generally available from regional travel surveys. If a recent regional survey is not available, averages from the National Household Travel Survey can be used (FHWA, 2024).

Average driving trip length: Data on the average length of driving trips is generally available from regional travel surveys. If a recent regional survey is not available, averages from the National Household Travel Survey can be used (FHWA, 2024).

Nearly all studies reviewed in the Evidence Assessment Report (Handy et al., 2024) and cited in the CARB briefs and the CAPCOA Handbook were conducted before the COVID-19 pandemic, which dramatically impacted both transit service and transit ridership. The effect sizes identified in these studies may no longer be applicable.

Some regional travel demand forecasting models incorporate transit networks. These models can be used to estimate the effects of improvements in transit service and coverage as well as reductions in fares, although estimates are likely to be highly uncertain.

Table 2. Public Transit Measures – Quantification Options

Measures	UC Davis assessment	CARB briefs	CAPCOA Handbook	Travel Demand Model
Transit service headways/frequency	X	X	X	X
First/last mile connectivity	Insufficient evidence			
Transit service coverage	X	X	X	X
Transit-supportive roadway design	Not quantified		X	
Transit fares	X	X	X	X
Transit reliability	Not quantified			
Mobility hubs	Insufficient evidence			
TNC/transit partnership	Not quantified			
Transit stop amenities	Not quantified			
Transit vehicle amenities	X			
Park-and-ride lots	Not quantified			
Marketing transit	Insufficient evidence			
On-demand transit	Not quantified			
Commuter/regional rail	Not quantified			X

Transit service headways/frequency: A strong body of evidence suggests that increases in transit service frequency (equivalent to a reduction in headways) can increase transit ridership. The effect can be quantified with a moderate degree of certainty, though all studies were conducted before the COVID-19 pandemic.

Nine studies reviewed in the Evidence Assessment Report (Handy et al., 2024) provide a quantification of the effect of increases in frequencies. Estimated effect sizes range from a 0.27% to 0.83% increase in ridership per 1% increase in service frequency (elasticity from 0.27 to 0.83), though one national study found a 1.17% increase in ridership per 1% increase in service frequency (elasticity of 1.17).

The 2014 CARB brief on Transit Service concludes that the elasticity for service frequency is around 0.5, meaning that a 1% increase in service frequency could produce a 0.5% increase in ridership.

The CAPCOA method for transit frequency (Measure T-26, Increase Transit Service Frequency) provides an estimate of the percent change in VMT rather than an amount of VMT (pg. 183). It employs the 0.5 elasticity reported in the CARB brief. One limitation is that it assumes that all new transit trips replace driving trips. It does, however, account for the average vehicle occupancy for driving trips in California of 1.7 persons per vehicle, meaning that the reduction in vehicle trips is 57.8% (1/1.7) of the reduction in person trips, in this case transit trips. It assumes that the percent reduction in VMT will be equal to the percent reduction in driving trips, which is equivalent to assuming that trips are of equal length regardless of mode.

The CAPCOA method for bus rapid transit (Measure T-28, Provide Bus Rapid Transit) could be helpful in quantifying this measure. This method quantifies the effect of the percent increase in transit frequency due to Bus Rapid Transit (BRT) (pg. 193).

In regions in which the travel demand forecasting model includes a transit network, the model could be used to estimate the effects of increasing transit service frequency on VMT. Travel demand forecasting models are better suited to estimate VMT impacts for regionwide rather than localized changes.

> Recommendation: Estimate the change in number of transit trips using an elasticity of 0.5 applied to the base number of transit trips affected by the change in service frequency (e.g. the number of trips on the lines on which the frequency is increased). Convert change in transit trips to change in VMT using the method described earlier. If a regional travel demand model with a transit network is available and if the increases in frequency are widespread across the region, consider using the regional travel demand model to estimate the VMT reductions.

First/last mile connectivity: Studies suggest that policies that improve first-mile/last-mile connectivity—for example, by coordinating with micromobility and ridehailing services—do not have a statistically significant impact on transit ridership. This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook, though first and last mile transportation network company (TNC) incentives are included as a non-quantified measure (T-38, Provide First and Last Mile TNC Incentives, pg. 47).

> Recommendation: Do not quantify this measure.

Transit service coverage: A moderate body of evidence suggests that increases in transit service coverage can increase transit ridership. The effect can be quantified but is highly uncertain and depends on the local context. The effect sizes reported below reflect changes in passenger travel but do not account for increases in transit vehicle mileage.

Two studies reviewed in the Evidence Assessment Report (Handy et al., 2024) provide a quantification of the effect, though their measures of coverage differ. One study found a 3% to 9% increase in ridership per additional bus stop within a 200 meter buffer. The second study found a 0.95% increase in ridership per 1% increase in route density (elasticity of 0.95) where route density is measured as revenue miles of service/service area.

The 2014 CARB brief for Transit Service specifies a 0.7% increase in ridership per 1% increase in service hours or miles (elasticity of 0.7). The 2025 CARB brief for Transit Access (Distance to Transit) concludes that VMT decreases by 0.75% to 4.3% per mile closer to rail stations and by 1.5% per quarter mile closer to a bus stop.

The CAPCOA method for transit network coverage (T-25, Extend Transit Network Coverage or Hours) provides an estimate of the percent change in VMT rather than an amount of VMT (pg. 179). It employs the 0.7 elasticity reported in the CARB brief. One limitation is that it assumes that all new transit trips replace driving trips. It does, however, account for the average vehicle occupancy for driving trips in California of 1.7 persons per vehicle, meaning that the reduction in vehicle trips is 57.8% (1/1.7) of the reduction in person trips, in this case transit trips. It assumes that the percent reduction in VMT will be equal to the percent reduction in driving trips, which is equivalent to assuming that all trips are of equal length.

In regions in which the travel demand forecasting model includes a transit network, the model could be used to estimate the effects of increased transit service coverage on VMT. Travel demand forecasting models are better suited to estimate VMT impacts for regionwide rather than localized changes.

> Recommendation: Estimate the change in number of transit trips using an elasticity of 0.7 for change in service hours or an elasticity of 0.95 for change in route density. Apply the elasticity to the base number of transit trips in the area affected by the change in service coverage. Convert change in transit trips to change in VMT using the method described earlier. If a regional travel demand model with a transit network is available and if the increases in frequency are widespread across the region, consider using the regional travel demand model to estimate the VMT reductions.

Transit-supportive roadway design: Studies suggest that implementation of transit-supportive roadway design, such as signals that prioritize transit, but do not provide a clear quantification of the effect on transit ridership. This measure was not evaluated in the CARB briefs.

The CAPCOA method for transit-supportive roadway treatments (T-27, Implement Transit-Supportive Roadway Treatments) provides an estimate of the percent change in VMT rather than an amount of VMT (pg. 189) for one type of transit-supportive roadway design, transit signal prioritization. It assumes that this strategy will produce a travel time savings of 10% and that the elasticity of transit ridership with respect to transit travel time is -0.4 (based on a 2007 report). This method incorporates auto mode share to account for the likelihood that not all new transit trips replace driving trips, and it accounts for the average vehicle occupancy for driving trips in California of 1.7 persons per vehicle, meaning that the reduction in vehicle trips is 57.8% (1/1.7) of the reduction in person trips, in this case transit trips. It assumes that the percent reduction in VMT will be equal to the percent reduction in driving trips, which is equivalent to assuming that all trips are of equal length. It adjusts for the share of transit routes in the system for which traffic signal prioritization is implemented.

In regions in which the travel demand forecasting model includes a transit network, the model could be used to estimate the effects of increased transit speeds stemming from signal prioritization on VMT. Travel demand forecasting models are better suited to estimate VMT impacts for regionwide rather than localized changes.

> Recommendation: If a regional travel demand model is available and if the signal prioritization is widespread across the region, consider using the regional travel demand model to estimate the VMT reductions. Otherwise, do not quantify.

Transit fares: A strong body of evidence shows that increases in transit fares are likely to reduce transit ridership, suggesting that a decrease in fares is likely to lead to an increase in transit ridership, though the effect may not be symmetrical. The effect of transit fare reductions can be quantified.

Four studies reviewed in the Evidence Assessment Report (Handy et al., 2024) provide a quantification of the effect. Estimated effect sizes range from a 0.22% to 0.57% increase in ridership per 1% decrease in fares for bus service (-0.22 to -0.57 elasticity), and from 0.35% to 0.40% for rail service (-0.35 to -0.40 elasticity), rising to 0.80% in the long term (-0.80 elasticity). One national study suggests a 1.19% increase in ridership per 1% decrease in fares (-1.19 elasticity).

The 2025 CARB brief for Transit Fare Policies reports elasticities for transit ridership from a number of studies. A study of 198 transit operators in the U.S. (Schimek, 2015) found that a 1% decrease in fares was associated with a 0.48% increase in transit ridership in larger urban areas (elasticity of -0.48) and a 73% increase in ridership in smaller urban areas (with less than 1 million population; an elasticity of -0.73).

The CAPCOA method for transit fares (T-29, Reduce Transit Fares) provides an estimate of the percent change in VMT rather than an amount of VMT (pg. 200) for transit fare reductions. It specifies a 0.3% increase in ridership per 1% decrease in fares (-0.30 elasticity), citing the CARB brief. This method incorporates auto mode share to account for the likelihood that not all new transit trips replace driving trips, and it accounts for the average vehicle occupancy for driving trips in California of 1.7 persons per vehicle, meaning that the reduction in vehicle trips is 57.8% (1/1.7) of the reduction in person trips, in this case transit trips. It assumes that the percent reduction in VMT will be equal to the percent reduction in driving trips, which is equivalent to assuming that all trips are of equal length. It adjusts for the share of transit routes in the system for which fares are reduced.

In regions in which the travel demand forecasting model includes a transit network, the model could be used to estimate the effects of decreased transit fares on VMT. Travel demand forecasting models are better suited to estimate VMT impacts for regionwide rather than localized changes.

> Recommendation: Estimate the change in number of transit trips using an elasticity of -0.48 for large urban areas and -0.73 for small urban areas for change in fares applied to the base number of transit trips on the routes affected by the change in fares. Convert change in transit trips to change in VMT using the method described earlier. If a regional travel demand model with a transit network is available and if the decreases in fares are widespread across the region, consider using the regional travel demand model to estimate the VMT reductions.

Transit reliability: Studies suggest that improvements in transit reliability, measured as on-time performance, have a positive effect on transit ridership, but they do not provide a clear quantification of the effect on transit ridership. This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook.

> Recommendation: Do not quantify.

Mobility hubs: Studies from Europe suggest that mobility hubs have a positive effect on transit ridership, but they do not provide a clear quantification of the effect on transit ridership. This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook.

> Recommendation: Do not quantify.

TNC/transit partnership: Evidence is mixed as to the effect of ride-hailing services provided by TNCs on transit ridership: studies point to a decrease in bus ridership but a potential increase in rail ridership. Three studies suggest that partnerships between TNCs and transit agencies can increase transit ridership but they do not provide a clear quantification of this effect. The 2025 CARB brief for TNC and Transit Partnerships cites a study of TNC/transit partnership that found a range of effects from a five percentage-point reduction to a 13 percentage-point increase in transit ridership. This measure is not included in the CAPCOA Handbook.

Recommendation: Do not quantify.

Transit-stop amenities: A moderate body of evidence suggests that transit-stop amenities such as shelters and lighting could increase transit ridership, but studies do not provide a clear quantification of the effect. This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook.

Recommendation: Do not quantify.

Transit-vehicle amenities: A moderate body of evidence suggests that transit-stop amenities such as shelters and lighting could increase transit ridership. Two studies reviewed in the Evidence Assessment Report (Handy et al., 2024) provide a quantification of the effect of real-time information (RTI) systems on ridership. Effects ranged from a 1.7% to 2.2% increase in ridership for routes with RTI. This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook, though two relevant measures are included as non-quantified measures (T-43, Provide Real-Time Transit Information, and T-46, Improve Transit Access, Safety, and Comfort).

Recommendation: Estimate the change in number of transit trips using an effect size of a 2% increase in transit ridership on routes on which RTI is implemented. Convert change in transit trips to change in VMT using the method described earlier.

Park-and-ride lots: A moderate body of evidence suggests that park-and-ride lots could increase transit ridership, but studies do not provide a clear quantification of the effect. This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook.

Recommendation: Do not quantify.

Marketing transit: No studies of the effect of marketing on transit ridership are available for the U.S. This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook.

Recommendation: Do not quantify.

On-demand transit: Few studies have yet been conducted of the effect of on-demand transit on overall ridership. Two studies from Canada reviewed in the Evidence Assessment Report (Handy et al., 2024) provide evidence that on-demand transit increases ridership but they do not provide a clear quantification of the effect. The 2025 CARB brief for Microtransit found that the use of microtransit has mixed impacts on transit ridership. This measure is not included in the CAPCOA Handbook, though on-demand microtransit is included as a non-quantified measure (T-45, Provide On-Demand Microtransit).

Recommendation: If a study of a new microtransit system or an expansion of an existing system is available and provides an estimate of the expected net increase in transit trips (accounting for a shift from conventional transit service to microtransit service), use this value. Convert change in transit trips to change in VMT using the method described earlier.

Commuter/regional rail: A moderate body of evidence suggests that implementation of commuter or regional rail in place of or in addition to bus service can increase transit ridership, but studies do not provide a clear quantification of the effect. This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook. In regions in which the travel demand forecasting model includes a transit network, the model could be used to estimate the effects of expanding rail on VMT.

> Recommendation: For increases in service frequency for commuter or regional rail, use the method recommended for transit frequency. If a regional travel demand model is available and includes a transit network, consider using the regional travel demand model to estimate the VMT reductions.

3. TDM Mitigation Measures

Travel demand management (TDM) measures generally focus on reducing vehicle trips, particularly commute trips during peak commute hours. The effects of programs are often measured in terms of vehicle trip rates, calculated as the number of vehicle trips to the site divided by the number of employees working there.

For the TDM measures for which sufficient evidence is available (see Table 3), VMT reductions can be estimated using an effect-size approach. For most measures, elasticities would be applied to the population participating in the program. For some measures, a region-wide elasticity is available.

Table 3. TDM Measures – Quantification Options

Measures	UC Davis assessment	CARB briefs	CAPCOA Handbook	Travel demand model
Telecommuting	X	X		
Employer-based Commute Trip Reduction programs	X	X	X	
Transit pass subsidies	X	X	X	X
Ridesharing Programs	Insufficient evidence	X	X	
Car-sharing programs	Insufficient evidence	X	X	
Community-based travel planning		X	X	
Safe Routes to Schools (SRTS) and other school-based programs	Not quantified			
Broadband improvements	Insufficient evidence			

Telecommuting: Despite a strong body of evidence, the impacts of telecommuting on VMT are uncertain. While telecommuting reduces commute VMT, it may lead to an increase in non-commute VMT that at least partially offsets this reduction. If workers change their residential location in response to telecommuting, VMT reductions may be further offset. The total impacts of telecommuting on VMT depend on the number of workers telecommuting, the number of days each worker telecommutes, and the impact on VMT per telecommuting day. Studies provide evidence on the last element: the impact on VMT per telecommuting day. In evaluating a telecommuting incentive program as a mitigation strategy, the effectiveness of the program in increasing the number of workers telecommuting would also have to be estimated.

Most of the studies reviewed in the Evidence Assessment Report (Handy et al., 2024) are cross-sectional, meaning that they compare VMT for telecommuters and non-telecommuters, and are not appropriate for estimating the effect on VMT when workers adopt telecommuting. One longitudinal study suggests that telecommuting leads to a net reduction in a worker's daily travel distance (across all modes) of 9.1%. It is reasonable to assume that the reduction in VMT would be similar. A state-level longitudinal study conducted in the first two years of the pandemic found that a 1% decrease in onsite workers (or a 1% increase in remote workers) was associated with a 0.99% decrease in state-level VMT (elasticity of -0.99).

The 2025 CARB Telecommuting brief also cites a reduction in person miles traveled of 9.1% for telecommuters on telecommuting days. The 2014 brief specified much higher reductions in VMT based on studies from the 1980s and 1990s. The higher effect sizes from the earlier studies could reflect the fact that far smaller shares of workers were telecommuting at that time in comparison to the pandemic period. These workers might not have been typical of all workers in terms of their residential locations and non-commute travel patterns.

The CAPCOA Handbook does not include a method for estimating the impact of telecommuting on VMT. However, the methods for commute trip reduction programs, both voluntary (T-5, Implement Commute Trip Reduction Program (Voluntary)) and mandatory (T-6, Implement Commute Trip Reduction Program (Mandatory Implementation and Monitoring)), may be relevant, as such programs often include policies on telecommuting.

> Recommendation: Estimate the reduction in VMT by applying the 9.1% reduction to the average VMT per worker times the estimated increase in the number of workers telecommuting. Data on average VMT for workers is generally available from regional travel surveys. If a recent regional survey is not available, averages from the National Household Travel Survey can be used (FHWA, 2024). Alternatively, apply an elasticity of -0.99 to the expected increase in the percentage of workers telecommuting in the area to estimate the percent decrease in VMT; apply the estimated percent decrease to the estimated total VMT for the region.

Employer-based Commute Trip Reduction programs: A strong body of evidence suggests that commute trip reduction (CTR) programs can reduce VMT depending on the elements included in the program.

The five studies reviewed in the Evidence Assessment Report (Handy et al., 2024) suggest that transit passes and charging for parking tend to reduce vehicle trips, while some evidence suggests that ride-matching programs increase vehicle trips. The studies do not provide a clear quantification of the effect.

The 2025 CARB Employer-Based Trip Reduction brief specifies a VMT reduction of as much as 76% for participants of an employer bike-lending program but a much more modest 4% to 12% reduction in commute VMT for sites implementing more conventional CTR programs and a 1% to 2% reduction in peak-hour VMT for a region in which large employers are required to adopt CTR programs.

The CAPCOA method for voluntary commute trip reduction programs (T-5, Implement Commute Trip Reduction Program (Voluntary)) assumes a 4% reduction in commute VMT, citing the CARB brief (pg. 84). For mandatory programs (T-6, Implement Commute Trip Reduction Program (Mandatory Implementation and Monitoring)), the CAPCOA method assumes a 26 percentage-point reduction in vehicle mode share for employee commute trips for participating employees (pg. 87). It assumes that the percentage reduction in commute VMT is proportional to the percent reduction in vehicle trips. Note that the method treats the 26 percentage-point reduction as equivalent to a 26% reduction (the value should be 28.9%, reflecting a reduction from 90% driving to 64% driving). For both voluntary and mandatory programs, the share of employees eligible for the program is taken into account. The CAPCOA method also specifies a 4% reduction in commute vehicle trips resulting from the marketing of the CTR (T-7, Implement Commute Trip Reduction Marketing) (again assuming a proportional reduction in commute VMT). It appears that this reduction can be added to the reduction for the program itself and that the caps built into the CAPCOA method would not reduce the combined effect.

> Recommendation: Estimate the reduction in VMT by applying an 8% reduction in commute VMT for the employers implemented new programs. Estimate the commute VMT for these employers by multiplying the round-trip commute distance for employees by the number of employees eligible for

the program. Use the average round-trip commute distance provided by employers or assume the average commute distance for the region. Data on average VMT for workers is generally available from regional travel surveys. If a recent regional survey is not available, averages from the National Household Travel Survey can be used (FHWA, 2024).

Transit pass subsidies: A moderate body of evidence suggests that transit pass subsidies can increase transit use and thus reduce VMT. In percentage terms, the effect on VMT will be less than the effect on transit use, as not all new transit trips replace driving trips. The method outlined for transit mitigation measures (see above) can be used to translate increases in transit trips into reductions in VMT.

The four studies reviewed in the Evidence Assessment Report (Handy et al., 2024) provide consistent evidence that transit pass subsidies increase transit use but do not provide a clear quantification of the effect.

The 2025 CARB brief for Transit Fare Policies reports elasticities for transit ridership from a number of studies. A study of 198 transit operators in the U.S. (Schimek, 2015) found that a 1% decrease in fares was associated with a 0.48% increase in transit ridership in larger urban areas (elasticity of -0.48) and a 73% increase in ridership in smaller urban areas (with less than one million population; an elasticity of -0.73). These elasticities could be applied if transit pass subsidies are translated into a percent decrease in transit fares. In this case, the effect would be applied only to the population to whom the subsidies are offered.

The CAPCOA method for transit pass subsidies (T-9, Implement Subsidized or Discounted Transit Program) assumes that a 1% decrease in transit fare price would lead to a 0.43% increase in transit boardings (elasticity of -0.43) and that 50% of these transit trips would otherwise have been made in a vehicle, citing the CARB Transit Services brief (pg. 96). The share of employees or residents eligible for the subsidy is accounted for, as is the share of the VMT generated by the project that stems from employees or residents (as opposed to customers).

In regions in which the travel demand forecasting model includes a transit network, the model could be used to estimate the effects of transit pass subsidies on VMT. Travel demand forecasting models are better suited to estimate VMT impacts for regionwide rather than localized changes.

> Recommendation: Translate the subsidy into a percent decrease in fares for the eligible segment of the population. Apply an elasticity of -0.48 in larger urban areas and -0.73 in smaller urban areas to the percent decrease in fares to estimate the percent increase in ridership. Apply the percent increase in ridership to the population eligible to estimate the increase in transit trips, apply assumption about substitution and vehicle trip length. Use the method outlined for transit mitigation measures (see above) to translate increases in transit trips into reductions in VMT.

Ride-sharing: Ride-sharing in the form of carpooling and vanpooling has been studied as an element of employer-based trip reduction programs. Some ride-hailing services also include the option of ride-sharing. The available body of evidence is inconclusive about the effects of ride-sharing programs on VMT.

Studies of employer-based trip reduction programs reviewed in the Evidence Assessment Report (Handy et al., 2024) generally find that ride-sharing subsidies and ride-matching programs increase rather than decrease commute vehicle trips. Studies reviewed in the Evidence Assessment Report (Handy et al.,

2024) provided mixed results as to the impact of ride-hailing on VMT, with two concluding that ride-hailing increased VMT and one finding no statistically significant effect.

This measure was not evaluated in the CARB briefs.

The CAPCOA Handbook includes a method for employer-sponsored vanpool programs (T-11, Provide Employer-Sponsored Vanpool). The method makes the following assumptions based on data from San Diego (though local values can be substituted for these): 2.7% of employees participate in the vanpool program, the average one-way length of the vanpool trip is 42 miles, and the average vanpool occupancy is 6.25 (pg. 105). The average one-way vehicle commute trip length for the region is also factored in.

> Recommendation: Use local data on commute trip lengths, the anticipated number of vanpools, and the anticipated occupancy of each van to estimate commute VMT reductions.

Car-sharing: A weak body of evidence on car-sharing programs provides inconclusive evidence about their effects on VMT. A recent quasi-experiment study reviewed in the Evidence Assessment Report (Handy et al., 2024) found no statistically significant change in VMT for users of a car-sharing service. The 2025 CARB Carsharing brief concluded that the net effect of carsharing is a reduction in car ownership and use, but the size of the effect is not easily quantified based on the available evidence. Car-sharing is not included in the CAPCOA Handbook.

> Recommendation: Do not quantify.

Community-based travel planning: A weak body of evidence points to a possible reduction in VMT from community-based travel planning programs that include providing personalized travel information and facilitating access to alternatives to driving. Studies reviewed in the Evidence Assessment Report (Handy et al., 2024) show that pilot programs have succeeded in shifting driving trips to other modes but do not provide a clear quantification.

The 2025 CARB Voluntary Travel Behavior Change Programs brief concludes that such programs reduce VMT by 5% to 9% for participants.

The CAPCOA method for community-based travel planning (T-23, Provide Community-Based Travel Planning) assumes that 19% of eligible residences will participate, that vehicle trips will decline 12% for participating residences, and that a reduction in VMT proportional to the reduction in vehicle trips (pg. 172).

> Recommendation: Apply a 7% reduction in VMT for participating households. Apply this reduction to the estimated number of participating households and assume and assume the average regional VMT per household.

Safe-routes-to-school and other school-based programs: A moderate body of evidence provides evidence that school-based programs can reduce VMT. Studies reviewed in the Evidence Assessment Report (Handy et al., 2024) suggest that programs such as walking school buses and bike trains can increase walking and reduce vehicle trips but do not provide a clear quantification of the effect. This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook.

> Recommendation: Do not quantify.

Broadband improvements: No studies of the effect of broadband improvements on VMT are available. This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook.

Recommendation: Do not quantify.

4. Land Use Mitigation Measures

For the land use measures for which sufficient evidence is available (see Table 4), VMT reductions can be estimated using an effect-size approach. In general, there is strong evidence of an association between land use characteristics and VMT, suggesting that if policies are effective in changing land use characteristics, they are likely to reduce VMT. However, achieving wide-spread change in land development patterns is a long-term proposition. Such changes depend not just on public policies but also the private land development market. A change in local policy that allows for higher densities, for example, does not guarantee that higher density development will occur, even in the long run. This complicates the use of land use policies as mitigation measures and increases the uncertainty of the quantification and timing of their effects. The effects of a mitigation measure that provides support for a specific development project are possibly more assured, but projects are not always completed even after they are started, and the effects of the project on the surrounding community may be difficult to assess in advance.

Land use mitigation measures can reduce VMT for existing residents of an area, though this depends on their ability to cause a significant enough change in land use patterns to trigger changes in their travel behavior. Land use mitigation measures can also make it possible for more people to live in areas in which VMT is lower than the regional average, whether the new residents are relocating from within the region or from other regions. In this case, the reduction in VMT is relative to the "counterfactual"—what would the VMT have been for these residents if they were living in an average location compared to their VMT when living in a lower VMT area. In this case, regional VMT declines, but it also shifts within the region towards lower VMT areas, meaning that the amount of VMT in that area increases. The recommendations for quantifying the effects of the measures focus on the net reduction in VMT for the region rather than changes within localized areas.

Travel demand forecasting models can be used to estimate the effects of land use mitigation measures if those measures can be represented in the land use scenario that feeds into the model. These scenarios consist of data on population, population characteristics, employment, and employment types for spatial units called traffic analysis zones. These models are better suited to estimating the effects of widespread than localized changes in land use patterns.

Table 4. Land Use Measures - Quantification Options

Measures	UC Davis assessment	CARB briefs	CAPCOA Handbook	Travel Demand Model
Transit-Oriented Development (TOD)	X	X	X	X
Residential density	X	X	X	X
Employment density	Insufficient evidence	X	X	X
Affordable housing	Insufficient evidence		X	
Land preservation as growth management	Insufficient evidence			X
Land-use mix/ 15-minute cities	X			X
Delivery Hubs	Not quantified			
Improving jobs/housing balance	X	X		X

Transit-oriented development: A moderate body of evidence suggests that transit-oriented development (TOD) can reduce VMT. Studies reviewed in the Evidence Assessment Report (Handy et al., 2024) suggest that households living in TOD areas tend to drive less than other households, though the effect depends on the specific context, particularly the quality of transit service, and studies vary in their definition of TOD. Evidence suggests that the effect holds across income levels.

The 2025 CARB brief for Transit-Oriented Development finds that TOD residents have 28% to 41% lower VMT per household than non-TOD residents.

The CAPCOA method for TOD (T-3, Provide Transit-Oriented Development) provides a quantification of percent GHG reduction rather than VMT reduction but assumes that the VMT reduction would be equivalent to the GHG reduction (pg. 77). The method defines TOD as a residential or office project that is within a 10-minute walk or 0.5 miles of a high frequency transit station and assumes that the ratio of transit mode share for the TOD is 4.9 times the transit mode share for the surrounding city. Depending on the transit mode and auto mode shares in the surrounding city, the percent reduction in GHG emissions and thus VMT compared to an identical project not in close proximity to transit would range from 6.9% to 31.0% for California cities.

In regions in which the travel demand forecasting model includes a transit network, the model could be used to estimate the effects of TOD on VMT. Such models are better suited to estimating the effects of region-wide rather than localized measures.

> Recommendation: Estimate the number of people who will be living in the transit-oriented development. Calculate a baseline level of VMT by multiplying the number of TOD residents by the average VMT per capita for an appropriate comparison area. Estimate the reduction in VMT by multiplying the baseline VMT by 31%. If a regional travel demand model is available and the TOD is extensive, consider using the regional travel demand model to estimate the VMT reductions.

Residential density: Residential densities can be increased through changes in zoning ordinances to allow for higher densities, though other incentives may be needed to encourage the market to take advantage of the zoning changes. A strong body of evidence suggests that higher residential densities can reduce VMT.

Studies reviewed in the Evidence Assessment Report (Handy et al., 2024) suggest that higher residential densities are associated with lower VMT. According to a meta-analysis, after controlling for self-selection (the possibility that individuals who are inclined to drive less are more like to choose locations with higher population density), the effect of a 1% increase in density is a 0.22% decrease in VMT (elasticity of -0.22) (Stevens, 2017)**.**

The 2025 CARB brief for Residential Density finds strong evidence that a doubling of residential density is associated with a reduction in VMT of 7 to 12%, equivalent to a 0.07% to 0.12% decrease in VMT for a 1% increase in density (or an elasticity of -0.07 to -0.12). The brief cites two studies, including the Stevens study, that suggest that the elasticity could be as high as -0.19 to -0.22.

The CAPCOA method for residential density (T-1, Increase Residential Density) assumes an elasticity of -0.22, meaning that a 1% increase in density results in a 0.22% reduction in VMT, based on the Stevens (2017) meta-analysis (pg. 71). This value does not account for self-selection and likely overestimates the VMT reductions. Reductions are estimated for the population density of a proposed development project relative to a typical residential density of 9.1 dwelling units per acre.

Travel demand forecasting models can be used to assess the impact on VMT of increased residential densities. Travel demand forecasting models are better suited to estimate VMT impacts for large areas rather than localized changes.

> Recommendation: Estimate the percentage increase in residential density in a given area that can be expected from the proposed mitigation measure. Apply an elasticity of -0.22 to the percentage increase in residential density to estimate the percentage decrease in VMT in that area. Apply the percentage decrease in VMT to the average VMT per capita before the change in density and the expected population in the area following the change in density (including existing and new residents). (Note that this approach gives credit for reductions in VMT for new as well as existing residents at an equal rate). If a regional travel demand model is available and the increase in density is extensive, consider using the regional travel demand model to estimate the VMT reductions.

Employment density: Employment densities can be increased through changes in zoning ordinances to allow for higher densities, though other incentives may be needed to encourage the market to take advantage of the zoning changes. A weak body of evidence on employment density provides inconclusive evidence about its effects on VMT.

The studies reviewed in the Evidence Assessment Report (Handy et al., 2024) show that employment density has a weak negative impact on VMT and, in certain circumstances, may be positively associated with VMT.

The 2025 CARB brief for Employment Density concludes that the impact of employment density on VMT per capita is relatively weak and varies depending on the area of study. The available evidence suggests that a doubling of employment density is associated with at most a 3% reduction in VMT, equivalent to a 0.03% decrease in VMT for a 1% increase in density (or an elasticity of 0.03).

The CAPCOA method for job density (T-2, Increase Job Density) assumes an elasticity of -0.07, meaning that a 1% increase in density results in a 0.07% reduction in VMT (pg. 74). Reductions are estimated for the job density of a proposed development project relative to a typical job density of 145 jobs per acre.

Travel demand forecasting models can be used to assess the impact on VMT of increased residential densities. Travel demand forecasting models are better suited to estimate VMT impacts for large areas rather than localized changes.

> Recommendation: If a regional travel demand model is available and the increase in employment density is extensive, consider using the regional travel demand model to estimate the VMT reductions. Otherwise, do not quantify.

Affordable housing: A weak body of evidence on affordable housing provides inconclusive evidence about its effects on VMT. The studies reviewed in the Evidence Assessment Report (Handy et al., 2024) show that affordable housing has the potential to contribute to reductions in VMT, especially if located within areas with good transit access and mixed land uses. This measure was not evaluated in the CARB briefs.

The CAPCOA method for affordable housing (T-4, Integrate Affordable and Below Market Rate Housing) assumes a 28.6% reduction in VMT for affordable units in comparison to market-rate units (pg. 81). This value is based on evidence as to difference in vehicle trip rates between affordable and market-rate housing and assumes that trip lengths are similar.

> Recommendation: Assume average VMT per unit for the region. Apply a 28.6% reduction in VMT per unit times the number of affordable units resulting from the mitigation measure to estimate the reduction in VMT relative to market-rate units.

Land preservation as growth management: Land preservation can be used as a growth management tool to create a more compact city. A weak body of evidence on compact development provides inconclusive and indirect evidence about the effect of land preservation as growth management on VMT. The studies reviewed in the Evidence Assessment Report (Handy et al., 2024) suggest that land preservation as a part of a growth management policy can reduce VMT do not provide a clear quantification of the effect.

The 2025 CARB brief for Urban Growth Boundaries and Land Conservation cites evidence that more compact urban areas have lower VMT. If urban growth boundaries and land conservation programs slow low-density expansion and/or induce infill development, they are likely to reduce per capita VMT, but the possible magnitude of this effect is difficult to assess.

This measure is not included in the CAPCOA Handbook.

Travel demand forecasting models can be used to assess the impact on VMT of land development patterns. To estimate the impact on VMT of land preservation, it can be accounted for in the land use scenario that is input to the travel demand model.

> Recommendation: If a regional travel demand model is available and the amount of land preservation is extensive, consider using the regional travel demand model to estimate the VMT reductions. Otherwise, do not quantify.

Land-use mix: Land-use mix can be increased through changes in zoning ordinances to allow for multiple land uses within an area, though other incentives may be needed to encourage the market to take advantage of the zoning changes. A strong body of evidence suggests that mixed land-uses can reduce VMT, though quantifying the effect is complicated owing to the variety of ways that land-use mix is measured.

Studies reviewed in the Evidence Assessment Report (Handy et al., 2024) show that land-use mix is negatively associated with VMT. According to a meta-analysis, after controlling for self-selection (the possibility that individuals who are inclined to drive less are more like to choose locations with greater land-use mix), the effect of a 1% increase in land-use mix is a 0.11% *increase* in VMT (Stevens, 2017)**.** Land-use mix is measured using a variety of different indexes across the studies included in the meta-analysis.

The 2025 CARB brief for Land-Use Mix suggests that a 1% increase in land-use mix is associated with a 0.3% to 0.10% decrease in VMT. Land-use mix is measured using a variety of different indexes across the studies reviewed.

This measure is not included in the CAPCOA Handbook.

Travel demand forecasting models can be used to assess the impact on VMT of land development patterns. To estimate the impact on VMT of an increase in land-use mix in a given area, the increase can be accounted for in the land use scenario that is input to the travel demand model.

> Recommendation: If a regional travel demand model is available and the changes in land use mix are extensive, consider using the regional travel demand model to estimate the VMT reductions. Otherwise, do not quantify.

Delivery hubs: No studies of the effect of delivery hubs on VMT are available. This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook.

> Recommendation: Do not quantify.

Jobs/housing balance: Policies that increase housing in housing-poor areas and/or jobs in job-poor areas can help to increase jobs/housing balance. A moderate body of evidence provides inconclusive evidence of the impact of jobs/housing balance on VMT. The studies reviewed in the Evidence Assessment Report (Handy et al., 2024) show that jobs/housing balance is negatively associated with VMT after controlling for other factors, but the effect is small. According to a meta-analysis, after controlling for self-selection (the possibility that individuals who are inclined to drive less are more like to choose locations with better jobs/housing balance), jobs/housing balance has no effect on VMT (Stevens, 2017).

The 2025 CARB brief for Jobs-Housing Balance found evidence that a 1% improvement in the ratio of jobs to housing in an area is associated with a 0.17% to 0.35% reduction in VMT, though some studies who no effect. The fit between wage levels and housing affordability is an important factor; jobs-housing balance is usually measured within a six to 10-mile radius around place of residence.

This measure is not included in the CAPCOA Handbook.

Travel demand forecasting models can be used to assess the impact on VMT of land development patterns. To estimate the impact on VMT of an increase in job-housing balance in a given area, the increase can be accounted for in the land use scenario that is input to the travel demand model.

> Recommendation: If a regional travel demand model is available and the changes in jobs/housing balance are extensive, consider using the regional travel demand model to estimate the VMT reductions. Otherwise, do not quantify.

5. Road Management Measures

Road management measures (see Table 5) generally focus on deterring, slowing, and/or otherwise managing vehicle trips. The primary aim of these measures is not to reduce VMT, though they have the potential to do so. For congestion pricing and curb management, the primary goal is to reduce congestion, which can be achieved without reducing VMT. For road diets/complete streets and traffic calming, the primary goal is to improve safety for pedestrians, bicyclists, and transit riders.

For the road management measures for which sufficient evidence is available (see Table 4), VMT reductions can be estimated using an effect-size approach.

Table 5. Road Management Measures – Quantification Options

Measures	UC Davis assessment	CARB briefs	CAPCOA Handbook	Travel Demand Model
Congestion pricing	X	X		X
Road diets/complete streets	Insufficient evidence			
Local network connectivity	X	X	X	
Traffic calming	Not quantified			
Curb management	Not quantified			

Congestion pricing: Congestion pricing increases the cost of driving at selected times and thus potentially discourages both the number and length of trips, though it may simply shift trips to off-peak periods. The evidence is strong that congestion pricing can reduce VMT, though most of the empirical studies are from an international context and they typically report impacts on traffic counts and/or transit ridership rather than VMT. Studies of congestion pricing in New York City, implemented in 2025, should produce solid empirical evidence of the effect of this strategy in a U.S. context, albeit an extreme one.

The studies reviewed in the Evidence Assessment Report (Handy et al., 2024) show that congestion pricing is negatively associated with traffic counts and positively associated with transit ridership. Reported price elasticities for traffic counts ranged widely: -0.16 in Gothenburg, -0.28 in Stockholm, -0.45 in Norway in the short term, and -0.82 in Norway in the long term.

The 2025 CARB brief for Road Pricing distinguishes between link or point pricing, cordon pricing, and distance-based charging. In all three cases, prices can be varied by levels of congestion. The brief suggests that a 10% toll increase would result in a 3% decrease in traffic volume (elasticity of -0.3) on the tolled facility. The implementation of cordon pricing leads to a 4.5 to 9% reduction in counts of vehicles crossing the cordons. Studies from London and Gothenburg suggest that a 10% increase in the cost of entering the cordoned area could result in a decrease in vehicle counts of 4.7 to 8.7% (elasticities from -0.47 to -0.87). Decreases in vehicle counts are not directly translatable into decreases in VMT, though the magnitudes are likely to be similar.

Evidence on the effect of the cost of driving on VMT could also be helpful. The 2025 CARB brief for Gas Taxes, Distance-Based Charges, and TNC Charges reports that a 10% increase in gas prices leads to a 1% to 1.5% decrease in VMT (elasticities from -0.1 to -0.15) and that a 10% increase in distance-based charges leads to a 1% to 2% decrease in VMT (elasticities from -0.1 to -0.2).

This measure is not included in the CAPCOA Handbook, which focuses on mitigation measures for development projects.

Travel demand forecasting models can be used to assess the impact of congestion pricing on VMT. Congestion pricing can be represented as a component of the monetary cost of driving that is incorporated into the mode choice model. It may also factor into the auto ownership model, for those regional models that have one.

> Recommendation: If a regional travel demand model is available and the congestion charges affect a wide area, consider using the regional travel demand model to estimate the VMT reductions. An effect-size approach can be used if the pricing is limited to specific facilities. Apply an elasticity of -0.3 to traffic counts on that facility to estimate reductions in trips. If possible, use an estimate of trip lengths for that facility to convert trip reductions into VMT reductions; else assume that the VMT reductions are proportionate to the trip reductions. Note that this approach does not account for VMT that shifts to other facilities and thus may be an overestimate of VMT reduction. For a wider increase in the cost of driving, such as through a distance-based charge, apply an elasticity of -0.15 to estimate the reduction in VMT.

Road diets/complete streets: Road diets and complete streets projects reallocate street space with the goal of improving safety for pedestrians, bicyclists, and transit users. They have the potential to reduce VMT by encouraging a shift to these modes. The studies reviewed in the Evidence Assessment Report (Handy et al., 2024) show that pedestrian and bicycle counts tend to increase while vehicle counts tend to decrease on the facilities on which road diet complete streets projects are implemented. Reductions in vehicle counts are likely to mean a reduction in VMT. However, the effect on VMT depends on the share of trips that disappear (rather than dispersing to other routes) and the length of these trips. Most studies reviewed in the Evidence Assessment Report (Handy et al., 2024) do not assess whether vehicle counts increase on parallel routes and do not provide estimates of the effect of such projects on VMT.

Relatedly, the California Induced Travel Calculator should not be used to estimate decreases in VMT for road diets and complete streets projects. The Calculator is based on studies that estimate the change in VMT associated with increases in roadway capacity. While some evidence suggests that the effects of capacity reductions are symmetric with the effects of capacity increases, the evidence is not sufficient for quantifying the effect of capacity reductions (Volker and Handy, 2024). Although the calculator can be used for expansion projects on principal arterials (Federal Highway Administration (FHWA) class 3 facilities), the presence of signals and turning movements on these arterials complicates the estimation of the effects on VMT, in that travel times on a stretch of an arterial depend not just on the number of lanes but also signalization and turning lanes. As argued by the FHWA, reducing the number of through lanes on an arterial does not necessarily increase congestion, and road diets are often designed in a way that maintains the roadway's effective capacity (FHWA, 2016). If so, the impact on VMT could be limited, even if the project produces other important benefits.

Overall, there is good evidence of a possible reduction in VMT from road diets and complete streets projects, but not enough direct evidence to quantify the effect.

Recommendation: Do not quantify.

Local network connectivity: Improving the connectivity of the local network can create more direct routes to destinations, thereby reducing travel distances and potentially leading to direct decreases in VMT while also encouraging a shift to walking and bicycling. Network connectivity is largely fixed at the time that an area is developed and, for residential developments, is influenced by the local subdivision ordinance. Local governments can retrofit existing networks so as to increase connectivity through the construction of new network connections. Examples include at-grade "cut throughs" and grade-separated facilities for pedestrians and bicyclists, as well as the extension of existing roadways to connect to other existing roadways.

The cross-sectional studies reviewed in the Evidence Assessment Report (Handy et al., 2024) measure connectivity as intersection density, block size, or the share of four-way intersections. A meta-analysis of these studies suggests that a 1% increase in the number of four-way intersections in the roadway network is associated with a 0.06% decrease in VMT (elasticity of -0.06) and that a 1% increase in intersection or street density is associated with a 0.14% decrease in VMT (elasticity of -0.14) (Stevens, 2017).

The 2025 CARB brief for Network Connectivity concludes that the effect of connectivity on VMT is likely to be negative, though two of ten studies reviewed found a positive effect on VMT. The magnitude of the effect is thus highly uncertain, given the wide range of effect sizes across studies and differences in the ways that these studies measure network connectivity. The brief does not provide a recommended range for the effect size.

The CAPCOA method for street connectivity (T-17, Improve Street Connectivity) adopts the higher elasticity from Stevens (2017): a 14% reduction in VMT for a 1% increase in connectivity within the development relative to the average intersection density for the U.S. (pg. 131).

Recommendation: Define the area likely to be affected by the mitigation project based on local travel patterns. Apply a 14% reduction to the estimated VMT in the defined area for every 1% increase in network connectivity in that area. If a regional travel demand model is available and uses a fine-grained roadway network (more common in activity-based models) and if the project is on an arterial street and/or is likely to affect trips across a large area, consider using the regional travel demand model to estimate the VMT reductions.

Traffic calming: No studies of the effect of traffic calming on VMT are available. This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook

Recommendation: Do not quantify.

Curb management: No studies of the effect of curb management on VMT are available. This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook.

Recommendation: Do not quantify.

6. Active Travel Measures

For the active travel measures for which sufficient evidence is available (see Table 6), VMT reductions can be estimated using an effect-size approach. A few case studies—mostly of shared micromobility programs—have estimated the actual VMT effects of active travel measures, as discussed in the Evidence Assessment Report (Handy et al., 2024). However, those case studies might not necessarily be generalizable. Apart from those select case studies, most studies of the effectiveness of active transportation measures (as summarized in the Evidence Assessment Report (Handy et al., 2024)) report indirect effects, often bicyclist or pedestrian counts or frequency of active travel trips. In that case, the elasticity is the percent change in active travel volumes or trip frequency given a one percent (or in some cases, a one unit) change in the measure. Translating the estimated change in active travel into an estimated change in VMT requires assumptions about the share of new active travel trips that replace driving trips, average vehicle occupancy, and the average length of those driving trips. In general, the change in VMT can be estimated in two steps as follows:

> Change in number of active travel trips = (elasticity x % change in measure) x current active travel trips in the area affected by the measure
>
> Change in VMT = Change in number of active travel trips x share of active travel trips that replace driving trips x 1/average vehicle occupancy x average length of driving trips replaced

When the effect size is in the form of an elasticity, the percent change in the measure is used. The extent of the measure to which it applies, e.g. the boundaries of the corridor to which a bike lane was added or the expected number of users of a new bike or scooter share program, should be taken into account in determining the current number of active travel trips to which to apply the effect size. Recommended elasticities are presented in the following subsections. Recommendations for the conversion of change in active travel trips to change in VMT are as follows:

Share of new active travel trips replace driving trips: The recommended approach is to use survey data on mode substitution, collected using a hypothetical “what would you have done” question. For example, the evidence indicates that the overall stated substitution rate for new trips on a new bicycle facility is around 0.3 (which includes all substitution from automobile trips, transit trips, walking trips, and any other mode for bicyclists who did not bike on the same route prior to bicycle facility installation) and that the automobile substitution rate is about 0.1 (Volker et al., 2019).

For pedestrian facilities, Thakuriah et al. (2012) found that the auto substitution percentages for five new sidewalks in Chicago ranged from 6.25% to 38.1%, with an approximate average of 21.5%. However, it is unclear if the study’s respondent pool included any people who walked the same route before facility installation anyway (if so, the substitution rate would be even higher).

For e-bikes, two relevant studies analyzed a survey of 1,796 e-bike owners in the U.S. and Canada, including 402 in California. MacArthur et al. (2018) estimated that 64% of the e-bike trips reported by respondents were made for utilitarian purposes, and that e-bikes were much more likely to replace automobiles for utilitarian trips than trips for recreation or exercise. McQueen et al. (2020) estimated that 67.9% of utilitarian e-bike trips replaced automobile trips, and that 72.4% of the person miles traveled for utilitarian e-bike trips replaced automobile travel (indicating that longer e-bike trips were more likely to replace automobile trips). Multiplying the percentage of e-bike trips that are utilitarian (64%) by the percentage of person miles traveled for utilitarian e-bike trips that replaced automobile travel (72.4%) indicates an overall automobile substitution rate of 46.3%.

For bike share trips, the substitution rate ranged from 11% to 37% across the eight relevant studies we identified in the Evidence Assessment Report (Handy et al., 2024). The most comprehensive assessment—using data from 22 different programs or cities—estimated an automobile substitution rate of 37% across all types of bike share and scooter share programs (North American Bikeshare Association, 2023).

A recent comprehensive literature review of scooter share studies found a much greater range in the automobile substitution rate for scooter share trips—6% to 71% across the 20 U.S. studies that did not allow survey respondents to select multiple substitution modes for their e-scooter trips (Wang et al., 2023). However, 17 of those 20 studies estimated substitution rates between 32% and 49%. Meroux et al. (2023) similarly calculated an average substitution rate of 40% across nine U.S. studies.

Average vehicle occupancy: Active travel trips are not directly equivalent to vehicle trips, in that each active travel trip represents one person while each vehicle trip reflects more than one person trip on average. Each new active travel trip that replaces driving replaces less than one vehicle trip. Data on average vehicle occupancy is generally available from regional travel surveys. If a recent regional survey is not available, averages from the National Household Travel Survey can be used (FHWA, 2024).

Average driving trip length: There are multiple ways to estimate the average length of driving trips replaced by active travel trips. In some cases, there might be data on the average length of trips for which users reported replacing an automobile trip. Meroux et al. (2023) used this distance-weighted approach to estimate the effect on VMT of scooter share programs in four U.S. cities. Where data on length of replaced automobile trips is not available, the average length of active travel trips or the average length of automobile trips can be used instead. Data on the average length of walking, bicycling, and driving trips is generally available from regional travel surveys. If a recent regional survey is not available, averages from the National Household Travel Survey can be used (FHWA, 2024). Data on the average length of e-bike and shared micromobility trips is often available from user surveys, as detailed in the Evidence Assessment Report (Handy et al., 2024).

Many of the studies reviewed in the Evidence Assessment Report (Handy et al., 2024) and cited in the CARB briefs and the CAPCOA Handbook were conducted before the COVID-19 pandemic, which dramatically impacted travel patterns. The effect sizes identified in these studies may no longer be applicable.

Some travel demand forecasting models incorporate bicycle and pedestrian facility networks. However, the models generally do not accurately forecast the effects of active travel programs or infrastructure expansions.

Table 6. Active Travel Measures – Quantification Options

Measures	UC Davis assessment	CARB briefs	CAPCOA Handbook	Travel Demand Model
Bicycle facilities	X	X	X	
Pedestrian facilities	X	X	X	
E-bike incentives	X			
Bike share and scooter share	X		X	

Bicycle facilities: A strong body of evidence suggests that adding bicycle facilities can increase bicycle ridership. The studies summarized in the Evidence Assessment Report (Handy et al., 2024) show that providing class I, class II, class III, and class IV bicycle facilities increases ridership within the same corridor. The effect can be quantified with a strong degree of certainty, though most studies were conducted before the COVID-19 pandemic. The average percentage increases reported in the studies listed in Table 27 of the Evidence Assessment Report (Handy et al., 2024) were lowest for class III bike boulevards or greenways (77%), and relatively similar for class I (100%), class II (112%), and class IV (105%) facilities. For class IV facilities, the average increase was noticeably greater (125%) for those not reported to have replaced existing bike lanes. Class IV facilities that replaced existing bike lanes showed an average ridership increase of 61%. Class IV facilities more than a mile long generally showed greater percentage increases in ridership, but the sample sizes are so small that definitive conclusions cannot be drawn about the relationship between facility length and ridership increases. Facility lengths were not reported for most class I, class II, and class III facilities. With respect to substitution, the evidence indicates that the overall stated substitution rate is around 0.3 (which includes all substitution from automobile trips, transit trips, walking trips, and any other mode for bicyclists who did not bike on the same route prior to bicycle facility installation) and that the automobile substitution rate is about 0.1 (Volker et al., 2019).

The 2014 CARB brief on Bicycling Strategies identifies only two studies that examined the effect of bicycling facilities on a VMT-related outcome. Both studies were cross-sectional and assessed the correlation between the citywide amount of class II bike lanes and commute mode share. One study examined 24 medium-sized cities in California and found that a 1% increase in the percent of citywide street length with class II bike lanes correlated to a 0.35-0.36% increase in the share of workers commuting by bicycle, and a 0.004-0.010% reduction in the share of workers commuting by driving (Marshall & Garrick, 2010). The other study examined 33 of the largest cities across the U.S. and found that a 1% increase in miles of class II bike lanes per square mile correlated to a 0.32% increase in the share of workers in the city commuting by bicycle, though the effect on driving mode share was not reported (Dill & Carr, 2003). Neither study considers the effect of bike facilities on non-work travel.

The CAPCOA method for constructing bike facilities (T-19-A, Construct or Improve Bike Facility) provides an estimate of the percent change in VMT (rather than an amount of VMT) for new class I, II, or IV bike facilities and conversions of class II facilities to class IV facilities (pg. 138). It employs a formula based on CARB's method for estimating VMT reductions from bike and pedestrian facilities. CARB's method relies on average daily vehicle traffic (ADT) on the affected corridor, rather than existing bicycling ridership (CARB, 2023). It then applies a series of adjustment factors, including a seasonal adjustment, an adjustment based on ADT, bike facility length, city size, and the presence of a university, an activity center credit, and a growth adjustment factor that gives much greater weight to class I and IV facilities. However, it is unclear how CARB derived the activity center credits, the convoluted adjustments based on ADT, bike facility length, city size, and university presence, or the growth factor adjustment. Furthermore, the growth adjustment factors do not align with empirical ridership growth rates detailed in the Evidence Assessment Report (Handy et al., 2024). Volker et al. (2019) examine these and other concerns with CARB's method in more detail, and ultimately recommend using the simpler and more robustly supported (by empirical evidence) method of estimating VMT reductions from new bicycle facilities based on existing bicycle counts, empirically based growth factors, empirically based automobile substitution rates, automobile occupancy rates, and trip lengths (as summarized above and recommended again below).

Another concern with the CAPCOA method (T-19-A, Construct or Improve Bike Facility) is how it uses the adjustment factors—it applies them to the average regional one-way bike trip length, and then divides that product by the average regional one-way vehicle trip length (pg. 138). That amounts to saying that new bike facilities increase bike trip lengths and that the ratio of bike trip lengths to automobile trip lengths determines the amount of VMT reduction. Neither proposition is true. New bike facilities tend to induce new bike trips (more ridership) rather than increase trip lengths, and the amount of VMT those new trips reduce depends on what percentage of the new trips replace automobile trips and how long those replaced auto trips are.

The CAPCOA method for adding bike boulevards (T-19-B, Construct or Improve Bike Boulevard) provides an estimate of the percent change in VMT (rather than an amount of VMT) for new class III bike boulevards (pg. 138). It curiously employs a different formula than for estimating the VMT reductions from class I, II, and IV facilities, despite the fact that the CARB method on which the CAPCOA Handbook relies for T-19-A (Construct or Improve Bike Facility) also applies to class III facilities. Instead, the CAPCOA method for bike boulevards (T-19-B, Construct or Improve Bike Boulevard) uses a bike ridership growth factor to adjust the bike mode share for work trips in the region. A primary limitation of that approach is that it focuses only on commute trips and excludes other utilitarian and even recreational bike trips that might replace vehicular trips (Volker et al., 2019). It also appears that the growth factor is (1) applied incorrectly, and (2) not based on the best available evidence. On the first point, the stated growth factor is based on a study of 10 class III facilities that found a 114% average increase in ridership after installation of the facility (Sam Schwartz, 2021), which is equivalent to a growth factor of 2.14, not the 1.14 used in the CAPCOA method. The way the growth factor is applied in the CAPCOA method amounts to a +14% adjustment to the bike commute mode share. On the second point, the study relied on by the CAPCOA method (Sam Schwartz, 2021) is less comprehensive than the review in the Evidence Assessment Report (Handy et al., 2024), which reports an average facility-level ridership change of 77% for 19 class III facilities.

> Recommendation: Estimate the change in corridor-level bike ridership by applying the facility type-specific elasticities listed above to the base (pre-facility installation) bike ridership on the affected corridor. Convert the change in bike ridership to change in VMT using the method described earlier and explained in more detail in Volker et al. (2019), which also includes guidance on converting point-in-time bicycle counts to annual ridership numbers.

Pedestrian facilities: A moderate body of evidence suggests that adding pedestrian facilities (like sidewalks) can increase walking and reduce VMT. Two studies summarized in the Evidence Assessment Report (Handy et al., 2024) found that increased sidewalk coverage in a household's neighborhood was associated with a statistically significant reduction in household VMT (Frank et al., 2011; Guo & Gandavarapu, 2010), with Frank et al. (2011) estimating an elasticity of -0.05 (0.5% reduction in VMT with a 10% increase in sidewalk coverage) in the Seattle region. However, Cervero and Kockelman (1997) found no statistically significant correlation between sidewalk width and household VMT. And most studies found no statistically significant association between pedestrian infrastructure and automobile mode choice. Another three facility-level studies summarized in the Evidence Assessment Report (Handy et al., 2024) report changes in pedestrian counts after installation of pedestrian infrastructure, with increases ranging from 10% to 850%. In addition to the wide variation, it is hard to generalize from these facility-specific studies because the counts from Fitzhugh et al. (2010) do not distinguish between bicyclists and pedestrians, the counts from Boarnet et al. (2005) are specific to children walking to and from school, and the infrastructure changes studied in Barnes and Schlossberg (2013) included more than just widening sidewalks. With respect to substitution, Thakuriah et al. (2012) found that the auto substitution percentages for five new sidewalks in Chicago ranged from 6.25% to

38.1%, with an approximate average of 21.5%. However, it is unclear if the study's respondent pool included any people who walked the same route before facility installation anyway (if so, the substitution rate would be even higher).

The 2014 CARB brief on Pedestrian Strategies identifies many of the same studies that examine the effect of pedestrian facilities on VMT-related outcomes as the Evidence Assessment Report (Handy et al., 2024). It concludes that it is "impossible to identify an accurate range of effect sizes" from the empirical literature, due to the many differences in study design and other limitations (pg. 6). However, it emphasizes that "all studies show a positive, non-zero effect on walking" (pg. 6).

The CAPCOA method for improving the pedestrian network (T-18, Provide Pedestrian Network Improvement) provides an estimate of the percent change in VMT (rather than an amount of VMT) for new sidewalks or improving degraded sidewalks (pg. 134). It employs a simple formula using the elasticity estimated by Frank et al. (2011)— -0.05 (0.5% reduction in VMT with a 10% increase in sidewalk coverage)—the existing sidewalk length in the area, and the length of the sidewalk to be added.

> Recommendation: Use the CAPCOA method. While the CAPCOA method is based on a single study outside of California (Seattle, Washington), there is not enough empirical evidence to indicate that another method would be better.

E-bike incentives: A moderate body of evidence suggests that e-bikes (bikes that use electric motors to either assist the user in pedaling or propel the bicycle via throttle controlled by the user) and programs to incentivize them can reduce VMT. All three studies summarized in the Evidence Assessment Report (Handy et al., 2024) indicate that e-bike ownership could have a substantial effect on VMT. Johnson et al. (2023) analyzed survey data from nearly 600 e-bike owners in three California counties and estimated that they had replaced about 35% to 44% of their VMT with e-bike trips within a month or two of purchasing their e-bike. The two other studies both analyzed a survey of 1,796 e-bike owners in the U.S. and Canada. MacArthur et al. (2018) found that 91.5% of owners rode their e-bike at least once per week, which conservatively translates to about 200 e-bike trips per year per owner, as detailed in the Evidence Assessment Report (Handy et al., 2024). MacArthur et al. (2018) also estimated that 64% of the e-bike trips reported by respondents were made for utilitarian purposes, and that e-bikes were much more likely to replace automobiles for utilitarian trips than trips for recreation or exercise. McQueen et al. (2020) estimated that 67.9% of utilitarian e-bike trips replaced automobile trips, and that 72.4% of the person miles traveled for utilitarian e-bike trips replaced automobile travel. Multiplying the percentage of e-bike trips that are utilitarian (64%) by the percentage of person miles traveled for utilitarian e-bike trips that replaced automobile travel (72.4%) indicates an overall automobile substitution rate of 46.3%. They also estimated that the average length of a utilitarian e-bike trip was 4.65 miles.

This measure was not evaluated in the CARB briefs and is not included in the CAPCOA Handbook.

> Recommendation: E-bike studies in the U.S. remain sparse. However, the available evidence from two separate surveys of e-bike owners supports two methods to roughly estimate VMT reductions from increased e-bike ownership. The first method would be to use the 35% to 45% reduction in VMT per capita estimated by Johnson et al. (2023) in their analysis of e-bike owners in three California counties. Total VMT reduction from a proposed e-bike incentive program could be estimated by multiplying that percentage by the number of new e-bike owners expected from the program and the average VMT per capita in the relevant region. The second method would use the

results from the larger survey of e-bike owners in the U.S. and Canada analyzed by McQueen et al. (2020) and MacArthur et al. (2018) to solve the general VMT estimation equation described in the introduction to the active travel section. That would entail multiplying the number of new e-bike owners expected from the proposed e-bike incentive program by the average number of e-bike trips taken by e-bike owners (~200/year, using the rough estimate just discussed), the automobile substitution rate just discussed (46.3%), the average length of a utilitarian e-bike trip (4.65 miles), and the automobile occupancy factor.

Bike share and scooter share: A strong body of evidence suggests that bike share and scooter share programs reduce VMT, as summarized in the Evidence Assessment Report (Handy et al., 2024). Ample data exists to estimate VMT reductions from shared micromobility programs using the general VMT estimation equation described in the introduction to the active travel section because shared micromobility programs routinely collect trip length data and also frequently survey users about modal substitution. With respect to trip lengths, the North American Bikeshare Association (2023) reported that average trip lengths were 1.4 miles for pedal bike share programs in North America, 2.0 miles for bike share programs with e-bikes, and 1.2 miles for scooter share programs. With respect to modal substitution, the most comprehensive assessment reviewed in the Evidence Assessment Report (Handy et al., 2024) used data from 22 different programs or cities to estimate an automobile substitution rate of 37% across all types of bike share and scooter share programs, accounting for substitution of both private automobile trips (including carpooling) and taxi and ride share trips (North American Bikeshare Association, 2023). For just bike share trips, the seven other relevant studies identified in the Evidence Assessment Report (Handy et al., 2024) estimated automobile substitution rates between 11% and 35%, including separate estimates of 28% and 35% for a former dockless e-bike share program in Sacramento, California, the only California program studied individually (Fitch et al., 2021; Fukushige et al., 2023). For programs offering only human-powered pedal bikes, the substitution rates were generally lower (13% to 19%) than for programs offering e-bikes. For scooter share trips, a recent comprehensive literature review found a much greater range in the automobile substitution rate than for bike share trips—6% to 71% across the 20 U..S studies that did not allow survey respondents to select multiple substitution modes for their e-scooter trips (Wang et al., 2023). However, 17 of those 20 studies estimated substitution rates between 32% and 49%. Meroux et al. (2023) similarly calculated an average substitution rate of 40% across nine US studies.

An increasing number of studies have also gone the extra step and directly estimated the effect of shared micromobility use on VMT, often using trip length and modal substitution data. For bike share programs, Fishman et al. (2014) estimated that each trip with the docked pedal bike share programs in Washington, D.C. and the Twin Cities region in Minnesota 0.08 and 0.21 VMT, respectively, after accounting for the VMT associated with operation of the bike share programs (picking up and dropping off bikes). More recently, Fitch et al. (2021) found an inconclusive effect of the former dockless e-bike share program in California's Sacramento region, though they relied on user-reported VMT estimates. However, Fukushige et al. (2023) revisited the same Sacramento-area program using a more robust data set and statistical approach, and estimated an average reduction of 0.79 miles per bike share trip on weekdays, accounting for both the added VMT associated with operation of the bike share program and the reduced VMT from deadheading and searching associated with foregone ride share trips. Fukushige et al. (2023) also estimated the length of automobile-replacing trips, rather than using average bike share trip length (which is generally less than for auto-replacing trips).

For scooter share programs, Meroux et al. (2023) estimated reductions of 0.58 VMT per trip in San Francisco, 0.66 VMT per trip in Portland, 0.68 VMT per trip in Tampa, and 0.54 VMT per trip in

Washington, D.C. Like Fukushige et al. (2023), they employed a distance-weighted approach, using the average length of trips that users reported they would have otherwise made by automobile. However, they did not account for the VMT associated with operation of the scooter share programs, which would offset the VMT reductions to some degree.

The 2025 CARB brief on Micromobility Services identifies the same studies that estimate the effects of bike share and scooter share programs on VMT as the Evidence Assessment Report (Handy et al., 2024) and highlights a similar range of VMT effect sizes.

The CAPCOA Handbook has three relevant estimation methods. The CAPCOA method for pedal bike share programs (T-22-A, Implement Pedal (Non-Electric) Bikeshare Program) provides an estimate of the percent change in VMT (rather than an amount of VMT) for new human-powered pedal bike share programs, though it does not account for the VMT associated with program operation (pg. 160). The method uses reasonable assumptions for the length (1.4 miles) and automobile substitution rate (19.6%) of shared pedal bike trips, albeit based on a less comprehensive body of evidence than summarized above. However, it requires five additional inputs to estimate VMT reductions—the percent of residents in the relevant community with access to a bike share system at baseline, the percent of residents who would have access to a bike share system, daily bike share trips per person, daily vehicle trips per person, and regional one-way average vehicle trip length (pg. 160). It would be simpler to employ the general VMT estimation equation described in the introduction to the active travel section, as recommended below.

The CAPCOA method for electric bike share programs (T-22-B, Implement Electric Bikeshare Program) provides an estimate of the percent change in VMT (rather than an amount of VMT) for new bike share programs with e-bikes (bikes that use electric motors to either assist the user in pedaling or propel the bicycle via throttle controlled by the user), though it does not account for the VMT associated with program operation (pg. 164). The method uses reasonable assumptions for the length (2.1 miles) and automobile substitution rate (35%) of shared e-bike trips, based on the Fitch et al. (2021) study discussed above. However, it also requires five additional inputs to estimate VMT reductions—the percent of residents in the relevant community with access to a bike share system at baseline, the percent of residents who would have access to a bike share system, daily bike share trips per person, daily vehicle trips per person, and regional one-way average vehicle trip length (pg. 164). It would be simpler to employ the general VMT estimation equation described in the introduction to the active travel section, as recommended below.

The CAPCOA method for scooter share programs (T-22-C, Implement Scootershare Program) provides an estimate of the percent change in VMT (rather than an amount of VMT) for new scooter share programs, though it does not account for the VMT associated with program operation (pg. 168). The method uses reasonable assumptions for the length (2.14 miles) and automobile substitution rate (38.5%) of shared scooter trips, albeit based on a less comprehensive body of evidence than summarized above. However, it also requires five additional inputs to estimate VMT reductions—the percent of residents in the relevant community with access to a scooter share system at baseline, the percent of residents who would have access to a scooter share system, daily scooter share trips per person, daily vehicle trips per person, and regional one-way average vehicle trip length (pg. 168). In addition, the daily scooter share trip input is based on bike share trip density data, rather than scooter share. Overall, it would be simpler to employ the general VMT estimation equation described in the introduction to the active travel section, as recommended below.

Recommendation: Ample data exists to estimate VMT reductions from new shared micromobility programs using the general VMT estimation equation described in the introduction to the active travel section. This method would be simpler than the three CAPCOA methods summarized above. The method would entail multiplying the number of new shared micromobility trips expected from the proposed shared micromobility program (which would be an essential component of the business plan for the program, and would account for any preexisting shared micromobility programs in the area) by the automobile substitution rate indicated by the empirical research summarized above and in the Evidence Assessment Report (Handy et al., 2024) for the relevant program type (somewhere in the neighborhood of 10% to 20% for pedal bike share programs, 20% to 35% for dockless e-bike share programs, and 30% to 50% for scooter share programs), the average trip length by the relevant mode (1.4 miles for pedal bike share programs, 2.0 miles for bike share programs with e-bikes, and 1.2 miles for scooter share programs, using comprehensive data from the North American Bikeshare Association), and the automobile occupancy factor. Another even simpler method would be to use the per-trip VMT reduction estimates calculated for a few specific shared micromobility programs, as summarized above. However, those VMT estimates are based on far fewer programs than the underlying trip length and automobile substitution numbers summarized above and in the Evidence Assessment Report (Handy et al., 2024).

7. Parking Management Measures

Parking management measures include both parking pricing and parking restrictions. Parking pricing includes measures such as pricing workplace parking (including cash-out programs), pricing on-street parking, and adaptive parking pricing. Parking restrictions include measures such as minimum parking requirements (or residential parking supply, more generally) and unbundling of residential parking costs from property costs (rent or purchase price). A few studies—mostly of residential parking supply or parking cash-out programs—have estimated the actual VMT effects of parking measures, as discussed in the Evidence Assessment Report (Handy et al., 2024). Apart from those select studies, most studies of the effectiveness of parking management measures (as summarized in the Evidence Assessment Report (Handy et al., 2024)) report indirect effects, often parking volume (parking space demand) or commute mode choice.

For the parking management measures for which sufficient evidence is available (see Table 7), VMT reductions can be estimated using an elasticity-type approach. For two measures (parking cash-out programs and residential parking supply restrictions), a direct VMT elasticity could be applied to either the existing commute VMT for the participating business (for parking cash-out programs) or the forecasted VMT for a new residential development (for residential parking supply restrictions). For workplace and on-street parking measures, price elasticities of parking volume would need to be translated into an estimated change in VMT using the assumption that the reduction in parking volume equals a reduction in automobile trip generation, with the resulting reduction in VMT estimated as follows:

> Change in VMT = Change in parking volume x average length of driving trips (average across all trips for on-street parking pricing or average of commute trips for workplace parking pricing)

One major caveat about this method is that reductions in parking volume in an area affected by parking pricing might not equal reductions in automobile trips. Some drivers may attempt to avoid parking charges by parking outside of the priced zone or select alternative destinations (Peng et al., 1996; Yan et al., 2019).

Many of the studies reviewed in the Evidence Assessment Report (Handy et al., 2024) and cited in the CARB briefs and the CAPCOA Handbook were conducted before the COVID-19 pandemic, which dramatically impacted travel patterns. The effect sizes identified in these studies may no longer be applicable.

Many travel demand forecasting models incorporate parking-related variables. However, they generally do not fully capture the effects of parking management measures. For one, traditional four-step models typically only consider parking options at the mode choice stage, despite the fact that parking cost and availability can also affect trip generation, destination, and route. In addition, even with activity-based models, parking-related variables are often not granular enough to capture the effects of a project-specific measure.

Table 7. Parking Management Measures – Quantification Options

Measures	UC Davis assessment	CARB briefs	CAPCOA Handbook	Travel demand model
Pricing workplace parking	X	X	X	
Cash-out programs	X	X	X	
Pricing on-street parking	X	X	X	
Adaptive parking pricing	Insufficient evidence			
Residential parking supply restrictions	X		X	
Unbundling parking costs from property costs	Insufficient evidence		X	

Pricing workplace parking: A strong body of evidence suggests that pricing workplace parking can reduce VMT. The majority of empirical studies on workplace parking estimate the effect on parking demand, though studies on the effect of workplace parking pricing on commute mode choice show consistent effects. Lehner and Peer (2019) recently conducted a meta-analysis of 50 studies that estimated elasticities of parking demand with respect to parking price. They found a baseline elasticity of workplace parking volume of -0.52, based on revealed preference studies. They also found an elasticity of -1.07 based on stated preference studies, but indicated that the elasticity based on revealed preference studies would likely be more accurate.

The 2025 CARB brief on Parking Pricing identifies the same studies that examine the effects of pricing workplace parking on VMT-related outcomes as the Evidence Assessment Report (Handy et al., 2024) and highlights the same elasticity of parking demand with respect to parking price (-0.52).

The CAPCOA method for pricing workplace parking (T-12, Price Workplace Parking) provides an estimate of the percent change in VMT (rather than an amount of VMT) resulting from pricing workplace parking (pg. 110). The method relies on an elasticity from same meta-analysis cited above (Lehner & Peer, 2019), though it uses the lower bound of the 95% confidence interval for the elasticity estimate (-0.40) rather than the actual point estimate (-0.52).

> Recommendation: Estimate the change in workplace parking volume using an elasticity of -0.52. Convert the change in parking volume to change in VMT using the method described earlier—multiplying the change in parking volume by the average commute trip length by automobile. Use workplace-specific commute trip lengths if they are available; otherwise, use the average commute trip length for the relevant city, county, or region. Note, however, that the elasticities of parking demand with respect to parking pricing can inform, but cannot be used directly to estimate, the VMT-related effects of instituting pricing in areas where parking had previously been free.

Parking cash-out programs: Parking cash-out programs generally work by providing employees equivalent subsidies for parking and alternatives to parking (like transit, bicycling, or walking). The primary empirical evidence about parking cash-out programs comes from a study of eight businesses with at least 120 employees in urban areas of Los Angeles County (Shoup, 1997). That study found a 12% reduction in commute VMT per employee, using weighted results from seven of the eight studied businesses.

The 2025 CARB brief on Parking Pricing identifies the same study (Shoup, 1997) and highlights the same VMT outcome (12% reduction in commute VMT per employee).

The CAPCOA method for parking cash-out programs (T-13, Implement Employee Parking Cash-Out) provides an estimate of the percent change in VMT (rather than an amount of VMT) resulting from parking cash out programs (pg. 114). The method relies on same study (Shoup, 1997) and VMT outcome (12% reduction in commute VMT per employee) discussed above.

> Recommendation: Estimate the change in VMT using the estimate from Shoup (1997)—12% reduction in commute VMT per employee. Multiply the number of employees affected by (eligible for) the parking cash-out program by the average commute VMT per employee and again by the 12% effect factor. Use workplace-specific commute VMT averages if they are available; otherwise, use the average home-based work VMT per employee for the relevant city, county, or region.

Pricing on-street parking: A strong body of evidence suggests that pricing on-street parking can reduce VMT. Lehner and Peer (2019) assessed the effect of parking price on parking volume for non-commute trips. Their meta-analysis estimated an elasticity of -0.32, based on revealed preference studies, and an elasticity of -0.87, based on stated preference studies. They noted that the lower-magnitude elasticity would likely be more accurate in areas with high parking demand and occupancy, while the higher-magnitude elasticity would be more accurate in areas with occupancy rates significantly lower than 100%.

The 2025 CARB brief on Parking Pricing identifies the same studies that examine the effects of on-street parking pricing on VMT-related outcomes as the Evidence Assessment Report (Handy et al., 2024) and highlights the same elasticity of non-commute parking demand with respect to parking price (-0.32).

The CAPCOA method for pricing on-street parking (T-24, Implement Market Price Public Parking (On-Street)) provides an estimate of the percent change in VMT (rather than an amount of VMT) resulting from pricing on-street parking (pg. 175). The method relies on the same elasticity used for pricing workplace parking in method T-12 (-0.4), though based on a different empirical study (Pierce & Shoup, 2013). Pierce and Shoup (2013) do indeed estimate an average elasticity of -0.4, but it is an elasticity of parking occupancy with respect to parking price. Parking occupancy is not the same as parking volume and cannot as easily be translated into VMT. Parking occupancy must be divided by dwelling time to calculate parking volume.

> Recommendation: Estimate the change in on-street parking volume in areas affected by an on-street pricing program using an elasticity of -0.32. Convert the change in parking volume to change in VMT using the method described earlier—multiplying the change in parking volume by the average automobile trip length in the city, county, or region. Note, however, that the elasticities of parking demand with respect to parking pricing can inform, but cannot be used directly to estimate, the VMT-related effects of instituting pricing in areas where parking had previously been free.

Adaptive parking pricing: Adaptive pricing—also called performance-based pricing—adjusts parking prices to obtain a target on-street occupancy rate. It does this by varying the prices by location and time of day to balance parking supply with demand on a block-by-block basis. Studies of the adaptive pricing programs in San Francisco (SFpark) and Seattle indicate that the programs have had a negative (VMT-reducing) effect on VMT-related outcomes, such as cruising for parking and parking occupancy. However, most results either cannot be easily translated into an estimate of VMT reductions or are uncertain. Overall, there is insufficient evidence to quantify the effect of adaptive pricing programs on

VMT. The 2025 CARB brief on Parking Pricing comes to a similar conclusion. The measure is not included in the CAPCOA Handbook.

> Recommendation: Do not quantify.

Residential parking supply restrictions: A moderate body of evidence suggests that restricting off-street residential parking can reduce vehicle ownership, vehicle trip generation, vehicle trip mode share, and VMT. The two empirical studies identified in the Evidence Assessment Report (Handy et al., 2024) that estimate the effect of off-street residential parking supply on VMT both found similar results. The first study, Guo (2013), estimated that households in the New York City metropolitan area who only had access to on-street residential parking had much lower odds of choosing to drive for a given trip, made fewer vehicle trips, and drove approximately 14.3 fewer kilometers on a typical weekday (about a 10% reduction) than households who also had access to off-street residential parking. More recently and more relevant to California, Currans et al. (2023) analyzed 2017 National Household Transportation Survey data from about 2,000 households from the California add-on sample. They found that constrained off-street parking (less than or equal to one parking space per dwelling unit) was associated with a statistically significant decrease in vehicle ownership, which in turn was associated with a statistically significant increase in both total and home-based work VMT. They then conducted a scenario analysis for typical households in Los Angeles County, using a hypothetical 100-unit development. They estimated that constraining off-street parking (to less than or equal to one parking space per dwelling unit) accounted for between a 10 and 21 percentage point reduction in VMT compared to modeled VMT that does not account for parking constraints, depending on the place type and type of VMT (total or home-based work VMT). These two studies suggest that housing developments with one or fewer off-street parking spaces per dwelling unit could produce at least 10% fewer total VMT per capita than an average housing development of similar type.

This measure was not evaluated in the CARB briefs. The CAPCOA method for restricting residential parking supply (T-15, Limit Residential Parking Supply) provides an estimate of the percent change in VMT (rather than an amount of VMT) resulting from limiting the amount of parking available at residential projects (pg. 123). The method relies on a study from New Jersey that estimated the effect of scarce off-street parking (one or fewer off-street spaces per adult) on commute mode share (Chatman, 2013). The study found that the odds of commuting by automobile decrease for households with scarce off-street parking. However, it is unclear how the CAPCOA method derived the effect size it attributes to Chatman (2013)—a 37% reduction in commute mode share by driving among households with scarce off-street parking. Chatman (2013) estimated odds ratios, not direct changes in the probability of commuting via auto. The study estimated that households with scarce off-street parking had 43% lower offs of commuting by auto. Nonetheless, the numbers used in the CAPCOA method—37% reduction in automobile mode share for commute trips and 37% of total VMT coming from commute trips—result in a similar effect size (14%) as the 10% reduction in total VMT indicated by the studies discussed above.

> Recommendation: Use the 10% reduction in total VMT indicated by the studies discussed above to estimate the change in VMT from restricting off-street parking supplies for new residential developments to one or fewer spaces her dwelling unit. Estimate the total VMT for a new residential development using available VMT estimation tools, then multiply that number by 10% to get a ballpark estimate of the total VMT reduction.

Unbundling parking costs from property costs: Very few studies examine how unbundling residential parking costs from property costs affects VMT-related outcomes, and the results are inconclusive and insufficient to quantify a VMT effect. The measure was not evaluated in the soon-to-be-updated CARB brief on Parking Pricing. The CAPCOA method on unbundling (T-16, Unbundle Residential Parking Costs from Property Cost) provides an estimate of the percent change in VMT (rather than an amount of VMT) resulting from unbundling residential parking costs (pg. 127). The method estimates how parking cost affects vehicle costs and thence vehicle ownership and VMT. However, the elasticity of vehicle ownership with respect to total vehicle cost that it relies on does not appear to be supported by the cited source.

Recommendation: Do not quantify.

References

Atlanta Regional Commission. (2024). 2019 Regional Transit On-Board Survey. https://atlregional.github.io/ActivityViz/src/index.html?region=atlanta&scenario=OnboardSurvey

Barnes, E., & Schlossberg, M. (2013). Improving Cyclist and Pedestrian Environment While Maintaining Vehicle Throughput: Before- and After-Construction Analysis. Transportation Research Record: Journal of the Transportation Research Board, 2393(1), 85–94. https://doi.org/10.3141/2393-10.

Boarnet, M. G., Day, K., Anderson, C., McMillan, T., & Alfonzo, M. (2005). California's Safe Routes to School Program: Impacts on Walking, Bicycling, and Pedestrian Safety. Journal of the American Planning Association, 71(3), 301–317. https://doi.org/10.1080/01944360508976700.

CAPCOA (2010). Quantifying Greenhouse Gas Mitigation Measures: A Resource for Local Government to Assess Emission Reductions from Greenhouse Gas Mitigation Measures. https://www.aqmd.gov/docs/default-source/ceqa/handbook/capcoa-quantifying-greenhouse-gas-mitigation-measures.pdf

CAPCOA (2022). Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity. https://www.caleemod.com/handbook/index.html

CARB (2023). Clean Mobility Benefits Quantification Methodology. https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/Clean_Mobility_QM_FINAL_November2023.pdf

CARB (n.d.). Research on the Effects of Transportation and Land Use-Related Policies. https://ww2.arb.ca.gov/our-work/programs/sustainable-communities-program/research-effects-transportation-and-land-use

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. Transportation Research Part D: Transport and Environment, 2(3), 199–219. https://doi.org/10.1016/S1361-9209(97)00009-6.

Chatman, D. G. (2013). Does TOD need the T? On the importance of factors other than rail access. *Journal of the American Planning Association*, *79*(1), 17-31. https://doi.org/10.1080/01944363.2013.791008

Currans, K. M., Abou-Zeid, G., McCahill, C., Iroz-Elardo, N., Clifton, K. J., Handy, S., & Pineda, I. (2023). Households with constrained off-street parking drive fewer miles. *Transportation*, *50*(6), 2227-2252. https://link.springer.com/article/10.1007/s11116-022-10306-8

Dill, J., & Carr, T. (2003). Bicycle commuting and facilities in major US cities: if you build them, commuters will use them. *Transportation research record*, *1828*(1), 116-123. https://doi.org/10.3141/1828-14

Federal Highway Administration. (2016). Road Diet Mythbusters. https://safety.fhwa.dot.gov/road_diets/resources/pdf/roadDiet_MythBuster.pdf

Federal Highway Administration. (2024). National Household Travel Survey. https://nhts.ornl.gov/

Fishman, E., Washington, S., & Haworth, N. (2014). Bike share's impact on car use: Evidence from the United States, Great Britain, and Australia. Transportation Research Part D: Transport and Environment, 31, 13–20. https://doi.org/10.1016/j.trd.2014.05.013.

Fitch, D. T., Mohiuddin, H., & Handy, S. L. (2021). Examining the Effects of the Sacramento Dockless E-Bike Share on Bicycling and Driving. Sustainability, 13(1), 368. https://doi.org/10.3390/su13010368.

Fitzhugh, E. C., Bassett, D. R., & Evans, M. F. (2010). Urban trails and physical activity: A natural experiment. American Journal of Preventive Medicine, 39(3), 259–262. https://doi.org/10.1016/j.amepre.2010.05.010.

Frank, L. D., Greenwald, M. J., Kavage, S., & Devlin, A. (2011). An Assessment of Urban Form and Pedestrian and Transit Improvements as an Integrated GHG Reduction Strategy. Washington State Department of Transportation. https://rosap.ntl.bts.gov/view/dot/20279/dot_20279_DS1.pdf.

Fukushige, T., Fitch, D. T., & Handy, S. (2023). Estimating Vehicle-miles traveled reduced from Dock-less E-bike-share: Evidence from Sacramento, California. Transportation Research Part D: Transport and Environment, 117, 103671. https://doi.org/10.1016/j.trd.2023.103671.

Greenwald, M. J. (2003). The road less traveled: New urbanist inducements to travel mode substitution for nonwork trips. *Journal of Planning Education and Research*, *23*(1), 39-57. https://doi.org/10.1177/0739456X03256248

Guo, J. Y., & Gandavarapu, S. (2010). An economic evaluation of health-promotive built environment changes. Preventive Medicine, 50, S44–S49. https://doi.org/10.1016/j.ypmed.2009.08.019.

Guo, Z. (2013). Does residential parking supply affect household car ownership? The case of New York City. *Journal of Transport Geography*, *26*, 18-28. https://doi.org/10.1016/j.jtrangeo.2012.08.006

Handy, S., Volker, J. M. B., & Hosseinzade, R. (2024). Assessing the Effectiveness of Potential Vehicle-Miles-Traveled (VMT) Mitigation Measures. Pacific Southwest Region University Transportation Center.

Johnson, N., Fitch-Polse, D. T., & Handy, S. L. (2023). Impacts of e-bike ownership on travel behavior: Evidence from three northern California rebate programs. Transport Policy, 140, 163–174. https://doi.org/10.1016/j.tranpol.2023.06.014.

Lehner, S., & Peer, S. (2019). The price elasticity of parking: a meta-analysis. *Transportation Research Part A: Policy and Practice*, *121*, 177-191. https://doi.org/10.1016/j.tra.2019.01.014

MacArthur, J., Harpool, M., Schepke, D., & Cherry, C. (2018). A North American Survey of Electric Bicycle Owners. Transportation Research and Education Center. https://doi.org/10.15760/trec.197.

Marshall, W. E., & Garrick, N. W. (2010). Street network types and road safety: A study of 24 California cities. *Urban Design International*, *15*, 133-147. https://doi.org/10.1016/j.aap.2010.10.024

McQueen, M., MacArthur, J., & Cherry, C. (2020). The E-Bike Potential: Estimating regional e-bike impacts on greenhouse gas emissions. Transportation Research Part D: Transport and Environment, 87, 102482. https://doi.org/10.1016/j.trd.2020.102482.

Meroux, D., Broaddus, A., Telenko, C., & Wen Chan, H. (2023). How should vehicle miles traveled displaced by e-scooter trips be calculated?. *Transportation research record*, *2677*(1), 356-368. https://doi.org/10.1177/03611981221099506

North American Bikeshare Association. (2023). 5th Annual Shared Micromobility State of the Industry Report. https://nabsa.net/about/industry/.

Peng, Z., Dueker, K. J., & Strathman, J. G. (1996). Residential Location, Employment Location, and Commuter Responses to Parking Charges. Transportation Research Record: Journal of the Transportation Research Board, 1556(1), 109–118. doi:10.3141/1556-13.

Piatkowski, D. P., Krizek, K. J., & Handy, S. L. (2015). Accounting for the short term substitution effects of walking and cycling in sustainable transportation. *Travel Behaviour and Society*, *2*(1), 32-41. https://doi.org/10.1016/j.tbs.2014.07.004

Pierce, G., & Shoup, D. (2013). Getting the Prices Right: An Evaluation of Pricing Parking by Demand in San Francisco. Journal of the American Planning Association, 79(1), 67–81. https://doi.org/10.1080/01944363.2013.787307.

Sam Schwartz (2021). Planning for Stress Free Connections. https://drive.google.com/drive/folders/1DGYYuAPyZUf66zg3IwU4YiIar2LeiuPN

Schimek, P. (2015). Dynamic Estimates of Fare Elasticity for U.S. Public Transit. Transportation Research Record, 2538, 96-191.

Shoup, D. C. (1997). Evaluating the effects of cashing out employer-paid parking: Eight case studies. *Transport Policy*, *4*(4), 201-216. https://doi.org/10.1016/S0967-070X(97)00019-X

Stevens, M. R. (2017). Does compact development make people drive less?. *Journal of the American Planning Association*, *83*(1), 7-18. https://doi.org/10.1080/01944363.2016.1240044

Thakuriah, P. V., Metaxatos, P., Lin, J., & Jensen, E. (2012). An examination of factors affecting propensities to use bicycle and pedestrian facilities in suburban locations. Transportation Research Part D: Transport and Environment, 17(4), 341–348. https://doi.org/10.1016/j.trd.2012.01.006.

Volker, J., & Handy, S. (2024). Background on Induced Travel. https://travelcalculator.ncst.ucdavis.edu/about.html

Volker, J. M. B., Handy, S., Kendall, A., & Barbour, E. (2019). Quantifying Reductions in Vehicle Miles Traveled from New Bike Paths, Lanes, and Cycle Tracks: Technical Documentation. https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/pedestrian_facilities_technical_041519.pdf

Wang, K., Qian, X., Fitch, D. T., Lee, Y., Malik, J., & Circella, G. (2023). What travel modes do shared e-scooters displace? A review of recent research findings. Transport Reviews, 43(1), 5–31. https://doi.org/10.1080/01441647.2021.2015639.

Yan, X., Levine, J., & Marans, R. (2019). The Effectiveness of Parking Policies to Reduce Parking Demand Pressure and Car Use. Transport Policy, 73, 41–50. https://doi.org/10.1016/j.tranpol.2018.10.009.