Induced Vehicle Travel Impact Analysis

Technical Guidance – 1.0

INTRODUCTION

In response to recent revisions to the CEQA Guidelines, CEQA case law, and guidance issued by the Office of Planning and Research (OPR), Caltrans has determined that Vehicle Miles Traveled (VMT) is the most appropriate metric for determining transportation impacts for capacity-increasing transportation projects on the State Highway System (SHS). VMT impact analysis may also be required for NEPA purposes. For roadway capacity projects on local roadways, lead agencies have the discretion to select their preferred metric consistent with CEQA expectations. This has traditionally been the case for NEPA projects as well. Beyond transportation impacts, VMT is still a required input for air quality, greenhouse gas (GHG), and energy impact analysis.

Induced vehicle travel effects are the driving forces behind VMT changes associated with roadway capacity expansion projects. These effects can also diminish expected benefits of building new capacity on congestion relief. The main resources on induced vehicle travel for environmental impact analysis of transportation projects are listed below. These documents should be reviewed prior to use of this guidance.

- OPR's *Technical Advisory on Evaluating Transportation Impacts in CEQA*, December 2018. https://opr.ca.gov/docs/20190122-743_Technical_Advisory.pdf

- Caltrans' *Transportation Analysis Framework (TAF) First Edition: Evaluating Transportation Impacts of State Highway System Projects*, September 2020. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/sb-743/2020-09-10-1st-edition-taf-fnl-a11y.pdf

- Caltrans' *Transportation Analysis Under CEQA (TAC) First Edition: Evaluating Transportation Impacts of State Highway System Projects*, September 2020. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/sb-743/2020-09-10-1st-edition-tac-fnl-a11y.pdf

- *CARB 2017 Scoping Plan – Identified VMT Reductions and Relationship to State Climate Goals*, January 2019. https://ww2.arb.ca.gov/sites/default/files/2019-01/2017_sp_vmt_reductions_jan19.pdf

- *CARB Research on Effects of Transportation and Land-Use Related Policies*
  https://ww2.arb.ca.gov/sites/default/files/2020-06/Impact_of_Highway_Capacity_and_Induced_Travel_on_Passenger_Vehicle_Use_and_Greenhouse_Gas_Emissions_Policy_Brief.pdf
  https://ww2.arb.ca.gov/sites/default/files/2020-06/Impact_of_Highway_Capacity_and_Induced_Travel_on_Passenger_Vehicle_Use_and_Greenhouse_Gas_Emissions_Technical_Background_Document.pdf

- NEPA Travel and Use Forecasting
  https://www.environment.fhwa.dot.gov/env_topics/other.aspx

- Ronald T. Milam, et al., *Closing the Induced Vehicle Travel Gap between Research and Practice*, Transportation Research Record (TRR) #2653, 2017, p10-16.
  https://pdfs.semanticscholar.org/48aa/57a40a71f7c6ba90106f0acdbfccb37de0b2.pdf

This guidance explains the potential approaches to forecast induced VMT for roadway capacity projects based on the above documents and CEQA compliance. This guidance may also be applied for NEPA projects.

POTENTIAL APPROACHES TO FORECAST INDUCED VMT

As indicated in the OPR's Technical Advisory and Caltrans' TAF and TAC First Editions, two methods are highlighted to forecast induced VMT: 1) an empirical approach using elasticities, and 2) a travel demand model. Each method has its pros and cons, and practitioners must examine how to reconcile these two methods to perform a complete analysis satisfying the CEQA (and NEPA) expectations. Appendix A contains more detailed insights into methodology limitations and options for application.

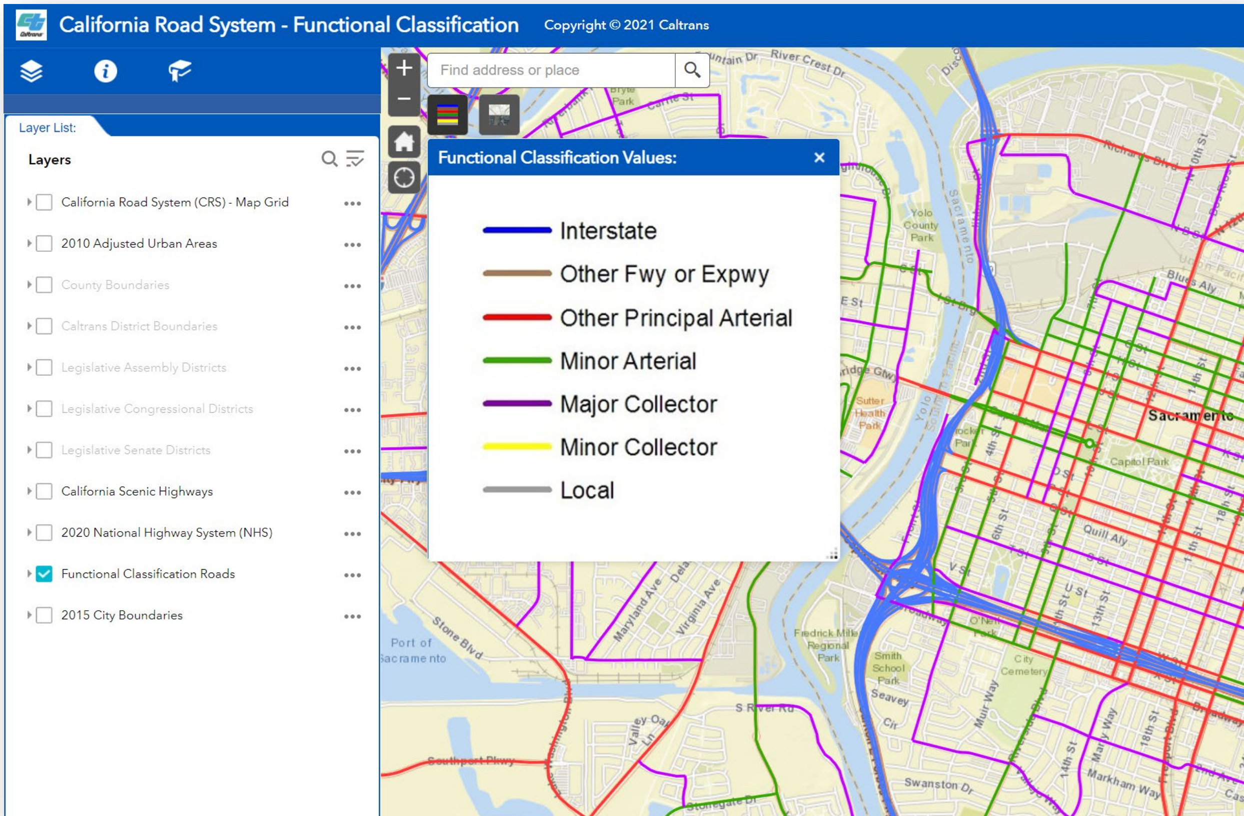
Elasticity Methods

The elasticity method is based on statistical studies that quantify induced vehicle travel that is exclusively associated with expanding roadway capacity (i.e., adding lane miles). The elasticity of VMT to lane miles includes short-term and long-term estimates of induced vehicle travel effects. Short-term effects occur in the short period of time (1-2 years) after a roadway capacity project is open to traffic. Long-term effects tend to occur within a 10 to 20-year timeframe although the most recent research tends to focus on 20 years. In general, the elasticities reflect the change in total VMT attributable to the project while controlling for other factors that contribute to VMT growth. Some researchers have also included an accounting of the specific sources of induced VMT including the proportion from passenger versus commercial vehicles. This accounting is relevant for CEQA purposes since different types of VMT may be required depending on the impact subject.

Under the elasticity method, Caltrans recommends the use of National Center for Sustainable Transportation (NCST) Induced Travel Calculator (https://blinktag.com/induced-travel-calculator) to forecast long-term induced VMT. As explained below, the calculator has limitations that practitioners should address either in qualitative discussion or through use of an alternative elasticity method described in Appendix A.

The NCST Calculator includes 2016-2019 VMT and lane-mile data so the user only needs to input the baseline year (preferably the latest year), change in lane miles associated with a proposed project, and the type of functional classification (selected from a drop-down menu). For interstate highways (class 1), the VMT forecast is based on inputs for the corresponding Metropolitan Statistical Area (MSA) and using an elasticity of 1.0. For other freeways and expressways (class 2) and other principal arterials (class 3), the calculator uses county-level inputs and an elasticity of 0.75.

According to NCST, the calculator is applicable for General Purpose (GP), High Occupancy Vehicle (HOV), or high-occupancy toll (HOT) lane projects involving the addition lanes to class 1, 2, and 3 facilities, which cover the SHS and most major arterials. For a specific map of class 1, 2, and 3 facilities, refer to the Caltrans statewide functional classification map available at the following website - https://dot.ca.gov/programs/research-innovation-system-information/highway-performance-monitoring-system/functional-classification. Users of the map need to zoom in closely to their study area for the map to reveal all functional classes.



The Induced Travel Calculator limitations are listed below. Analysts should consider each limitation and how it may contribute to over- or under-estimates of induced travel effects.

- The elasticities produce a forecast of total VMT attributable to a project. This is important since the CEQA Guidelines Section 15064.3(a) states, "For the purposes of this section, "vehicle miles traveled" refers to the amount and distance of **automobile** travel attributable to a project." One of the main research studies used for the calculator contains the following sources of induced vehicle travel effects.[1]
    - Changes in commercial driving = 19 to 29%
    - Changes in individual or household driving = 9 to 39%
    - Changes in population due to in-migration to the MSA = 5 to 21%
    - Diversion of traffic = 0 to 10%

---

[1] *The Fundamental Law of Road Congestion: Evidence from US Cities*, Gilles Duranton and Matthew A. Turner, American Economic Review 101, October 2011.

Concentrating on the effects associated only with automobile travel produces lower elasticity values ranging from 0.14 to 0.70 with changes in individual or household driving being 0.39 to 0.49 (see Appendix A for more information). The lower elasticity range is aligned with the long-term elasticity of 0.39 that was estimated by Cervero based on California data and relying on a modeling methodology that accounted for the effect that previous development and roadway capacity investment had on influencing lane mile increases.[2] Other studies have also found an elasticity of lane-miles with respect to total VMT of 0.33 revealing a strong two-way relationship where every 10% increase in VMT, lane-miles grew by 3.3%.[3] It should also be noted that the Duranton research (footnote 1 above) revealed a 17% decline in interstate lane mile per capita compared to a 63% increase in VMT per capita during the 1983-2003 study timeframe. From the Duranton paper, it is not clear how the statistical analysis accounted for the difference in directionality on a per capita basis.

- Most of the data used in the research studies ranges from the 1980s to the early 2000s, although one study extended its data from 1981 to 2015.[4] This period may not be reflective of current VMT trends and may not produce induce travel elasticities that accurately represent HOT lane effects given their limited availability in comparison to GP and HOV lanes.

- The elasticities are not sensitive to network effects associated with some roadway capacity projects such as bottlenecks that may have larger effects on travel times as well as bridges that can substantially reduce the distance between origins and destinations. Bridges that close a network gap have the greatest potential for reducing VMT due to shorter trip lengths.

- The elasticities are not sensitive to land use context, geographic constraints (e.g., water or topography barriers), or the amount of existing congestion. Without sensitivity to the project corridor context, the calculator results may over- or under-estimate induced VMT effects. Bridges are particularly useful example. A new bridge has the potential to substantially reduce existing trip lengths, which could offset potential induced vehicle travel effects. The elasticity method does not recognize this benefit.

- The calculator produces an annual VMT forecast. Project analysis typically requires weekday forecasts. Simply dividing by 365 days does not produce a reasonable weekday forecast. Use of

---

[2] *Road Expansion, Urban Growth, and Induced Travel – A Path Analysis*, Robert Cervero, APA Journal, Spring 2003, Vol. 69, No. 2.

[3] *Induced Travel Demand and Induced Road Investment: A Simultaneous Equation Analysis,* Journal of Transport Economics and Policy, Vol. 36, No. 3, pp 469-490. September 2002.

[4] *If you build it, they will drive: Measuring induced demand for vehicle travel in urban areas,* Kent Hymel, Transport Policy, 76, pp 57-66, 2019.

Performance Measurement System (PeMS) or similar data to estimate an annualization factor is recommended to create weekday values.

- The VMT forecast represents the project generated effect and does not include information about the no project condition. This is one of the bigger limitations of elasticity methods because understanding what would otherwise happen without the project is required for CEQA/NEPA impact analysis and essential information for decision making. Travel demand models help isolate what may happen if the project is not built.

- The VMT forecast does not include a distribution of VMT by speed bin, which is commonly needed for air quality and greenhouse gas (GHG) analysis.

- The VMT forecasts do not include potential VMT effects beyond the MSA or county boundaries.

- The elasticity values were derived from research data representing a period when substantial socioeconomic changes were contributing to increasing VMT per capita (e.g., 1980s to early 2000s). This period was also prior to widespread use of transportation network companies (TNCs), substantial internet shopping, expanded food delivery, and recent COVID-19 travel disruptions.

- In uncongested suburban areas, the VMT forecasts from the calculator may be unreasonably high and would not be compatible with observed trip rates and trip lengths. Without congestion, vehicle trip rates and lengths are not influenced or suppressed in these areas. This lack of sensitivity to corridor land use and congestion context means that adding lane miles in a suburban area with no congestion will have the same proportional effect as adding lane miles in an urban area with multiple hours of congestion. As additional evidence, residential vehicle trip rates in suburban areas have been stable over time across multiple versions of the ITE Trip Generation Manual.

- The most recent input data for the calculator is 2019 conditions. More current VMT and lane-mile estimates will become available in the future from the Caltrans Highway Performance Monitoring System (HPMS) and PeMS websites below.

    - https://dot.ca.gov/programs/research-innovation-system-information/highway-performance-monitoring-system
    - https://dot.ca.gov/programs/traffic-operations/mpr/pems-source

Given CEQA Guidelines expectations that the baseline year is normally the year in which the notice of preparation (NOP) is released for a project, the induced vehicle travel analysis would be strengthened by using the most recent input data available.

A final note about the use of elasticities derived from research is to recognize the difficulty of 'controlling for' the wide variety of factors that contribute to traffic growth over time. First, travel speed or travel time is the more relevant variable for predicting travel behavior changes. Lane miles serve as a proxy and are used in the research because the data is easier to obtain, but that should not be interpreted to mean that lane miles are the sole or even the most relevant variable. Second, one matched-pairs study presented in *Revisiting the notion of induced traffic through a matched-pairs study*, Patricia Mokhtarian, Francisco J. Samaniego, Robert H. Shumway, and Neil H. Willits, Transportation 29:193-220, 2002 revealed no statistically distinguishable difference in traffic volume growth rates between highways with capacity expansion versus those without in San Diego, California. Contrary to other research, this finding would suggest that VMT increases resulting from induced vehicle travel effects are solely attributable to longer trip lengths. Hence, this may be an example of the limitation noted above where the elasticity-method is not sensitive to a unique local context. The combination of evidence above suggests that the treatment of induced vehicle travel in transportation impact analysis consider and acknowledge these limitations (see Appendix A for more information).

Travel Demand Models

When utilizing a travel demand model (possibly with off-model post processing), the requirements for analyzing the full impacts of vehicle travel from a capacity-increasing project include changes in VMT due to changes in:

- Trip length (generally increases VMT);
- Mode shift (generally shifts from other modes toward automobile use, increasing VMT);
- Route choice (can act to increase or decrease VMT but is likely to decrease emissions because more direct or preferred facility routing occurs); and
- Newly generated trips (generally increases VMT).

The major issue for practitioners using the travel demand model approach in impact analysis is that most models in California and the rest of the U.S. do not have feedback processes that influence trip generation rates or land use growth allocation. Hence, these components of the models tend to be 'fixed' versus being dynamically linked to changes in accessibility associated with a transportation network modification. Models also tend to lack dynamic validation to help users understand their level of sensitivity to small network changes. Additional processing is required to handle these limitations of a model as outlined below.

- No sensitivity to trip generation – If a trip generation module is not sensitive to travel time and cost, the analyst can manually adjust the vehicle trip generation rates or use off-model processing to increase the VMT forecasts. An important part of the adjustment process is to verify that it is warranted. Adjustments may not be appropriate in suburban or rural areas where congestion is not severe enough to suppress existing vehicle trip making. In these settings, land uses are already generating vehicle trips at full demand levels (i.e., rates similar to those in the ITE Trip Generation Manual) and further increases would not be reasonable due to a roadway capacity change. A comparison to ITE rates could be used as the evidence to determine an appropriate adjustment.

- No sensitivity to land use – Analysts can follow OPR's recommendations to incorporate the VMT effects that are caused by the subsequent land use changes.
    - Employ an expert panel, including local agencies' land use planners, to develop a scenario of anticipated land use growth for project alternatives. This process should recognize whether land use effects are intra- or inter-regional. If population is being attracted from an adjacent region, the difference in VMT per capita generation rates may also need to be addressed.
    - Employ a land use model, running it iteratively with a travel demand model. A wide range of land use models exist but most are likely to be too time consuming or costly to apply for an individual project.
    - Adjust model results to align with the short-term elasticity research. Note that this is only possible for short-term elasticities, which range from 0.1-0.60 as documented in the CARB research noted above. VMT forecasts from travel models is not directly comparable to long-term elasticity-based VMT forecasts as explained in more detailed below and in Appendix A.

Travel demand models may also suffer from limited sensitivity due to their structure or design. These types of limitations are often revealed through dynamic validation testing and are commonly associated with lack of convergence in trip assignment or lack of feedback processes to trip distribution and mode choice. Regional and local models commonly lack dynamic validation despite industry recommendations to verify the sensitivity of the model's features.[5] Appendix A addresses this issue in more detail.

Another common problem is the use of fixed parameters for internal-external (IX) and external-internal (XI) trips as well as commercial vehicle trips. These are issues that can be rectified through model refinements and modifications. If these types of sensitivity issues exist with a current model, then projects should rely on the elasticity method for long-term induced VMT forecasts until the model is modified or

[5] Specific dynamic tests are specified in the *2017 Regional Transportation Plan Guidelines for Metropolitan Planning Organizations,* California Transportation Commission, 2017 and the *Travel Model Validation and Reasonability Checking Manual, Second Edition*, Federal Highway Administration, 2010.

enhanced to produce forecasts that include all applicable induced travel effects. Verification of the model's sensitivity is a specific requirement of the TAF First Edition. It includes a checklist to evaluate a model's adequacy and sensitivity to long-term induced vehicle travel effects.

A final issue that is whether (and how) use of static traffic assignment (STA) instead of dynamic traffic assignment (STA) in travel demand models affects VMT forecasts. One research paper directly comparing STA and DTA estimates revealed how the limited sensitivity of STA over-predicts traffic volumes, which would contribute to overestimates of VMT.[6]

Despite the noted model limitations, a model may still be useful to understand the incremental difference between project alternatives that the NCST Calculator or other elasticity methods will not reveal. The model's forecasts of VMT can also be stratified by speed bin, which is important for emissions analysis. Thus, use of a travel demand model may be useful under the following conditions.

1) Comparisons between no build and build alternatives in the same analysis year are useful for impact-related decisions. This comparison can be used to estimate a short-term induced vehicle travel elasticity that can be compared against the short-term academic elasticity estimates for reasonableness. See Appendix A for details.
2) The NCST Calculator is not applicable or has greater limitations than a travel demand model.
3) VMT by speed bin is needed to evaluate emissions for air quality or greenhouse gas analysis.

SUGGESTED APPROACHES

Based on the assessments of the two methods, three approaches may apply for CEQA (and NEPA) analysis.

Approach #1: Model Method

The model method, as the name indicates, uses the best available travel demand model to perform the analysis to meet CEQA expectations. The benefit of this method is to generate a complete set of model outputs that can be used to prepare the transportation, air quality, GHG, and energy impact analyses. This method does require the most effort to address model limitations. Before using the model method, the following two steps should be performed to ensure the model is sufficiently sensitive to long-term land use and trip generation changes.

[6] *Forecasting the impossible: The status quo of estimating traffic flows with static traffic assignment and the future of dynamic traffic assignment,* Research in Transportation Business & Management, Vol. 29, pp 85-92. 2018.

- Step 1: Long-term land use change
  Reduced congestion along a project corridor could lead to land development occurring farther from urban centers, which could generate more and/or longer trips that increase VMT. Given that most travel demand models do not include a feedback process to land use allocation, an expert panel (such as one comprised of local agencies' planners) could estimate changes to land use growth allocations that would likely result from the project. The resulting allocations could then be input to the travel demand model to analyze effects on vehicle travel. Note that different alternatives associated with the same project, e.g., GP lane alternative vs. HOT lane alternative, may lead to different amounts of land use change.

- Step 2: New trip generation
  The travel demand model trip rates should be assessed on whether they reflect suppressed travel due to congestion. In other words, is congestion severe enough in the study area that residents, workers, or visitors choose not to make some trips? If suppressed travel is confirmed, then an increase in vehicle trip rates may occur due to the improved traffic condition resulting from the project. An expert panel, which could be the same as the one for the long-term land use change, could be employed to evaluate the potential adjustments needed to trip rates. As noted above, the ITE Trip Generation Manual may serve as a source for 'full demand' vehicle trip rates or household travel surveys based on place or community types without congested conditions.

In addition, the following model parameters should be checked, and if warranted, adjusted to improve sensitivity.

- If the model has fixed IX XI trips, then projects that would be expected to influence IX XI patterns may require post-processing or other adjustments to appropriately account for expected effects.

- Verify that the model's assignment step reaches a stringent convergence criterion such that volume forecasts produced by the model contain limited noise (i.e., unexpected changes in magnitude or distance from the network change). Appendix B contains a sample dynamic validation evaluation with assignment testing.

- Induced commercial vehicle travel effects are often not included in regional and local travel demand models and would require re-estimation or post-processing. In some cases, application of statewide models such as the California Statewide Travel Demand Model may be appropriate to capture commercial vehicle effects. Off-model approaches are another option.

- TNCs and future autonomous vehicles (AV) are not commonly included in travel demand models and may become a larger share of VMT in the future. Creative application of these models similar to the Fehr & Peers AV testing or post-processing of model outputs would be necessary to approximate TNC and AV effects.[7] Use of TrendLab+ or other scenario modeling tools including VisionEval may also be appropriate. Guidance from traditional sources such as TRB is still evolving and should be monitored. A recent example is the *Updating Regional Transportation Planning and Modeling Tools to Address Impacts of Connected and Automated Vehicles,* Volume 2: Guidance, Washington DC: The National Academies Press: https://doi.org/10.17226/25332.

As noted above, the TAF First edition includes a checklist (Table 4 of Section 4.5) that specifies model capabilities required for induced vehicle travel assessment, including:

- Land use response to network changes;
- Sensitivity of trip-making behavior to network travel times and travel costs;
- Sufficiency of detail and coverage of modelled roadway and transit networks;
- Network assignment processes – whether the model reaches appropriate convergence; and
- Model calibration and validation.

As required by Caltrans, a model should pass all five checks before the analyst concludes that the model is appropriate for making projections of induced vehicle travel. In addition, if the NCST Calculator can be applied to the project, Caltrans recommends that the induced VMT estimated by the model should be within 20 percent of the value provided by the NCST Calculator. ***However, this recommendation does not recognize that current travel demand model forecasts and elasticity-based long-term induced vehicle travel forecasts are not directly comparable.*** Current models do not account for all long-term effects such as changes in trip generation and land use.

While a model or model process can be developed to include full sensitivity to long-term effects, it will always be challenging to produce a direct comparison to the elasticity-based methods. The elasticity method forecasts VMT changes attributable to a project while controlling for variables such as population growth, employment growth, and income changes because the method is trying to isolate the VMT effect of just adding lane miles.

By contrast, a travel demand model forecasts VMT changes based on variables such as population and employment growth, and income changes in addition to changes in the transportation network. Extracting the VMT change solely associated with the lane-mile changes over time is not an output that can be directly calculated from a travel demand model. Instead, long-term comparisons of base year to future year conditions produce forecasts inclusive of population and employment growth, income changes, travel cost changes, and network changes. An elasticity derived between long-term VMT growth and lane mile changes that includes all of these variables is likely to be much higher than the Caltrans accepted range of 0.80 to 1.20. For California, the elasticity of VMT to lane miles was 1.99 between 2001

[7] https://www.fehrandpeers.com/autonomous-vehicle-research/

and 2019. A statewide travel demand model for this same time period could be benchmarked against the 1.99 elasticity but should not be compared to the 1.0 elasticity where factors such as population and employment growth have been controlled for.

The model results can be used to compare no build and build differences typically caused by changes in trip distribution (activity choice), mode choice, and trip assignment. If feedback to long-term land use growth allocation and vehicle trip generation rates is added to the modeling process, then a travel demand model may better capture long-term induced vehicle travel effects but will still suffer the inability to isolate just the long-term VMT change attributable to the increase in lane miles. The expectation of a model appropriately sensitive to short-term and long-term induced vehicle travel effects is that the long-term change in VMT associated with the project should be greater than the short-term change. Assessments made for models that do not satisfy all the checks above should include disclosure of specific limitations and how they may have affected any associated analysis results.

Use of a model does not exclude use of the elasticity-based method discussed below. The short-term elasticities can be used as a reasonableness check for model no build versus build comparisons. Scenario analysis can also be used to isolate some of the long-term induced vehicle travel effects to verify the reasonableness of model forecasts. For any of these checks, the analyst should clearly identify whether the elasticity method is being used to predict total VMT attributable to the project or select types of VMT such as that associated with induced household driving versus commercial driving.

Approach #2: Elasticity Method

Given the limitation of a travel demand model in estimating long-term induced vehicle travel effects, the empirical-based NCST Induced Travel Calculator, or directly using elasticities, is another way to generate the long-term induced vehicle travel effects on VMT. However, whether to use the full elasticity is an important question given the information presented above about the individual sources of induced VMT that were attributed to lane mile increases. Appendix A offers an alternative elasticity approach that has been designed to address noted limitations of the NCST calculator.

The online NCST Calculator uses the following standard formula based on published research to estimate VMT attributable to a project (induced VMT):

> *Project-Induced VMT = [%Δ Lane Miles] x [Baseline VMT] x [Elasticity]*
> where,
> %Δ Lane Miles = The increase of lane miles expressed as a percentage of the total lane miles in the study area (i.e., MSA or County as noted above). This must be a positive number.

The benefit of an elasticity-based method is that it requires little effort, however it has the limitations noted in the previous section and expanded upon in Appendix A. Relying on this method alone may not provide a complete picture of potential VMT effects and may over- or under-estimate the impact of induced vehicle travel by not accounting for other factors contributing to long-term traffic increases.

Approach #3: Hybrid Method

A hybrid method is to integrate both the model and elasticity methods. This approach allows the same land uses for all alternatives but would acknowledge the limitation of using fixed land use inputs. Notably, the discussion would describe which alternative the land use forecasts best reflect and how the accessibility differences between the alternatives could affect the allocation of future growth. The model will be used to forecast the short-term induced travel effect for the build condition of project alternatives, while the NCST calculator is used to forecast long-term VMT effects of the project build alternatives. The details of this method are listed below:

Step 1: The travel demand model will be used to generate volume forecasts and VMT information for no build and build alternatives with a fixed set of land use forecasts.

- The agency that developed the land use forecasts will inform the analyst whether these land use forecasts represent the build or no build condition.
    - Typically, project development and environmental impact analysis is only performed on projects that have already been included in a regional transportation plan, so typical MPO or RTPA land use forecasts are most likely to represent build conditions.
- The environmental document will disclose the limitations of the model with an acknowledgement that the actual land use will likely differ among alternatives. If feasible, the analyst can qualitatively explain how the project could affect land use and what the likely outcome would be in terms of the direction of change with respect vehicle trips and VMT. This could include how the project alternatives could affect the allocation of future growth, whether that reallocation would place additional growth in locations likely to generate higher or lower levels of VMT per capita, and whether the project will increase regional growth totals and VMT or just the regional distribution of the overall growth.
- The model will generate short-term (1-2 year) induced vehicle travel effects for each of build alternatives.
    - For base year and opening year with project scenarios, the Home-based Work and Home-based University/School trips should be held constant as in the corresponding no build scenarios, because the work and university/school locations will not change immediately upon the opening of the project to traffic.

Step 2: For the environmental document, the NCST Induced Travel Calculator, or directly the long-term elasticities, will be employed to generate the long-term induced travel effect for VMT.

- If multiple alternatives are involved, the NCST Calculator, or directly the long-term elasticities, will be used to generate the long-term induced travel for the "Base" Build Alternative, e.g., the GP alternative, or the HOV alternative if the GP alternative is not available. The VMT attributable to the project should be separated into the categories noted above from the Duranton research and disclosed so reviewers understand that some of the induced VMT is directly related to the economic benefits that are likely part of the purpose and need justification for the project. Refer to Appendix A for more details.

- For the other build alternatives not appropriate for the NCST Calculator, a pivot method may be used to estimate their long-term induced travel effect for VMT. HOT or full toll lanes are expected to have a dampened level of induced VMT due to the higher costs of travel in these lanes. The travel model can provide the relative percentage differences in VMT between each alternative. These percentages can be applied to the NCST Calculator VMT forecast for the "Base" Build Alternative.
  - The model and the NCST induced VMT forecasts can be reported as a range, and the environmental assessment could be based on the VMT forecast that is best suited to the specific corridor context given the documented limitations of each method above. For example, the NCST Calculator should probably not be used for bridge projects as it will systematically overestimate VMT associated with new bridge lane miles.

For Caltrans projects, this method should be reviewed with Caltrans staff prior to application given the TAF recommendations and the potential for the TAF to continuously be updated as new information and research is published. Analysts will need to consider that the induced vehicle effects not captured by the travel demand model could influence the peak hour design volumes used in traffic operations analysis and the VMT by speed bin estimates used for emissions analysis. At a minimum, these limitations will be acknowledged and disclosed in the environmental documents.

APPENDIX A

Justification for Using Alternate Elasticities

The NCST and guidelines from OPR and CARB recommend applying a long-run elasticity of 1.0 to evaluate the induced travel impacts of capacity expansion projects on interstate freeways and an elasticity of 0.75 for FHWA class 2 or 3 facilities. The 1.0 elasticity is subject to change over time as new research relies on more recent data and improved analytical methods. Further, it does not isolate the amount of automobile VMT that is induced. While the OPR Technical Advisory accepts the use of total VMT, Section 15064.3(a) of the CEQA Guidelines specifies, "For the purposes of this section, "vehicle miles traveled" refers to the amount and distance of automobile travel attributable to a project."

The argument that added capacity always produces added traffic does not apply in all cases nor is the effect size always constant. This is especially true if congestion is not present under baseline conditions or if anticipated corridor growth, over time, consumes the added capacity and suppresses the induced effect. CEQA is intended to disclose impacts of discretionary decisions without 'speculating' and by 'intelligently' accounting for effects.[8] Use of the elasticity method or a travel demand model will come with a variety of limitations as explained above and neither method is likely to serve all the environmental impact analysis requirements. Therefore, the analyst will need to acknowledge and address the known limitations with either method.

For the elasticity method, individual projects and their local context may differ from the larger national MSA data set used to estimate the elasticity values. Practitioners should be particularly aware that the elasticity method is not capable of producing a negative result and that effect size does not vary by context, only by functional classification. An example of the first limitation is that some roadway capacity expansion projects such as bridges could reduce baseline or existing VMT because they may substantially reduce existing trip lengths. The lack of local context sensitivity may contribute to over- or under-estimates of VMT effects since the research derived elasticities represent an average from a large group of data (i.e., all MSAs in the U.S.).

So, to responsibly examine the induced travel phenomenon, analysts need to consider the counterfactual: what would have happened if capacity was not added? Travel demand models help address this question more directly and should not be ignored in favor of the elasticity method. In this sense, the two methods

---

[8] CEQA Guidelines Section 15151 – *An EIR should be prepared with a sufficient degree of analysis to provide decision makers with information which enables them to make a decision which intelligently takes account of environmental consequences.*

CEQA Guidelines Section 15187(d) – *The environmental analysis shall take into account a reasonable range of environmental, economic, and technical factors, population and geographic areas, and specific sites. The agency may utilize numerical ranges and averages where specific data is not available, but is not required to, nor should it, engage in speculation or conjecture.*

can be treated as complementary. Analysts can also rely on the Duranton and Cervero studies cited above to provide some perspective on this question as well as the Mokhtarian study.

Duranton investigates the various components of traffic growth that occur on interstate freeways when capacity is added to distinguish the amount that occurs from other major factors such as population growth and socioeconomic changes. It is a comprehensive study across all US MSAs, and it concludes that the potential sources of traffic growth that occur following capacity expansion consist of the following four categories.

- Changes in commercial driving = 19 to 29%
- Changes in individual or household driving = 9 to 39%
- Changes in population (includes population growth and migration) = 5 to 21%
- Diversion of traffic = 0 to 10%

From this accounting, the elasticity specific to automobile VMT change ranges from 0.39 to 0.70 using the high end of the ranges above. The 0.39 elasticity captures automobile VMT from increased individual or household driving while changes in population and traffic routing could add to this value. Population migration effects would be the result of the economic benefits of capacity expansion. Basically, more people moved to the area and more economic activity occurred. These people and this economic activity would have occurred elsewhere so the VMT associated with these categories may or may not be 'new' depending on the specific environmental effects under consideration and the scale of the analysis. For air quality analysis, this VMT will be new to the study area and result in higher emissions compared to no build conditions.

At a scale bigger than the MSA, the effect of induced vehicle travel may not produce 'new' VMT compared to what would have occurred otherwise. The same population and employment growth will occur when considering a large enough scale such as an MPO or state boundary. Within this larger area, roadway capacity expansion improvements to accessibility generally change the allocation of population and employment growth within the region and not the absolute amount. Where that growth is attracted from may have higher or lower VMT generation rates. This is where context matters. If the growth is attracted from a low VMT generating area to a higher one, then the net effect would be an increase in VMT attributable to the project. The reverse could also occur. Unfortunately, predicting where the growth would come from requires a land use allocation model, which is not commonly available. If this type of model is available, it should be used to assess this effect more fully. Without the land use model, an analyst is limited to accepting the potential increase from population change as a net increase in VMT attributable to the project, which would add 0.21 to the 0.39 starting elasticity for automobile VMT for a value of 0.60.

For diversion effects, if traffic shifts from local roads that were being used to bypass freeway congestion, then the diversion effect likely reduces trip distances and results in drivers selecting more suitable facilities. The new route will offer shorter distances, smoother traffic flows for more hours of the day, and lower emissions per mile. This result is likely what explains the potential for traffic diversion to have a 0% contribution the induced VMT effect. A travel demand model that is appropriately calibrated and validated (see discussion above and Appendix B) should be sensitive the diversion effect especially if the model uses dynamic traffic assignment. Running the assignment only portion of the model can isolate the project's expected effect on VMT largely due to path or route changes. This result can help inform whether the long-term induced vehicle travel elasticity for automobile VMT should be held at 0.60 or increased up to 0.70. Use of 0.70 value would presume that commercial driving effects have all been isolated separately per the accounting presented above.

Cervero modeled the two-way relationship between road supply (as measured in terms of improved travel times) and travel demand considering latent demand, mode shifts, changes in destination choice, route switching, and induced land development resulting from 24 California freeway expansion projects. The basic finding of the research as stated as, "…while about 80 percent of added road capacity was absorbed by demand induced by rising speeds and building activity, less than half (39%) of this absorption can be attributed to lane-mile additions." The findings on the proportions of traffic occurring concurrently with or after the addition of capacity were:

- Ambient changes unrelated to the added capacity = 40%
- Reserve capacity available for future growth = 20%
- Induced demand = 40%
    - Land use shifts = 9%
    - Behavioral shifts = 31%

This proportions above are not directly comparable to Duranton because the nature of the research question differs. Cervero accounts for how new road capacity is consumed over time. Duranton sought to explain how much induced VMT is attributable to new lane miles. One way to align the studies is to accept that Duranton captured the induced VMT effect and then check the accounting of the contributing factors.[9] Table A-1 below shows this comparison.

[9] We have previously debated whether Cervero and Duranton are directly comparable elasticity values and attempted to obtain input from the Duranton on this and related questions. Duranton indicated that additional analysis would be required to answer these questions, which was beyond his availability.

Table A-1
Sources of Induced VMT Following Capacity Expansions

Induced VMT Components	Percent of Induced VMT Attributable to Component	
	Duranton	Cervero
Land Use Change (Attracted growth from accessibility improvement)	21%	23%
Behavioral Change (Passenger and commercial driving)	78%	77%

This comparison suggests general alignment in the contribution to induced VMT but is subject to further review and investigation. Presuming behavioral change stands as the largest contributor, analysts focused on induced VMT impacts and mitigation should consider that individual or household related driving is most subject to influence. In other words, commercial driving that makes up about 29 percent of the 1.0 elasticity found in Duranton is not likely subject to much change. Individual driving that makes up about 39 percent of the 1.0 elasticity is the largest single contributor. Individual drivers tend to be the most sensitive to the cost and convenience of driving, which directly influences baseline VMT levels and the potential effectiveness of mitigation actions.

This information also suggests that impact analysis focusing on automobile VMT should start with a long-term elasticity of 0.39 and then determine if sufficient evidence exists to increase this value to account for changes in population and traffic diversion.

APPENDIX B

Dynamic Validation Example

FEHR & PEERS

TECHNICAL MEMORANDUM

Date: 8/26/2020

To: Brian Smolke, Anup Kulkarni, OCTA

From: Jinghua Xu, Ph.D., PE, and Ron Milam, AICP, PTP, Fehr & Peers

Subject: Orange County Transportation Analysis Model Assessment and Induced Vehicle Travel Estimation

The purpose of this memorandum is to provide an assessment of the Orange County Transportation Analysis Model (OCTAM) to perform CEQA transportation impact analysis. This document describes the criteria that can be used to assess travel forecasting model suitability to generate VMT forecasts for CEQA analysis and the general outcomes of applying that criteria to OCTAM in the Orange County region.

Following the criteria, a series of model tests have been performed to evaluate the model's sensitivity to VMT effects, targeting how the model responds to changes in land use and transportation inputs. Based on the findings from the model tests, recommended steps are provided to improve OCTAM for CEQA and SB 743 compliance.

ASSESSMENT CRITERIA BASED ON CEQA EXPECTATIONS

The intent of developing the criteria and performing the model assessment is to help OCTA understand the potential 'benchmarks' that could be used to assess model suitability for CEQA compliance.

CEQA compliance has two basic elements. One, is the legal risk of challenge associated with inadequately analyzing impacts due to use of models that do not meet benchmark expectations. Two, is the mitigation risk of mis-identifying the impact and the mitigation strategies to reduce the impact. Agencies with a high risk of legal challenges will likely be concerned about both elements while agencies with less legal risk should still be concerned about the second element since it is also relevant for all other transportation analysis based on model forecasts.

The CEQA Guidelines contain clear expectations for environmental analysis as noted below; however, the Guidelines are silent about what data, analysis methods, models, and mitigation approaches are adequate for transportation impacts.

CEQA Guidelines – Expectations for Environmental Impact Analysis

§ 15003 (F) = fullest possible protection of the environment…

§ 15003 (I) = adequacy, completeness, and good-faith effort at full disclosure…

§ 15125 (C) = EIR must demonstrate that the significant environmental impacts of the proposed project were adequately investigated…

§ 15144 = an agency must use its best efforts to find out and disclose…

§ 15151 = sufficient analysis to allow a decision which intelligently takes account of environmental consequences…

All of these suggest accuracy is important and have largely been recognized by the courts as the context for judging an adequate analysis. So, then what is the basis for determining adequacy, completeness, and a good faith effort when it comes to forecasting and transportation impact analysis? A review of relevant court cases suggests the following conclusions.

- CEQA does not require the use of any specific methodology. Agencies must have substantial evidence to support their significance conclusions. (Association of Irritated Residents v. County of Madera (2003) 107 Cal.App.4th 1383.)
- CEQA does not require a lead agency to conduct every test or perform all research, study, and experimentation recommended or demanded by commenters. (CEQA Guidelines, § 15204, subd. (a))
- CEQA does not require perfection in an EIR but rather adequacy, completeness and a good faith effort at full disclosure while including sufficient detail to enable those who did not participate in the EIR preparation to understand and consider meaningfully the issues raised by the project. (Kings County Farm Bureau v. City of Hanford (1990) 221 Cal.App.3d 692)
- Lead agencies should not use scientifically outdated information in assessing the significance of impacts. (Berkeley Keep Jets Over the Bay Comm. v. Board of Port Comm. (2001) 91 Cal.App.4th 1344.)
- Impact analysis should improve as more and better data becomes available and as scientific knowledge evolves. (Cleveland National Forest Foundation v. San Diego Association of Governments, Cal. Supreme Ct. S223603, 2017).

These conclusions tend to reinforce the basic tenet of CEQA that requires having substantial evidence to support all aspects of the impact analysis and related decisions. Further, analysis should produce accurate and meaningful results. This expectation is grounded in the basic purpose behind environmental regulations like CEQA that attempt to accurately identify and disclose potential impacts and to develop effective mitigation. Having accurate and reliable travel forecasts is essential for meeting these expectations.

In setting specific CEQA expectations for travel forecasting models, an important consideration is that expectations may vary based on the variety of factors listed below.

- Complexity of the transportation network and number of operating modes
- Available data
- Urban versus rural setting
- Planned changes in the transportation network (particularly to major roads or transit systems)
- Availability of resources to develop and apply travel demand models
- Population and employment levels
- Congestion levels
- Regulatory requirements
- Types of technical and policy questions posed by decision makers
- Desired level of confidence in the analysis findings
- Anticipated level of legal scrutiny

In California, travel forecasts are generated using various forms of models that range from simple spreadsheets based on historic traffic growth trends to complex computer models that account for numerous factors that influence travel demand. According to *Transportation and Land Development*, 2nd Edition, ITE, 2002, the appropriate model depends on the size of the development project and its ability to affect the surrounding area. As projects increase in size, the likelihood of needing a complex model (such as a four-step model) increases because of the number of variables that influence travel demand and transportation network operations. The study area can also influence the type of model needed especially if congestion occurs or if multiple transportation modes operate in the study area. Either of these conditions requires robust models that can account for the myriad of travel demand responses that can occur from land use or transportation network changes.

The other relevant national guidance on model applications and forecasting is the *NCHRP Report 765, Analytical Travel Forecasting Approaches for Project-Level Planning and Design*, Transportation Research Board, 2014. This is a detailed resource with many applicable sections. A few direct excerpts worth noting about forecasting expectations for models are listed below.

- *A travel forecasting model should be sensitive to those policies and project alternatives that the model is expected to help evaluate.*
- *A travel forecasting model should be capable of satisfying validation standards that are appropriate to the application.*
- *Project-level travel forecasts, to the extent that they follow a conventional travel model, should be validated following the guidelines of the Travel Model Validation and Reasonableness Checking Manual, Second Edition from FHWA. Similar guidelines are provided in NCHRP Report 716. This level of validation is necessary, but not sufficient, for project-level forecasts. Project-level forecasts often require better accuracy than can be obtained from a travel model alone.*
- *The model should be subject to frequent recalibrations to ensure that validation standards are continuously met.*

MODEL ASSESSMENT

The information above was used as the basis for developing specific questions that could be used to assess OCTAM. These questions are organized into two components. The first component considers model ownership and maintenance and the second component assesses model conditions and performance against select criteria from the guidance material above.

Model Ownership and Maintenance Assessment

Public agencies that develop travel forecasting models for planning and impact analysis must maintain those models and frequently update and recalibrate them as explained above to ensure they remain accurate and dependable for generating travel demand forecasts. To assess the status of model ownership and maintenance, agencies were asked about their control of the following model components.

- Model documentation – Does the agency have the model development documentation and any related user guidance?
- Model files – Does the agency maintain the model input and output files?
- Model distribution – Does the agency control the distribution of the model files to users?

The specific assessment for OCTAM is shown in **Table 1** below.

Table 1: Agency Control of OCTAM

Model	Documentation	Files	Distribution
OCTAM	Yes	Yes	Yes

Assessment

Based on the CEQA Guidelines, the following specific criteria are developed to assess OCTAM performance. The criteria that are unique to SB 743 are highlighted in bold text.

- Model documentation – this criterion relies on the availability of documentation about the model's development including its estimation, calibration, and validation as well as a user's guide.
- Completed calibration and validation within the past 5 years – recent calibration and validation is essential for ensuring the model accurately captures evolving changes in travel behavior. Per NCHRP Report 765, "The model should be subject to frequent recalibrations to ensure that validation standards are continuously met."
- Demonstrated sensitivity to VMT effects across demographic, land use, and multimodal network changes – validation reporting will be checked for static and dynamic tests per the *2017 Regional Transportation Plan Guidelines for Metropolitan Transportation Planning Organizations*, CTC, 2017 and *Travel Model Validation and Reasonableness Checking Manual, Second Edition*, TMIP, FHWA, 2010.
- Capable of producing both "project-generated VMT" and "project effect on VMT" estimates for households, home-based trips, and total trips – both metrics are essential for complete VMT analysis. Project-generated VMT is useful for understanding the VMT associated with the trips traveling to/from a project site. The 'project's effect on VMT' is more essential for understanding the full influence of the project since it can alter the VMT generation of neighboring land uses.
- **Capable of producing regional, jurisdictional, and project-scale VMT estimates –** VMT analysis for air quality, greenhouse gases, energy, and transportation impacts requires comparisons to thresholds at varying scales. For SB 743, the *Technical Advisory on Evaluating Transportation Impacts in CEQA*, December 2018, California Governor's Office of Planning and Research (OPR) recommends thresholds based on comparisons to regional or city-wide averages.
- **Level of VMT estimates that truncate trip lengths at model or political boundaries** – The OPR Technical Advisory states that lead agencies should not truncate any VMT analysis because of jurisdictional or model boundaries. The intent of this recommendation is to ensure that VMT forecasts provide a full accounting of project effects.

The specific assessment findings for the OCTAM v5 are contained in **Table 2** on the following page.

Table 2: Assessment Summary of OCTAM

Screening Check	Screening Determination	Notes
Model documentation	The User's Guide and Validation Report are currently available for OCTAM v5.	The documentation is available upon request. The validation report includes detailed model structure for the overall model and individual model steps, and validation results. However model estimation and calibration information are not included. The current user's guide is currently under update to include the guidance on how to use the VMT tool, which is developed to generate VMT metrics compliant to SB 743.
Completed calibration and validation within the past 5 years	Yes - OCTAM v5 calibrated and validated to 2016	
Demonstrated sensitivity to VMT effects across demographic, land use, and multimodal network changes	No evidence of formal sensitivity testing in model documentation. Limited sensitivity tests have been performed as part of this project and documented in the next section in this Memo.	As revealed from the sensitivity test results in the next section, the model has limited sensitivity to some built environment characteristics such as density, uses fixed internal-external (IX) and external-internal (XI) trip tables, and produces variation in outputs for transportation projects that is due to the model algorithms (e.g., assignment convergence) and not due to the influence of the project under analysis. A more complete dynamic validation of the model is recommended.
Capable of producing both "project-generated VMT" and "project effect on VMT" estimates for households, home-based trips, and total trips.	Project-generated VMT – yes Project effect on VMT – yes Total VMT – yes Household VMT – no Home-based VMT – yes	As a four-step TDM, OCTAM cannot track households of the estimated trips.
Capable of producing regional, jurisdictional, and project-scale VMT estimates.	Regional VMT - yes Jurisdictional VMT - yes Project-scale VMT - uncertain	Scale of model may be too large for some project level applications. Verification of model sensitivity in project area required along with potential project scale refinements.
Level of VMT estimates that truncate trip lengths at model or political boundaries.	Depends on TAZ location.	The model includes the entire Orange County, Los Angeles County, Ventura County and part of Riverside County and San Bernardino County, but truncates trips leaving this area. TAZs central to the region will tend to have less truncation than TAZs at the model border.

DYNAMIC VALIDATION TESTS

One of the key potential limitations of OCTAM was the lack of demonstrated sensitivity to VMT effects. To be demonstrated, sensitivity must be measured through dynamic validation tests, which are also referred to as reasonableness checks. These tests measure the model's VMT output responses to input changes related to land use and the transportation network. These tests can, and should, be prepared for any output metrics that are used in a significant way for project applications.

To address the VMT sensitivity question, the model assessment included a series of dynamic validation tests. The results of these tests are explained in the next section and provide a direct measurement of OCTAM's sensitivity to VMT effects. In addition to the test results, this section provides information about potential improvements to strengthen the model's suitability for future CEQA purposes. This information does not indicate that previous applications of the model were not appropriate.

Test #1: Built Environment Sensitivity for Land Use Projects

One of the major project types that have been affected the most by SB 743 is land use projects. In this test, dwelling units and employment are increased incrementally to analyze how the trip production/attraction (PA) and VMT react. As density increases, research reveals that VMT per capita or per employee declines.

Table 3 lists the change in trip PAs and VMT by incrementally adding number of dwelling units in TAZ 869 in the order of 1, 100, 500, 1,000 and 5,000. Similarly, **Table 4** shows the results for a retail project, by increasing employment to TAZ 1206 in the same incremental order. Key findings from the test results are summarized below.

- Trip PA rates are relatively stable with incrementally increased dwelling units and employments. PA rates reflect person trips, which are expected to increase with more development. However, the VMT effects reveal that VMT per capita increases too. This result is inconsistent with academic research that shows VMT per capita declines when residential density increases (see *Impacts of Residential Density on Passenger Vehicle Use and Greenhouse Gas Emissions, Policy Brief,* California Air Resources Board, September 2014).
- Trip PAs change significantly before and after PA balancing, especially on the attraction side when adding large amounts of dwelling units or employment.

  If only adding dwelling units or only adding employments, which generates more on one trip end, the housing-employment relationship will become out of balance in the model. After balancing trip PAs at the end of the trip generation step, the resulting trip PAs may not be reasonable.

  Note that the PA balancing procedure is mainly designed to reconcile the discrepancy due to the different models used to estimate trip production and attraction, but not designed to resolve the inconsistency of the PAs due to the unbalanced housing-employment relationship.

Table 3: Trip Generation and VMT Metrics for Residential Project Test

Scenario	TAZ	HH	Balanced Person Trips		Balanced Person Trip Prod./HH	Unbalanced Person Trips		Unbalanced Person Trip Prod./HH	VMT	
			Production	Attraction		Production	Attraction		Total VMT/SP	Home-Based VMT/Capita
Base Year - Original	869	1,044	9,674	2,676	9.3	9,615	2,029	9.2	25.53	19.69
Base Year - Add 1 DU	869	1,045	9,683	2,677	9.3	9,624	2,030	9.2	25.53	19.70
Base Year - Add 100 DU	869	1,144	10,575	2,830	9.2	10,509	2,142	9.2	25.30	19.70
Base Year - Add 500 DU	869	1,544	14,176	3,448	9.2	14,086	2,598	9.1	24.67	19.75
Base Year - Add 1,000 DU	869	2,044	18,679	4,221	9.1	18,557	3,167	9.1		
Base Year - Add 5,000 DU	869	6,044	54,729	10,426	9.1	54,363	7,719	9.0		

Table 4: Trip Generation and VMT Metrics for Commercial Project Test

Scenario	TAZ	TOT EMP	Balanced Person Trips		Balanced Person Trip Attr./EMP	Unbalanced Person Trips		Unbalanced Person Trip Attr./EMP	VMT	
			Production	Attraction		Production	Attraction		Total VMT/SP	Home-Based Work (HBW) VMT/Emp
Base Year - Original	1206	87	525	1,443	16.6	401	1,026	11.8	102.12	23.91
Base Year - Add 1 Retail Emp	1206	88	532	1,460	16.6	406	1,038	11.8	102.19	23.95
Base Year - Add 100 Retail Emp	1206	187	1,149	3,133	16.8	875	2,223	11.9	102.08	23.85
Base Year - Add 500 Retail Emp	1206	587	3,641	9,884	16.8	2,773	7,010	11.9	101.05	23.77
Base Year - Add 1,000 Retail Emp	1206	1,087	6,750	18,305	16.8	5,146	12,994	12.0		
Base Year - Add 5,000 Retail Emp	1206	5,087	31,420	84,959	16.7	24,126	60,866	12.0		

- VMT metrics show different trends with the change in land use.

  As noted above, the residential project tests revealed that the model's VMT per capita output moved in the wrong direction. In commercial land use tests, total VMT per service population (SP) shows a similar trend to home-based work (HBW) VMT per employee. This is because the TAZ selected for the test does not have any dwelling units but only employment, which means there is no home-based (HB) productions but only non-home-based (NHB) productions and the attractions for all the purposes. In addition, the total VMT per SP is much larger than HBW VMT per employee because total VMT per SP includes all the trip purposes in addition to HBW [e.g., home-based shopping (HBSh), home-based other (HBO) and non-home based (NHB)]. Note that in OCTAM, where one retail employee would attract 3.47 HBSh trips, 4.30 other-based other (OBO) trips, and multiple trips for other purposes, total VMT per SP includes the VMT directly made by employees in the TAZ, and also the indirect VMT generated by customers and visitors.

Test #2: Induced Travel for Roadway Expansion Projects

Roadway expansion projects are another major project type affected significantly by SB 743. For this project type, the major challenge is how to account for induced vehicle travel effects as part of the VMT forecasts.

In this test, the project is to widen I-405 between SR-73 and SR-22 by adding one general-purpose (GP) lane each direction. This project would add a total of 19.74 lane-miles. The following four test runs are done to investigate how each model step reacts to the network change associated with the project, compared to the Baseline.

- Full Run: to run the entire 12-feedback loops for the Baseline plus project
- Assignment Only Run: assign the Baseline vehicle trip table to the network with project
- Mode Choice Only Run: run the mode choice step using the person trip tables from the Baseline while using the network related model files from Baseline plus project
- Distribution Only Run: run the trip distribution step using the PA tables from the Baseline while using the network related model files from Baseline plus project

The test results are summarized for region-wide and for the area within the 2-mile buffer of the project, as in **Table 5** and **Table 6** respectively. Key findings are summarized below.

- Academic research (see *Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions, Policy Brief*, California Air Resources Board, September 2014) reveals an elasticity of 0.10 to 0.60 for short-term induced VMT with respect to a change in lane miles. This type of short-term change can be used to assess model results that compare no build to build alternatives. The results in Table 4 for the 'boundary VMT' show the full model run produced an increase in VMT similar to the short-term range in the academic literature. The assignment only run revealed a reduction in VMT, which may be reasonable if congestion in the no build alternative was causing longer distance routes to avoid congestion.

- Person trips remain the same across all the four test runs region-wide, while have nominal variation within the 2-mile buffer area of the project. Note that in OCTAM, trip generation including auto ownership module is not included in feedback loops, therefore there is no change in PAs, which indicates no induced travel in trip generation due to this project. This is a limitation of the model and raises questions about whether other components of the model are too sensitive to roadway capacity expansion given the boundary VMT results discussed above.

  Figure 1 shows the trip length frequency of person trips and **Table 7** lists average person trip length out of trip distribution, for the Baseline, Baseline plus project Full Run, and the Distribution Only Run, for region-wide and for area within 2-mile buffer area respectively. The trip length frequency is significantly different between region-wide and area within 2-mile buffer, however the difference across these test runs is negligible within the same geographic area. The average person trip length is slightly longer in the test runs with project than in the Baseline, and longer within 2-mile buffer area than region-wide, while between the two test runs, the average trip lengths are close.

- Total number of vehicle trips region-wide decreases slightly in both Baseline with project Full Run and the Mode Choice Only Run, compared to the Baseline, though the Mode Choice Only Run has less reduction than the Full Run. Within the 2-mile buffer of the project, the total number of vehicle trips increases in these two test runs. Therefore, with more lane-miles, vehicle trips increase in the area close to the project, while reducing region-wide. Vehicle trips are expected to increase in both areas.

- Figure 2 shows the volume difference between the test runs with project and the Baseline. In the Assignment Only Run, given the vehicle trip tables are the same as in the Baseline while the only difference is the project in the network, the roadways with significant volume change are mainly those involved in the path change due to the project, especially for the project segment on I-405 between SR-73 and SR-22 with significant volume increase due to the additional GP lanes.. However, substantial changes in volumes (both increases and decreases) occur many miles away from the project site (e.g., CA-14 in north Los Angeles County) that are unexpected. This result was exacerbated in the Full Model Run. This type of result was investigated further (see Test #3 below) to determine what specific aspect of the model was contributing to this large variation so far away from the project site.

Table 5: Region-wide Summary for a Roadway Expansion Project – Adding One GP Lane on I-405 between SR-73 and SR-22

Scenario	Person Trips			Vehicle Trips					Boundary VMT					Average Vehicle Trip Length				
	PK	OP	Daily	AM	MD	PM	NT	Daily	AM	MD	PM	NT	Daily	AM	MD	PM	NT	Daily
Baseline	39,614,099	37,987,134	77,601,233	9,583,760	14,852,503	15,213,066	8,677,346	48,326,674	97,088,734	123,230,125	134,266,672	83,621,293	438,206,824	10.131	8.297	8.826	9.637	9.068
Baseline w/ Project - Full Run	39,614,099	37,987,134	77,601,233	9,583,001	14,852,529	15,211,728	8,677,359	48,324,617	97,135,368	123,223,528	134,379,849	83,601,042	438,339,787	10.136	8.296	8.834	9.634	9.071
Baseline w/ Project - Assign Only	39,614,099	37,987,134	77,601,233	9,583,760	14,852,503	15,213,066	8,677,346	48,326,674	97,038,142	123,233,843	134,229,348	83,622,797	438,124,131	10.125	8.297	8.823	9.637	9.066
Baseline w/ Project - Mode Choice Only	39,614,099	37,987,134	77,601,233	9,583,359	14,852,522	15,212,388	8,677,376	48,325,645										
Baseline w/ Project - Distribution Only	39,614,099	37,987,134	77,601,233															
Elasticity with respect to Lane-Miles	**Baseline w/ Project - Full Run**							**-0.0903**					**0.6434**					**0.7337**
	Baseline w/ Project - Assign Only												**-0.4001**					**-0.4001**
	Baseline w/ Project - Mode Choice Only							**-0.0451**										

Table 6: Summary within 2-mile of Buffer Area for a Roadway Expansion Project – Adding One GP Lane on I-405 between SR-73 and SR-22

Scenario	Person Trips			Vehicle Trips					Boundary VMT					OD VMT					Average Vehicle Trip Length				
	PK	OP	Daily	AM	MD	PM	NT	Daily	AM	MD	PM	NT	Daily	AM	MD	PM	NT	Daily	AM	MD	PM	NT	Daily
Baseline	1,795,522	1,637,241	3,432,763	475,180	655,289	718,081	389,457	2,238,007	1,778,297	1,928,638	2,420,974	1,316,706	7,444,614	4,653,226	4,881,070	6,093,855	3,474,621	19,102,772	9.793	7.449	8.486	8.922	8.536
Baseline w/ Project - Full Run	1,795,493	1,637,312	3,432,805	475,338	655,357	718,251	389,483	2,238,430	1,810,602	1,943,117	2,465,550	1,320,864	7,540,133	4,672,402	4,885,935	6,126,692	3,477,219	19,162,248	9.830	7.455	8.530	8.928	8.561
Baseline w/ Project - Assign Only	1,795,522	1,637,241	3,432,763	475,180	655,289	718,081	389,457	2,238,007	1,796,879	1,938,683	2,446,176	1,317,873	7,499,611	4,643,461	4,881,297	6,088,015	3,474,642	19,087,415	9.772	7.449	8.478	8.922	8.529
Baseline w/ Project - Mode Choice Only	1,795,522	1,637,241	3,432,763	475,381	655,297	718,330	389,462	2,238,471															
Baseline w/ Project - Distribution Only	1,795,489	1,637,313	3,432,802																				
Elasticity with respect to Lane-Miles	**Baseline w/ Project - Full Run**							**0.0104**					**0.7063**					**0.1714**					**0.1610**
	Baseline w/ Project - Assign Only												**0.4067**					**-0.0443**					**-0.0443**
	Baseline w/ Project - Mode Choice Only							**0.0114**															

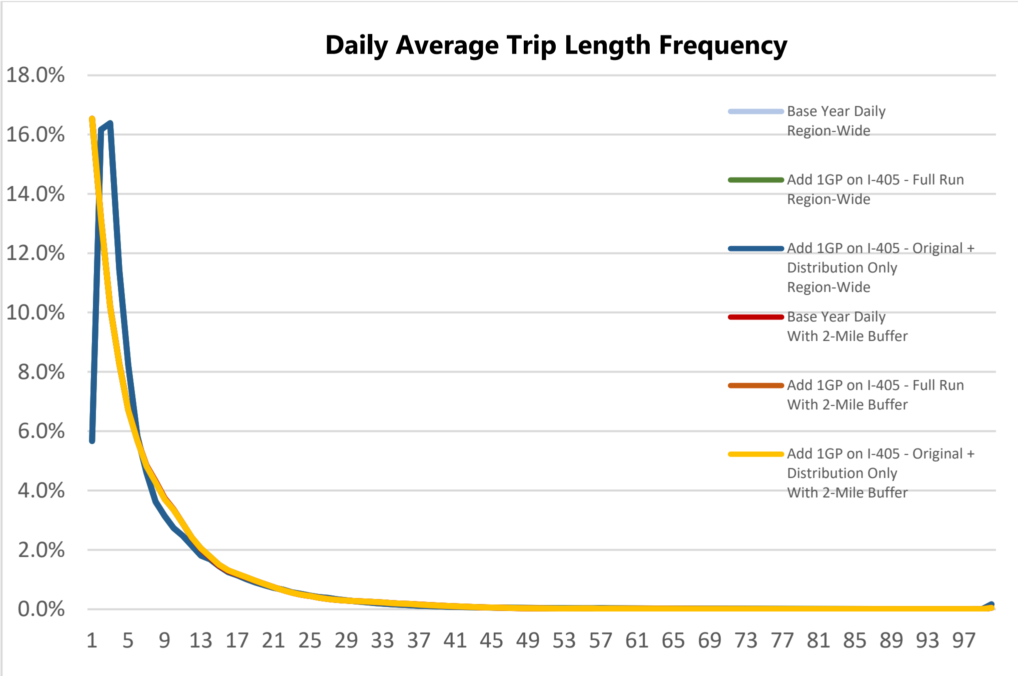


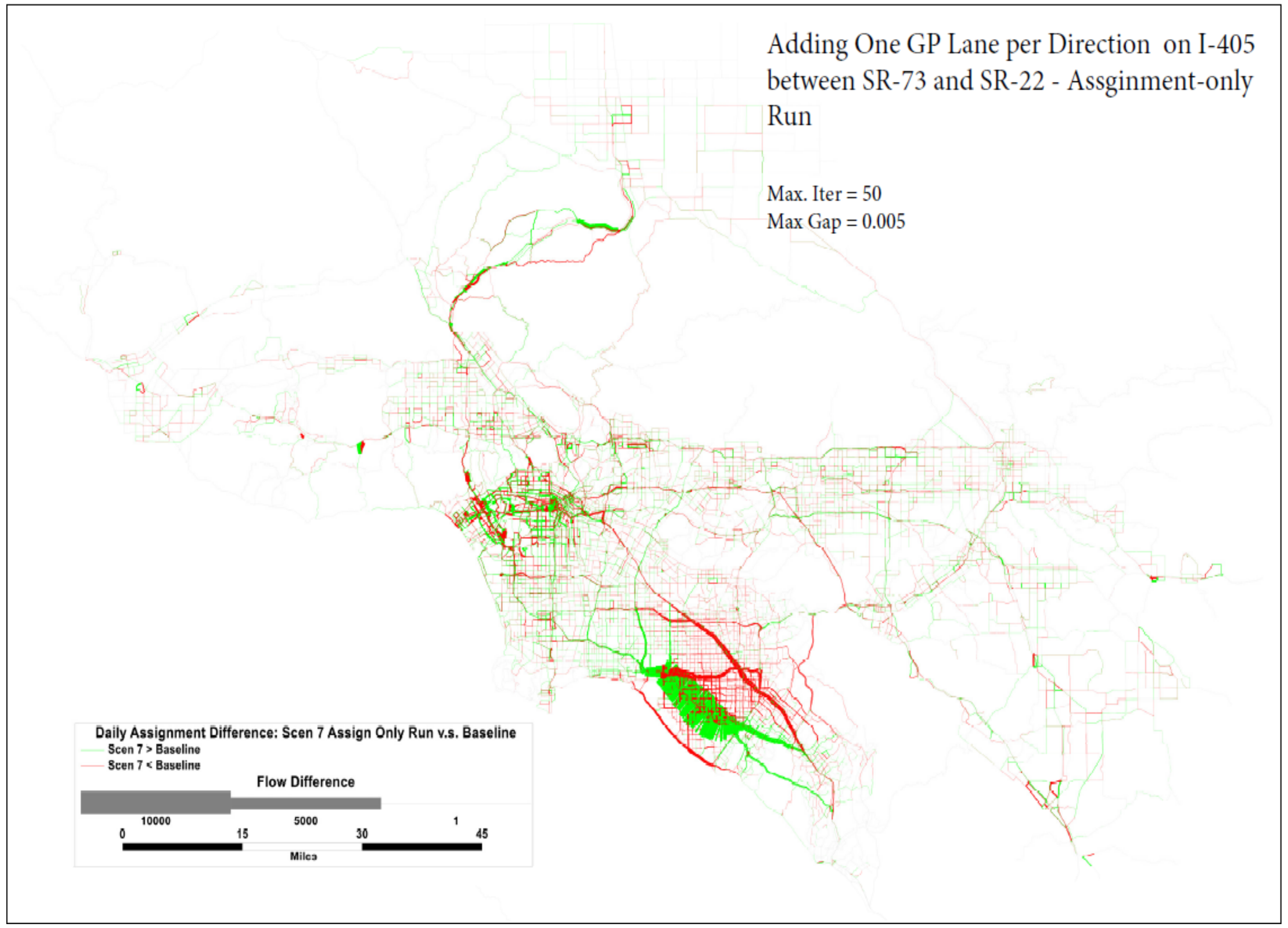
Figure 1: Daily Average Trip Length Frequency – Roadway Expansion Test

Table 7: Average Person Trip Length – Roadway Expansion Test

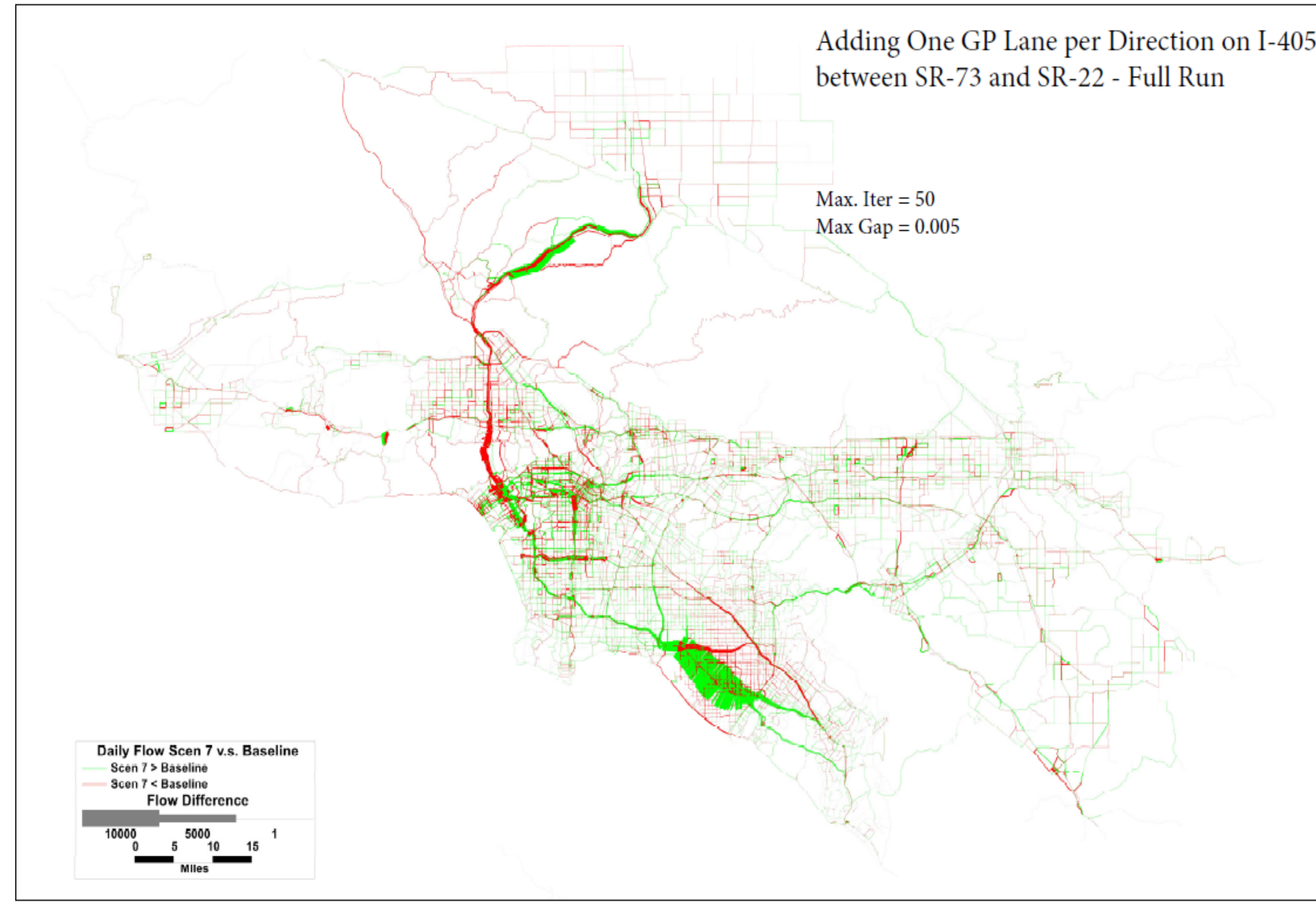
Scenario	Average Person Trip Length	
	Region-wide	2-Mile Buffer
Baseline	7.429	7.671
Baseline w/ Project - Full Run	7.438	7.686
Baseline w/ Project - Distribution Only	7.438	7.686

Figure 2: Volume Difference Plots – Baseline plus Project vs. Baseline Full Run

(Adding One GP Lane each Direction on I-405 between SR-73 and SR-22)



(a) Assignment Only Run vs. Baseline



(b) Baseline plus Project Full Run vs. Baseline

Test #3: Assignment Criteria Check

Trip assignment is an iterative process where the model evaluates all the paths between each origin-destination (OD) pair to find the shortest path. This process continues until reaching a stopping criterion intended to indicate that no further shorter paths can be found. The major parameters to control the convergence level in the OCTAM assignment procedure are (1) maximum relative gap, and (2) maximum number of iterations. With both criteria applied, the assignment process stops when one of the criteria is met first. If the gap is not set small enough or the maximum iterations not high enough, the model will not achieve an optimal condition where no further shorter paths can be found and the results between model runs may contain variation simply due to lack of convergence (see *Traffic Assignment and Feedback Research to Support Improved Travel Forecasting*, Federal Transit Administration, 2015).

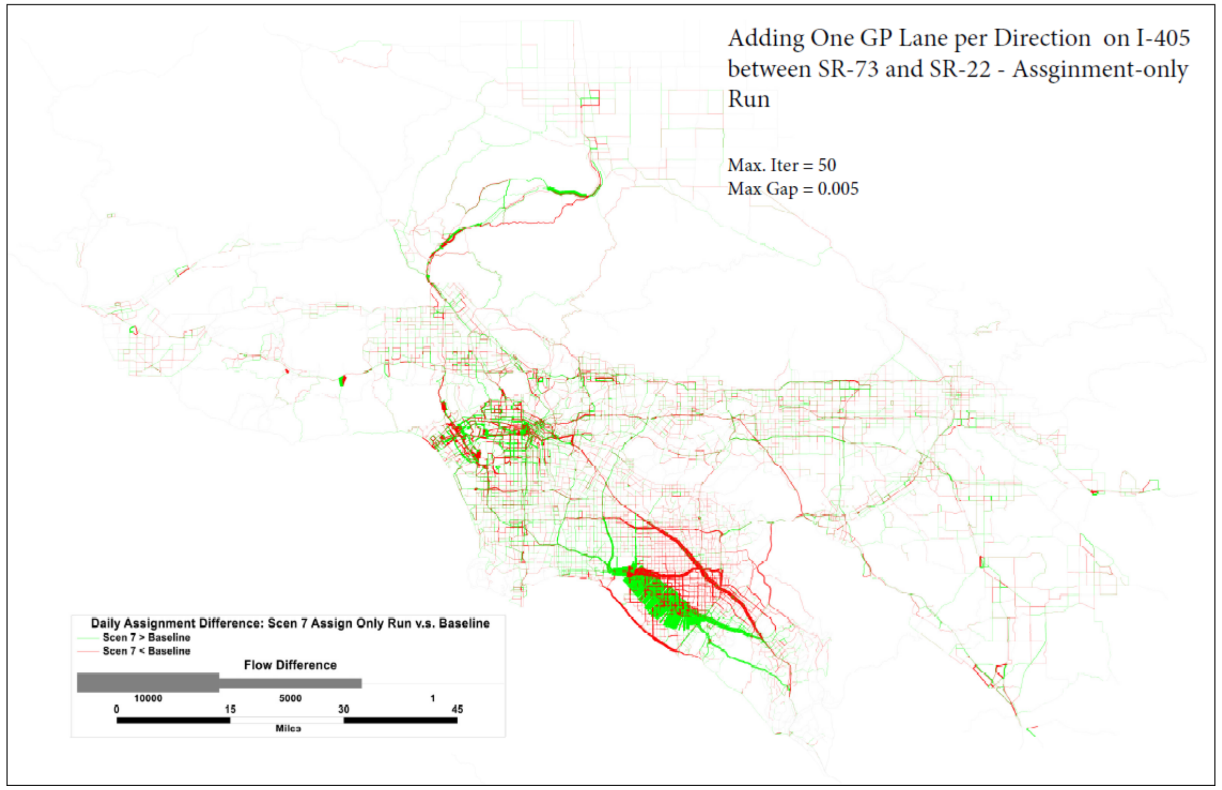
Assignment with various convergence levels has been tested for OCTAM, based upon the comparison between the Baseline and the Baseline plus project as used in Test #2, i.e., adding one GP lane each direction on I-405 between SR-73 and SR-22. **Table 8** summarizes the number of iterations required to satisfy the criteria of maximum relative gap and the approximate run time without the restriction of the maximum number of iterations. **Figure 3** and **Figure 4** show the volume difference across the entire modeling region with different convergence criteria, for the Assignment Only Run and the Full Run, respectively. The key findings are listed as follows:

Table 8: Assignment Criteria Test

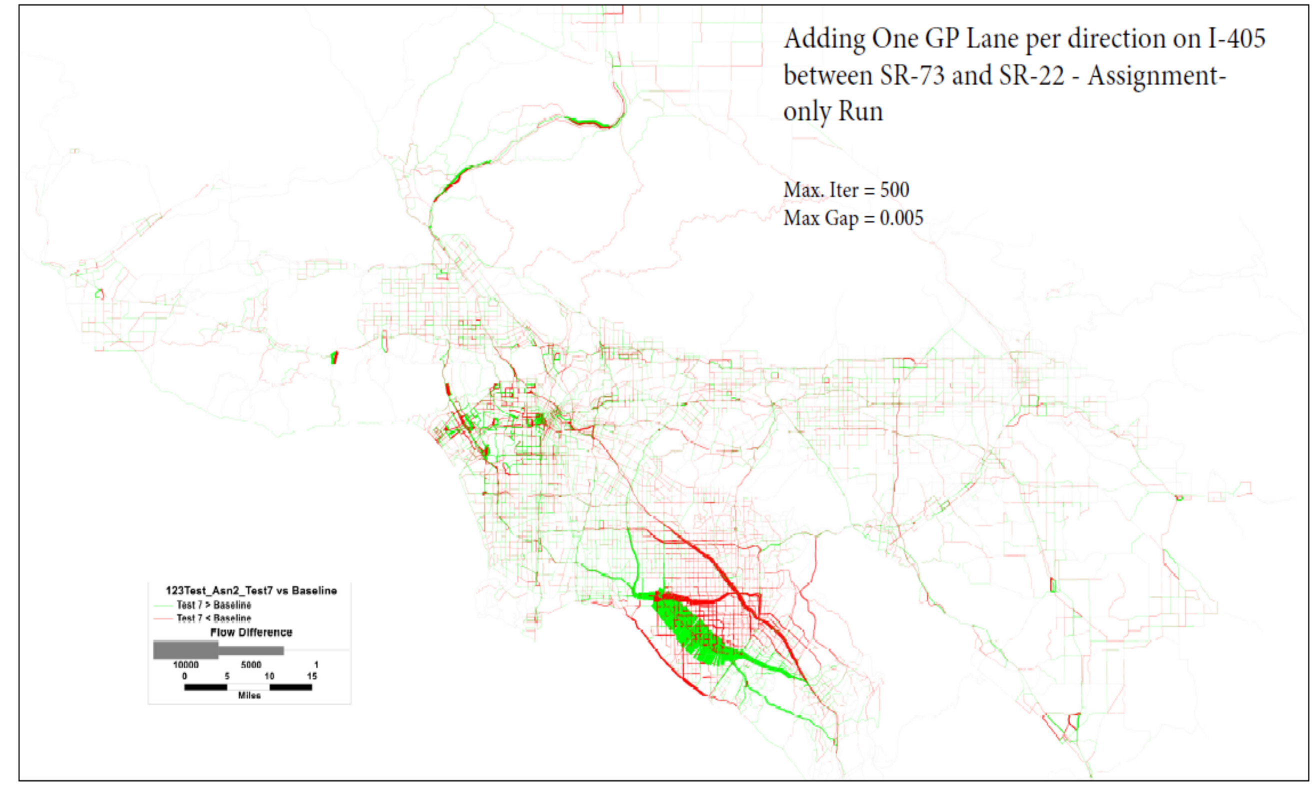
Max. Gap	Period	Required Iterations	Highway Assignment Run Time
0.005	AM	86	2.5 - 4 hours
	MD	13	
	PM	71	
	NT	4	
0.0005	AM	369	10.5 - 13 hours
	MD	49	
	PM	330	
	NT	18	
0.00001	AM	> 5,000	> 50 hours
	MD	1,028	
	PM	> 5,000	
	NT	295	

- In OCTAM v5, the assignment criteria are 0.005 for maximum relative gap and 50 for maximum number of iterations. As shown in the table, the assignments for the AM and PM peak periods stop at iteration #50 without reaching the 0.005 gap criteria.

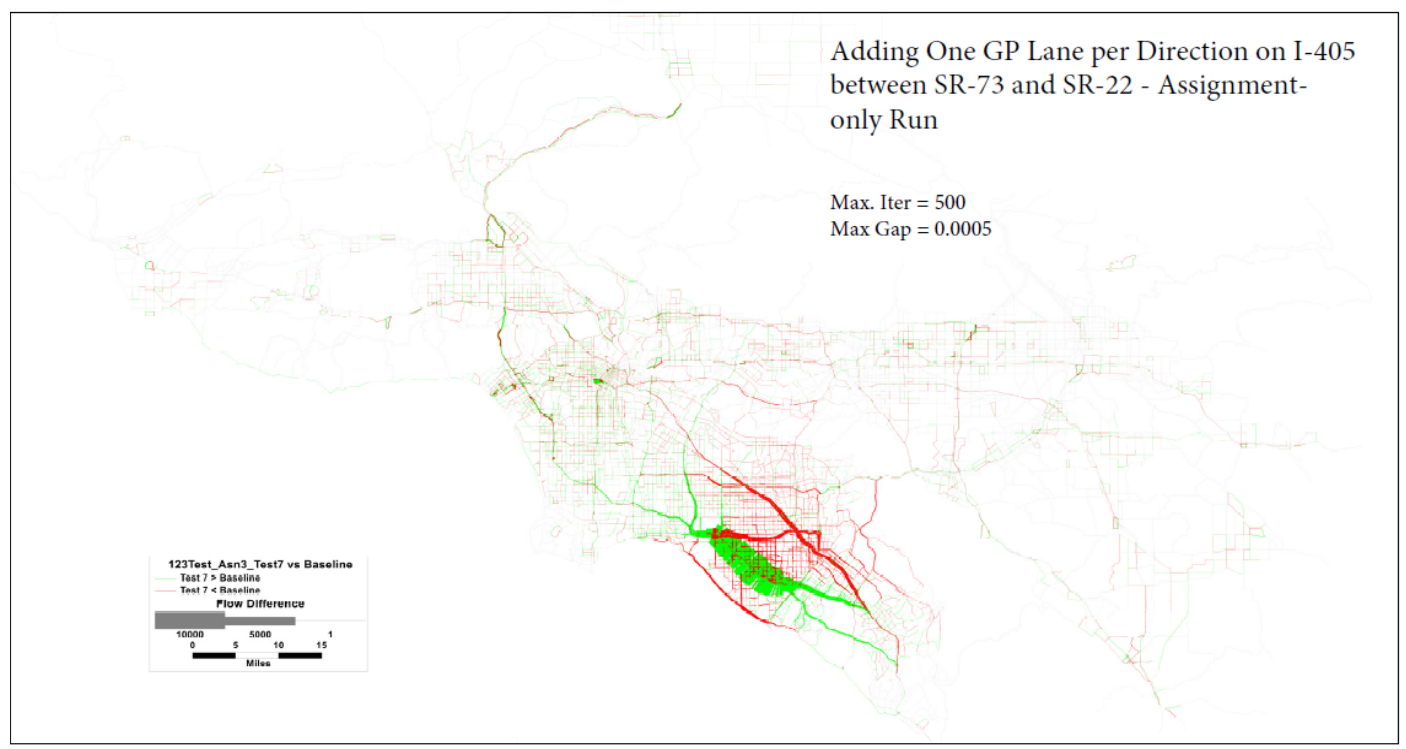
Figure 3: Volume Difference Plots with Different Assignment Convergence Criteria – Baseline plus Project vs. Baseline Assign-Only Run



(a)

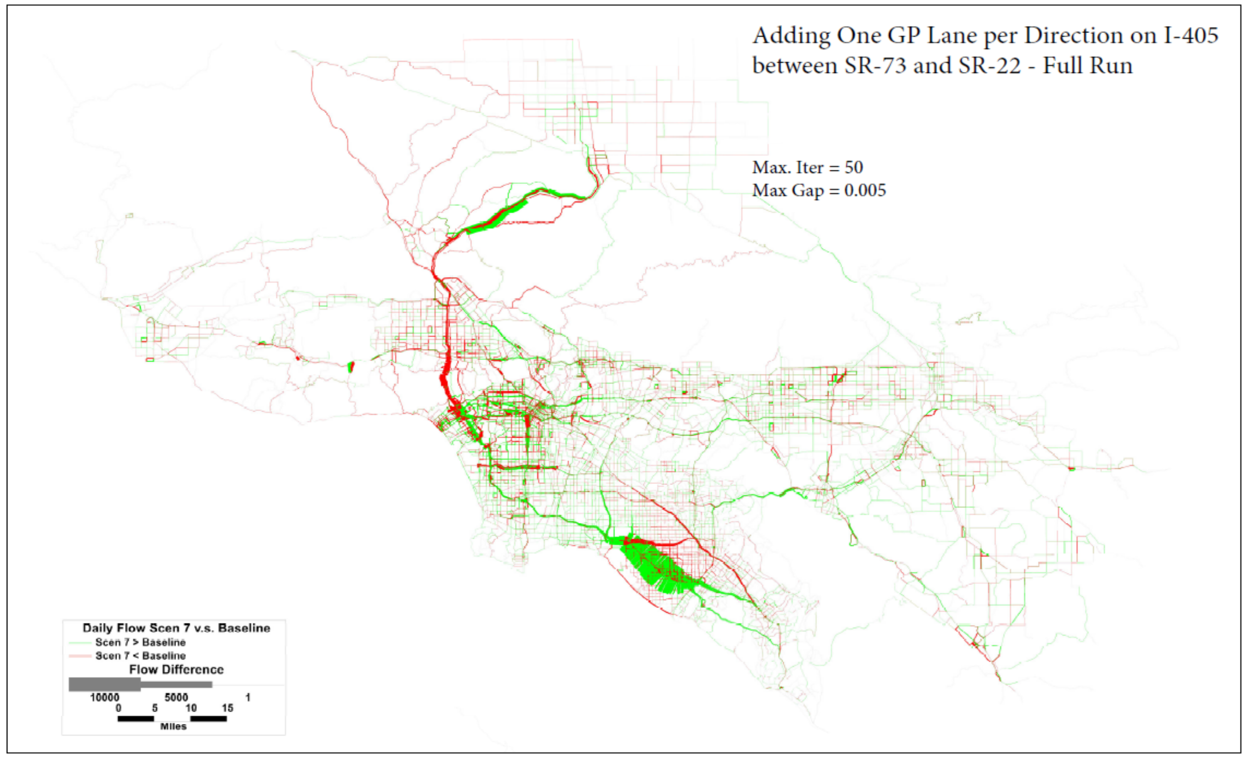


(b)

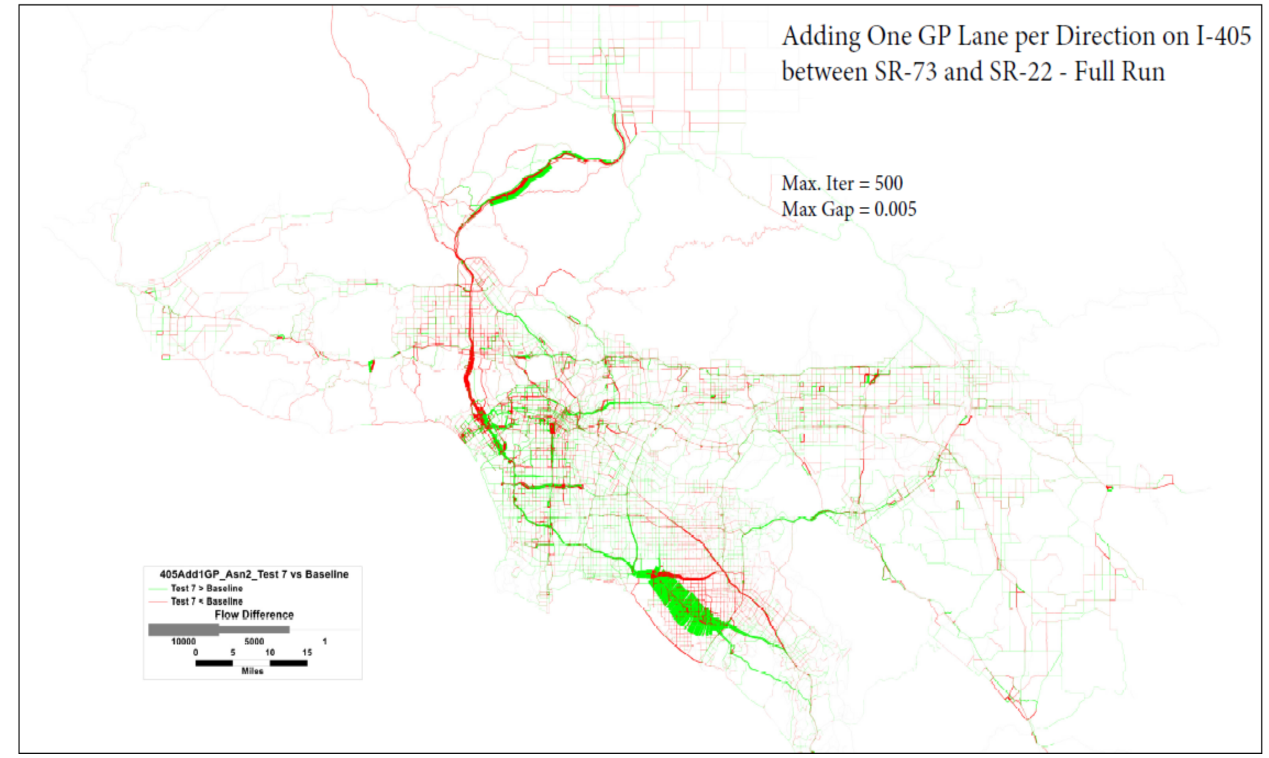


(c)

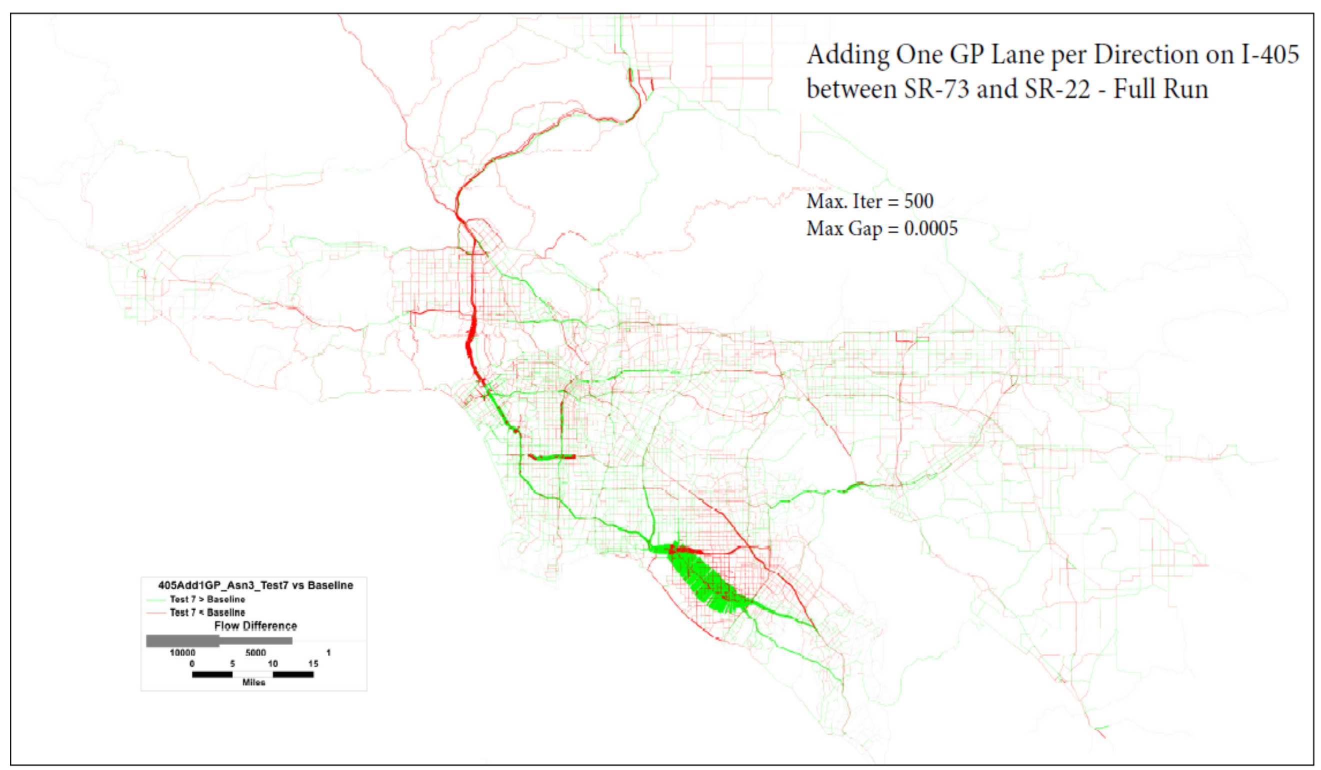
Figure 4: Volume Difference Plots with Different Assignment Convergence Criteria – Baseline plus Project vs. Baseline Full Run



(a)



(b)



(c)

- Figure 3 shows volume changes at different convergence criteria for Assignment Only Run. As shown in the figure, less stringent convergence criteria as in Figure 3(a) generates more significant variation/noise in assigned volume, and when the convergence criteria becomes more stringent as in Figure 3(b) and 3(c), the volume becomes more consistent, and the noise in the model results diminishes.
- The pattern in the Full Run is similar to the pattern in the Assignment Only Run, as described above. Note that in the Full Run, the vehicle trip tables are different in addition to the network from the Baseline, therefore volume difference reflects changes not only in path choice but also in travel behavior. However, the volume differences under different convergence criteria also show a clear trend that with more stringent convergence criteria, the model results are more consistent.
- The test also shows that more stringent convergence criteria leads to longer model run time. A trade-off needs to be made to balance the model result stability and model run time.

Test #4: Toll Sensitivity

Given current interests in investing toll facilities, such as high-occupancy toll (HOT) lanes, tests have been done to check the model's sensitivity on tolls. In this test, the project is to double the tolls on SR-91 at the Orange County – Riverside County Border. Similar to Test #2. The following four test runs are done to investigate how each model step reacts to the toll change, compared to the Baseline.

- Full Run: to run the entire 12-feedback loops for the Baseline plus project
- Assignment Only Run: assign the Baseline vehicle trip table to the network with project
- Mode Choice Only Run: run the mode choice step using the person trip tables from the Baseline while using the network related model files from Baseline plus project
- Distribution Only Run: run the trip distribution step using the PA tables from the Baseline while using the network related model files from Baseline plus project

The test results are summarized for region-wide and for the area within the 2-mile buffer of the project in **Table 9** and **Table 10** respectively. Key findings are summarized below.

Table 9: Region-wide Summary for Toll Analysis – Doubling Tolls on SR-91 at Orange County - Riverside County Border

Scenario	Person Trips			Vehicle Trips					Boundary VMT					Average Vehicle Trip Length				
	PK	OP	Daily	AM	MD	PM	NT	Daily	AM	MD	PM	NT	Daily	AM	MD	PM	NT	Daily
Baseline	39,614,099	37,987,134	77,601,233	9,583,760	14,852,503	15,213,066	8,677,346	48,326,674	97,088,734	123,230,125	134,266,672	83,621,293	438,206,824	10.131	8.297	8.826	9.637	9.068
Baseline w/ Project - Full Run	39,614,099	37,987,134	77,601,233	9,583,032	14,852,190	15,212,209	8,677,130	48,324,560	97,120,433	123,250,111	134,358,206	83,591,697	438,320,447	10.135	8.298	8.832	9.634	9.070
Baseline w/ Project - Assign Only	39,614,099	37,987,134	77,601,233	9,583,760	14,852,503	15,213,066	8,677,346	48,326,674	97,116,623	123,250,863	134,330,469	83,622,196	438,320,152	10.133	8.298	8.830	9.637	9.070
Baseline w/ Project - Mode Choice Only	39,614,099	37,987,134	77,601,233	9,582,974	14,852,336	15,212,236	8,677,209	48,324,755										
Baseline w/ Project - Distribution Only	39,614,099	37,987,134	77,601,233															

Table 10: Summary within 2-mile of Buffer Area for Toll Analysis – Doubling Tolls on SR-91 at Orange County - Riverside County Border

Scenario	Person Trips			Vehicle Trips					Boundary VMT					OD VMT					Average Vehicle Trip Length				
	PK	OP	Daily	AM	MD	PM	NT	Daily	AM	MD	PM	NT	Daily	AM	MD	PM	NT	Daily	AM	MD	PM	NT	Daily
Baseline	609,925	532,984	1,142,909	173,795	219,252	253,293	136,317	782,658	2,066,589	2,461,505	2,700,055	1,992,210	9,220,359	2,168,109	2,161,792	2,766,846	1,579,581	8,676,329	12.475	9.860	10.924	11.588	11.086
Baseline w/ Project - Full Run	609,997	532,990	1,142,987	173,828	219,238	253,333	136,309	782,707	2,083,534	2,472,710	2,740,222	1,963,255	9,259,720	2,169,737	2,160,002	2,772,319	1,577,776	8,679,833	12.482	9.852	10.943	11.575	11.089
Baseline w/ Project - Assign Only	609,925	532,984	1,142,909	173,795	219,252	253,293	136,317	782,658	2,095,255	2,494,187	2,755,134	1,993,565	9,338,141	2,166,868	2,161,336	2,769,095	1,579,192	8,676,492	12.468	9.858	10.932	11.585	11.086
Baseline w/ Project - Mode Choice Only	609,925	532,984	1,142,909	173,776	219,237	253,276	136,306	782,595															
Baseline w/ Project - Distribution Only	609,997	532,989	1,142,987																				

- Same as in Test #2, person trips remain the same across all the test runs region-wide while have nominal variation within the 2-mile buffer area of the project. There is no induced travel in trip generation due to this project.

Figure 5 shows the trip length frequency of person trips and **Table 11** lists average person trip length out of trip distribution, for the Baseline, Baseline plus project Full Run, and the Distribution only Run for region-wide and within 2-mile buffer area, respectively. The trip length frequency is significantly different between region-wide and within 2-mile buffer area, while they are nearly identical across the test runs within the same geographic coverage. The average person trip length is slightly longer in the test runs with project for region-wide, while slightly shorter within the 2-mile buffer area. The trip length is longer within 2-mile buffer area than region-wide. The average trip lengths are close in the two test runs.

In addition, by comparing to the average trip lengths in Test #2, this test case shows more impact on the person trip length with the 2-mile buffer area of the project, therefore more impact in the overall travel pattern due to the project.

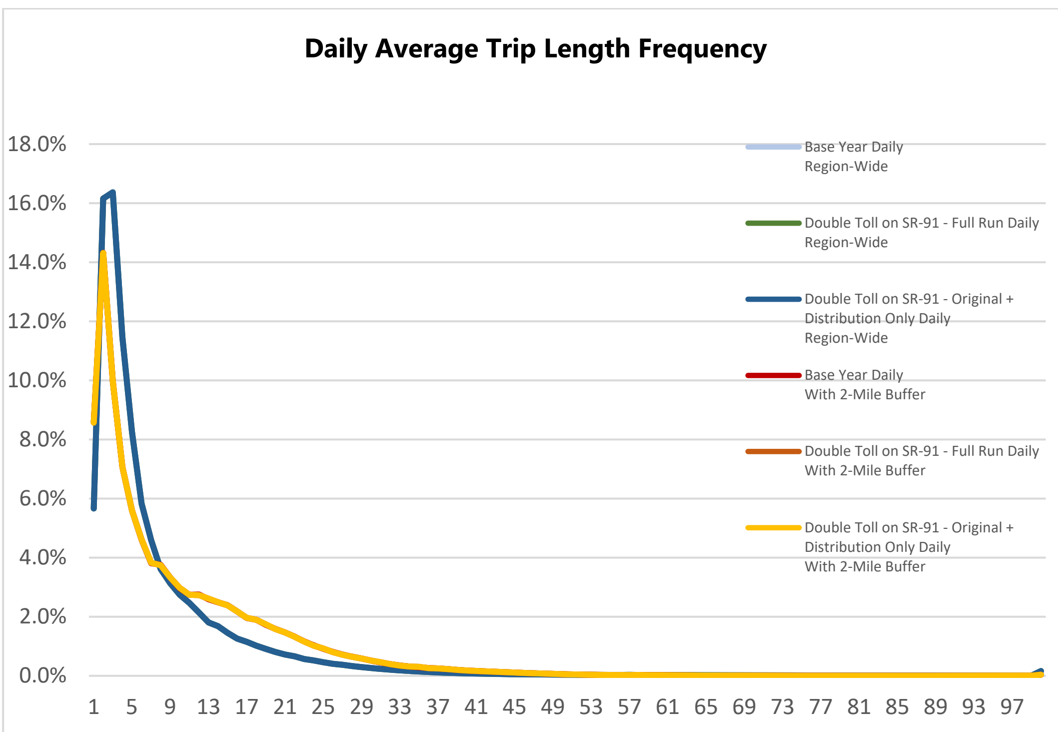


Figure 5: Daily Average Trip Length Frequency – Toll Sensitivity Test

Table 11: Average Person Trip Length – Toll Sensitivity Test

Scenario	Average Person Trip Length	
	Region-wide	2-Mile Buffer
Baseline	7.429	10.093
Baseline w/ Project - Full Run	7.435	10.091
Baseline w/ Project - Distribution Only	7.435	10.091

- Total number of vehicle trips region-wide reduces in both Baseline with project Full Run and the Mode Choice Only Run. While within the 2-mile buffer area of the project, the total number of vehicle trips slightly increases in the Full Run while slightly decreasing in the Mode Choice Only Run, compared to the Baseline. It makes sense that the number of vehicle trips reduces due to the higher travel cost because of tolls. However in the Full Run, the total number of vehicle trips have nominal increase within the 2-mile buffer area of the project.

- The boundary VMT region-wide increases in the Baseline plus project Full Run; and combined with the reduced vehicle trips, the average vehicle trip length increases mainly due to the trip re-routing to avoid the toll path with higher tolls. For the Assignment Only Run, both region-wide VMT and average vehicle trip length increases from the Baseline due to the same reason.

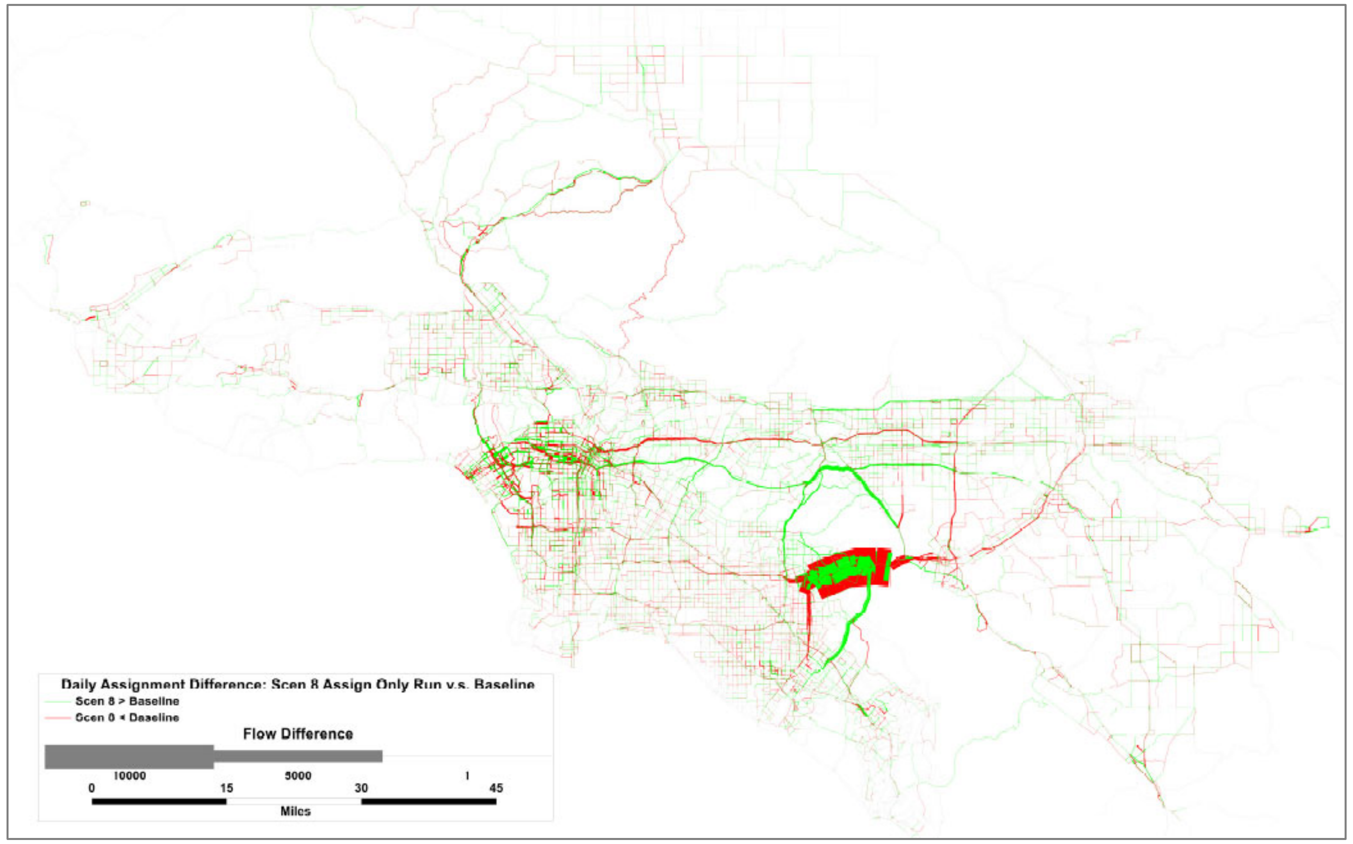
  Within the 2-mile buffer of the project, both boundary VMT and VMT associated with the trips generated within the buffer area increase in both Full Run and Assignment Only Run. Similarly, the average trip length for the trips generated within the 2-mile buffer area also increases in the Full Run and in the Assignment Only Run.

- **Figure 6** shows the volume difference between the test runs with project and the Baseline. As shown in the figure, the volume on the HOT lane drops while the volume on GP lanes increases significantly on SR-91 between SR-55 and the county line, where the project locates. The Assignment Only Run has less deviation in the volume from the Baseline compared to the Full Run, as the deviation in the Full Run compared to the Baseline is not only from the network difference but also from different travel patterns that the Assignment Only Run does not have.

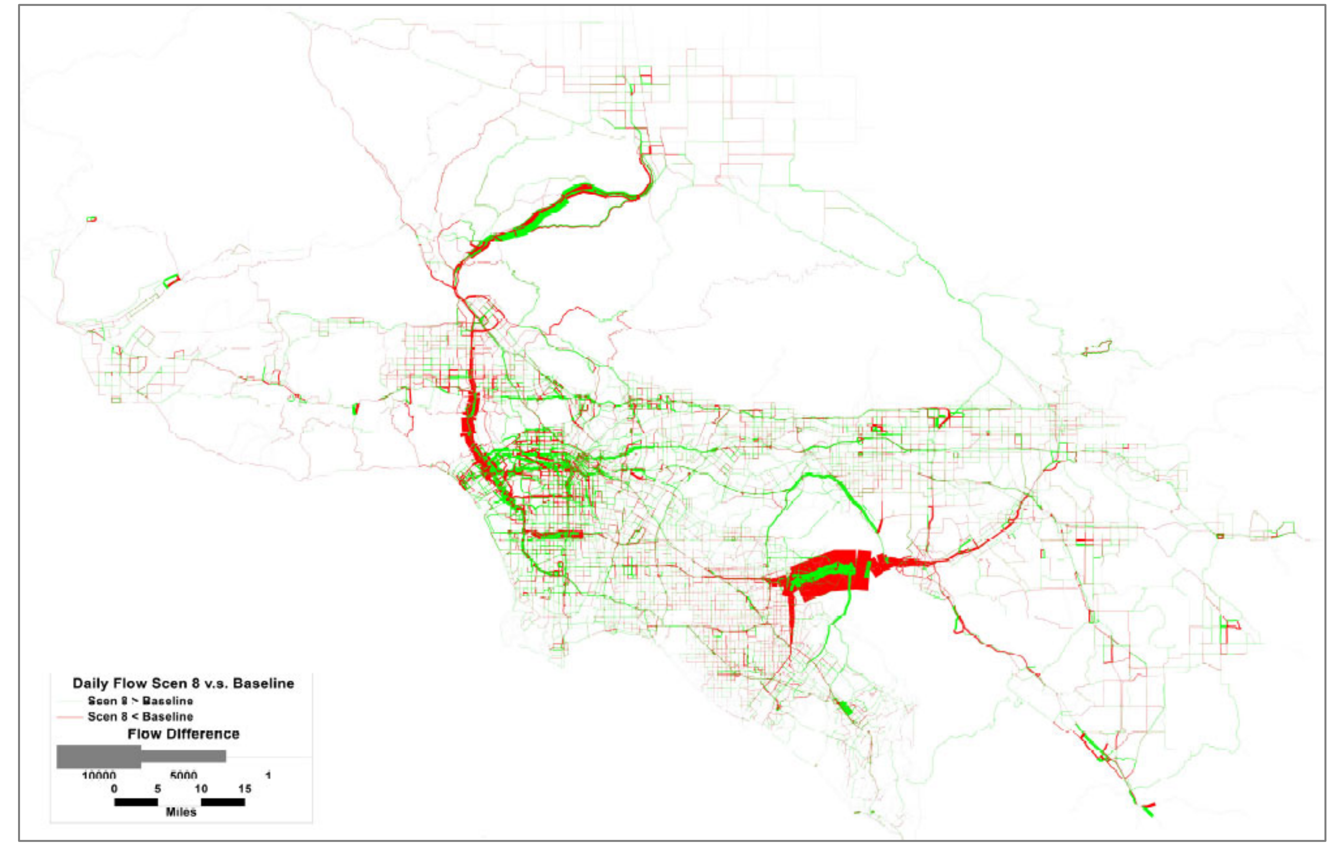
  Similar to Test #2, relatively significant variation in the volume results is shown in both test runs due to the less stringent assignment convergence criteria. Hence, this is not an outcome based on the toll change, but a result due to the model specifications in assignment convergence. Test #3 includes the detailed explanation on how model noise occurs.

Figure 6: Volume Difference Plots – Baseline plus Project vs. Baseline Full Run

Doubling Tolls at Orange County – Riverside County Border



(b) Assignment Only Run vs. Baseline



(b) Baseline plus Project Full Run vs. Baseline

Test #5: General Review

Additional model tests have been conducted to provide a more comprehensive review of the model performance in estimating VMT and average vehicle trip length. More specifically, these tests focus on the impact from auto operating cost (AOC), auto ownership, and roadway congestion, each of which is analyzed in this section below.

Auto Operating Cost

Table 12 shows the impact in vehicle trips, VMT and vehicle trip length change with 50% reduction in AOC. As shown in the table, when AOC reduces, vehicle trips, VMT and average vehicle trip length generally increase for daily conditions and for each time period. This change is expected because AOC reduction would reduce auto travel cost therefore travelers intend to make longer trips or make more trips using autos.

In addition, with lower AOC, more travelers choose to drive by themselves, instead of sharing the ride with others, especially to HOV3+ trips. GP and HOV3+ trips show opposite trend but consistent across time periods, while HOV2 trips vary. For those trips using HOV2 lanes, the model predicts slightly longer trips in the peak periods while shorter trips in the off-peak periods.

Elasticities are calculated as the ratio of the percent of change in VMT to the percent of change in AOC. As shown in the table, the elasticities are negative for GP, HOV2 and total trips, while positive for HOV3+ trips only, indicating the direction of change in VMT is opposite to the direction of change in AOC for GP and HOV2 trips, while in the same direction of change in AOC for HOV3+, consistent with the analysis above.

Based on the literature review in the Oak Ridge National Laboratory report on *Analysis of Automobile Travel Demand Elasticities with Respect to Travel Cost*, prepared for Federal Highway Administration (*https://www.fhwa.dot.gov/policyinformation/pubs/hpl-15-014/TCElasticities.pdf*), academic research reveals a wide range of elasticities values across studies for both short-term and long-term elasticity estimates. In all cases the elasticities fall between 0.0 and -0.7 for the short-term and between 0.0 and -0.9, with larger absolute values for Operating and Maintenance (O&M) elasticities that combine fuel with other cost components. The results in Table 12 show the full model run produced the change in VMT within the short-term range in the academic literature and close to the low end.

Table 12: The Impact of Auto Operation Cost Reduction to VMT/Vehicle Trip Length

Period	Mode	General Purpose	HOV2	HOV3	Total
Difference% to the Baseline					
Daily	Vehicle Trips	1.3%	7.8%	-1.4%	1.4%
	VMT	4.3%	8.4%	-6.3%	4.3%
	Vehicle Trip Length	2.9%	0.6%	-4.9%	2.8%
AM	Vehicle Trips	1.2%	5.9%	-2.1%	1.3%
	VMT	3.6%	6.7%	-6.7%	3.5%
	Vehicle Trip Length	2.3%	0.8%	-4.7%	2.2%
MD	Vehicle Trips	1.4%	21.6%	2.5%	1.4%
	VMT	4.8%	18.2%	-4.4%	4.9%
	Vehicle Trip Length	3.4%	-2.8%	-6.7%	3.4%
PM	Vehicle Trips	1.2%	5.1%	-2.3%	1.3%
	VMT	2.5%	5.1%	-7.0%	2.4%
	Vehicle Trip Length	1.3%	0.0%	-4.8%	1.1%
NT	Vehicle Trips	1.6%	22.7%	2.1%	1.7%
	VMT	7.1%	19.3%	-4.9%	7.1%
	Vehicle Trip Length	5.4%	-2.8%	-6.9%	5.4%
Elasticity in VMT with 50% AOC Reduction					
Daily		-0.0864	-0.1690	0.1250	-0.0853
AM		-0.0723	-0.1342	0.1339	-0.0706
MD		-0.0967	-0.3637	0.0885	-0.0986
PM		-0.0509	-0.1028	0.1392	-0.0484
NT		-0.1415	-0.3868	0.0988	-0.1429

Auto Ownership

In this test, two test scenarios are included, i.e., (1) increasing # of vehicles per household by 1 and (2) decreasing # of vehicles per household by 1. **Table 13** shows the impact in vehicle trips, VMT and vehicle trip length change with the changes in number of vehicles per household.

As shown in the table, with more vehicles in each household in scenario #1, the total number of vehicle trips increases, however the model predicts longer trips in the peak periods and shorter trips in the off-peak periods, therefore resulting in higher VMT in the peak periods while lower VMT in the off-peak periods. Looking closer to individual trip types, the overall change pattern also applies to GP trips for each time period, while the average daily trip length of GP trips reduces because the reduction in trip length of GP trips in the off-peak periods offsets the increase in the trip length in the peak periods, therefore daily VMT for GP trips still reduces even though the daily GP trips increase. The average vehicle trip length for HOV2 and HOV3+ trips decreases in all the time periods, however due to significant increase in vehicle trips, the VMT associated with HOV2 and HOV3+ still increase.

With reduced number of vehicles in each household in scenario #2, the total number of vehicle trips reduces in all the time periods overall and for GP trips, while HOV2 and HOV3+ trips increase. The change in vehicle trip length follows the same pattern as in scenario #1, for each trip type in each time period. The pattern of the change in VMT and vehicle trip length for GP trips dominates across all the trip types, which determines the overall change pattern.

Elasticities calculated from the results in Scenarios #1 and #2 are not consistent, indicating more autos per household does not always generate more VMT while fewer autos per household does not always generate lower VMT, as the use of the autos is also subject to the number of drivers in a household. The model-estimated VMT does not change monotonously, mainly due to the impact in the pattern of the change in vehicle trip length across the time periods.

Most of the academic research on Auto Ownership elasticity is to analyze the vehicle ownership elasticities with regards to income (Goodwin et al., 2004, Schimek 1996, and Canada, Barla, et al. 2009, etc.). Given the impact of the auto ownership to VMT could be much different (even in different directions) under different contexts, (e.g., the number of vehicles already owned in a household and the number of drivers in a household, household income, etc.), these tests do not have formal elasticities to compare the reasonableness of model sensitivity.

Table 13: The Impact of Auto Ownership to VMT/Vehicle Trip Length

Period	Mode	General Purpose	HOV2	HOV3	Total
Difference%: Scenario #1 - Increased Autos Vs. Baseline					
Daily	Vehicle Trips	0.4%	89.5%	88.8%	2.2%
	VMT	-2.6%	64.2%	60.2%	1.1%
	Vehicle Trip Length	-3.0%	-13.3%	-15.2%	-1.0%
AM	Vehicle Trips	0.4%	30.7%	32.6%	1.5%
	VMT	5.8%	21.1%	20.6%	7.0%
	Vehicle Trip Length	5.3%	-7.3%	-9.0%	5.5%
MD	Vehicle Trips	0.8%	455.4%	341.1%	3.1%
	VMT	-12.0%	225.6%	157.6%	-6.7%
	Vehicle Trip Length	-12.7%	-41.4%	-41.6%	-9.5%
PM	Vehicle Trips	1.0%	39.1%	39.9%	2.3%
	VMT	6.8%	31.4%	31.7%	8.9%
	Vehicle Trip Length	5.8%	-5.5%	-5.9%	6.5%
NT	Vehicle Trips	-1.4%	379.6%	290.4%	1.3%
	VMT	-12.4%	188.6%	132.7%	-6.8%
	Vehicle Trip Length	-11.2%	-39.8%	-40.4%	-8.1%
Difference%: Scenario #2 - Reduced Autos Vs. Baseline					

Daily	Vehicle Trips	-10.8%	70.6%	64.8%	-9.2%
	VMT	-9.7%	51.7%	44.4%	-6.4%
	Vehicle Trip Length	1.3%	-11.0%	-12.4%	3.2%
AM	Vehicle Trips	-6.1%	21.7%	18.4%	-5.2%
	VMT	2.1%	15.5%	11.3%	3.0%
	Vehicle Trip Length	8.7%	-5.1%	-6.0%	8.7%
MD	Vehicle Trips	-14.5%	389.5%	283.9%	-12.5%
	VMT	-22.2%	193.7%	130.6%	-17.4%
	Vehicle Trip Length	-9.1%	-40.0%	-39.9%	-5.7%
PM	Vehicle Trips	-9.4%	23.4%	19.5%	-8.4%
	VMT	-0.1%	20.1%	16.4%	1.4%
	Vehicle Trip Length	10.2%	-2.6%	-2.6%	10.7%
NT	Vehicle Trips	-12.2%	337.3%	249.2%	-9.7%
	VMT	-19.0%	169.0%	113.9%	-13.8%
	Vehicle Trip Length	-7.8%	-38.5%	-38.7%	-4.6%
Elasticity in VMT with Auto% of change					
Daily	Scenario #1	-0.0450	1.1202	1.0505	0.0197
	Scenario #2	0.1845	-0.9835	-0.8443	0.1210
AM	Scenario #1	0.1003	0.3690	0.3602	0.1219
	Scenario #2	-0.0392	-0.2939	-0.2141	-0.0578
MD	Scenario #1	-0.2088	3.9367	2.7504	-0.1169
	Scenario #2	0.4223	-3.6808	-2.4827	0.3315
PM	Scenario #1	0.1190	0.5480	0.5524	0.1547
	Scenario #2	0.0026	-0.3826	-0.3124	-0.0274
NT	Scenario #1	-0.2170	3.2900	2.3150	-0.1190
	Scenario #2	0.3615	-3.2114	-2.1643	0.2624

Roadway Congestion

In this test, two test scenarios are included, i.e., (1) less congestion by reducing travel time by 20% and (2) more congestion by increasing travel time by 20%. **Table 14** show the impact in vehicle trips, VMT and vehicle trip length change with the different congestion level.

As shown in the table, when the roadways are less congested, not only vehicle trips but also VMT and average trip length increases across all the time periods for all trip types, except for the HOV2 and HOV3+ trips in the off-peak periods with opposite change. On the other hand, when the roadways are more congested, vehicle trips, VMT and vehicle trip lengths all reduce for GP trips and all trips for all the time periods. As to HOV2 and HOV3+, the vehicle trips and VMT are lower in the peak periods but higher in the off-peak periods, while the average trip length shows the opposite pattern.

Elasticities calculated from the results in Scenarios #1 and #2 are mostly consistent. More congestion leads to lower VMT, and vice versa, with the exception of HOV2 and HOV3+ trips in the off-peak periods. Limited research has been done on the relationship between travel time change and induced VMT.

Although limited, academic research[1] reveals an elasticity of -0.3 to -1.0 for short-term induced VMT with respect to travel time change. The results in Table 14 show the full model run produced a change in VMT within the short-term range in the academic literature.

Table 14: Roadway Congestion vs. VMT/Vehicle Trip Length

Period	Mode	General Purpose	HOV2	HOV3	Total
Difference%: Scenario #1 - Reduced Travel Time Vs. Baseline					
Daily	Vehicle Trips	0.6%	5.0%	5.6%	0.7%
	VMT	12.1%	8.4%	8.9%	11.9%
	Vehicle Trip Length	11.5%	3.3%	3.1%	11.2%
AM	Vehicle Trips	0.6%	8.2%	9.2%	0.8%
	VMT	11.1%	10.6%	10.7%	11.1%
	Vehicle Trip Length	10.5%	2.2%	1.3%	10.2%
MD	Vehicle Trips	0.7%	-17.8%	-14.7%	0.6%
	VMT	13.8%	-8.9%	-6.0%	13.2%
	Vehicle Trip Length	13.0%	10.8%	10.2%	12.5%
PM	Vehicle Trips	0.3%	10.4%	12.1%	0.6%
	VMT	11.1%	15.2%	16.9%	11.5%
	Vehicle Trip Length	10.7%	4.3%	4.3%	10.8%
NT	Vehicle Trips	0.9%	-17.9%	-14.6%	0.7%
	VMT	12.3%	-9.4%	-6.2%	11.6%
	Vehicle Trip Length	11.4%	10.4%	9.9%	10.8%
Difference%: Scenario #2 - Increased Travel Time Vs. Baseline					
Daily	Vehicle Trips	-0.6%	-2.8%	-2.2%	-0.7%
	VMT	-8.7%	-2.4%	-0.7%	-8.3%
	Vehicle Trip Length	-8.1%	0.4%	1.5%	-7.7%
AM	Vehicle Trips	-0.7%	-6.6%	-6.1%	-0.8%
	VMT	-8.2%	-3.8%	-1.1%	-7.8%
	Vehicle Trip Length	-7.6%	3.1%	5.3%	-7.0%
MD	Vehicle Trips	-0.7%	20.5%	17.2%	-0.6%
	VMT	-9.8%	8.8%	7.4%	-9.3%
	Vehicle Trip Length	-9.1%	-9.7%	-8.3%	-8.7%

[1] Barr, L.C. 2000, *Testing significance of induced highway travel demand in metropolitan areas*, Transportation Research Record 1706.

Goodwin, P.B. 1996, *Empirical evidence of induced traffic, a review and synthesis*. Transportation, Volume 23, p35-54.

PM	Vehicle Trips	-0.4%	-8.1%	-8.2%	-0.7%
	VMT	-8.0%	-6.9%	-5.7%	-7.9%
	Vehicle Trip Length	-7.6%	1.3%	2.8%	-7.3%
NT	Vehicle Trips	-0.9%	20.5%	17.0%	-0.7%
	VMT	-8.7%	9.1%	7.8%	-8.1%
	Vehicle Trip Length	-8.0%	-9.5%	-7.9%	-7.5%
Elasticity in VMT with travel time% of change					
Daily	Scenario #1	-0.6061	-0.4213	-0.4442	-0.5954
	Scenario #2	-0.4355	-0.1219	-0.0373	-0.4145
AM	Scenario #1	-0.5570	-0.5282	-0.5352	-0.5547
	Scenario #2	-0.4116	-0.1879	-0.0570	-0.3879
MD	Scenario #1	-0.6923	0.4460	0.3012	-0.6625
	Scenario #2	-0.4886	0.4415	0.3714	-0.4637
PM	Scenario #1	-0.5528	-0.7587	-0.8462	-0.5734
	Scenario #2	-0.4011	-0.3432	-0.2828	-0.3942
NT	Scenario #1	-0.6167	0.4686	0.3089	-0.5813
	Scenario #2	-0.4373	0.4543	0.3881	-0.4074

RECOMMENDATIONS

To comply with CEQA expectations for transportation and VMT impact analysis, OCTAM would benefit from strengthening its sensitivity to land use and transportation network changes. Land use changes related to important built environment effects are not included in the model while the model produces noisy variations in vehicle travel outputs due to the model's trip assignment specifications. Specific recommendations are summarized below.

Built Environment Sensitivity

As indicated in the limited sensitivity test described in Test #1, the model does not show enough sensitivity to built environment characteristics. Research shows that there are several built environment variables knows as the "Ds" that influence individual travel behavior. These influences include:

- **D**ensity – Land use density as measured by total population and employees per square mile.
- **D**iversity – The mix of housing, jobs, and retail and the degree to which they are evenly distributed within a particular location.
- **D**esign – The design of the street network, measured in terms of the number of intersections per square mile
- **D**estination Accessibility – The ease of access to regional destinations from the origin, typically measured in terms of the number of destinations that can be reached within a specified travel time

- **D**istance to Transit – The average of the shortest routes from housing units or workplaces to the nearest transit stop.
- **D**evelopment Scale – The overall number of jobs and residents.
- **D**emographics – The sociodemographic characteristics of the residents living in the study area that can impact travel behavior (automobile ownership, household size, and income).

Each "D" factor can influence travel in a variety of ways. For example:

- Density
  - Shortens trip lengths
  - Promotes walking and bicycle trips
  - Supports high quality transit
- Diversity
  - Links trips and shortens trip distances
  - Promotes walking and bicycling
  - Allows for share parking
- Design
  - Improves connectivity
  - Encourages walking and bicycling
  - Reduces travel distance
- Destination Accessibility
  - Links different travel purposes
  - Shortens trip lengths
  - Offers transportation options
- Distance from Transit
  - Facilitates transit uses
  - Livens streetscapes
  - Encourages trip-linking and walking
- Development Scales
  - Provides a critical mass
  - Increases local opportunities
  - Integrates transportation modes
- Demographics
  - Suits households to preferred settings and travel modes
  - Allows business to locate convenient to clients
  - Allows socio-economic "fit among residents, business, and activities.

Improvements to these built environment characteristics have been shown to reduce VMT. Additionally, research has shown that these reductions are a result of three separate interactions including internal capture, shifts from personal automobile travel to walking or bicycle, and shifts from personal automobile travel to transit. The travel demand model can be enhanced to incorporate these "D" variables in the model to add sensitivities of the model estimation in built environment. Another option is to apply the elasticities associated with the "D" variables from the related research to estimate the VMT reduction.

IXXI Trip Induced Travel

In OCTAM, the IX/XI/XX trips are fixed for a scenario year, and the current standard process does not update IX/XI/XX trips associated with a project. This setup indicates that the model is insensitive to how individual land use projects may change IX and XI patterns. This is particularly important when land use projects cause imbalances in Ps and As. For projects occurring at the model boundaries, this limitation may be more severe. Future model updates or enhancements should include separate IX and XI components for each TAZ and trip purpose. IX and XI trips are often a function of differences in housing costs and wage rates so these additional factors should be integrated into the IX and XI forecasting process. .

Assignment Convergence to Improve Model Stability

As analyzed in Test #3, OCTAM uses less stringent convergence criteria (e.g., maximum relative gap 0.005 and a maximum of 50 iterations) than necessary for the model reach a stable convergence. More stringent convergence criteria in the highway assignment process will stabilize the assignment results, which is recommended to strengthen the model's output for use in CEQA analysis. The specific changes in the convergence criteria comes with added run time so OCTA should assess an appropriate balance of assignment stability and reasonable run time.

Additional Recommendations for Induced Vehicle Travel Analysis

CEQA analysis expectations set forth by the California Governor's Office of Planning and Research (OPR) and by Caltrans set expectations (see websites below) that roadway capacity expansion projects must account for induced vehicle travel effects. .

- https://opr.ca.gov/docs/20190122-743_Technical_Advisory.pdf
- https://dot.ca.gov/programs/transportation-planning/office-of-smart-mobility-climate-change/sb-743

For projects that increase roadway capacity, quantitative estimates of induced VMT is critical to calculating both transportation and other related impacts of these projects. The current OCTAM has limitations for producing appropriate VMT forecasts due to a lack of feedback to trip generation and land use growth allocation as well as the incomplete assignment convergence noted above. Having fixed IX and XI trip patterns is also a potential limitation. Overcoming these limitations can be done through adjusting the model process or applying induced vehicle travel elasticities as explained in the Caltrans and OPR guidance.

APPENDIX B

Justification for Using Alternate Elasticities

The NCST and guidelines form OPR and CARB recommend applying a long-run elasticity of 1.0 to evaluate the induced travel impacts of capacity expansion projects on interstate freeways and an elasticity of 0.75 for FHWA class 2 or 3 facilities. Using this elasticity runs the risk of overstating the adverse impacts and ignoring the benefits of such projects, many of which are a product of a deliberate and public planning process that attempts to anticipate growing demand and identify capacity expansions to address that growth. The 1.0 elasticity itself is subject to on-going debate.

Many studies on induced travel confuse correlation with causation, or worse, assume the arrow of causation points in the wrong direction. The argument that added capacity always produces added traffic is not accurate and not settled in science or law.

- Credible science is careful to avoid asserting that just because two events occur mutually proves that one causes the other. Researchers conduct controlled double-blind experiments to ascertain cause and effect. Scientists don't assume that, because they see people carrying umbrellas on rainy days, the umbrellas must have caused the rain.
- CEQA is intended to disclose impacts of discretionary decisions without 'speculating' and by 'intelligently' accounting for effects. The elasticity method has as many limitations (if not more) than using travel demand models with a significant bias in that the result is only one-directional. Further, the elasticities are derived from a large group of data (i.e., all MSAs in the U.S.) but applied to individual projects that may not share the characteristics of the group (a potential ecological fallacy).

So, to responsibly examine the induced travel phenomenon, we need to consider the counterfactual: what would have happened if capacity was not added? Travel demand models help address this question more directly and should not be ignored in favor of the elasticity method. We can also rely on the Duranton and Cervero studies cited above to provide a broad perspective on this question as well as the Mokhtarian study.

Duranton investigates the various components of traffic growth that occur when capacity is added to distinguish the amount that occurs in the form of additional travel per capita and the amounts that result from the economic benefits of capacity expansion. It is a comprehensive study across all US MSAs, and it concludes that the potential sources of traffic growth that occur following capacity expansion consist of the following four categories.

- Increase in household driving = 9 to 39 percent
- Increase in commercial driving = 19 to 29 percent
- Migration (increase in population) = 5 to 21 percent
- Diversion of traffic from other routes = 0 to 10 percent

Migration and increased commercial driving are a result of the economic benefits of capacity expansion. Basically, more people moved to the area and more economic activity was generated. These people and this economic activity would have occurred elsewhere so the VMT associated with these categories should not be treated as 'new'. The diversion of travel is generally a favorable outcome because it implies that traffic is finding a more suitable facility class by leaving facilities that produce greater community impacts, and/or that travel flow is smoother and generating lower emissions and related impacts, and/or that they're travelling shorter distances and reducing regional VMT. Hence, the truly induced VMT that would not have occurred otherwise may be as low as 9% and not higher than 39%.

Cervero modeled the two-way relationship between road supply and travel demand taking into account latent demand, mode shifts, changes in destination choice, route switching, and induced land development resulting from 24 California freeway expansion projects. The analysis also accounted for growing ambient population and incomes. The findings on the proportions of traffic occurring concurrently with or after the addition of capacity were:

- Ambient changes unrelated to the added capacity = 40%
- Reserve capacity available for future growth = 20%
- Induced demand = 40%
    - Land use shifts = 9%
    - Behavioral shifts = 31%

Taken together, the two studies that fully and quantitatively consider all of the effects of adding road capacity reach similar conclusions: that only about 40% of the additional traffic correlated with added capacity is a result of directly attributable land use shifts or induced travel per household. In other words, we should be skeptical of assessments that apply elasticities greater than 0.4 to estimate induced vehicle travel impacts especially if the focus is on the change in passenger vehicle travel. The remaining 60% is a manifestation of the very goals that led to the original decision to add capacity: anticipated regional growth from added population and commerce, and a desire to ease congestion and traffic diversion onto routes unacceptably burdened with traffic.