Calculating and Forecasting Induced Vehicle Miles of Travel Resulting from Highway Projects: Findings and Recommendations from an Expert Panel

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Final – September 2020

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

1 PURPOSE OF THE PROJECT

In the context of implementing California Senate Bill (SB) 743 (Steinberg, 2013), California Department of Transportation (Caltrans) staff have been developing guidance documents on how to calculate induced travel, working with their counterparts at the California Air Resources Board (CARB) and the Governor's Office of Planning and Research (OPR). OPR's technical advisory discusses two methods for estimating induced travel: one approach based on the application of travel models and another using elasticities drawn from peer-reviewed literature, such as the National Center for Sustainable Transportation (NCST) induced travel calculator (https://blinktag.com/induced-travel-calculator). Caltrans is developing internal guidance to help its analysts choose the best method, or combination of methods, for assessing induced travel from projects on the State Highway System and has been holding meetings to provide stakeholders with opportunities to express their views and voice their concerns about the drafts.

Each method being recommended for evaluating induced travel—elasticity based or travel-model based—raises concerns about model specification and assumptions, the capability of dealing with key issues that arise in assessing induced travel, and the resulting validity and accuracy of the results. NCST's induced travel calculator does not differentiate between general purpose and HOV lanes and does not address HOV-to-HOT conversions or rural highways. Travel models in use in California vary greatly in their level of analytical detail and sophistication and show varying levels of sensitivity to travel times and costs and to different operations and management strategies—factors that affect induced travel. Non-MPO models tend to be limited in scope and accuracy compared to the models used by the MPOs, especially the larger ones.

Caltrans requested technical assistance from the University of California, Berkeley Institute of Transportation Studies Technology Transfer Program. Elizabeth Deakin, professor emerita at UC Berkeley, led the project and chaired the panel. The agenda for the panel meeting was developed in collaboration with Caltrans and its partner agencies, and the panel of experts was selected by mutual agreement. The panel was charged with making recommendations on how to estimate travel "attributable to the project," best tools to use, reasons for differences in estimates from various tools, and ways to resolve or reconcile differences if they occur. The panel also provided advice on next steps, including the need for further guidance and research.

This paper provides background information on induced travel, documents how the project was carried out, and presents the findings and recommendations of the panelists.

2 BACKGROUND ON INDUCED TRAVEL

Induced travel is a well-established concept in transport economics (e.g., Downs, 1962; Downs, 1992; Downs, 2005; Goodwin, 1996; DeCorla-Souza and Cohen, 1999). A project that reduces user travel costs—reduces travel time, uncertainty, risks, or expenditures—can lead to changes in traveler behavior that can increase the overall amount of travel. For example:

- Changes in the route chosen: Travelers change their route to take advantage of the lower costs that an improved facility offers. Route changes could shorten or lengthen trips, and they could open up road space for others. If trips are longer or others make use of freed-up road space, the incremental travel is induced.
- Changes in the time of travel: Travelers schedule their trips for a more desired time. Although this change alone does not produce additional travel, it can free up road space for others.
- Additional trips: Travelers choose to make trips that they previously would not have made because travel costs are lower.
- Changes in destination: Travelers choose to travel to farther away destinations because reduced travel times and costs make these destinations more attractive than previously. Alternatively, some changes in networks could make closer destinations more accessible and therefore reduce travel.
- Changes in mode: Travelers change their mode to take advantage of an improved facility.
- Location and land-use changes: In choosing where to live or where to establish a business, decision-makers take the changed travel costs into account. These changes can lead to further changes in other aspects of travel (routes, modes, destinations, number of trips made) as travelers adjust to the choices available at the new locations.

The increases in travel are based on basic principles of supply and demand. Figure 1 illustrates the general concept.

A variety of road projects can create the conditions in which induced travel can occur (Noland and Lem, 2002). However, the potential for such shifts is not limited to road projects. Other modal investments can also lead to changes in travel behavior. Indeed, many projects being pursued today are intended to induce demand for travel by transit or nonmotorized modes or reduce the need for motorized travel through compact, mixed-use community development, while others aim to ease the commute between housing developments at the urban fringe and urban and suburban jobs centers.

Figure 1. A Simple Representation of Induced Travel

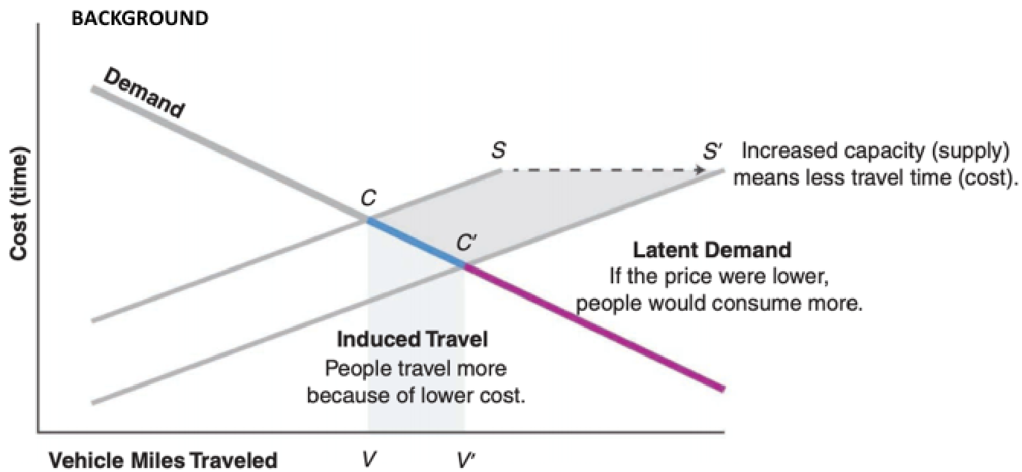
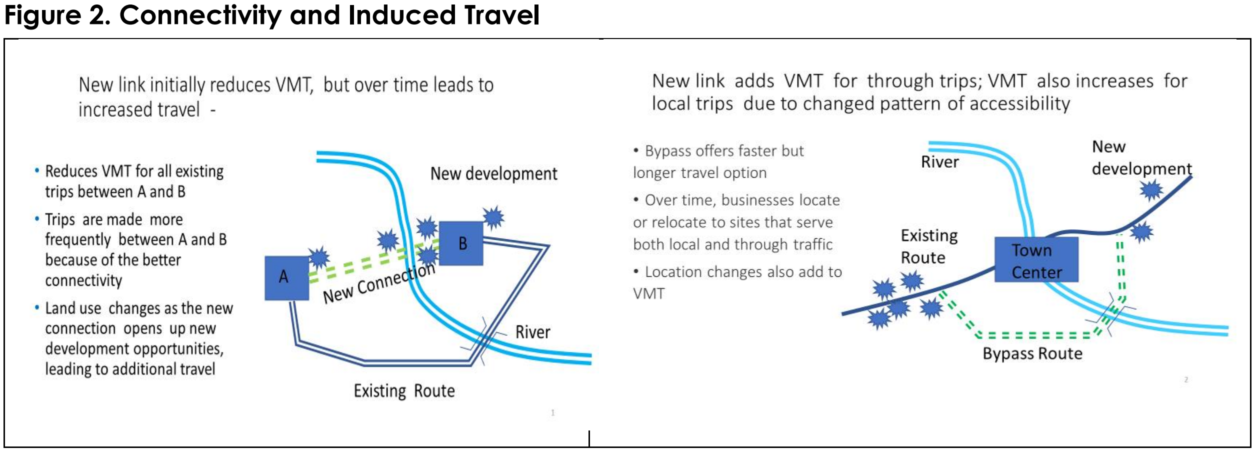


FIGURE 2 Supply and demand relationships for induced travel (C = initial cost; C' = new cost; S = initial supply/capacity; S' = new supply/capacity; V = initial VMT; V' = new VMT).

Source: Milam et al., 2017

The resulting changes in travel are not limited to the specific project and its environs nor do they necessarily appear immediately. Some changes are visible in the short term and in the project corridor, while others occur over a wider area (potentially, the commute shed and beyond) and play out over a time frame of many years. Even roads that are designed to provide greater access under conditions of little or no congestion or to simply reroute through traffic can facilitate significant changes in local and regional travel patterns, as well as changes in development locations that lead to increased travel. Figure 2 illustrates real cases in rural areas where changes in relative accessibility resulting from highway investments led to increased travel—in one case, despite the new route actually shortening the trip between locations.

Figure 2. Connectivity and Induced Travel



Additional vehicle travel options can support expanded access to housing and employment opportunities, easier access to outdoor recreation, and more consumer-responsive goods delivery because truck trips can increase due to lower travel costs (DeCorla-Souza and Cohen, 1999; DeCorla-Souza, 2000). However, additional travel also tends to increase negative externality costs. Induced travel reduces the effectiveness of capacity expansion as a strategy for alleviating traffic congestion. Desired benefits, such as higher speeds or reduced community disruption due to traffic diversion, can be temporary. The consideration of induced travel also becomes an issue of concern when calculating impacts, such as air pollution emissions (see, e.g., Hansen et al., 1993). Induced travel can be an issue in benefit-cost analysis, where the benefits of increased mobility and accessibility are weighed against costs, including the externality costs of added travel (see, e.g., Burris and Sullivan, 2006).

While the theory behind induced travel is straightforward, empirically estimating the effect has proven to be complicated, as a brief overview of the literature illustrates. The extent to which travel changes occur depends on the elasticity of travel demand, but how to estimate that elasticity and its effects over a network and over time has been debated (see, e.g., literature reviews in Cervero, 2002; Noland and Lem, 2002; Duranton and Turner, 2011). Tables in Appendix A present the elasticities of VMT with respect to capacity increases, as reported in several papers that provide overviews of the literature (Currie and Delbosc, 2010, citing Schiffer et al., 2005; Noland and Hanson, 2013; Handy and Boarnet, 2014). The tables show short- and long-term estimates and illustrate the range of reported results. It is important to note that some of the studies listed have been critiqued due to limitations in scope or methodological shortcomings.

While a detailed review of the literature is beyond the scope of this project, it is possible to offer some general observations about the work that has been done on induced travel and its evolution. Early studies of induced travel often examined the highway improvement without considering system impacts, although most did attempt to factor out population and economic growth effects. Most early studies ran simple ordinary least squares regressions to estimate the factors underlying induced demand. Some studies looked at only a few variables while others included many variables that are highly correlated, leading to biases in estimation and problems in interpreting the results.

Later studies of induced travel improved the statistical framework of the analysis, but their widely varied geographies of interest, time scales, and methodologies make direct comparisons problematic. (See, e.g., the scale and method variations used in Strathman et al., 2000; Mokhtarian et al., 2002; Cervero, 2003; Hymel et al., 2010; as well as the multiple methods, geographies, and time scales examined in Duranton and Turner, 2011.) Several studies looked only at changes in the project corridor—the project's own extent plus a narrow band around it, thus omitting consideration of impacts that might occur some distance from the project (e.g., Cervero, 2003). Some studies reported national or state-level effects, averaging out substantial differences by location without evaluating the impact of this approach. Others reported cases for particular regions, but did not place the regions in comparative context (e.g., Fulton, et al., 2000; Marshall, 2000). A few studies analyzed relatively short-term impacts only, 5–10 years or less (e.g., Barr, 2000). While these studies offer insights into induced travel, their applicability to other cases is not straightforward.

Advances in methodology included the use of instrumented variables and two stage least squares approaches to deal with model estimation issues (e.g., Hanson and Huang, 1997; Cervero and Hansen, 2002; Duranton and Turner, 2011). However, in some cases, the specific application had shortcomings. For example, some of the studies' instrumented variables have been questioned on grounds that the instrumentation might not actually succeed in removing correlations. In addition, many studies did not address potential endogeneity: the issue that road-building can respond to growing traffic levels as well as provoke increases. While nearly all studies found induced travel resulting from capacity increases, the underlying differences among the studies have produced a wide range of elasticity estimates, and the methodological limitations are problematic. (See Duranton and Turner, 2011, for a discussion of the issues.)

The most recent work on induced travel has attempted to correct the shortcomings of the earlier literature by using panel data and employing a variety of advanced econometric techniques to improve model formulation (for example, fixed effects models, two- and three-stage least squares models, lagged variables, and instrumented variables). Several papers report the results from multiple model specifications and test the directionality of effects. Handy and Boarnet (2014) cite six studies published between 1997 and 2011 as high quality: Hansen and Huang, 1997; Noland, 2001; Noland and Cowart, 2000; Cervero and Hansen, 2002; Cervero, 2003; Duranton and Turner, 2011. These six studies include a corridor-level model, a state-level model, and models of metropolitan areas and counties. While the reported elasticities in these studies are not directly comparable, they all show substantial short- and longer-term elasticities of VMT with respect to capacity additions. (See Appendix A for details.)

In the NCST induced travel calculator, elasticities are extracted from two studies: a national study by Duranton and Turner (2011) for interstate elasticities (calculated at the MSA level) and a California study by Cervero and Hansen (2002) for class 2 and 3 facilities in urban counties (calculated at the county level). Both studies are widely cited. As of June 2020, the Duranton and Turner study has received over 700 citations, and the Cervero and Hansen paper has received over 200 citations.

Duranton and Turner's paper has a strong methodological framework, tests multiple model specifications, and presents decade-to-decade comparisons (1983–2003). Among their many findings, they report that "…the elasticity of MSA interstate highway VKT with respect to lane kilometers ranges between 0.71 and 0.94 [while] fixed-effect estimates of the interstate VKT elasticity of interstate lane kilometers are slightly above one." They conclude that for interstate-level facility capacity expansions, the average long-term elasticity is not statistically different from one at standard levels of confidence.

The Cervero and Hansen paper presents simultaneous models of induced travel demand and induced road investment using an array of instrumented variables with panel data consisting of 22 years of observations for 34 California urban counties. The authors' estimates of the elasticity of VMT with respect to lane miles are comparable to earlier models: .59 in the short term (one year) and .79 after five years. While the research has been criticized as being over-instrumented, it is generally regarded as producing a reasonable and reliable estimate of the elasticities of travel with respect to capacity increases at the urban county level.

3 PROJECT METHODOLOGY

This project was carried out in four tasks, each documented with detailed notes.

At the start of the project (March 23, 2020), the UC Berkeley project manager participated in a phone call with the Caltrans project team to review the work program, schedule, and deliverables, clarify roles and responsibilities, and discuss expectations and logistics for the expert panel meeting (Task 1).

In Task 2, the UC Berkeley project manager engaged with the interagency group (staff from Caltrans, CARB, and OPR) in a 90-minute scoping meeting on May 12, 2020, to develop a preliminary agenda for the expert panel meeting, identify possible panelists, and propose dates for the meeting. The participants also listed key reference documents and arranged to make them available electronically. The following issues were prepared for panelist review and possible discussion during the expert panel meeting:

1) Need to grapple with the question of how best to accurately assess induced VMT using an empirical, elasticity-based approach, a travel model-based approach, or both with a process for reconciliation.

2) Assess whether the following are the right distinctions around which to organize the discussion (importance of distinctions among lane types in assessing induced VMT; evidence base for such distinctions).

- Lane type
    - General purpose
    - High-occupancy vehicle (HOV)
    - High-occupancy toll (HOT)
    - Truck only
    - Bus only
    - Other?
- Location type
    - Urban counties in Metropolitan Statistical Area (MSA) with Class 1 facilities
    - Other urban counties
    - Rural counties with existing or forecasted congestion at or near project site
    - Rural counties with no existing or forecast congestion at or near project site
    - Other?
- Special context
    - Critical link (e.g., Bay Bridge)
    - New link (not expansion) that provides a shortcut or significantly shortens existing trips (e.g., bridge across river between two cities)
    - Other?

3) Evaluate the capabilities and limitations of available tools (elasticity based, travel model based) considering, for example, the sensitivity of the analysis tool to effects of lane type, location type, context; guidance on how to look at varying results and reconcile outputs from different methods.

- Sensitivity to effects of specific local features
- Sensitivity to effects on land use
- Sensitivity to effects on trip generation
- Ability to simulate restricted flow associated with roadway capacity
- Other?

4) Recommend other background information, data, or research that would help facilitate effective assessments of induced travel.

Two additional issues were noted:

- Where does mitigation fit into this?
- Which projects should be exempt?

Because other groups are looking into how mitigation fits into the evaluation of traffic-inducing projects and whether mitigation banks might be a useful way forward, this topic was not included in the panel's assignment. Likewise, because other groups are assessing the potential for tiering environmental reviews (considering the overall impact of projects at the long-range plan or program level), this topic was not assigned to the panel.

In Task 3, the UC Berkeley project manager recruited four subject matter experts; three practitioner-experts were recruited under a separate contract with Caltrans. The panel members were Susan Handy, UC Davis; Joan Walker, UC Berkeley; Alex Skabardonis, UC Berkeley; Michael McNally, UC Irvine, and Caltrans consultants Fred Dock, Elizabeth Sall, and Gordon Garry. See Appendix A for bios of the panel members and the project manager, who also served as panel chair. The panel members were provided links to draft OPR and Caltrans documents addressing SB 743 and the work program and preliminary reference list for the project. The first-cut set of issues to be addressed in the meeting were also provided with the caveat that it would be necessary to prioritize topics to get through the long list in a four-hour panel meeting.

The project manager held follow-up phone calls with the interagency group members and with each expert panel member to discuss the key issues and refine the meeting agenda. The project manager also discussed the issues with other experts in the field (see acknowledgments). Each phone call ranged from 45 minutes to over an hour. Based on these discussions, the agenda was revised (see Table 1) to focus on the key issues and to ensure that the topics could be covered in the time allotted.

Task 4 involved convening the expert panel meeting, documenting it through detailed notes, and carrying out follow-up discussions with the panelists and members of the interagency group as needed, leading to this report. Due to COVID-19 considerations, the four-hour meeting was carried out electronically and was run fishbowl-style to reduce the complexities of communication: the panelists discussed the topics on the agenda with the interagency team listening and asking questions and making comments via chat and discussion at the end of each topic. Two Caltrans staff members took extensive notes of the meeting. These notes were combined into a single text and then augmented based on notes taken by the UC Berkeley graduate student researcher and project manager. The detailed notes were then circulated to the panelists and were edited slightly by each panelist to clarify the text. The resulting edited meeting notes included a discussion of each agenda item.

The UC Berkeley project manager presented the results of the expert panel at a webinar organized by Caltrans on June 24, 2020. In a few cases, comments received were discussed with members of the interagency group and with the panelists to further clarify the points that the panelists wanted to make. These comments, clarifications, and elaborations also are reflected in this report.

Table 1. Agenda for Expert Panel on Induced Travel

June 11, 2020 1:30–5:30 p.m.

Time	Topic
10 min	1. Introductions and Purpose of the Meeting
60 min	2. Induced Demand and Estimation Methods
	2.1. Strengths and limitations of NCST tool and travel demand models
	2.2. Applicability to various project types and contexts
90 min	3. Reconciling Estimates
	3.1. When multiple methods are used, how can we diagnose the differences? (Why are we getting different results?)
	3.2. How can we move toward reconciliation?
	3.3. What should we do (short term and longer term) if we are not able to reconcile differences?
20 min	4. Next Steps
	4.1 Short term – documenting this discussion; focusing on how to proceed now; circulate draft for comment and revise (end of June)
	4.2. Longer term recommendations?
	4.3. Other issues, concerns?

Adjourn

4 FINDINGS

The findings presented in this section are based on the discussions at the expert panel meeting and the panelists' clarifications based on their reviews of the notes from the meeting and follow-up discussions.

4.1 INDUCED TRAVEL

Panelists indicated that they prefer to use the term "induced travel" for observed VMT rather than "induced demand" (while noting that the literature uses both terms). The distinction is important: Induced travel is the increase in travel that we observe, whereas induced demand is a shift in the underlying demand curve.

Many factors cause growth in VMT, including increases in population and economic activity, a higher share of adults participating in the workforce, more disposable income, inexpensive fuel, affordable motor vehicles, and infrastructure that supports vehicular travel. VMT increases have been observed for single unit and combination trucks and light duty cars and trucks, with the freight vehicle increase significantly larger than that for personal vehicles in recent years (Litman, 2017; Duranton and Turner, 2011).

Rising income has multiple effects. It allows increased participation in activities outside the home but also increases the effective cost of time spent traveling, which is a deterrent to activity increases that involve significant travel. In this context, transportation projects that reduce the cost of travel enable more travel to occur.

Projects that have been seen to result in more travel are ones that reduce the cost of travel, either on existing roadways (widenings, added lanes) or as new connections. Congested facilities are often targeted for such projects, and one result is that projects designed to alleviate congestion also encourage travel that had been previously deterred by congestion. However, projects in uncongested areas can also lead to induced travel to the extent that they reduce the cost of travel—costs of travel are time, vehicle operating expenses, and costs associated with unreliable travel times or stress resulting from travel on a road with, for example, poor sight distances.

Measuring the amount of induced travel attributable to a project is complex because of the need to distinguish population and economic growth from project effects, and because changes can occur over many years and a large area. It is not a simple matter of monitoring traffic on a facility and its immediate environs, because some travel changes are likely to affect other elements of the overall transportation system. For example, trips might be diverted to different routes or times of day or switched to different modes. Travelers also might make longer trips, choosing destinations farther away, or additional trips (more frequently or new types). In addition, transportation improvements can affect the relative attractiveness of different locations for both housing and commercial development, and those locations in turn can reshape the pattern of transportation activity in the region and sometimes beyond.

Because of these complexities, studies of induced travel have turned to models to help sort out the key factors affecting VMT. Both short-term and long-term estimates of the effects of transportation projects on VMT have been produced. Highway improvements are commonly measured in lane miles or kilometers for different types of facilities and for different geographic scales, and VMT/VKT data are taken from counts. Increasingly sophisticated methods for controlling for the overall effects of growth and the potential for endogeneity between capacity increases and VMT have been employed.

4.2 Methods for Estimating Induced Travel

Methods used to study induced travel include econometric models aimed specifically at investigating the effects of transportation investments on induced travel, travel models designed for a number of analysis and forecasting tasks and sometimes used to estimate the share of travel that is induced, and case studies of travel growth and its causes in particular corridors and regions. Caltrans, OPR, and CARB have been developing guidance on how to estimate induced travel for projects within the state and advise using both the NCST induced travel calculator and travel models. Figure 3 shows the recommended application of these methods, as presented in Caltrans guidance, 2020.

Figure 3. Selection Matrix for the Preferred Induced Travel Assessment Method for SHS Projects

Project Type / Project Location	GP or HOV Lane Addition to Interstate Freeway	GP or HOV Lane Addition to Class 2 & 3 State Routes	Other VMT Inducing Projects and Alternatives
County in MSA with Class I Facility	Apply the NCST calculator by MSA and/or TDM benchmarked with the NCST calculator	Apply the NCST calculator by county and/or TDM benchmarked with the NCST calculator	Apply TDM or other quantitative methods
Other MSA County	Apply TDM[2] or other quantitative methods		
Rural County	Apply TDM[2] or other quantitative methods		

Note: NCST = National Center for Sustainable Transportation at UC Davis; TDM = travel demand model; GP = general purpose; HOV = high occupancy vehicle; VMT = vehicle miles of travel

Therefore, the panel focused on the areas in which the Caltrans guidance suggested use of either the NCST calculator (and more generally, the use of elasticities from the literature to estimate induced travel resulting from highway projects) or travel models.

4.2.1 NCST CALCULATOR (ELASTICITY-BASED SKETCH PLANNING METHODS)

The NCST induced travel calculator lets users estimate the VMT resulting from the addition of general purpose or HOV lane miles to roadways. As currently formulated, the calculator uses 2016 lane-mile data from the urbanized county or MSA in which the project is located, as reported in Caltrans databases, together with long-term elasticities taken from the literature, specifically the Duranton and Turner (2011) nationwide estimate for interstate facilities, which the calculator rounds to 1.0. The Cervero and Hansen (2002) elasticity is used for urbanized counties (.75 as implemented in the calculator). The calculator cautions that it applies only to Caltrans-managed facilities with Federal Highway Administration (FHWA) functional classifications of:

- Class 1 – interstate highways
- Class 2 – other freeways and expressways
- Class 3 – other principal arterials

Further, the calculator applies only to urbanized counties within an MSA. To obtain an annual induced VMT estimate for a roadway capacity expansion project, the user enters the project length in lane miles added and geography (MSA for additions to interstates, or county for additions to other Caltrans-managed class 2 or 3 facilities). A standard formula is embedded in the calculator for estimating project-induced VMT:

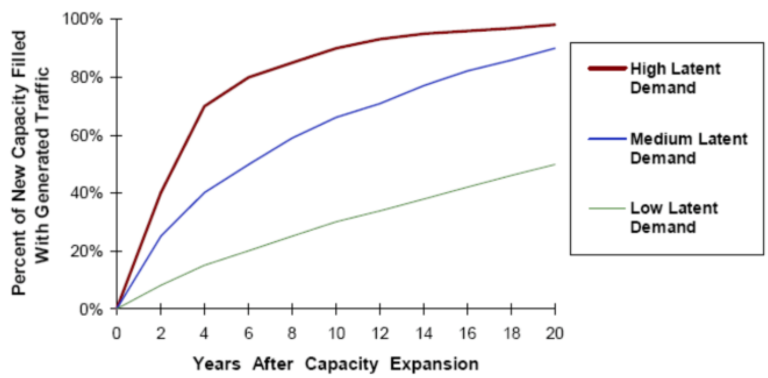
$$\%\Delta \text{ Lane Miles} \times \text{Existing VMT} \times \text{Elasticity} = \text{Project-Induced VMT}$$

For more information about the calculator, visit https://blinktag.com/induced-travel-calculator. Caltrans is developing guidance that provides a list of counties to which the calculator does not apply or applies only in part.

The panel noted that this approach could be applied without resort to the calculator using the formula with other baseline VMT estimates and different elasticities. The panel also concluded that the calculator is based on a careful review of peer-reviewed literature and that the studies that the calculator has chosen to rely on are widely considered to be the best available. The standard errors for the models estimating the elasticities are reported in the papers and are at acceptable levels, and the elasticities extracted from the studies account for long-term impacts and distinguish infrastructure-induced VMT impacts from other factors that could be driving observed changes, such as general growth in population and economic activity. In addition, panel members reported that other recent studies have found similar elasticities, adding credence to those used. (See Graham et al., 2014, Hymel, 2019, and Appendix A.)

The calculator elasticities are long-term elasticities. Some studies also produce short-term elasticities (see Appendix A), either by looking at a short time frame or by omitting factors that tend to appear over the longer term, such as land-use changes. ("Short term" in this context means under five years and can be as little as a year or two. "Long term" can be 10 or more years in the future.) While the studies in the literature use differing time frames, Figure 4 provides a conceptual diagram rooted in empirical evidence. It depicts the rate at which new capacity would likely be "used up" by capacity-induced traffic.

Figure 4. Diagram of Induced Travel over Time: Rate of Capacity Uptake by Latent Demand



Source: Litman, 2001, as cited in Currie and Delbosc, 2010

As the Figure 4 diagram suggests, no single conclusion can be drawn from the literature regarding how fast the changes occur. Highly congested facilities are likely to have considerable latent demand, and therefore the response to new capacity might be rapid. Areas with little growth might see much slower change. Differences in the long-term elasticities also might be found. However, this is not a simple urban-rural distinction. Areas at the urban fringe have been found to generate high levels of induced traffic over time as new facilities alter development opportunities, business and housing locations, and users' overall travel patterns.

One issue that potential users have raised about the calculator is that the data in the underlying studies are from the late 1990s to early 2000s. There is interest in better understanding whether the rate of change has varied. The Duranton and Turner paper presents some evidence of a slowing in the rate of change from decade to decade in the periods that they studied, and an update covering changes in the past two decades might be informative. However, over the last two decades, the United State and California also have experienced major disruptions: the 2007–08 recession and the current COVID-19 pandemic. How to handle these events in examining traffic trends would require discussion—are they outliers or should the downturns be included in the analyses?

The NCST calculator's authors caution that because the underlying studies investigated urban impacts, the calculator should not be applied to rural counties and cannot be used for some facilities in metropolitan edge counties for which data are sparse. For example, the authors' description notes that there is insufficient data on interstates for Napa County. Also, the elasticities from the literature are regional or countywide averages of long-term effects. For any given project, the impact could be higher or lower, and short-term impacts would likely be lower than those that unfold over a decade or more. Thus, the calculator provides a first-order approximation of the likely change for projects to which it is applicable. As discussed in the next section, this estimate might be the most robust available if travel models for the area under study are not designed to estimate induced travel.

4.2.2 TRAVEL MODELS

Travel models (often called travel demand models, although they also include models of transport supply) are widely used in California and throughout the United States as transportation system analysis and forecasting tools. Current models range widely in their abilities. Some MPOs and a few counties and cities have developed advanced activity-based models. Many others use trip-based models. Some are run as part of an integrated land use–transportation modeling process while others handle current and future land use as a separate analysis step and apply the results as inputs to the travel models. Models also vary with the extent to which they cover such issues as trip scheduling and travel time-of-day, the specifics of transit service (for example, bus vs. rail), nonmotorized modes, and freight movements. Highway networks usually cover major collector and higher-level roads, but some models also include local roads. Among their many applications, travel models are used to measure network performance and identify deficiencies to forecast future levels of service under anticipated levels of growth and change and to generate the traffic data and projections needed for air pollution emissions estimates and forecasts.

Many improvements have been made to travel models over the past two decades, but considerable variation remains in the level of detail and the sophistication of the models in use in California (and elsewhere). Depending on the specifics of model formulation, estimation, and application, travel models can provide a reasonable estimate of induced travel, or they can ignore or seriously underestimate induced travel.

One reason for concern that the latter is a problem is that estimates of induced travel set forth in environmental documents are well below those in empirical studies reported in the literature or are missing altogether (Volker et al., 2020.) The panel called out several likely reasons for these differences between the findings in the literature and those resulting from modeling processes, some having to do with model structure and others with the level of detail with which the models are applied.

- Land-use changes and the travel associated with those changes are a significant component of induced travel, but some transportation planning models treat land use as exogenous, and some further assume it is fixed (invariant with level of service).

- Some travel models, either in specification or in application, do not feed network travel times and travel costs back to land use, trip generation, mode choice, destination choice, and trip frequency modeling elements.
- Price and income are sometimes treated in limited ways. Therefore, important impacts on travel choices are not well represented in the models. For example, heterogeneity in responses to price has been found by income, mode, and trip purpose. (See, e.g., Algers et al., 1998; Brownstone and Small, 2005; Fosgerau, 2005; Abou-Zeid et al., 2010.) More generally, differences in attitudes toward travel and related values can affect choices (Abou-Zeid et al., 2010).
- Reliability is not addressed in the models. A small reduction in travel time can be accompanied by a large reduction in travel standard deviation, but reliability is often omitted from the travel model even though it can be important to the traveler. (See, e.g., Lam and Small, 2001; Small et al., 2005.)
- Network levels of detail might be insufficient to reflect traffic conditions as well as the full set of route and mode choices available.
- Boundary cutoffs are needed, but tend to be dealt with in simple ways. If a substantial portion of travel occurs outside the boundaries, it might not be well represented in model analyses.
- Models are not always run to traffic assignment equilibrium where network congestion is minimized—that is, users cannot save time by switching routes.
- Models are often calibrated to observed data such that the alternative-specific constants take on a large (outsized) importance in the choice models, rendering the models less sensitive to time and cost.
- Models might not have been thoroughly validated over a period of time in which travel times and costs have changed. Checking performance when these key variables have changed would make it possible to see if the models would have predicted such changes.

Reports and webinars providing guidance on travel modeling and evaluating errors in models could be valuable sources of advice. Guidance on travel modeling has been produced by State of California agencies, including the California Transportation Commission and the Governor's Office of Planning and Research (CTC, 2017; OPR, 2018). The FHWA has also produced extensive advice on modeling, especially through its Travel Model Improvement Program (TMIP) (FHWA, various years). TMIP materials discuss best practices on how to calibrate (adjust) and validate (test) travel models, checking them for reasonableness, and note that checking the model can reveal underlying problems that need to be corrected. For example, if VMT per household is unreasonably high or low, it would be advisable to make sure that data errors were not introduced. Data from the U.S. Census and national travel surveys provide useful comparisons. The travel surveys cover trip modes, lengths, and purposes for all areas of the country, urban and rural.

For long-term forecasts, the panel emphasized the importance of robust models that reflect land-use changes, including changes that can result from transportation investments. Studies have found that a key source of error is the amount of growth forecasted (population, employment) and its allocation to various parts of the region (see, e.g., Rodier et al., 2001). While agencies are usually expected to use exogenously provided regional totals for population and employment, allocation to zones in a travel model is a modeling step that needs to consider different levels of accessibility that might be available in the future.

Differences in travel behavior among different population groups also can be an important element in project performance, especially for projects that apply pricing or travel time savings as a means of inducing particular travel choices. Heterogeneity results from differences in choices available to (or considered available by) different groups because of income, age, physical and mental capacity, and in some cases, gender, race, and ethnicity. Heterogeneity also reflects taste variations among the members of the population, which are reflected in differing lifestyles, in turn shaped by psychological factors, such as attitudes and perceptions that affect decision-making processes.

Models that address heterogeneity have been in the literature for two decades, continue to be refined, and have been shown to be feasible to integrate with traditional modeling frameworks (see, e.g., Gopinath, 1996; Ben Akiva et al., 1999; Ben Akiva et al., 2002; Vij, Carrel, and Walker, 2013). However, such models have not been widely implemented in practice. Panelists commented that it would be desirable to have error bands around model estimates for both travel demand models and sketch planning models and calculators. However, firm rules on how much error is acceptable are not available, partially because it depends on what the model is being used for. TMIP and National Cooperative Highway Research Program (NCHRP) reports offer guidance.

The TMIP advice is that to be useful, tests of reaction to change must be done through applications of the model in full production mode. However, this is not always done in practice. Also, many models are validated on a reserved set of base-year data. It would be useful to further validate predictive capabilities against a future year when such data become available.

If models are constructed to reflect the full set of travel, land use, and location impacts that new capacity is believed to have, and have been validated appropriately, they should be useful in estimating induced travel. As the panel noted, induced travel results from changing travel times and costs, which in turn can change origin-destination patterns, trip lengths, modes used and, over time, the area-wide development pattern. Impacts are not limited to the immediate project area. Therefore, regional or county-level models must account for all these potential changes to capture induced travel.

Data quality and forecasts of key drivers of urban change are also in need of attention. Several panelists made the point that it would be useful to focus on key factors that are driving VMT increases and to identify factors that are of secondary importance. Duranton and Turner (2011) analyze this and find that the largest shares of VMT increases are due to increased travel by individuals and freight vehicles.

4.3 Applicability to Various Project Types and Contexts

The panel was asked to discuss the applicability of both the elasticity-based method and travel demand models to various project types and contexts. The panelists commented on the capabilities and limitations of the two methods under consideration, but also discussed the induced travel issue based on established economic supply-demand relationships.

4.3.1 PROJECT TYPES

The panel focused on HOV and HOT lanes because of their growing use in California, especially in congested areas. Members of the interagency panel reported concern that HOV lanes are treated the same as general purpose lanes in the calculator and that specialized lanes (HOT lanes, truck lanes) are not addressed. Panel members commented in response that any project that adds capacity or increases connectivity has the potential for generating additional travel, even though the motivations for the lane might be focused elsewhere, for example, on improving safety, restoring neighborhood quality, or supporting ridesharing and electric vehicles. Adding a lane but restricting it to particular users can induce more travel by those users and can also free up capacity in general purpose lanes, which then experience an increase in traffic as others find travel in the general lanes to be improved, at least in the short run.

Both HOV and HOT lanes merit further investigation in regard to their impact on VMT. It can be complex to determine how much capacity a special purpose lane adds. Its design, such as the number of entry and exit points and the amount of weaving and merging needed to enter and exit it, can make a difference in performance and use. For HOV and HOT lanes, there is the added need to account for mode shifts, both to and from high-occupancy vehicles. Such mode shifts might be induced by the travel times and costs offered by the HOV or HOT lane. How much capacity is added is also an issue and depends on the lane's operating "rules," for example, required vehicle occupancy, number of hours, price levels, speed targets, volume limits imposed to meet those targets, and violation and enforcement rates. With managed lanes, the access rules are adjusted on an ongoing basis, so it is not obvious what rules to use in modeling lane performance.

The panelists noted that there are complex issues regarding the choice to travel in HOT and HOV lanes. For example, not all HOVs move into the HOV lane. Some of the reasons reported are: Travelers are going a short distance and the time savings is trivial; the lane design does not support their entry or exit preferences; they do not like being "trapped" in the far-left lane; do not like moving over through heavy traffic; and do not know the rules.

In addition, trends for carpooling are discouraging, making it unclear what incentives are necessary to attract more HOV use. Nationwide, carpooling has been on the decline for decades (see Ferguson, 1997) and dropped to under half of its 1980s levels by 2013 (Polzin and Pisarski, 2015). Among the possible explanations for this decline are:

- Rising real incomes, higher levels of auto ownership, and low fuel costs have reduced the monetary incentive for sharing a ride (transit or other).
- Travel time and cost savings need to exceed the costs of carpool pickup and drop-off (or transit wait time and circuity) and do not always do so, even with HOV lanes, preferential parking, express bus services, transit pass subsidies, and so on.
- Loss of scheduling flexibility can be a deterrent (another cost), and a larger number of today's workers hold jobs that reward flexibility.

Nationwide, three-quarters of carpools are two people, and many carpools are familial, with the second passenger making a school, daycare, or other nonwork trip. It is unclear how much congestion these carpools relieve or how many single-occupancy vehicles (SOV) they take off the road (see, e.g., Li et al., 2007; Polzin and Pisarski, 2015). In addition, carpooling has been found to be relatively high among immigrants, especially those who live in ethnic enclaves (Blumenberg and Smart, 2014), suggesting a heterogeneity of attitudes toward sharing a ride.

In evaluating the effects of HOV and HOT lanes, another consideration is that these lanes have been hard to regulate and enforce and otherwise operate as offering a distinct advantage over general purpose lanes, as documented in Caltrans' 2018 HOV degradation report (and those of other states.) While efforts are being made to provide more targeted enforcement, current evidence makes it hard to justify treating these lanes as distinct from general use lanes.

HOT lanes, whereby SOVs can legally use the HOV lane for a toll, are even more complex. They are relatively new and therefore have not been studied extensively, although HOT lanes have been used in California and several other states (for example, in Texas and Minnesota) for long enough to generate case studies and scenario-based analyses. Peer-reviewed studies that examine these issues are beginning to appear (see, e.g., Small et al., 2006; Yang and Huang, 1999; Konishi and Mun, 2010; Shewmake, 2012; Rentziou et al., 2011). While these cases are informative, the panel concluded that more studies on HOT lanes is desirable to assess their impact on VMT and for broader policy purposes. New types of data and modeling might be needed because of the high level of heterogeneous behavior occurring. The choice to use a HOT lane is complex and so is the toll charge actually paid. Not only do HOT lane tolls vary, but for some travelers, the toll might be paid by an employer or charged to a client, and therefore, not related to the user's income.

Because HOT lanes offer a wider range of quality, cost, and convenience choices than general purpose lanes, they can attract some regular SOV toll payers—those with high incomes or high values of time might be indifferent to toll amounts. HOT lanes also attract occasional users when a trip is urgent, for example, to get to the airport, a job interview, an important meeting, or a sick family member.

Like an HOV lane, a HOT lane moves some already existing HOVs from general purpose lanes to the new lane, and its priority treatment for transit and HOVs might lead to more HOV use. However, the toll option is likely to lead to even more complex travel behaviors than HOV lanes, such as moving SOVs from general purpose lanes to the HOT lane, attracting new trips and longer trips formerly deterred by congestion, inducing mode shift to HOV or moving HOV users (carpooling or transit) to SOVs.

In short, the panel's assessment was that special purpose lanes, including HOV and HOT lanes, add capacity, and this capacity increase has the potential to support additional travel. How much additional capacity is added is a function of how the lane is designed, managed, and used and the travel behaviors, particularly for HOV and for HOT lanes, and these factors are complex and not completely understood. The panel concluded that more investigation of these issues is important to establish a strong evidentiary basis for estimating the induced travel effects of these lane types.

4.3.2 PROJECT CONTEXT

Stakeholders who had participated in meetings and webinars on the proposed induced travel guidance raised concerns about project context. For example, there is concern that background conditions—land-use patterns and densities, modal options, route options, and so on—that underlie the studies on which the calculator is based might not be a good match for some areas where projects are being proposed, particularly smaller MPOs and rural areas of larger MPOs.

The panel noted that the calculator is not recommended for use in areas not covered in the studies it incorporates, including rural counties. A few national studies do include smaller MPOs and rural areas—for example, Duranton and Turner, 2011, includes a panel on VKT for interstate highways outside urbanized areas within MSAs—but it would be necessary to dig deeper into those studies, well beyond what can be done in this project, to determine whether enough data and strong enough analyses are available to make use of the studies' small MPO and rural area results.

Panel members also noted that the same concern about sensitivity to context could apply to travel demand models based on aggregate data and heavily reflecting in their estimated coefficients the more urbanized, populous, modally diverse portions of the region.

Panel members pointed out that whether MSA or urban county data would apply to the more rural areas of a county depends on how integrated the areas are into the broader urban economy. The MSA designation assumes that the area is integrated into the economy, but given the large size of some California counties, greater granularity in the assessment might be needed. Commute patterns are a significant indicator of interconnectedness. While a review is beyond the scope of this project, it is worth noting that there is a large and still-growing literature on the impact of highway capacity and accessibility on economic development, including business locations, commuter housing choices, and the location of new towns. There is also a robust literature on the emergence of mega-regions and the factors, including accessibility considerations, that have driven their emergence. Case examples show that rural areas and areas with limited congestion and limited linkages to nearby urban districts can still experience induced travel resulting from new capacity, because the new capacity improves travel times or reduces costs and creates new patterns of accessibility and new location and land-use opportunities. These studies could form the starting point for a study of growth and change in rural areas and the impacts that highway capacity increases have on rural areas under various circumstances.

While available studies do not offer a definitive answer about whether outlying areas are more or less likely to experience induced travel resulting from capacity increases, several studies suggest that the elasticity of demand might be higher in the outlying areas, partly because of the relative percent increase in capacity, and partly because of the potential for location and land-use shifts and increased travel to and from other parts of the metropolitan region.

Studies also indicate that accounting for transit services at the levels of service and geographic scales of availability experienced in most U.S. contexts do not significantly alter the induced travel estimates (Duranton and Turner, 2011).

4.4 Reconciling Estimates

The discussion of elasticity-based estimates and travel model estimates of VMT identified possible reasons for differences, including differences in estimates for project types covered by the calculator. The panel's general reaction to this question was in line with the aphorism attributed to the esteemed statistician George Cox, to paraphrase: "All models are wrong, but some are useful."

Both elasticity-based estimates and travel model estimates are subject to uncertainty. As one panelist put it, “Different models give different results, but then even the best long-range forecast gives results that are quite different from what will actually result.” For this reason, the panel members argued that rather than focus on reconciliation of results, a better emphasis would be to improve both types of models and use the best available tool for the analyses needed.

The panel reiterated that because the elasticities in the calculator are based on traffic count and lane mileage data and are derived from econometric analyses that use advanced methods to control for possible confounding variables, they are a strong indicator of likely regional average, long-run responses. In their assessment, if travel models forecast different results, the analysts and project sponsors must be prepared to explain why such differences are credible. Models must be checked carefully, as must the underlying data. If the models have the capacity to fully reflect all the factors that result in induced travel, the data are sound, and the results are still different, a substantive explanation is needed. Because elasticities reported in the best available peer-reviewed literature range by about +/-20%, such a difference in estimates between travel models and the calculator is not a cause for concern. A bigger difference, however, calls for a substantive fact-based explanation.

An explanation about the model needs to go beyond mere assertions that the project or the context is different—it is not merely storytelling but telling a story backed up with evidence from data and examples. Or, as the panelists put it, “storytelling with guardrails”. For instance, if an elasticity estimate suggests a higher level of induced travel than project analysts believe will occur, which specific factors set the project apart from the average estimate and what is the evidence that such factors are in place or will develop?

The panelists endorsed the proposition that model statistics and error bands around estimates be reported for both types of models. Several panelists noted that TMIP reports and webinars strongly urge that travel model validation reports be prepared and updated from time to time. A validation report would include, for example, a discussion of post-estimation adjustments made to the models in the calibration phase, including reasonableness checks performed, adjustments to model coefficients, speed estimates and so on made as a result, and any post-calibration validation tests carried out. NCHRP Report 934 (Ehrhardt et al., 2019) offers advice on assessing the accuracy of forecasts, and the TMIP has many valuable reports and webinars, including two reports by Cambridge Systematics that offer sound advice on model validation and reasonableness checking (Cambridge Systematics, 2008; Cambridge Systematics, 2010).

The panelists also suggested ways to bring the results together if reconciliation is deemed necessary. First, they recommended that analysts and project sponsors treat the elasticity-based results as a reasonable initial estimate for the project (remembering that the calculator produces annual results and that the model results must be annual as well to be comparable).

After the models and data have been thoroughly validated and checked for reasonableness, boundary conditions should be checked, especially if the project is near the edge of the zone system for the geography being analyzed (MSA, county). Boundary issues can arise when institutional boundaries do not coincide with economic regions. The resulting modeling issues can be resolved in several ways, including by agreement with neighboring jurisdictions to include extra-territorial "gateway zones" and data collection, but panelists noted that this is not always easy to achieve. Over the long run, it might be possible to turn to the statewide model for use in select link analysis to get an indication of the amount of VMT spilling over boundaries.

If adjustments are made to the approach used by the calculator because the analysts or project sponsors believe conditions are different from the average, the adjustments should be clearly supported by quantitative evidence and documented so that others can review and understand what was done. For example, it might be reasonable to assume that travel increases could take 20 years instead of 10 years to achieve "long-term" levels if congestion is largely absent and historic growth rates in population, economic activity, and VMT have been slow and are projected to remain so. In such a case, the analyst documents the assumption and backs it up with growth rates based on data and forecasts from, for example, state agency reports and regional projections. Likewise, the analyst might choose to use a somewhat lower elasticity than the one embedded in the calculator, based on recent literature that covers the full range of travel-generating phenomena, if the conditions that produced the elasticity can be shown to be a good match for local conditions. In this case, the citations are needed.

If travel models are missing some elements necessary to estimate induced travel, the calculator could be used for those cases where it applies. Alternatively, the analyst could use supplementary methods to adjust the forecast results. For example, areas that lack a land-use model could use a Delphi method (Dalkey, 1969; Linstone and Turoff, 1975; Cavalli-Sforza and Ortolano, 1984; Melander, 2018) to evaluate likely land-use changes and develop land-use scenarios for the various alternatives under consideration. Another approach is to assume that the model results amount to a partial estimate, or a short-to-medium estimate, producing interim year results, and then interpolate to match "long-term" results based on the elasticity estimate. This could be a simple, straight-line interpolation. Documentation of supplementary methods and pre- and post-processing adjustments is needed.

5 CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the panel's conclusions and recommendations and proposes some next steps that Caltrans and its partner agencies could take to assist project sponsors and analysts in estimating induced travel. The panel members also worked with agency staff to devise a series of questions to answer when using travel models to estimate induced travel.

5.1 RECOMMENDATIONS ON INDUCED TRAVEL ASSESSMENT

The panel summarized its key conclusions as follows.

- Projects that lower travel costs (time, money, uncertainties) are likely to induce travel. Projects that increase capacity, especially where there is congestion, or provide significantly different levels or patterns of connectivity can induce travel. The debate is primarily over how much and how fast induced travel occurs, not whether it occurs.
- Induced travel can occur over a large area; it is not restricted to the vicinity of a project. Corridor-level analyses picks up only a portion of the potential for induced travel. In addition, induced travel occurs over a period of years, with some immediate responses and others that accrue as travelers acclimate to changed opportunities and conditions. Short-term effects can occur in the first year to 5 years, and long-term effects can accrue over 10 years. In areas with slow growth, minor congestion, and little development pressure, induced travel can still occur but take longer to appear.
- Models and calculators are tools that require judgment, including judgment on which tools are the best to use for a particular task. Both the NCST calculator and travel models are dependent on the accuracy of the data that they rely on and reflect numerous assumptions that might or might not hold for a specific case. Neither the calculator nor the best travel model can be expected to be a perfect predictor of the effects of a specific project on VMT. Fortunately, perfection is not required. Instead, the goal is to produce a reasonable, evidence-based estimate.
- In the NCST calculator, the elasticities of VMT with respect to capacity increases are extracted from the best available peer-reviewed papers on the topic, and other recent high-quality studies have reported similar elasticities. The cited studies control for other factors that could confound the estimates. The use of these elasticities in the estimation of induced travel is therefore reasonable.
- Because the elasticities used in the NCST calculator are long-term average elasticities for the specific highway types and contexts studied. and some project-to-project variation (higher or lower elasticity) is to be

expected, there can be cases where the NCST elasticities do not apply. If analysts believe that the elasticities are inappropriate for a particular location or project, evidence-based justifications should be given for a different elasticity or model-based analysis approach. Evidence could include high-quality, peer-reviewed research that indicates a different level of response for the project or location type under study, for example.

- Travel demand models vary considerably in their specifications and, as a result, in their ability to estimate induced travel resulting from highway investments. A review of travel demand model capabilities and their applications is therefore in order before relying solely on their outputs. Based on members' experience with models in use in California, the panel's assessment is that some models are capable of estimating induced travel reasonably well and some are not. For example, some model systems do not have the capability to account for changes in origin-destination patterns, increases in trip frequencies, and changes in location and land use resulting from transportation investments. In addition, models are not always applied in a way that fully exercises these capabilities. It is valuable to document the models, the calibration steps taken, the reasonableness tests performed, and if possible, the validation tests carried out against later-year conditions.
- If the travel model does not have the full set of capabilities needed to estimate induced travel, the panel recommends that the analysis use the elasticity models as reasonable estimates of long-term induced travel effects. Alternatively, the analyst could adjust travel model inputs and/or outputs using supplementary analysis methods. Examples of supplementary methods are the development and modeling of land-use and travel-pattern scenarios in response to proposed transport projects and their alternatives, or post-processing results to reflect the likely increases in VMT resulting from factors that the models do not fully reflect.
- If models capable of capturing the full range of induced travel impacts are run to equilibrium and produce results that differ from elasticity estimates, the magnitude of the difference should be assessed. Given the range of elasticity estimates in the current, high-quality literature, differences of +/- 20% are acceptable. If results differ by a greater amount, the analyst and project sponsor should provide reasons based on statistical evidence, the literature explaining why the differences are occurring, and document their findings so that others can review them.

5.2 Next Steps

The panel recommended some next steps that Caltrans and its partner agencies could take to assist project sponsors and analysts in effectively estimating induced travel. While these topics were deemed to be beyond the scope of this project, the expert panel felt that they have the potential to be important elements of an overall strategy for dealing with induced travel.

- Update, and if possible, expand the elasticity-based approach. Its advantages are simplicity, low cost, quick turnaround, and transparency, but currently the available tools are limited in geographic coverage and project types. Investigate the feasibility of producing induced travel elasticities for more geographic areas and project types where sufficient data exist. When additional studies are needed, seek ways to fund them.
- If data are not currently sufficient to support a quantitative analysis of the induced travel effects of specialized lanes, sponsor a study design aimed at data collection that enables such analysis. In the meantime, document case studies on the VMT impacts of specialized lanes. HOV and HOT lanes should be a high priority, given the interest in them in California.
- Update the literature review on induced travel to include studies of HOV and HOT lanes in the full range of applications and give priority to case studies and quantitative assessments of these lanes.
- Provide additional travel model "best practices advice" focused on estimating induced travel, and provide model-improvement assistance focused on improving VMT estimates.
- Work with project sponsors to improve project purpose and need statements. A clear statement of project purpose and need can help clarify intent and expectations, including the changes in travel that are expected to result from the project.

In addition, the panelists supported the following.

- Consider other ways to estimate induced travel, such as the use of tiered EIRs to allow the consideration of VMT changes resulting from an entire regional (or even statewide) transportation plan or program of projects rather than dealing with individual project impacts.
- Work on the development of county-wide, MPO-level, and state-level mitigation funds, along with advice on mitigation strategies, for addressing induced travel concerns.

5.3 Draft Checklist for Evaluating Whether to Use a Travel Model

Following the panel discussion, panel members worked with agency staff to create a draft checklist of questions to answer when using a travel model to estimate induced travel, as shown in Table 2. Caltrans and OPR continue to refine this checklist and to develop a set of recommended responses to deficiencies.

Table 2. Draft Checklist for Evaluating Adequacy of Travel Models for Estimating Induced Travel

Confirm the following when a travel model is used for estimating induced travel.*

Section 1. Land-use response to network changes

Confirm one of the following:

1a) Is the model's specification of future land use sensitive to travel time and cost, i.e., varying across scenarios to simulate the land-use response to network changes?

1b) If future-year land use is exogenous to the modeling process, are land-use assumptions determined via a Delphi method or through examination of outcomes under a range of plausible scenarios, including the build and no-build alternatives?

Section 2. Mode choice, destination choice, and trip frequency: Sensitivity of trip-making behavior to network travel times and travel costs

Confirm all of the following:

2a) Do changes in network travel times and travel costs (e.g., vehicle operating costs, tolls, parking costs, transit fares, etc.) by mode influence mode choice, destination choice (including workplace location), and trip frequency?

2b) Are network travel times and costs fed back into the mode choice, destination choice, and trip frequency models so that travel times and costs are roughly consistent with the "converged" travel times and costs from traffic assignment?

2c) Are the heterogeneity and complexity of travelers' responses to time and cost changes relevant to the examined project reflected in the modeling?

2d) If the project is likely to influence travel time reliability, is that influence modeled, and is its effects on mode choice, destination choice, and trip frequency accounted for?

Section 3. Sufficiency of detail and coverage of modeled roadway and transit networks and assignment processes

Confirm all of the following:

3a) Are the roadway and transit networks provided in sufficient detail and coverage to reflect the full set of route and mode choices available to the traveler?

3b) Is the catchment area sufficient to reflect the impacts of both no-build and build scenarios to appropriately illustrate the differences between them?

3c) If the project would lead to induced travel extending beyond the model's boundary, has the model been modified to incorporate the larger geography, or has an off-model assessment captured the additional travel generated?

3d) Is FHWA guidance followed to provide a sufficient level of convergence in network assignment such that the differences in outcomes between scenarios can be reliably attributed to the differences in scenario definitions, rather than the network assignment process itself?

Section 4. Model calibration and validation

4a) Has the model been validated across points in time and changes in travel time and cost to confirm that it is appropriately sensitive to changes in these factors?

***** This panel version draft was superseded. Refer to the Transportation Analysis Framework for the latest version.

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APPENDIX A: ELASTICITIES OF VMT WITH RESPECT TO HIGHWAY CAPACITY INCREASES

a) Induced-travel regression models and travel demand models cited in Noland and Hansen, 2013, Tables 4.1 and 4.2

Table 4.1 Parameter estimates from induced-travel regression models

		Fixed effects			Elasticities	
Reference	Scale	Area	Time	Causality	Short-term	Long-term
Models with aggregate data: all with lane mile elasticities						
(Hansen et al. 1993)	Facility	X			0.2–0.3	0.3–0.4
(Hansen, Huang 1997)	County	X	X	Lag model	0.21	0.6–0.7
(Hansen, Huang 1997)	Metro	X	X	Lag model	0.19	0.9
(Fulton et al. 2000)	County	X	X	Granger test	0.2–0.6	
(Noland, Cowart 2000)	Metro	X	X	Instrumental variable model	0.28	0.90
(Noland 2001)	States	X	X	Distributed lag model	0.2–0.5	0.7–1.0
(Cervero, Hansen 2002)	County			Simultaneous equations		
VMT dependent	County	X	X	Granger test	0.59	0.79
LM dependent	County	X	X	Granger test	0.33	0.66
(Cervero 2003)						
Direct	Facility	X	X	4-element path model	0.24	0.81
Indirect	Facility	X	X	4-element path model	0.10	0.39
(Duranton, Turner 2009)	States	Cross-sectional		Instrumental variable model	0.92–1.32	
(Hymel, Small, & VanDender 2010)	States	X	X	3-stage least squares	0.037	0.186
(Rentziou, Gkritza, & Souleyrette 2011)	States	Random effects		Error component model	Urban, 0.256	Rural, 0.068

Models with disaggregate

Data	Scale	Type of elasticity	Elasticities
Strathman et al. (2000)			
Direct	Corridor	Lane-miles	0.29
Indirect	Corridor	Lane-miles	0.033
Barr (2000)	Corridor	Travel time	–0.3 to –0.5

Table 4.2 Estimates using travel-demand models

Model	Method	Scale	Type	Long-term Elasticities
DeCorla-Souza (2000) No Feedback	Four step	Facility	Travel time	-0.7
Feedback	Four step	Facility	Travel time	–1.1
Rodier et al. (2001) 25 years	MEPLAN	Metro	Lane-miles	0.8
50 years	MEPLAN	Metro	Lane-miles	1.1

b) From Handy and Boarnet, 2014

Study	Study location	Study year(s)	Results: *Change in VMT/ change in lane miles*	Results: *Time period*
Duranton and Turner, 2011	U.S.	1983 - 2003	1.03	10 years
Cervero, 2003	California	1980 - 1994	0.1	Short term
			0.39	Long term
Cervero and Hansen, 2002	California	1976 - 1997	0.59	Short term (1 year)
			0.79	Intermediate term (5 years)
Noland, 2001	U.S.	1984 - 1996	0.30 to 0.60	Short term
			0.70 to 1.00	Long term
Noland and Cowart, 2000	U.S.	1982 - 1996	0.28	Short term
			0.9	Long term
Hansen and Huang, 1997	California	1973 - 1990	0.2	Short term
			0.60 to 0.70	Long term – counties
			0.9	Long term – metro areas

c) From Currie and Delbosc, 2010, citing Schiffer et al., 2005

Table 5.2: Review of induced travel elasticities

		Lane km elasticity		**Travel time elasticity****		
Paper	**Data used**	**Short-term***	**Long-term***	**Short-term**	**Long-term**	**Improvement type**
Cervero, Hansen 2001	32 CA counties	0.56	0.78			Widening
Hansen, Huang 1997	CA counties	0.3	0.68			Not specified
Hansen, Huang 1997	CA metro level	0.5	0.94			Not specified
Marshall, 1996	TTI Congestion Study	-	.76 - .85			Not specified
Rodier, et al 2001	Sacramento regional	-	.8 - 1.1			New road and widening
Strathman, et al 2000	Nationwide NPTS data	-	0.29			Not specified
Cervero, 2001	24 CA corridors	0.29	0.64			Widening
Fulton, et al 2000	MD, VA, NC, DC counties	.3 - .5	.47 - .89			Not specified
Hansen, et al 1993	CA highway	.2 - .3	.3 - .6			Widening
Mokhtarian, et al 2000	CA highway	0.0	-			Widening
Noland 2001	State-level	.3 - .68	.7 – 1.0			New road and widening
Noland 2001	State -level	-	.5 - .8			New road and widening
Noland, Cowart 2000	Nationwide metro level	-	.81 – 1.0			Not specified
Noland, Cowart 2000	Nationwide metro level	0.3	-			Not specified
Cervero 2002	24 CA corridors	0.1	0.39			Not specified
Hansen, et al 1993	California county	.46 - .5	-			Widening
Hansen, et al 1993	California metro level	.54 - .61	-			Widening
Goodwin 1996	Petrol price evaluation			-0.5	-1.0	Not specified
Barr 2000	Nationwide NPTS data			-0.3	-0.4	Not specified

Overall	Range	.0 - .68	.29 – 1.1	-.3 – -.5	-.4– -1.0
	Average	0.35	0.69	-0.4	-0.7
Widening projects	Range	.0 - .58	.45 - .78		
	Average	0.36	0.62		

*Depending on the study, "short-term" is generally one to five years; "long-term" is generally five to ten years.

**Travel time elasticities compare induced traffic to savings in travel time. An elasticity of -.5 means that a reduction in travel time of 10% will increase traffic volumes by 5%.

Source: (Schiffer et al. 2005)

PANELIST BIOGRAPHICAL SKETCHES

Elizabeth Deakin (panel chair) is professor emerita of city and regional planning and urban design at UC Berkeley and an affiliated faculty member of the Energy and Resources Group. She previously was director of the UC Transportation Center (1999–2008) and co-director of the Global Metropolitan Studies Center (2004–2009). She also served as vice-chair and then chair of the UC Berkeley Academic Senate (2013–2015).

Deakin's research and teaching focus on transportation and land-use policy, the environmental impacts of transportation, and equity in transportation, and she has published over 300 journal articles, conference papers, book chapters, and research reports. Since her retirement, she has continued to carry out research projects and mentor students and has co-edited a book on international experiences with high-speed rail and edited a book on transportation, land use, and environmental planning.

She has been appointed to several government posts, including city and county commissions and state advisory boards in California. She has testified on transportation legislation before the U.S. Senate Public Works Committee, the House Technology and Infrastructure Committee, and the House Science Committee and California Senate and Assembly committees and city councils.

She was the co-creator of several transportation–land use plans that won prizes from APA and AIA and has received awards for best paper (TRB Energy Committee) and best reviewer for a journal (ASCE). She was selected for the Association of Collegiate Schools of Planning Distinguished Educator Award in 2019, the UC Berkeley Institute of Transportation Studies Distinguished Legacy Award (2017), and the Faculty Distinguished Service Award, UC Berkeley Academic Senate (2012). In 2010, she received an honorary PhD in recognition of her contributions to research in transportation, pricing, and the environment from the Royal Institute of Stockholm (KTH). She holds SB and SM degrees in political science and transportation systems analysis from MIT (where she also completed minors in math and psychology) and a law degree from Boston College Law School.

Fred Dock is the former director of transportation for the City of Pasadena, California. During his tenure and under his direction, Pasadena pioneered the use of VMT and multimodal transportation performance metrics and developed a Complete Streets framework that focused on achieving Pasadena's goals for safety and sustainability. Now retired from the City, he advises on transportation policy and practice with an emphasis in urban transportation issues and performance measures.

Prior to joining the City of Pasadena, Mr. Dock consulted for engineering and planning firms in Northern and Southern California, Chicago, and Minneapolis for

30 years. He directed and prepared a variety of engineering and planning projects, ranging from impact analysis to corridor studies to regional plans. He was one of the principal investigators for the University of Minnesota's research on transportation and regional growth. His work in operations included advanced traffic control systems and simulation modeling of complex traffic networks.

He led a nationwide initiative on urban street design that developed a context-based framework for street design and resulted in the publication of *Designing Walkable Urban Thoroughfares* (ITE, 2010). That work is the basis for the modified system of functional classification in the 7th edition of the *AASHTO Green Book*. His work with transit-oriented development is nationally recognized by the Transportation Research Board for both policy and practice and by the Urban Land Institute, for which he authored *Developing Around Transit* (ULI, 2005) with other nationally recognized individuals.

Mr. Dock has received various awards, including the 2015 Dale Prize for Excellence in Urban and Regional Planning when the theme was *Streets for Everyone: Advancing Active Transportation*. He earned a BA and MA in civil engineering from UC Berkeley. He is currently a registered civil engineer and traffic engineer in California, a PTOE, and an AICP. He was previously registered as a professional engineer in the states of Illinois, Michigan, and Montana.

Gordon Garry is mostly retired after a professional career of 40 years. He keeps an active role professionally through various projects with government agencies and NGOs.

From 1990 to 2017, he was a senior staff member at the Sacramento Area Council of Governments (SACOG). Mr. Garry developed and managed an increasing array of data, forecasting, and scenario programs to support the agency's transportation, air quality, land-use planning, and climate change efforts. Mr. Garry was responsible for modeling projections and analyses in these areas that meet local, state, and federal planning requirements. While at SACOG, he worked with a number of regional agencies across California and the country to develop and implement technical tools to support better decision-making for public agencies.

Prior to joining SACOG, he worked for the City of Santa Rosa, SRF Consulting in Minneapolis, and the South Dakota Department of Transportation. Mr. Garry received his BS in economics at South Dakota State University and his master's in city and regional planning at the Harvard Kennedy School of Government.

Susan Handy is a professor in the Department of Environmental Science and Policy and the director of the National Center for Sustainable Transportation at UC Davis. She is internationally known for her research on the relationships between transportation and land use, particularly the impact of neighborhood design on travel behavior. Her current work focuses on bicycling as a mode of transportation and on strategies for reducing automobile dependence.

Dr. Handy holds a BSE in civil engineering from Princeton University, an MS in civil engineering from Stanford University, and a PhD in city and regional planning from UC Berkeley.

Michael McNally is a professor of civil and environmental engineering and urban planning and public policy, and a faculty associate of the UC Irvine Institute of Transportation Studies. He received his PhD in engineering from UC Irvine in 1986 and was with the School of Urban and Regional Planning and the Department of Civil Engineering at the University of Southern California prior to joining the faculty at UC Irvine in 1987. His research interests focus on complex travel behavior, interrelationships between transportation and land use, and the development of new technologies and modeling methodologies that reflect and support these research areas.

Among various research awards, he received a Presidential Young Investigator Award from the National Science Foundation. He has served as principal investigator on a variety of funded projects, including research and development relating to operational models of activity-based travel forecasting; web-based, self-administered travel surveys; GPS-based, wireless in-vehicle data collection systems; information technology for shared-use station car programs; multi-jurisdictional corridor decision support systems with integrated traffic microsimulation models; the role of information on traveler behavior; and the evaluation of advanced traffic management and control technologies.

Elizabeth Sall is a principal at UrbanLabs LLC, a mission-driven urban science and research firm. Ms. Sall specializes in the intersection of policy with data and technology, especially as it relates to travel behavior and multimodal transportation network management. She is currently serving as the Mobility Data Team lead for the California Integrated Travel Project at CalSTA/Caltrans and is the technical lead on several travel model development projects.

As an avid advocate for improving the applicability and usefulness of research, Ms. Sall has served in numerous capacities as a consultant and through appointed volunteer positions with the Transportation Research Board (TRB) and the Zephyr Foundation. She has served as a task lead for the recently published NCHRP Report 934 *Travel Forecasting Accuracy Assessment Research* and is serving on the panel for NCHRP 08-121 *Accessibility Measures in Practice: Guidance for Agencies*. In the past, she has served as the chair for SHRP2 C46 *Resource on Advanced Integrated Models and Implementation Strategy*, on the panel for NCHRP Report 775 *Applying GPS Data to Understand Travel Behavior*, and as a researcher for NCHRP Report 716 *Travel Demand Forecasting: Parameters and Techniques.* Ms. Sall is currently serving on the TRB as a member of the Committee on Travel Demand Forecasting and the

Transportation Research Record Advisory Board and has served in the past on the following committees: Planning Applications, Travel Forecasting Resource, Metropolitan Policy and Practices, and the Task Force on Bring Activity-Based Models to Practice. She has served on seven of the past eight organizing committees for the TRB Innovations in Travel Modeling Conference series and six of the past TRB Planning Applications Conferences, including as conference chair and technical track leads. Outside TRB, she is the co-founder and workforce development lead for the Zephyr Foundation, a former leader of the Washington, DC Chapter of ITE, and frequent collaborator and presenter with NACTO, MobilityData IO, and a variety of universities. Ms. Sall serves frequently on peer review panels facilitated by the Travel Model Improvement Program and a variety of other expert panels for both research and policy.

As the former deputy director of technology, data, and analysis for the San Francisco County Transportation Authority, Ms. Sall was responsible for developing, maintaining, and applying an activity-based travel demand model that served as the basis for local, long-range planning documents, FTA new- and small-starts submissions, the environment review process, and various land-use and transportation studies. Ms. Sall began her career as a consultant working on projects ranging from project-level forecasting and travel impact analysis to urban and rural long-range transportation plans and neighborhood planning studies. She has civil engineering degrees from North Carolina State University (BS) and the University of Texas at Austin (MS).

Alex Skabardonis is an internationally recognized expert in traffic flow theory and models, traffic management and control systems, design, operation and analysis of transportation facilities, intelligent transportation systems (ITS), energy, and environmental impacts of transportation. He is a professor at UC Berkeley and program leader at California PATH, a statewide ITS research center. He has worked extensively in the development and application of models and techniques for traffic control, performance analysis of highway facilities, and applications of advanced technologies to transportation. He has served as principal researcher for 85 extramurally funded contracts and grants, totaling over $30 million, and has published over 350 papers and technical reports. He is co-developer of the California Freeway Performance Measurement System (PeMS) and the Berkeley Highway Laboratory that produced the NGSIM vehicle trajectories database used by transportation researchers worldwide.

Dr. Skabardonis teaches graduate courses on transportation modeling and analysis, traffic operations, and intelligent transportation. He has advised and supported more than 120 graduate students toward their MS and PhD degrees at UC Berkeley. He also developed and taught workshops on traffic management, control systems, and traffic simulation models, attended by more than 500 transportation professionals. He holds an undergraduate degree in civil engineering from the Technical University of Athens and master's and PhD degrees in civil engineering from the University of Southampton.

Joan Walker conducts research on behavioral modeling, with an expertise in discrete choice analysis and travel behavior. She works to improve the models that are used for transportation planning, policy, and operations. Professor Walker joined UC Berkeley in 2008 as faculty in the Department of Civil and Environmental Engineering and a member of the interdisciplinary Global Metropolitan Studies (GMS) initiative. She received her bachelor's degree in civil engineering from UC Berkeley and her master's and PhD degrees in civil and environmental engineering from MIT. Prior to joining UC Berkeley, she was director of demand modeling at Caliper Corporation and an assistant professor of geography and environment at Boston University. She is a recipient of the Presidential Early Career Award for Scientists and Engineers (PECASE), the highest honor bestowed by the U.S. government on scientists and engineers beginning their independent careers. She served for six years as the chair of the Committee on Transportation Demand Forecasting (ADB40) for the Transportation Research Board of the National Academies. She is an instigator and founding stakeholder of the Zephyr Foundation, which aims to advance rigorous transportation and land-use decision-making for the public good, and bestowed its Leadership Award in 2020. She has served as acting director of the UC Berkeley Institute of Transportation Studies and as co-director of GMS.

ACKNOWLEDGMENTS AND DISCLAIMER

This document and the work described within were performed by the University of California, Berkeley, under contract to the California Department of Transportation, Agreement No. 65A0631, Task ID 3072. The contents of this report reflect the views of the author(s), who are responsible for the facts and the accuracy of the information presented herein. The University and State of California assume no liability for the contents or use thereof. Nor does the content necessarily reflect the official views or policies of the University or State of California. This report does not constitute a standard, specification, or regulation.

We thank the members of the Caltrans – CARB – OPR interagency group for their advice and support throughout the project. We also are grateful to professors Robert Cervero of UC Berkeley, Robert Noland of Rutgers University, Marlon Boarnet of the University of Southern California, and Robert Johnston of UC Davis and post-doctoral researcher Jamie Volker of UC Davis for their willingness to discuss their research on induced travel and the complexities of modeling it. Any errors and omissions are the responsibility of the principal author.