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A Framework for Projecting the Potential Statewide Vehicle Miles Traveled (VMT) Reduction from State-Level Strategies in California

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March 2017

A White Paper from the National Center for Sustainable Transportation

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EXECUTIVE SUMMARY

The California Global Warming Solutions Act of 2006 (Assembly Bill 32) created a comprehensive, multi-year program to reduce greenhouse gas (GHG) emissions in the state to 80% below 1990 levels by 2050. With the recent passage of Senate Bill 32, the State of California has adopted an additional target of reducing greenhouse gas emissions to 40% below 1990 levels by 2030. To meet these goals, analysis shows that California will need to achieve an additional 7.5 percent reduction in light-duty vehicle miles of travel (VMT) by 2035, and an additional 15 percent reduction in light-duty VMT by 2050.

The California Air Resources Board (ARB) is thus considering a wide range of strategies for the 2016 Scoping Plan Update that focus on reducing demand for driving. These strategies fall into four general categories: Pricing, Infill Development, Transportation Investments, and Travel Demand Management Programs. The State has the ability to directly implement some of these strategies through state policy; for other strategies, the State can adopt policies that encourage or require the implementation of the strategy on the part of regional agencies, local governments, and/or the private sector.

In this paper, we consider the evidence available and assumptions needed for projecting statewide VMT reductions for each category of strategies. Our goal is to provide a framework for projecting the magnitude of reductions that the state might expect for the different strategies. This framework helps to illuminate the sequence of events that would produce VMT reductions and highlights important gaps in knowledge that increase the uncertainty of the projections. Despite uncertainties, the evidence justifies state action on these strategies: the available evidence shows that the strategies considered in this paper are likely to reduce VMT if promoted by state policy.

We do not in this paper examine the potential co-benefits of VMT-reduction strategies, including health, equity, and other benefits, but the evidence of these benefits is also strong and further justifies state action.

Strategy Category	State Policy to VMT Link	Effect on Individual VMT	Potential for Statewide Implementation and Adoption – Strategy Extent
Pricing	Most direct	Strong effect Solid evidence	Can be applied state-wide (fuel taxes, VMT fees) and in targeted areas (link pricing, cordon pricing, parking pricing). Most effective where individuals have good alternatives to driving. Strategies have equity implications. Generates revenues that can be invested in transportation system.
Infill Development	Direct and indirect	Moderate effect Solid evidence	Most applicable in metro areas. Will affect populations living and working in infill areas. May depend on changes in local land use policy. May require financial incentives. Land use changes and VMT effects accrue over the long term.
Transportation Investments			
Bike/Ped	Direct and indirect	Small effect Moderate evidence	Most applicable in metro areas. Will affect populations living and working where investments are made. May depend on changes in local investments. May require financial incentives. May require package of strategies. Many co-benefits.
Transit	Direct and indirect	Small effect Moderate evidence	Most applicable in metro areas. Will affect populations living and working where investments are made. May depend on changes in transit agency action. May require financial incentives. May require package of strategies. Many co-benefits.
Highways	Direct	Strong *induced VMT* effect Solid evidence	New capacity that reduces travel times leads to VMT growth. Effect is greatest in congested areas. Operational improvements that reduce travel times can also induce VMT.
Transportation Demand Management	More indirect	Moderate effect Solid evidence	Most applicable in metro areas. Generally implemented by large employers in response to state or local requirements or financial incentives. Some applications appropriate for rural areas.

Introduction

The California Global Warming Solutions Act of 2006 (Assembly Bill 32) created a comprehensive, multi-year program to reduce greenhouse gas (GHG) emissions in the state to 80% below 1990 levels by 2050. With the recent passage of Senate Bill 32, the State of California has adopted an additional target of reducing greenhouse gas emissions to 40% below 1990 levels by 2030.

The AB 32 Scoping Plan, first adopted in 2008, outlines how the state will meet these targets. In 2015, Governor Brown directed the California Air Resources Board (ARB) to update the Scoping Plan. The transportation sections of previous Scoping Plans were primarily focused on cleaner fuels and cleaner vehicles; VMT reduction strategies were limited to continuing implementation of SB 375. With the 2016 Scoping Plan Update, the California Air Resources Board (ARB) is considering a wider range of strategies that focus on reducing demand for driving. ARB projects that vehicle miles of travel (VMT) will grow 11 percent from today to 2030. A recent visioning scenario analysis done by ARB for the Mobile Source Strategy, which will be incorporated into the updated Scoping Plan, concluded that in addition to existing initiatives such as continued implementation of SB 375 and improvements in vehicle and fuel technology, California will need to achieve an additional 7.5 percent reduction in light-duty VMT by 2035, and an additional 15 percent reduction in light-duty VMT by 2050, in order to meet the State's overall GHG goals.[1]

State-level policies, priorities, and investments will have a profound effect on trends in VMT and are critical to shifting the state from the projected increases in VMT to the needed reductions in VMT. There is extensive evidence on strategies that can reduce VMT, as documented in a series of research briefs we produced for ARB.[2] In response to SB 375, the State has already taken action to implement some of the strategies that research shows are likely to reduce VMT. State-funded grant programs, for example, provide funding and financing for infill development, transit, bicycle facilities, and other changes to the built environment that will enable Californians to reduce their driving. At the same time, it is important to recognize that many long-standing state policies are likely to contribute to increased VMT trends even though this was not their primary objective. Most notably, decades of expansions of the state highway system, declines in the inflation-adjusted state gas tax, and financial and policy barriers to infill development and housing production have contributed to an upward VMT trend.[3] State policies often work against each other in influencing how much the state's residents drive.

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[1] Mobile Source Strategy, May 2016. Available at:

[2] Senate Bill 375 - Research on Impacts of Transportation and Land Use-Related Policies. Available at: https://arb.ca.gov/cc/sb375/policies/policies.htm

[3] For a summary of the evidence on how highway capacity increases lead to move VMT, see the ARB policy brief on highway capacity and induced travel, at https://www.arb.ca.gov/cc/sb375/policies/hwycapacity/highway_capacity_brief.pdf.
https://www.arb.ca.gov/cc/sb375/policies/hwycapacity/highway_capacity_brief.pdf.

The strategies for reducing driving that the State is considering for the Scoping Plan Update fall into four general categories: Pricing, Infill Development, Transportation Investments, and Travel Demand Management Programs. The State has the ability to directly implement some of these strategies, particularly pricing and some infrastructure strategies, through state policy and direct investment. For other strategies, the State can adopt policies that encourage or require the implementation of the strategy on the part of regional agencies, local governments, and/or the private sector. Infill development, for example, depends largely on local land use policies. For some strategies, such as bicycle infrastructure, state policy can both directly and indirectly influence its implementation.

Projecting the state-wide impact of state policy on VMT thus depends on two components: the "strategy effect," the effect of the strategy, when implemented, on the behavior of Californians and the amount that they drive; and the "strategy extent," the extent of the implementation of the strategy across the state in response to state policy and other forces. The evidence base on strategy effect is strong for most of the strategies under consideration: we can be confident that, if implemented, these strategies will produce a reduction in VMT, even if the magnitude of that reduction is uncertain. In contrast, the evidence on how to increase the strategy extent is often more limited.

Strategy Effect and Strategy Extent

Strategy Effect: The strategy effect is how a strategy (or policy) would change VMT. For example, if the fuel tax in the state were increased by ten percent, how would one driver's VMT change?

Strategy Extent: Strategy extent is how many drivers (or persons) can or would be affected by a strategy. For example, if the State offers incentives for infill development, how many more infill units will be built, and hence how many persons are affected by the strategy?

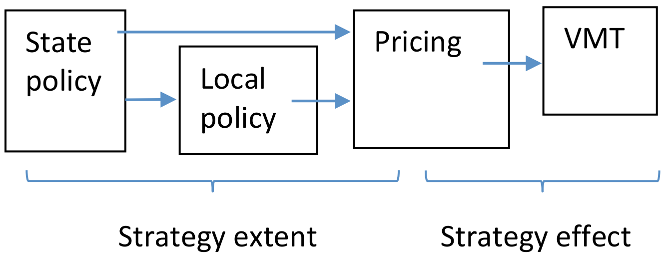
We can simplify by imagining that the overall policy impact is the strategy effect multiplied by the strategy extent.

For example, the influence of state subsidies or affordable housing policy on the actions that local governments take with regard to providing more infill development is sometimes debated, suggesting a need for more research on actions the state could take to foster more infill development. The existing evidence base, however, clearly shows that increased infill development leads to reduced VMT. For infill development, the question is not whether infill development would lead to reduced driving – it will – but rather which state policies would lead to more infill and, if those policies are implemented, how much would VMT be reduced. This is only one example; we discuss the difference between strategy effect and strategy extent for all four categories of policies that are covered in this document. In this paper, we consider the evidence available and assumptions needed for projecting statewide VMT[4] reductions for each category of strategies. Our goal is to provide a framework for at least roughly projecting the magnitude of reductions that the state might expect for the different strategies. The projection methods differ for each strategy depending on its "causal chain" – the sequence of events triggered by state policy that ultimately produce reductions in VMT, including both strategy extent (the causal chain from state policy to strategy implementation) and strategy effect (the causal chain from strategy implementation to VMT reduction). The form in which each strategy effect is reported in the literature also determines the projection method; in discussing strategy effect we rely on our reviews of the evidence base as reported in the ARB Research Briefs, mentioned above. We also outline the critical gaps in knowledge, data, or methods that must be filled before more robust projections are possible. California has staked a cutting-edge position with its GHG reduction framework, and that gives the state an opportunity to push our knowledge base forward. By highlighting knowledge gaps we are noting areas where California can continue and extend its tradition of leadership in environmental policy and environmental science.

We do not in this paper examine the potential co-benefits of VMT-reduction strategies, though they are potentially substantial. Reducing VMT not only reduces GHG emissions, it also reduces emissions of pollutants that harm human health as well as agricultural productivity and natural habitats. Infill development coupled with investments in transit services and bicycle and pedestrian infrastructure expands transportation options, reducing the need for owning a private vehicle and the financial burden that comes with it for lower-income households. Evidence of the benefits of VMT-reduction strategies for human health, social equity, the environment, and the economy is strong, and it further justifies state action to promote these strategies.

[4] For most of the strategies we examine here, the available research examines the effect of the strategy on VMT or other aspects of travel behavior rather than GHG emissions. While VMT reductions translate relatively directly into GHG emissions reductions, other factors may come into play. If, in addition to VMT reductions, the strategy also leads to changes in driving speeds (not just averages but distributions of speeds over the course of trips) or changes in the types of vehicles Californian's drive, then the conversion to GHG emissions is less straightforward. Infill development, for example, might reduce driving distances but also encourage smaller vehicles and produce more congestion and thus lower speeds. For the most part, the literature provides little basis for developing more nuanced conversions of VMT to GHG emissions for these strategies.

1. Pricing



Pricing is a particularly promising policy tool to reduce VMT and associated GHG emissions, for two reasons. First, the effect size from pricing interventions to VMT is larger than the effect size for other policy or planning tools. Second, pricing can be applied to a broad base, and state action can be particularly effective here. In other words, pricing can achieve a broad strategy extent quickly. Recall that the effect of a policy is the effect size (e.g. the amount that a driver's VMT would be reduced if the policy were applied to that driver) multiplied by the number of drivers exposed to the policy.

Pricing revenues can be used to expand non-automobile travel options, making the pricing policies themselves more effective at VMT reduction. Similarly, pricing policies can be used to address equity concerns, for example by expanding bus service, providing pedestrian or bicycle improvements, or mitigating environmental impacts in low-income neighborhoods.

Pricing also has the advantage of raising revenue to fund needed transportation projects. Statewide, our cities and counties have transportation needs that outstrip available revenue. For example, the State Transportation Plan identifies a $294 billion funding gap – funding only 45 percent of the State's transportation system needs through 2020.[5] Pricing and vehicle fees can fund infrastructure improvements, manage congestion, and maintain roadways while also improving air quality and better manage our transportation infrastructure.

There are several different ways to use pricing. We define those briefly here:

Link Tolls: Charge a toll to drive on a portion of a highway. The toll typically varies with congestion levels. Examples include the high-occupancy toll lanes on San Diego's SR-125 and Los Angeles I-110, and congestion priced toll lanes on SR-91 in Orange County. In the San Diego and Los Angeles examples, the toll adjusts based on traffic levels (more traffic implies a higher

[5] See http://www.dot.ca.gov/hq/tpp/californiatransportationplan2040/Final%20CTP/CTP2040-Appendices-WebReady.pdf.

toll) while the toll on the SR-91 in Orange County is based on time of day (peak periods have higher tolls.)[6]

Cordon Tolls: Charge a toll to cross into a downtown central business district or other congested area. There are currently no examples of cordon toll pricing in the U.S. Well known international examples of cordon tolls include London's toll ring, around the center of the city, and the cordon toll in Singapore.

VMT fees: Drivers are charged a fee based on miles driven (VMT). Oregon launched a VMT fee pilot experiment which enrolled drivers in pilot programs to test replacing the state's fuel tax with a VMT fee. California launched a similar pilot in 2016.[7] In 2008-2010, the University of Iowa led a national pilot program that examined VMT fees in lieu of fuel taxes in twelve locations. No VMT fee has moved beyond the pilot/study phase in the U.S.

Fuel taxes: Fuel taxes are applied by every state in the U.S. and the federal government. At-the-pump fuel taxes are assessed on a cents per gallon basis, and so are not adjusted for inflation. A relatively minor exception is cases where sales taxes are also applied to per-gallon fuel taxes. Increased fuel efficiency implies that persons can drive more per gallon, hence fuel taxes raise less revenue per mile driven as vehicle fuel efficiency increases.

Parking prices: There are many parking pricing schemes, from fixed-priced street meters to workplace parking cash-out schemes that offer employees cash in lieu of subsidized free parking to policies that charge employees or non-work travelers for parking to real-time metered parking prices that adjust to equilibrate supply and demand. All have been applied in California. To date, parking pricing policy in the state has been exclusively the domain of local governments, though AB 744 reduced parking space requirements statewide for affordable senior housing.[8]

Pay-as-you-go insurance: This policy proposes to change vehicle insurance from a monthly or six-month fee, which is typically assessed independent of driving, to a per-mile fee.

Freight low emission zones: This proposal would establish low emission zones, usually near residential areas, where trucks would either have to use low emission technology or pay a fee. The prospect of combining pricing with careful land use considerations is a promising way to

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6 Some highways in California use tolls that do not vary with time of day or congestion. The toll roads in south Orange County (portions of SR 73, 133, 241, and 261) have flat rate pricing. The tolls on those lanes were not designed to manage congestion, but are solely a financing tool. There is little evidence on whether and how flat-rate tolls reduce driving, although one can infer that the price effect may be similar. We focus our attention on congestion tolls, which bring the added benefit of congestion management and for which the evidence base is larger.

7 See https://www.californiaroadchargepilot.com and, for a related discussion, Marlon G. Boarnet, "Policy Approaches for California's Transportation Future," California Central, 2016, available at http://californiacentral.usc.edu/wp-content/uploads/2016/06/CA-Central-transportation-6-13-16.pdf.

8 See https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB744.

address environmental justice implications of truck emissions that disproportionately affect low-income communities. Yet this policy, because it is a hybrid of pricing, emission technology requirements, and land use patterns that would interact with the transportation network, is less a pure pricing strategy. Also, the response of truck traffic to pricing depends on the nature of driver contractual relationships with trucking companies and hence is best informed by evidence that is specific to pricing and trucking. For those reasons, we believe the existing pricing evidence, largely from passenger travel and mostly from pure pricing experiments or policies, cannot be as easily applied to low emission zones. We note, though, that the same basic theory applies to trucks as to passengers – higher prices would discourage driving activity in the locations and at the times for which the price is higher – and it is only the magnitude and detailed effect of a low emission zone that we do not discuss further here.

Strategy Effect: Impacts of Pricing on Individual or Household VMT

The available evidence on effect sizes can be grouped into four categories: (1) link and cordon tolls, (2) VMT fees, (3) Fuel prices (and hence fuel taxes), and (4) parking pricing. We know of no available evidence on the effect size of pay-as-you-go insurance, and for the reasons mentioned above we believe that freight low emissions zones, while promising, should be a separate topic of study.

Importantly, both theory and evidence suggest that the effect sizes are similar across the different pricing tools for which data are available. A price is a price, and, as an approximation, drivers should not care if they pay a dollar to buy gas, drive on the highway, or park; the effect of the price on driving might be quite similar for those different policies. As it turns out, the empirical range of pricing effect sizes across different policies are similar, and that allows some confidence to interpret from the existing evidence base to policies, such as pay-as-you-go insurance, for which there is not currently an effect size evidence base. It is reasonable to assume, for example, that pay-as-you-go insurance would look to drivers like a VMT fee, and hence that the VMT fee evidence would apply. As mentioned above, freight low emission zones, because they are a hybrid of pricing, emission technology requirements, and land use, would require additional evidence not discussed here.

The range of effect sizes in Table 1 is large in some cases (e.g. the long-run elasticity of VMT with respect to fuel price.) We note that a conservative estimate of an elasticity would be -0.1, which is toward the low end of the range for link and cordon tolls and for fuel prices. Similarly, results from the Oregon VMT fee pilot program suggest that replacing a fuel tax with a VMT fee in a revenue-neutral way could reduce VMT by 11 to 14 percent. Overall, we suggest that an elasticity of VMT with respect to pricing of -0.1 is a conservative estimate that might be used to apply across different pricing programs.

Most of the evidence on parking pricing relates price to the demand for parking spaces, and inferring a VMT elasticity for parking pricing can be more difficult. However, a recent program in San Francisco, SF*park*, adjusts on-street parking prices based on occupancy – raising the metered price for an on-street parking space when more than 80 percent of the spaces on a block are occupied (Millard-Ball, et al., 2014). Recent studies of SF*park* suggest that the program and it's demand-based pricing may reduce cruising for parking by 50 percent (Millard-Ball, et al., 2014).

Table 1: Effect Sizes for Pricing Policies

Pricing Policy	Elasticity (unless otherwise noted)	Source
Link and Cordon Tolls	-0.1 to -0.45	ARB policy brief on road user pricing
VMT fees	-11% to -14.6% reduction from shifting gas tax to VMT fee	ARB brief on road user pricing, from Oregon VMT fee experiment
Fuel prices	-0.026 to -0.1 (short-run) -0.131 to -0.762 (long-run)	ARB brief on gas price
Parking pricing	-0.3 for demand for parking spaces	ARB parking pricing and parking management brief

Source: ARB policy briefs, at https://arb.ca.gov/cc/sb375/policies/policies.htm

Strategy Extent: Impact of State Policy on Pricing

Pricing can be implemented in ways that achieve broad strategy extent. VMT fees and fuel prices can affect every driver in the state. Again, this paper provides a framework for at least roughly projecting the magnitude of reductions that the state might expect for the different strategies. There are few other State actions that could similarly achieve universal coverage without collaboration or leadership from a broad range of municipal governments. Link and cordon tolls have typically been the purview of local governments, and because such congestion pricing is applicable in congested locations, link and cordon tolls would likely continue to be a local government activity. But Caltrans is the owner operator of the state highway system, and so the State has many opportunities to encourage link pricing, in particular, on state highway routes. The State could, for example, offer subsidies or incorporate pricing more explicitly into the SB 375 Sustainable Communities Strategy (SCS) process. Similarly, the State could work closely with local governments and county transportation agencies to encourage innovative programs that use pricing while also addressing the equity questions that are raised by road or VMT pricing. Other efforts, such as pay-as-you-go insurance, could be implemented through State action. Overall, State action in pricing can have a broad extent and can take effect quickly, as opposed to land use policies which would have a sizeable effect but over a longer period of time as the built environment is modified.

The steps to use in quantifying the impact of State-level pricing strategies on VMT are shown in Table 2 below. Table 2 has four panels, for fuel taxes, VMT fees, link or cordon tolls, and pay-as-you-go insurance. Parking pricing is not shown, because the link from those policies to VMT has been less studied, although the nascent evidence from SF*Park* is promising and suggests that priced parking can substantially reduce the amount that drivers "cruise" to find parking spaces (Millard-Ball, Weinberger, and Hampshire, 2014).

Note that the data on the fuel prices gives direct estimates of the effect of changes in fuel prices (from, e.g., tax changes) on VMT; relatively few assumptions are needed compared to other policies that we discussed in this paper. The data on VMT fees similarly require few assumptions, although the state would require advances in modeling the location of traffic across the state and into and from neighboring states for a complete analysis. While the VMT fee data are from pilot programs, those programs and the current pilot in California provide an opportunity to get good evidence on the effect of VMT fees on driving. Tolls require an assumption about the amount of driving that would be diverted to routes or times of day that are not tolled, and the evidence on that is more limited.   Leape (2006) estimates that a quarter of the traffic reduction within the London cordon toll ring was diverted to other routes. Pay-as-you-go insurance requires an assumption that the elasticities from VMT fee or fuel tax studies apply, but such as assumption is theoretically sound. Overall, quantifying the effect of pricing on driving requires relatively few assumptions compared with other policies.

Table 2: Assumptions and Data Needed to Estimate Effect of State-Level Pricing Strategies on VMT

Panel A: Fuel Prices

Step	Assumptions or Data Needed	Validity of Assumption (Scale: 1 = poor, 5 = excellent)	Future research tasks to strengthen assumptions and data
1. Quantify percentage increase in fuel price	Compare proposed tax increases to existing fuel prices	Validity = 5 (excellent) Data are available on fuel prices, by state and for areas within the state. Fuel prices vary over time, often substantially so, and so analysts would have to address that variation over time in assessing the "base" (before-tax-increase) fuel price.	Data are available.
2. Determine population that will be affected by tax	Fuel taxes typically affect everyone in the state	Validity = 4 (good) to 5 (excellent) The literature on passenger travel and fuel taxes gives good evidence; less literature on freight travel and fuel taxes	To refine future estimates, the state can study how freight travel responds to fuel taxes and whether the strategy effect, from mostly passenger vehicle studies, applies to freight traffic.
3. Apply strategy effect to affected population	Use elasticity of -0.1 (minus 0.1), per discussion above	Validity = 4 (good) to 5 (excellent)	Studies on the effect size are high quality. Future research should examine how variation in fuel prices over time affect VMT, given the high month-to-month and year-to-year volatility in fuel prices. Over the long-term, taxes might be designed to adjust in the opposite direction of market fuel price variation, holding at-the-pump fuel prices more constant.

Panel B: VMT Fee			
Step	**Assumptions or Data Needed**	**Validity of Assumption (Scale: 1 = poor, 5 = excellent)**	**Future research tasks to strengthen assumptions and data**
1. Assess extent of VMT fee	Fees could be statewide or for sub-sets of state	Validity = 4 (good) to 5 (excellent)	Traffic will cross borders if VMT fee does not apply to entire state, and even if statewide, some traffic will enter and leave the state. Some improvement in statewide travel modeling could be needed to account for border effects.
2. Quantify whether VMT fee will be revenue neutral	Assumption about revenue neutrality will translate to amount of the VMT fee	Validity = 4 (good) to 5 (excellent)	Continue pilot programs to understand how revenue responds to fee levels
3. If fee is revenue neutral, apply evidence on effect	Oregon pilot program suggests revenue neutral VMT fee will reduce driving by 11 to 14 percent	Validity = 3 (fair) to 4 (good)	Evidence from California pilot program (now underway) should be used to supplement the Oregon evidence

Panel C: Link or Cordon Tolls			
Step	**Assumptions or Data Needed**	**Validity of Assumption (Scale: 1 = poor, 5 = excellent)**	**Future research tasks to strengthen assumptions and data**
1. Estimate toll amount and resulting change in cost of travel	Data on pre-existing travel needed -- use estimates of number of persons passing link from Caltrans link travel data (e.g. AADT), and estimate pre-toll dollar cost of travel based on average trip lengths	Validity = 3 (fair) Data on link travel can be obtained, but the literature does not clarify if the time-cost of travel should be included in the base amount to analyze change in travel cost.	California has existing toll lanes, and data from those lanes should be used to get better information about the appropriate measure of the population affected and how to measure toll costs for purposes of applying the elasticity of the strategy effect.
2. Estimate reduction in traffic in tolled area	Apply elasticities, which for link and cordon tolls will usually predict reduction in traffic in the tolled area, not reductions in VMT	Validity = 3 (fair) to 4 (good)	Continue research, particularly on cordon tolls which have not been implemented in U.S. and so require research from international settings
3. Estimate diverted traffic	Estimate the amount of driving that moved from the tolled area to a different route	Validity = 2 (poor)	The evidence on how tolls divert traffic is limited. Leape (2006) estimates 1/4 of reduced traffic in London cordon toll was diverted to other routes. Toll lane price changes in California can provide an opportunity for before-after studies of traffic diversion.
4. Estimate VMT reduction	Use data or assumptions about average trip lengths (before tolling), reduction in trips, and the fraction of trips diverted to get estimate of reduced VMT.	Validity = 2 (poor) to 3 (fair)	Diverted traffic is the weakest link here, and future research should focus on how toll price changes divert traffic.

Panel D: Pay-As-You-Go-Insurance			
Step	**Assumptions or Data Needed**	**Validity of Assumption (Scale: 1 = poor, 5 = excellent)**	**Future research tasks to strengthen assumptions and data**
1. Assess Population Affected by Pay-As-You-Go Insurance	If program is voluntary, use data from pilot programs or other markets to assess how many drivers would opt for pay-as-you-go insurance	Validitity = 3 (fair)	There is very limited experience with pay-as-you-go insurance. Pilot programs are advisable to understand the "take up" rate for this insurance product, particularly if pay-as-you-go competes with traditional flat-rate insurance.
2. Quantify percentage increase in cost of driving	Compare proposed pay-as-you go fees (per mile basis) to existing per-mile driving costs	Validity = 4 (good) to 5 (excellent)	Data are available on per-mile driving costs.
3. Determine effect size for drivers	Assume pay-as-you-go strategy effect is similar to VMT fees or fuel taxes, hence elasticity = -0.1	Validity = 4 (good)	The price effect is likely very similar to VMT fees or fuel taxes which change the marginal (e.g. per-mile) cost of driving. Pilot programs should be developed to confirm this theoretical prediction.
4. Apply effect size to affected population	Direct calculation from steps above	Validity = 4 (good) to 5 (excellent)	Again, if pay-as-you-go competes with flat-rate insurance, understanding consumer demand for pay-as-you-go will be important

Policy Considerations for Pricing

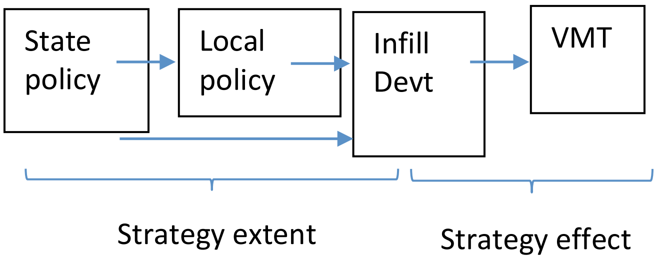
Pricing policies generate a revenue stream. That is an important potential benefit. Pricing also brings substantial policy advantages beyond VMT reduction. Pricing revenues can be used to expand non-automobile travel options, making the pricing policies themselves more effective at VMT reduction. Similarly, pricing policies can be used to address equity concerns, for example by expanding bus service, providing pedestrian or bicycle improvements, or mitigating environmental impacts in low-income neighborhoods.

Sales tax finance has become the primary means of transportation finance in most large California metropolitan areas. The sales tax is regressive, meaning that sales taxes are a larger fraction of income for lower income persons than for high income persons. Sales taxes are paid by persons irrespective of their use of roads, raising both efficiency and equity issues. From an efficiency perspective, sales taxes provide no nexus between revenues raised and use of the transportation system. From an equity perspective, sales taxes are paid by persons who do not use the system, with lower income persons paying a larger share of their income in sales taxes. Schweitzer and Taylor (2008) compared the toll-road finance of the SR-91 in Orange County with an equivalent (revenue-neutral) sales tax finance and found that under reasonable assumptions toll road finance would be more equitable, and that sales tax finance could in many cases place a larger burden on lower income households. Pricing policies have the prospect of providing much needed revenues for transportation, in ways that build a link between use of the system and financing while being more equitable than current transportation finance policies.

Pricing policies will be more effective in reducing VMT when and where there are easily available non-automobile options. Hence policymakers should be aware that implementing pricing in locations with many travel options, or with a plan to expand travel options, would be a preferred approach. Fortunately, congestion and parking pricing would likely be implemented first in congested urban areas or in locations where land values are high, which are typically the same locations with non-automobile transportation options.

While evidence suggests that state intervention to increase the price of driving is highly likely to yield reductions in VMT, estimating a more precise degree of impact from state actions – for the purposes of modeling by ARB and others to quantify anticipated VMT reductions from specific strategies – would require further analysis. Table 2 presents an outline of suggested steps for gaining more precision and clarity in this estimation.

2. Infill Development



Land use in California has long been a local domain, but many State actions and laws, such as Regional Housing Needs Assessment (RHNA) allocations and the California Environmental Quality Act (CEQA) influence outcomes. The State also provides subsidies, such as the Affordable Housing and Sustainable Communities (AHSC) program, which can assist localities that are pursuing infill development. State policy, and the link from state policy to local policy, is important. Yet the evidence is most clear on the strategy effect, the effect from land uses associated with infill development to VMT.

Many land use policies have the potential to reduce VMT. The ARB policy briefs discuss the effect of residential density, employment density, land use mix, street connectivity, distance to transit, regional accessibility to jobs, and jobs-housing balance. The literature provides strong evidence that persons who live in more centrally located, dense, mixed use developments with walkable infrastructure and near transit options will drive less. The effect of land use on reducing driving is, at least in part and possibly in largest part, causal, meaning that when persons move to a mixed-use transit-oriented or walkable neighborhood, the land use causes them to drive less (Cao, Mokhtarian, and Handy, 2009; National Research Council, 2009; Duranton and Turner, 2016.)

We will first discuss that body of evidence on the effect of land use and infill development on VMT (i.e. the strategy effect), then turn to the upstream question of the effect of state and local policy on infill development (i.e. the strategy extent). Note that policies to promote infill development are policies that will place more residents in locations that are more accessible to jobs and transit, with higher densities, more mixed land uses, and better street connectivity. Hence we use "infill development" as a summary measure of land use, both because it is a meaningful measure and because it clarifies policy approaches to metropolitan area planning. State policies can affect the prospects for infill development, and recent state actions (e.g. SB 743) are attempts to measure impacts in ways that change the attributed traffic/transportation impact of infill versus outlying development to more appropriately give environmental credit to infill projects that will reduce VMT in large metropolitan areas.

Strategy Effect: Impact of Infill Development on Individual or Household VMT

The first question is how to measure the effect of infill development on individual or household travel behavior.[9] We suggest that the best proxy measure for infill development is regional access to jobs. Both lay audiences and policy-makers often think about residential density when measuring land use, because density is intuitive (persons or dwelling units per land area) and easy to measure. Yet residential density is among the land use variables with the weakest links to VMT. The strategy effect size of residential density on VMT has an elasticity from -0.05 to -0.12, meaning that if density doubled, household VMT would be reduced by from 5 to 12 percent. The strategy effect size of regional job access is twice as large – an elasticity of from -0.13 to -0.25.[10] This implies that density alone is a less meaningful metric for VMT reduction than proximity to job centers. However, in practice, increased density is likely also needed to increase the number of households near job centers.

Not only is the strategy effect of density smaller than the strategy effect of regional job access, regional job access is a policy with a potentially broader strategy extent. Doubling residential density would be, in most locations, outside of the realm of feasible policy changes. As we show in the appendix, infill policies can double a household's regional job access in California's urban areas simply by providing housing options that are closer to job concentrations, and are likely feasible in ways that doubling density is usually not. Overall, regional job access is a much better measure of the strategy effect and the policy possibility (strategy extent) of infill development.

Improving regional access to jobs implies a planning focus on where, in the metropolitan area, new growth occurs. Would new growth be near the center, where more jobs are located and hence where access to jobs is good, or on fringe, where access to jobs is weaker?

A typical measure of jobs access is called a "gravity variable." Most gravity variables are a sum of the jobs that a resident can reach from their household, multiplying jobs by the inverse of the distance from a household's home to the job. Jobs that are closer to where a household lives count for more, and jobs farther away count for less. There are different mathematical formulations in the literature. Some authors sum only jobs within five miles of a household (for an application, see Salon, 2014, or Boarnet and Wang, 2016.) Other studies (e.g. Zegras, 2010) use distance from the downtown by itself, noting that a household's distance from downtown is strongly correlated with gravity variable measures of job access. For now, note that distance from downtown (e.g., whether a household live 10 miles from downtown, or 20 miles from downtown) is easier to measure than a gravity variable that sums all jobs in the metropolitan

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[9] Often times the academic literature looks at household travel, because family members within a household can trade trips, such that one person might go to the store while the other does the banking, or vice versa. Using household data allows researchers to treat the household as the behavioral unit. When the overall literature is summarized, as we do here, the disaggregate data are typically from studies of individual travelers or drivers, or from households.

[10] See the ARB Research Briefs on residential density and regional access to jobs, at https://www.arb.ca.gov/cc/sb375/policies/density/residential_density_brief.pdf and https://arb.ca.gov/cc/sb375/policies/regaccess/regional_accessibility_brief120313.pdf, respectively.

area weighted by the inverse of the distance from the household to those jobs. Having said that, much of the literature has used gravity variables, and so we discuss gravity variables first.

Figure 1 shows gravity variable measures of job access for the greater Los Angeles region, in five categories, or quintiles. Figure 1 shows that locations near downtown have the best job access, and job access declines as one moves further from downtown. The ARB policy brief for regional job accessibility suggests an elasticity of VMT with respect to job access ranging from -0.13 to -0.25, meaning that if job access were doubled (a 100 percent increase), household VMT would decline by from 13 to 25 percent. Note that high end of the range of this strategy effect is almost exactly the same as what you would get if you used a simpler measure of distance from downtown, for which the ARB policy briefs suggest an effect size of 022 to 0.23, meaning that if a household moves from 10 to 20 miles away from downtown (a 100 percent increase in their distance to downtown), their VMT would increase by 22 to 23 percent.[11]

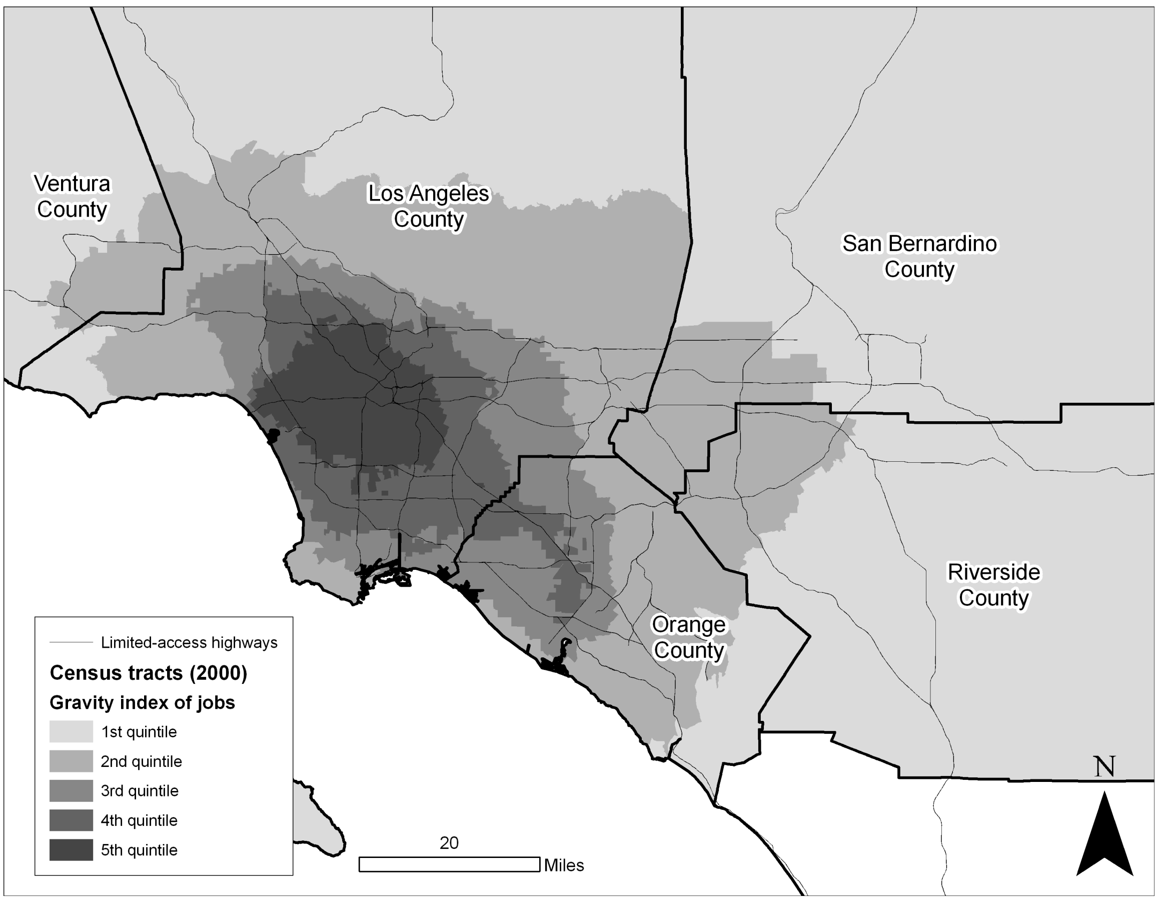

Figure 1. Gravity Variable of Regional Access to Jobs, metropolitan Los Angeles, 2000 (reprinted from Boarnet, Houston, Ferguson, and Spears, 2011, Figure 7.3)

[11] See the ARB Research Briefs on regional access to jobs, https://arb.ca.gov/cc/sb375/policies/regaccess/regional_accessibility_brief120313.pdf.

The strategy effect would measure moving persons (or changing the location of new development) from places with poor to better job access. As an example, the Southern California Association of Governments has proposed to focus almost half of the region's future growth and new development in high quality transit areas, defined as places within a half-mile of fixed-route transit or bus transit with peak-period transit service of 15 minutes or less.[12] Many other metropolitan areas have engaged in scenario planning exercises to simulate changes in growth patterns that would favor infill development. Referring back to the map in Figure 1, the darkest shaded areas have the best job access (they are in the fifth, or highest, quintiles of access.) The next darkest areas are in the fourth quintile, and the next highest areas are in the third quintile, and so forth. Example communities in those areas are shown in Table 3 below.

Table 3: Examples of Municipalities in 3rd, 4th, and 5th Quintile of Regional Access to Employment

Job access quintile [a]	Example neighborhood/municipality
5th quintile (highest job access)	Downtown Los Angeles Hollywood West Los Angeles Crenshaw Echo Park
4th quintile	Santa Ana Orange Fullerton Lakewood La Mirada Southern San Fernando Valley
3rd quintile	North Orange County Covina

An ideal measure of the effect of infill development would measure the effect of changing the location of development on VMT – for example, what would happen if, instead of building new residences near Covina (the third quintile of job access in Figure 1), the Los Angeles region added new residences in communities such as Santa Ana (the fourth quintile of job access) or Echo Park (the fifth or highest quintile of job access.) One method would be to assess, numerically, how much a measure of a household's job access would increase when they locate in, for example, Santa Ana or Echo Park as opposed to Covina. Such a method is outlined in the appendix. This approach would require several computational steps, and for simplicity we do

[12] SCAG's 2016 Regional Transportation Plan projects that 46 percent of new residential growth and 55 percent of new employment growth will be on the three percent of the region's land that is in high quality transit areas. See Southern California Association of Governments, 2016 RTP/SCS, Executive Summary, p. 8, http://scagrtpscs.net/Documents/2016/final/f2016RTPSCS_ExecSummary.pdf.

not go over that here, although we note that the estimated strategy effect computed in the appendix is similar to what we present here using simpler methods.

Rather than use a gravity variable for regional access to jobs, one could use distance from the downtown to approximate the change in the job access measure. Following the example, Covina is approximately 24 miles (driving distance) from downtown Los Angeles, while Echo Park is approximately 4 miles from downtown Los Angeles, a reduction in distance from downtown of 83 percent if infill development could allow a household to locate in Echo Park rather than Covina. Multiplying that change in distance by the 0.22 effect size of distance from downtown, this implies that moving households from Covina to Echo Park could reduce their driving by 18 percent. Using more sophisticated regression techniques, Boarnet and Wang (2016, Table 12, p. 36) predict that a household move across similar distances in the Los Angeles region could be associated with even larger VMT reductions – as large as 33 percent.[13]

We can use the literature, with effect sizes drawn from changes in gravity variables or simpler changes to distance from downtown, to predict the effect of increased infill development. Table 4 gives an illustration of the steps and the data and assumptions needed.

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[13] See Marlon G. Boarnet and Xize Wang, Urban Spatial Structure and the Potential for Reducing Vehicle Miles Traveled, National Center for Sustainable Transportation research report, April, 2016, available at http://ncst.ucdavis.edu/wp-content/uploads/2014/08/04-18-2016-NCST-Urban-Spatial-Structure-Boarnet-4_10_16.pdf, accessed Sept. 24, 2016.

Table 4: Assumptions and Data Needed to Estimate Effect of Infill Development on Household VMT

Step	Assumptions or Data Needed	Validity of Assumption (Scale: 1 = poor, 5 = excellent)	Future research tasks to strengthen assumptions and data
1. Measure land use patterns associated with infill development	Choose a measure that will proxy location in the region, and hence infill policies: Regional job access measures as a gravity variable or distance from downtown	Validity = 3 (fair) to 4 (good) If access to transit and access to non-auto transportation are included elsewhere in the analysis, evidence indicates that remaining land use patterns are correlated with regional job access; the evidence suggests that the size of the strategy effect is very similar whether measured by gravity variables or distance from downtown, even in highly sub-centered metro areas	Develop statewide GIS measures of land use characterized by either (1) distance from metropolitan area downtown, (2) gravity measure of regional access to jobs, or (3) the land use categories developed in research by Salon (2014) which can likely be analogs to regional job access
2. Use data across different locations to proxy infill development – translate infill to changes in a job access gravity variable or changes in distance from downtown.	Need assumptions or information from scenario models about different growth scenarios for metropolitan areas to understand how regional job access would change, and for how many households	Validity = 2 to 3 (poor to fair) There are several scenario tools, but all such tools are possible policy futures. There will be uncertainty regarding the amount of infill development, and we suggest modeling several possible future infill growth scenarios, from aggressive use of infill to somewhat less aggressive, to bound possibilities.	Recommend using or updating the scenario tool developed as part of Salon (2014) for statewide simulations of moves across development types.
3. Use an elasticity of household VMT with respect to regional job access to calculate percentage changes in household VMT	Use regional job access elasticity from ARB regional accessibility brief.	Validity = 4 (good) Job access elasticities vary within metropolitan areas, as demonstrated by Boarnet et al. (2010) and Salon (2014), but regional averages give a good mid-point or average effect.	Use ranges of elasticities from, e.g., Boarnet et al. (2010) or Salon (2014), or adapt and use the scenario tool from Salon (2014)
4. Apply predicted percentage change in household VMT to a base-year measure of household VMT to obtain predicted change in household VMT.	Apply predicted percentage change in household VMT to average household VMT for a metropolitan area or the state.	Validity = 2 to 3 (poor to good) The CHTS has data on household VMT in different locations. These data are available and reliable. The difficulty is understanding where households might have located absent infill policies, a point currently not sufficiently addressed in the literature. Scenario models can be used to assess where households would have lived absent infill policies.	More research on how changes in housing supply in specific locations (e.g. infill) affect residential location choices of households.

Table 4 illustrates four steps, (1) measuring land use patterns, (2) simulating changes in development patterns (e.g. from infill development) and translating those changes in development patterns into changes in a measure of regional job access or distance from downtown, (3) using elasticities in the literature to measure the impact of a change in regional access to jobs (or distance to downtown) on VMT, and (4) apply the predicted change in VMT to a base year level of household VMT.

Table 4 starts with a first step of measuring land use, either with gravity variables or with simpler measures of distance from downtown. Note that the Air Resources Board recently funded research by Salon (2014) which developed statewide categories of neighborhood types, and those neighborhood types might be close approximations to regional job access, and so we add those neighborhood types developed by Salon (2014) to the list of possible regional job access measures. A complementary approach could be based on the California Statewide Travel Demand Model, which has employment data for zones statewide.[14] The second step would assess how changes in the amount of infill development would lead to changes in job access and how many persons (households) would be affected by those changes. We suggest bounding possible amounts of new development in this second step, from a modest amount of infill to aggressive use of infill, relying on local policy expertise to inform how modest and aggressive would be quantified in terms of number of new housing units and hence the number of households affected. Step 3 in Table 4 applies elasticities from the ARB job access policy brief. We note that there is a nascent literature (Boarnet, 2011; Salon, 2014) that gives evidence that the strategy effect of regional job access on VMT varies depending on where, in the metropolitan area, a household lives, but we also note that mid-point or average estimates of the policy effect will both work well and, if anything, understate the VMT effect of infill development.[15] The last step would be to apply the strategy effect (percent reduction in VMT) to the number of households affected by the strategy.

The evidence is consistent and very strong that households that live in more central locations in urban areas drive less. That relationship is very common in the data, and sophisticated studies that attempt to control for household location choices suggest that more central locations with better multi-modal transportation access cause households to drive less (e.g. Duranton and Turner, 2016; Spears, Houston, and Boarnet, 2016.) While we suggest, in Step 4 of Table 4, that the state continue to research *how* different households choose their residential location, and hence which households would move into infill developments, we note that such information will be more important to understand questions of equity (e.g. gentrification and displacement)

[14] See the SB 743 Impact Assessment Web page, at http://www.dot.ca.gov/hq/tpp/offices/omsp/SB743.html. The data available there can provide a basis for measures of employment in zones throughout California, and hence for measures of employment access.

[15] The strategy effect of regional access to jobs might be larger in centrally located areas, implying that using the metropolitan-wide average effects from the ARB policy briefs might understate the VMT-reducing effect of infill development. For a discussion and evidence, see Boarnet et al. (2010) and Salon (2014).

rather than to understand whether households in central locations drive less. The literature provides strong evidence that households in more central parts of urban areas drive less.

Strategy Extent: Impacts of State Policies on Infill Development

While there is strong, evidence-based correlation between infill development and VMT reduction, estimating state-wide VMT effects of State policies to encourage infill development requires additional assumptions about the effectiveness of state policies in making infill development happen. There is still a lack of empirical literature on *how* state policies lead to more (or less) infill development, but the state's existing policy framework, including but not limited to SB 375, provide an opportunity to study how state goals and requirements influence development activity. For now, we note that the state has many policy tools that can influence development.

State Policy Considerations for Infill Development

The state has interests in increasing infill development, and the literature demonstrates that doing so will advance State VMT reduction goals (as well as multiple other State policy priorities). SB 743 changed the traffic impact metric in CEQA, and Governor Brown recently proposed a by-right housing proposal which was not acted upon by the legislature. The state has also recently taken action on auxiliary dwelling units.

More could be done by continued changes in the measurement of impacts required by state legislation (e.g. CEQA), or with legislation that allows (or even requires) streamlined development approval when certain conditions (possibly infill location and/or providing affordable housing) are met. The state could also subsidize infill development, or provide tax reductions, which could incentivize increased infill development, although we note that such tools, in isolation, would not get around restrictive local land use regulations. Additionally, the State could add to the "toolbox" of existing financing tools for infill development and also the financing that is available for critical, infill-supportive infrastructure, which would also likely incentivize an increased share of infill development. Financing tools are likely to be particularly critical in shaping future development patterns in areas of the state where infill is at an economic disadvantage compared to greenfield or more remote development due to market conditions and/or distressed conditions in infill areas. Finally, the State could directly incentivize consumer choice, for example through low-VMT housing rebates or "live where you work" incentive programs. The location of infrastructure, including highways, transit, schools, and major public buildings, can also influence growth patterns.[16] Aligning state infrastructure spending with infill goals, e.g. through performance metrics or other criteria, would be one way to ensure better leverage these investments to further VMT and GHG reduction goals.

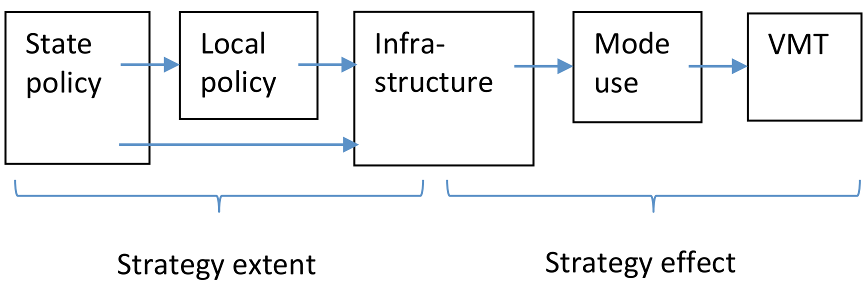
[16] For evidence of the effect of highways on growth patterns, see Funderburg, et al. (2010) and Baum-Snow (2007).

While evidence suggests that state intervention to increase infill development is highly likely to yield reductions in VMT, estimating a more precise degree of impact from state actions – for the purposes of modeling by ARB and others to quantify anticipated VMT reductions from specific strategies – would require further analysis. Table 4 presents an outline of suggested steps for gaining more precision and clarity in this estimation.

3. Transportation Investments

In this section, we separately consider the VMT impacts of three categories of transportation investments: bicycle and pedestrian infrastructure, transit service, and highway capacity. Although the impacts of bicycle infrastructure are distinct from the impacts of pedestrian infrastructure, the methods for projecting their impacts are similar, so we consider them together. The subsection on transit focuses on the impact of expansions in transit service rather than infrastructure per se, given the nature of the research available. We consider only intra-regional transit service, rather than inter-regional service such as high-speed rail, the potential GHG impacts of which have been quantified using an ARB-approved methodology.[17] The subsection on highway capacity differs from the first two in that the available research provides evidence on *increases* in VMT resulting from increases in capacity.

3.1 Bicycle and Pedestrian Infrastructure



Strategy Effect: Impact of Bicycle and Pedestrian Infrastructure on Individual or Household VMT

Investments in bicycle and pedestrian infrastructure have the potential to reduce VMT by encouraging a shift from driving to these active travel modes. A growing body of research shows a strong connection between the extent of bicycle and pedestrian infrastructure and the amount of bicycling and walking in a community. Many of the available studies focus on commute trips rather than active travel for all purposes; some studies do not separate active travel from recreational walking and bicycling. Most studies measure infrastructure investments in terms of miles of facilities or percentage increases in miles of facilities without accounting for the quality of the new facilities or their impact on the connectivity of the bicycle or pedestrian network, though current studies are beginning to provide insights into the effects of facility characteristics and network connectivity, not just extent (e.g. Monsere, et al. 2014).

As summarized in the ARB Research Briefs, differences between the studies do not enable a consensus estimate of the strategy effect, though results from individual studies could be used. A relatively recent study of 24 California cities found that a 1% increase in the percent of street length with bike lanes in a city was associated with an increase of about 0.35% in the share of

[17] https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/hsrinterimqm.pdf

workers commuting by bicycle (Marshall and Garrick, 2010). These results suggest that in a city where 1% of commuters bicycle, a 100% increase (i.e. a doubling) in the percent of streets with bike lanes would increase the bicycle commuter share to 1.35%. For walking, a North Carolina study found that a 1% increase in the portion of the route with sidewalks was associated with a 1.23% increase in the share of walk commuting (Rodriguez and Joo, 2004), though other studies suggest a much more modest effect.

While the literature strongly suggests that bike and pedestrian infrastructure increase biking and walking and therefore decrease VMT, quantifying the precise reductions in VMT is tricky. First, studies suggest that the effects of investments depend on the context, including the adoption of other strategies to promote walking and bicycling, such as educational programs or promotional events (Pucher, et al., 2010). Comprehensive efforts that combine strategic and high-quality infrastructure investments with promotion and education over a period of time have been shown to produce substantial increases in bicycling. In addition, investments in facilities that connect important destinations and contribute to the overall connectivity of the network will have more impact than stand-alone facilities that do not serve important destinations or help to build a larger network. Second, new walking and biking trips do not necessarily replace driving trips; they may replace transit trips, for example, or they may be entirely new trips. The degree to which walking and biking trips substitute for driving trips is difficult to pinpoint, as discussed by Piatokowski, et al. (2015). Third, when these trips do substitute for driving, they may be shorter than the trips they replace, particularly for non-commute trips. For example, an individual may choose to bike to a nearby store rather than driving to a store across town, in which case a measure of the increase in bicycling distance would underestimate the reduction in driving distance. Fourth, reductions in VMT from non-commute trips are also likely to occur. Thus, projected reductions in VMT based on the commute effects are almost certainly lower than the probable reductions. Projecting statewide reductions in VMT resulting from investments in bicycle and pedestrian infrastructure requires assumptions about each of these possibilities, as outlined in Table 5.

Strategy Extent: Impact of State Policy on Bicycle and Pedestrian Infrastructure

Investments in bicycle and pedestrian infrastructure are mostly made at the local level by cities and sometimes counties. State policy can influence such investments through grant programs, for example, Caltrans' Active Transportation Program. The state can (and indeed does) encourage such investments by allowing Metropolitan Planning Organizations to develop their own grant programs using the state and federal funds allocated to the MPO. However, research shows that simply allowing MPOs to spend federal funds on bicycle and pedestrian infrastructure does not guarantee that they will (Handy and McCann, 2011).

Estimating statewide reductions in VMT resulting from State policies and programs that support the expansion of bicycle and pedestrian infrastructure requires an estimate of the increase in bicycle and pedestrian infrastructure over a specified period of time (see Table 5, Step 2). This increase depends on what policies the state adopts, how MPOs and local governments respond to these policies, and how State actions influence the investments that local governments choose to make with their own funds – all very difficult to predict with precision. One approach to estimating the percent increase in bike/ped infrastructure is to estimate the funding available for these investments for the specified period of time, then convert this amount to miles of bike facilities and sidewalks using data on the per mile costs of such facilities. Another approach is to analyze increases in infrastructure for selected cities where good data on the extent of infrastructure at two or more points in time is available. San Francisco, for example, is planning to double its miles of protected bike lanes (from 15 to 30 miles) in the next 15 months.[18] Because bicycle facilities are less ubiquitous than pedestrian facilities, a given length of new facility will represent a larger percentage increase for bicycle infrastructure.

State Policy Considerations for Bike/Ped Infrastructure

The available evidence shows a strong connection between the extent of bicycle and pedestrian infrastructure and the amount of walking and bicycling. Although projecting the VMT impacts of new investments in such infrastructure involves a number of critical assumptions, given limitations in the available evidence, this strategy shows strong potential for reducing VMT, in addition to producing other benefits for the community (see Sallis, et al. 2015 for a discussion of co-benefits).

Research suggests that state actions to increase bicycle and pedestrian infrastructure would be most effective in reducing VMT if implemented in conjunction with promotional and educational programs (Pucher, et al. 2010). In addition, emerging evidence suggests that higher quality infrastructure, such as protected bicycle lanes, are more effective in promoting increases in active travel (e.g. Monsere, et al. 2014), so state actions could prioritize such high-quality infrastructure to ensure maximum VMT reduction per mile of infrastructure. Network connectivity is also now recognized as a critical consideration in prioritizing investments in bicycle and pedestrian infrastructure (Mekuria, et al. 2012), so state actions that prioritize connectivity improvements could again help to ensure the highest VMT reductions per mile of infrastructure.

State policy currently encourages such investments in bicycle and pedestrian infrastructure through grant programs and by giving MPOs flexibility in how they spend their state and federal funds. Stronger state measures could require MPOs to spend a certain share of state funding on these modes or set performance standards for walking and bicycling that MPOs must meet in order to receive funding. Additionally, the State could allocate a greater portion of state transportation funds to direct investments in pedestrian and bicycle infrastructure. Any of these measures can help ensure maximum VMT reduction per mile created by incorporating the considerations in the paragraph above into guidelines for the allocation of funds.

[18] https://www.sfmta.com/about-sfmta/blog/new-generation-bikeways-coming-san-francisco

While evidence suggests that state intervention to increase bicycle and pedestrian infrastructure is highly likely to yield reductions in VMT, estimating a more precise degree of impact from state actions – for the purposes of modeling by ARB and others to quantify anticipated VMT reductions from specific strategies – would require further analysis. Table 5 presents an outline of suggested steps for gaining more precision and clarity in this estimation.

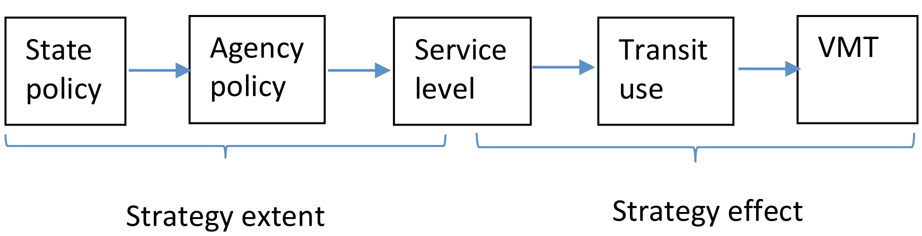
Table 5. Suggested Steps for Calculating VMT Impacts of Bicycle and Pedestrian Infrastructure Investments

Step	Assumptions or Data Needed	Validity of Assumption (Scale: 1 = poor, 5 = excellent)	Future research tasks to strengthen assumptions and data
1. Measure existing bicycle/pedestrian infrastructure	Most common measure is percent of street length with bike/ped facilities	Validity = 3 (fair) Most common measure does not account for quality of facilities or the connectivity of the network.	Develop statewide GIS database of bike/ped facilities, including characteristics of facilities. Develop measures of network connectivity.
2. Measure *changes in bicycle/pedestrian infrastructure* as percentage of current infrastructure	Estimate additional bike or ped infrastructure that could be constructed given funding available, for state or by region.	Validity = 3 (fair) Costs of infrastructure vary by facility type and context.	
3. Use an elasticity of % bike/ped commuting with respect to bike/ped infrastructure to calculate *percentage increase in %bike/ped commute trips*	Use bike or ped elasticity from ARB bicycle or pedestrian infrastructure brief.	Validity = 3 (fair) Bike/ped elasticities may vary by context. Available elasticities account only for bike/ped commuting, not bike/ped travel for other purposes.	Conduct studies of the impacts of bike/ped infrastructure investments that measure changes in all bicycling or walking trips, by trip purpose.
4. Apply predicted percentage change in %bike/ped commute trips to a base-year measure of annual statewide or regional bike/ped commute trips to estimate *increase in total annual bike/ped commute trips*	Use estimate of annual statewide bike/ped commute trips or estimates by region.	Validity = 4 (good) The CHTS has data on bike/ped commute trips statewide and by region. Bike/ped trips may be underreported. (Note that American Community Survey data reports only usual commute mode.)	Improve survey design to better capture bike/ped trips by purpose.

Table 5. Suggested Steps for Calculating VMT Impacts of Bicycle and Pedestrian Infrastructure Investments (Continued)

Step	Assumptions or Data Needed	Validity of Assumption (Scale: 1 = poor, 5 = excellent)	Future research tasks to strengthen assumptions and data
5. Adjust number of trips to reflect switching from modes other than driving to estimate *reduction in total annual driving commute trips*	Apply driving commute mode share for state or by region.	Validity = 2 (weak) Propensity to shift to bike/ped commuting may vary by current mode and by context.	Conduct studies of the impacts of bike/ped infrastructure investments that measure shifts between modes. Conduct such studies in different contexts.
6. Convert reduction in total annual driving commute trips to *reduction in total annual commute VMT*	Use estimate of average commute distance for bike/ped commuters statewide or by region.	Validity = 3 (fair) The CHTS has data on average commute distance for bike/ped commuters statewide and by region. Driving commute trips eliminated by new bike/ped trips may be longer (or shorter) than current bike/ped commute distances.	Conduct studies of the impacts of bike/ped infrastructure investments that measure commute distance for new bike/ped commuters.

3.2 Transit Investments



Strategy Effect: Impact of Transit Investments on Individual or Household VMT

Investments in transit service have the potential to reduce VMT by encouraging a shift from driving to transit. Many different types of investments are possible, including improved access to bus stops and rail stations, coordinated schedules and transfers between systems, real-time information about arrivals and departures, and electronic farecards. As summarized in the ARB Transit Service research brief, however, most research focuses on the effects of changes in fares, changes in service frequency (or changes in headways), or changes in miles of service. Most studies examine the effects of these changes for bus systems, though some report effects for rail systems. Outcomes are measured in terms of changes in transit ridership, i.e. the number of transit trips made for the specified period of time.

According to the ARB research brief, the available research shows that a 1 percent increase in service frequency will lead to a ridership increase of approximately 0.5 percent and that a 1 percent increase in service hours or miles could lead to a higher increase of around 0.7 percent. Effect sizes are likely to be higher in cases where the investments target “choice” riders who are not dependent on transit, higher-income riders, off-peak and non-commute trips, and small cities and suburban areas. These findings are applicable to metropolitan areas but not necessarily to rural areas where transit service is sparse.

As with bicycle and pedestrian investments, although transit investments are likely to reduce VMT, quantifying the effects of transit investments on VMT is not straightforward. First, studies suggest that the effects of investments depend on the context, as noted above. Second, not all new transit trips replace driving trips; they may instead replace bicycling or riding in a carpool, or they may be entirely new trips that would not otherwise have been made. Third, new transit trips may be shorter (or longer) in length than any driving trips they replace. For example, an individual may choose to take the bus to the nearest store rather than driving to a store across town, in which case a measure of the increase in transit distance would underestimate the reduction in driving distance. Projecting statewide reductions in VMT resulting from investments in transit service requires assumptions about each of these possibilities, as outlined in Table 6.

A recent study of the opening of the Expo Line in Los Angeles provides some of the most direct evidence available of the impact of transit investments on VMT (Spears, et al. 2016). This study, which measured VMT for households living near the new light-rail line before and after the opening of the line, found that households living within 1 mile of a new Expo station drove almost 11 miles less per day because of the new line 18 months after its opening. The authors conclude that large investments in light rail, coupled with supportive land use policies, have “the potential to help achieve climate policy goals.”

Strategy Extent: Impact of State Policy on Transit Investments

Because much of the funding for intra-regional transit flows directly from the US DOT to transit agencies, the state role in promoting transit investments is more limited than it is for other modes. In addition, transit improvements are increasingly funded through county and regional sales tax measures, such as the upcoming ballot measures in Sacramento, the Bay Area and Los Angeles. The state provides transit funding through State Transit Assistance[19], bond measures such as Prop 1B[20], and more recently, through the California Climate Investments Fund (cap and trade proceeds).

[19] http://www.sco.ca.gov/Files-ARD-Payments/Transit/statetransitassistanceestimate_1617_january16.pdf
[20] http://www.dot.ca.gov/hq/transprog/ibond.htm

Estimating statewide reductions in VMT resulting from improvements in transit service requires an estimate of the increase in transit service over a specified period of time (see Table 6, Step 2). This increase depends on what policies the state adopts, how transit agencies respond to these policies, and the investments that transit agencies choose to make with their own funds – all very difficult to predict with precision. One approach to estimating the percent increase in transit service is to estimate the funding available for service improvement for the specified period of time, then convert this amount to hours or miles of service using data on the per mile costs of such service. Another approach would be to compile proposed transit investments in the Regional Transportation Plans for the Metropolitan Planning Organizations in the state and assume this level or a proportionately higher level (to reflect new state policy) of investment in transit service.

State Policy Considerations for Transit Investments

The available evidence shows a strong connection between the extent of transit service and transit ridership. Although projecting the VMT impacts of new investments in transit service involves a number of critical assumptions, given limitations in the available evidence, this strategy shows strong potential for reducing VMT.

Service expansions are likely to have more impact when combined with other strategies such as improved access to bus stops and rail stations, coordinated schedules and transfers between systems, real-time information about arrivals and departures, and electronic farecards. The impacts of transit investments on VMT are likely to be higher in cases where the investments target "choice" riders, higher-income riders, off-peak and non-commute trips, and small cities and suburban areas. The State can increase the VMT-reduction impact of state actions to increase transit ridership by considering these conditions when, for example, developing guidelines for funding allocations, along with other considerations that achieve other policy goals, e.g. prioritizing investments in disadvantaged and low-income communities.

Although the bulk of transit funding comes from federal and local sources, the State does provide transit funding to regional and local transit agencies through a number of different programs. The state could ensure larger reductions in VMT by targeting this funding to areas and investments that are likely to have larger impacts. The State could also consider programs that directly encourage transit use, including tax breaks for employer-provided transit passes modeled on federal policy.[21] State policies that promote infill development around transit stations can also help to increase transit use (see section on Infill Development). Efforts to coordinate services among regional and local agencies could prove valuable as well.

While evidence suggests that state intervention to improve transit service is highly likely to yield reductions in VMT, estimating a more precise degree of impact from state actions – for

[21] http://www.nctr.usf.edu/programs/clearinghouse/commutebenefits/

the purposes of modeling by ARB and others to quantify anticipated VMT reductions from specific strategies – would require further analysis. Table 6 presents an outline of suggested steps for gaining more precision and clarity in this estimation.

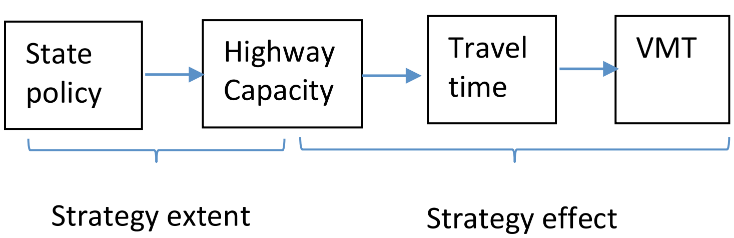
Table 6. Suggested Steps for Calculating VMT Impacts of Transit Investments

Step	**Assumptions or Data Needed**	**Validity of Assumption (Scale: 1 = poor, 5 = excellent)**	**Future research tasks to strengthen assumptions and data**
1. Measure current transit service in metro areas	Most common measures is service hours or miles.	Validity = 3 (fair) Measure does not account for quality of service or connectivity of the transit network.	Extract statewide data on transit service from National Transit Map and add data as needed. Develop measures of network connectivity.
2. Measure *increases in transit service* as percentage of current service by metro area	Compile planned increases in transit service from RTPs and assume proportionate increase based on proportionate increase in funding	Validity = 4 (good) Costs of expansion vary by service type and context.	Develop a GIS database of funded transit service increases
3. Use an elasticity of ridership with respect to transit service to calculate *percentage increases in transit ridership* by metro area	Use transit ridership elasticity from ARB transit brief	Validity = 3 (fair) Transit ridership elasticities may vary by type of improvement and context.	Conduct studies of the impacts of transit improvements of different types and in different contexts.
4. Apply predicted percentage change in transit ridership to a base-year measure of annual transit trips by metro area to estimate *increase in total annual transit trips* by metro area	Use estimate of transit trips by region	Validity = 5 (excellent) Transit agencies report annual ridership.	

Table 6. Suggested Steps for Calculating VMT Impacts of Transit Investments (Continued)

Step	Assumptions or Data Needed	Validity of Assumption (Scale: 1 = poor, 5 = excellent)	Future research tasks to strengthen assumptions and data
5. Adjust increase in total annual transit trips to reflect switching from modes other than driving to estimate *reduction in annual driving trips* by metro area	Apply driving mode share by metro area.	Validity = 2 (weak) Propensity to shift to transit may vary by current mode and by context.	Conduct studies of the impacts of transit improvements that measure shifts between modes.
6. Convert change in total annual driving trips to *change in total annual VMT* by metro area	Use estimate of average trip distance for transit riders by metro area.	Validity = 3 (fair) The CHTS has data on average distance for transit trips by metro area. Driving trips eliminated by new transit trips may be longer or shorter than current transit trip distances.	Conduct studies of the impacts of transit improvements that measure trip distance for new transit trips.

3.3 Highway Capacity



Strategy Effect: Impact of Highway Capacity on Aggregate VMT

Increased highway capacity is sometimes proposed as a strategy for reducing GHG emissions, following the logic that increased capacity will reduce congestion, smooth traffic flow, and thereby reduce GHG emissions through improved efficiency of vehicle operation. A strong body of evidence, however, supports the conclusion that increases in highway capacity do not measurably reduce congestion in the long-run. This phenomenon is referred to as "induced travel" or "induced traffic": the increase in capacity in effect reduces the (time) price of driving, and when the price goes down, consumption goes up.

The most recent and arguably most rigorous study shows an elasticity of around 1 after 10 years (Duranton and Turner, 2011). In other words, a 1% increase in highway lane miles leads to a 1% increase in VMT. Conversely, studies show that reductions in highway capacity, in the few places they have occurred, have not resulted in an increase in congestion, suggesting that VMT either disperses widely or decreases overall, though these effects have not been quantified. Estimating increases in VMT resulting from increases in highway capacity would be relatively straightforward (Table 7).

It is important to note that transportation systems management (TSM) strategies, such as eco-driving programs, incidence-clearance programs, roundabouts, and various other systems operations approaches[22] also have the potential to increase the effective capacity of the highway system. To the degree that they reduce travel times, they may induce additional vehicle travel that could offset whatever improvements in fuel efficiency or reductions in GHG emissions they produce. The VMT-inducing potential of these strategies has not been rigorously assessed.

Strategy Extent: Impact of State Policy on Highway Capacity

Over nearly a century, the State has built a highway system that now totals nearly 25,000 lane-miles of Interstates, freeways, and expressways.[23] In 2014 alone, the California Transportation Commission programmed $2.2 billion in projects for the State's highway system for a two-year period.[24] The Regional Transportation Plans adopted by the MPOs together with the State Transportation Plan outline continued expansions to the highway system, drawing on federal, state, and local funding sources, despite a growing share of the available funding going towards maintenance of the existing system. The projects listed in these plans could be compiled to project the percentage increase in highway capacity over a specified period. An important caveat is that proposed projects are often delayed, sometimes by decades, as priorities change or because of legal challenges to such projects, usually as a part of the environmental review process.

State Policy Considerations for Highway Capacity

As the owner-operator of the highway system, the State has direct control over projects that expand or reduce its capacity. Although county sales tax measures now account for a significant share of highway spending in the State, Caltrans and the California Transportation

[22] See the ARB Research Briefs on EcoDriving, Traffic Incidence Clearance, Roundabouts, and Traffic Operations, available at: https://arb.ca.gov/cc/sb375/policies/policies.htm
[23] Highway Statistics 2014. Table hm60. Available: https://www.fhwa.dot.gov/policyinformation/statistics/2014/
[24] http://www.catc.ca.gov/programs/STIP/2016_STIP/Rev_Fund_Estimate_Jan_16.pdf

Commission must approve these projects. Under current practices, the VMT-inducing potential of these projects is not generally accounted for in the decision-making process. Such analyses could very well show that state investments in highway capacity are at odds with state goals for reducing GHG emissions.

The State could use the California Transportation Plan, or another platform, to establish new policies that limit capacity expansion, e.g. through performance criteria for state funding that take VMT increases into account. The current plan continues to focus on capacity expansion as important for addressing congestion, though it acknowledges that such investments alone will not solve the congestion problem.[25] A state-level "fix-it-first" policy would ensure that maintenance needs are met before funding is approved for projects that expand capacity. New guidelines on analyzing the environmental impacts of proposed highway projects could ensure that potential VMT increases are adequately assessed.[26]

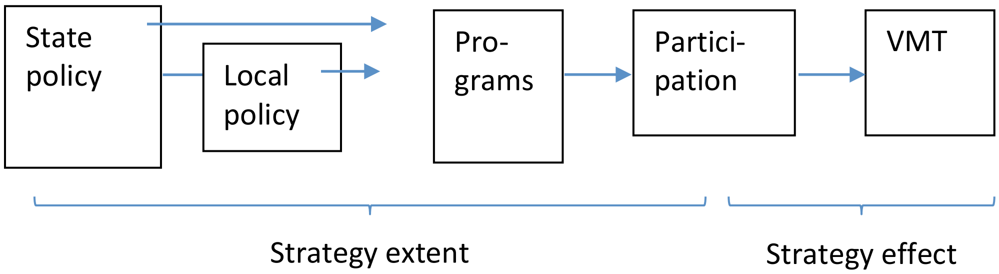
While evidence suggests that state intervention to increase highway capacity is highly likely to yield increases in VMT, estimating a more precise degree of impact from state actions – for the purposes of modeling by ARB and others to quantify anticipated VMT reductions from specific strategies – would require further analysis. Table 7 presents an outline of suggested steps for gaining more precision and clarity in this estimation

[25] http://www.dot.ca.gov/hq/tpp/californiatransportationplan2040/index.shtml
[26] http://www.dot.ca.gov/ser/cumulative_guidance/ceqa_guidelines.htm

Table 7. Suggested Steps for Calculating VMT Impacts of Highway Capacity Expansion

Step	Assumptions or Data Needed	Validity of Assumption (Scale: 1 = poor, 5 = excellent)	Future research tasks to strengthen assumptions and data
1. Measure current highway lane miles statewide	Caltrans data	Validity = 5 (excellent)	
2. Measure *increases highway capacity* as percentage of current capacity statewide	Compile planned highway capacity expansion from state and MPO plans	Validity = 4 (good) Timing of future highway projects beyond those currently programmed in a Transportation Improvement Program is uncertain. Proposed projects can be added or dropped when plans are updated.	Develop GIS database of existing highways, funded highway expansion projects, and proposed but unfunded highway expansion projects
3. Use an elasticity of VMT with respect to highway capacity to calculate *percentage increase in VMT*	Use capacity elasticity from ARB capacity brief	Validity = 4 (good) Evidence is consistent	
4. Apply predicted percentage increase in VMT to a base-year measure of annual statewide VMT to estimate *increase in total annual VMT*	Use VMT measure from Caltrans	Validity = 5 (excellent)	

4. Transportation Demand Management Programs



Transportation demand management programs encompass a variety of strategies, including employer-based trip reduction (EBTR) programs, telecommuting programs, and voluntary travel behavior change programs. Car-sharing services might also play a role in managing demand. While the literature provides strong evidence on the effects of participation in these programs on travel behavior, it provides limited insights into factors affecting the extent to which individuals choose to participate in these programs.

4.1 Employer-Based Trip Reduction Programs

Strategy Effect: Impact of EBTR Programs on Individual or Household VMT

Employer-based trip reduction programs, also known as commute-trip reduction programs, use various approaches to reduce single-occupant car travel to work. Employers may provide services that promote carpooling, such as carpool matching services, preferential parking for carpoolers, subsidized vanpools, or guaranteed rides home for carpoolers. Some programs include financial incentives for participants. Employers sometimes provide worksite facilities for employees who commute by active travel modes. Telecommuting programs and alternative work schedules are often offered as well.

Available studies, as summarized in the ARB research brief, suggest that commute VMT declines by 4% to 6% on average for employees at worksites participating in EBTR programs, including employees who switch from drive-alone to other modes and those who don't. Reductions are likely to be higher when programs offer a broad array of assistance and incentives and at sites with high levels of transit access.

Strategy Extent: Impact of State Policies on EBTR Programs

EBTR programs are implemented voluntarily or as a requirement of local, regional, or state policy. For example, Southern California's Regulation XV, implemented in 1988, required employers with work sites of more than 100 employees to develop employee trip reduction plans. In 1995, State legislation prohibited air districts or other public agencies from mandating employer trip reduction programs unless such mandates are required by federal law. But the State allowed the San Joaquin Valley Air District to adopt a commute-trip reduction program in 2009, and the Bay Area Air Quality Management District adopted a program in 2013. Several Silicon Valley cities have capped single-occupancy auto trips as part of entitlements for new tech company campus expansions.

The extent to which EBTR programs are implemented in the future depends on requirements for such programs as established by state or local policy. Projecting the state-wide VMT reduction potential of such programs requires an assumption about these requirements, for example, that they would apply to all worksites with 100 or more employees. The strategy effect would apply only to commute VMT for employees at the worksites with EBTR programs rather than to all commute VMT. Statewide reductions in VMT could be projected as outlined in Table 8.

Policy Considerations for EBTR Programs

The available evidence shows a strong connection between employer-based trip reduction programs and reductions in commute VMT. The statewide impact on VMT of state policies that require or encourage the adoption of EBTR programs depends on the total number of employees at worksites that adopt such programs. This strategy shows strong potential for reducing VMT depending on the aggressiveness of the state policy.

California could adopt an EBTR program requirement modeled on Washington State's, which requires employers with 100 or more employees in 9 of 39 counties to adopt trip-reduction programs. Such programs are traditionally implemented in metro areas with high levels of congestion, but programs like vanpooling and telecommuting could work in rural areas with long commute distances.

While evidence suggests that state intervention to increase employer-based trip reduction programs is highly likely to yield reductions in VMT, estimating a more precise degree of impact from state actions – for the purposes of modeling by ARB and others to quantify anticipated VMT reductions from specific strategies – would require further analysis. Table 8 presents an outline of suggested steps for gaining more precision and clarity in this estimation.

Table 8. Suggested Steps for Projecting VMT Impacts of Employer-Based Trip Reduction Programs

Step	Assumptions or Data Needed	Validity of Assumption (Scale: 1 = poor, 5 = excellent)	Future research tasks to strengthen assumptions and data
1. Use effect size for work sites to estimate *percentage decrease in commute VMT for participating worksites*	Use effect size from ARB EBTR brief	Validity = 3 (fair) Elasticities will vary by program and context	Conduct studies of the impacts of EBTR programs of different types and contexts.
2. Estimate *the number of employees at worksites of the size specified in the EBTR policy* by metro area	Data is collected by CA Franchise Tax Board	Validity = 5 (excellent)	
3. Use the average commute distance by metro area to estimate *the annual commute VMT for employees at worksites required to adopt EBTR programs* by metro area	Use commute VMT estimates from MPOs and/or Caltrans	Validity = 4 (good) American Community Survey and CHTS provide data on commute VMT	
4. Apply predicted percentage decrease in commute VMT to estimated annual commute VMT for EBTR worksites to estimate *decrease in total annual commute VMT* by metro area	Calculation		

4.2 Telecommuting Programs

Strategy Effect: Impact of Telecommuting Programs on Individual VMT

Telecommuting is the practice of working from home by employees who have a regular work place. Telecommuting may be encouraged as a part of an employer-based trip reduction program (see Section 4.1) or as a stand-alone program. The available research shows strong evidence that telecommuting reduces VMT. As summarized in the ARB Telecommuting research brief, reductions in commute VMT may be as high as 90% on telecommuting days, and personal VMT may decline by roughly 55 to 75% on telecommuting days. Annual VMT reductions for telecommuters depend on how frequently these workers telecommute. Available studies show that telecommuters average 1.2 to 2.5 days per week.

It is important to note that most of the research on the VMT impacts of telecommuting was conducted in the 1990s. With the advent of the Internet, wireless services, and smart phones, today's patterns of telecommuting may be quite different than in the past, and the impacts on driving may be more or less than previously. Anecdotally, it appears that work is increasingly done in places other than the office or home, the VMT implications of which are uncertain.

Strategy Extent: Impact of State Policy on Telecommuting Programs

State and local requirements for employer-based trip reduction programs may encourage the adoption of telecommuting programs. The State might also encourage employers to adopt telecommuting programs through tax incentives and other policies.

Projections from the 1990s as to the share of workers who would be telecommuting by now have not panned out, though telecommuting levels are not insignificant. Measuring the extent of telecommuting is challenging, given increasing flexibility in work sites and work hours. Statewide reductions in VMT could be projected as outlined in Table 9.

Policy Considerations for Telecommuting Programs

The available evidence shows a strong connection between telecommuting programs and reductions in VMT. The statewide impact on VMT of state policies that require or encourage the adoption of telecommuting programs depends on the total number of employees who choose to telecommute and how frequently they telecommute. This strategy shows strong potential for reducing VMT depending on employee demand for telecommuting.

California could encourage telecommuting by adopting a requirement for employer-based trip reduction programs that include a telecommuting program (see Section 4.1). Such programs are traditionally implemented in metro areas with high levels of congestion, but telecommuting programs could work in rural areas with long commute distances.

While evidence suggests that state intervention to increase telecommuting programs is highly likely to yield reductions in VMT, estimating a more precise degree of impact from state actions – for the purposes of modeling by ARB and others to quantify anticipated VMT reductions from specific strategies – would require further analysis. Table 9 presents an outline of suggested steps for gaining more precision and clarity in this estimation.

Table 9. Suggested Steps for Projecting VMT Impacts of Employer-Based Trip Reduction Programs

Step	Assumptions or Data Needed	Validity of Assumption (Scale: 1 = poor, 5 = excellent)	Future research tasks to strengthen assumptions and data
1. Use effect size to estimate *percentage decrease in personal VMT on telecommuting days*	Use effect size from ARB Telecommuting brief	Validity = 3 (fair) Available research is dated, and effect size may now be different	Conduct new studies of telecommuting patterns and impacts
2. Estimate the average number of telecommuting days per week	Use average telecommuting days from ARB Telecommuting brief	Validity = 3 (fair) Available research is dated, and telecommuting frequency may now be different	Conduct new studies of telecommuting patterns and impacts
3. Use the average daily VMT for workers by metro area to estimate *the annual commute VMT for employees who telecommute* by metro area	Use VMT estimates from MPOs and/or Caltrans	Validity = 4 (fair) American Community Survey and CHTS provide data on commute VMT. Telecommuters may have longer commuters than the regional average	Conduct new studies of telecommuting patterns and impacts
4. Apply predicted percentage decrease in daily VMT and average number of telecommuting days to estimate *decrease in total annual VMT for average telecommuter* by metro area	Calculation		
5. Multiply estimated decrease in total annual VMT for telecommuters by estimated number of telecommuters by metro area to get *decrease in total annual VMT* by metro area	Use telecommuter estimates from MPOs and/or Caltrans	Validity = 4 (fair) American Community Survey and CHTS provide data on share of workers telecommuting usually or on any given day, respectively	Develop improved survey questions to measure extent of telecommuting in travel surveys

Conclusions

The available evidence shows that the strategies considered in this paper are likely to reduce VMT if promoted by state policy. The connection between state policy and VMT reduction is more direct for some strategies than others (see Table 10), but the available evidence in all cases points to VMT reductions, even if projections of the magnitude of the statewide effects depend on a number of assumptions. The framework we have outlined for generating statewide projections of VMT reductions for these strategies helps to illuminate the sequence of causal events that would produce VMT reductions and highlights important gaps in knowledge that increase the uncertainty of the projections. Despite uncertainties, the evidence justifies state action on these strategies.

Most of the strategies discussed here are complementary: VMT reductions are likely to be greater if strategies are adopted in combination. For example, infill development coupled with investments in transit service and bicycle and pedestrian infrastructure will have more of an impact than infill development or transportation investments on their own. Pricing strategies will have more impact on VMT (with less impact on household budgets) if good alternatives to driving are available. The one exception to this complementarity rule is highway capacity: new highway capacity (whether from construction of additional lanes or implementation of transportation systems management strategies) is likely to increase VMT through the "induced travel" effect and will at least partly offset reductions in VMT achieved through other strategies.

The timeframe of the strategies is another important consideration. Some pricing strategies can be implemented quickly, if the State has the political will to do so, with direct impacts on the travel choices of Californians. Transportation investments may be a longer term proposition, requiring a series of investments over many years before transit or bicycle networks are extensive enough to attract substantial numbers of drivers. Infill development is also a longer term proposition, as new development represents a small increment of all development in any one year. But these longer term strategies are essential for providing and improving alternatives to driving that enable more painless VMT reductions; they also produce many other benefits for communities as discussed in the ARB research briefs (see also Sallis, et al. 2015).

We have also outlined the need for improved data and additional studies to reduce the uncertainty in projections of the statewide reductions in VMT that state policy might produce. Investments in data and research are well justified by the significance of the policies under consideration and the seriousness of the problem they would address. However, the State does not need to wait for new data or research to act. In fact, the State is already acting through numerous policies that directly and indirectly influence VMT whether that was their purpose or not. The existing evidence is strong enough to point the State in the right direction to achieve the needed reductions in VMT starting now and over the decades to come.

Table 10. Summary of State Policy Options

Strategy Category	**State Policy to VMT Link**	**Effect on Individual VMT**	**Potential for Statewide Implementation and Adoption – Strategy Extent**
Pricing	Most direct	Strong effect Solid evidence	Can be applied state-wide (fuel taxes, VMT fees) and in targeted areas (link pricing, cordon pricing, parking pricing). Most effective where individuals have good alternatives to driving. Strategies have equity implications. Generates revenues that can be invested in transportation system.
Infill Development	Direct and indirect	Moderate effect Solid evidence	Most applicable in metro areas. Will affect populations living and working in infill areas. May depend on changes in local land use policy. May require financial incentives. Land use changes and VMT effects accrue over the long term.
Transportation Investments			
Bike/Ped	Direct and indirect	Small effect Moderate evidence	Most applicable in metro areas. Will affect populations living and working where investments are made. May depend on changes in local investments. May require financial incentives. May require package of strategies. Many co-benefits.
Transit	Direct and indirect	Small effect Moderate evidence	Most applicable in metro areas. Will affect populations living and working where investments are made. May depend on changes in transit agency action. May require financial incentives. May require package of strategies. Many co-benefits.
Highways	Direct	Strong *induced VMT* effect Solid evidence	New capacity that reduces travel times leads to VMT growth. Effect is greatest in congested areas. Operational improvements that reduce travel times can also induce VMT.
Transportation Demand Management	More indirect	Moderate effect Solid evidence	Most applicable in metro areas. Generally implemented by large employers in response to state or local requirements or financial incentives. Some applications appropriate for rural areas.

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Appendix: Linking Scenario Planning Models of Infill Development to Fine-Grained Data on the Effect of Infill Strategies

Table A1 shows an example calculation of the effect size of moving from the third to fourth quintile of regional job access or from the fourth to fifth quintile of regional job access in the Los Angeles region, as shown in Figure 1 in the text. The data in Table 2 show mid-points of the gravity variable quintile from the ranges that are reported in Boarnet et al. (2011).

Following across columns in Table 2, moves from the mid-point of the third quintile of job access to the fourth quintile increase the gravity job access variable by 38.72 percent, based on the values reported in Boarnet et al. (2010). Using an elasticity range of -0.13 to -0.25 from the ARB briefs, the resulting change in household VMT is 38.72 percent multiplied by -0.13 or -0.25, or a reduction of from 5.03 to 9.68 percent in household vehicle travel. Similarly, moving from the fourth quintile of job access (e.g. in Lakewood, per Table XX) to the top quintile (e.g. near downtown) is a 102.65 percent increase in the job access measure, which when multiplied by the low and high values for the elasticity imply a reduction in household VMT ranging from 13.34 to 25.66 percent. These estimates bound the 18 percent VMT reduction that we obtained in the body of the report from distance measures rather than gravity measures, suggesting that using distance to the metropolitan area downtown can be a good approximation for more complex measures of job access.

Table A1: Example Calculation of Effect of Moves Across Job Access Quintiles on Daily Household VMT

						from ARB regional accessibility brief	
			elasticity from ARB brief			**% change VMT**	
Access quintile (from Boarnet et al. 2010)	mid-point of gravity variable range	% change mid-point access across adjacent quintiles	Low estimate	High estimate	HH VMT miles/day (from Boarnet et al. 2010)	Low estimate	High estimate
5th	524.75	102.65	-0.13	-0.25	47.81	-13.34%	-25.66%
4th	258.94	38.72	-0.13	-0.25	47.81	-5.03%	-9.68%
3rd	186.67		-0.13	-0.25	47.81		

Sources: Calculated from data in Boarnet et al. (2011) and ARB regional accessibility policy brief (https://arb.ca.gov/cc/sb375/policies/regaccess/regional_accessibility_brief120313.pdf.)