Evaluation of Sketch-Level VMT Quantification Tools

A Strategic Growth Council Grant Programs Evaluation Support Project

August 2017

A Research Report from the National Center for Sustainable Transportation

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National Center for Sustainable Transportation

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1. Introduction

The State of California has enacted ambitious policies that aim to reduce the state's greenhouse gas (GHG) emissions. Some of these policies focus on reducing the amount of driving throughout the state, measured in vehicle miles traveled (VMT), given that transportation, primarily automobile use, is the largest single source of California's GHG emissions.[1] To encourage local plans and projects that reduce VMT, California has established several grant programs to which local jurisdictions may apply.

These grant programs have generated a need for methods to estimate the potential VMT – and thus GHG – impacts of proposed planning efforts, land development projects, and transportation projects. A range of VMT estimation methods are available for use by funding applicants. Regional travel demand models, for example, are used to estimate the VMT and GHG implications of alternative scenarios in the development of federally-required regional transportation plans and state-required sustainable communities strategies. These models are resource intensive, however, requiring modeling expertise and sometimes many days to complete a single analysis. To fill the need for less resource-intensive methods more appropriate for localized plans and individual projects, upwards of a dozen "sketch" tools have been developed.

These sketch tools vary in their approach and appropriateness for the breadth of development projects and project locations in the state. Practitioners are often unsure as to which method to use for a particular project and have little information to guide their choice. In this report we compare and evaluate VMT estimation tools across a sample of land use projects. We compare the results from different tools for each project, consider the applicability of methods in particular contexts and for different types of projects, and assess data needs, relative ease of use, and other practical considerations.

Policy Basis

Assembly Bill 32, passed by the California legislature in 2006, established ambitious targets for reducing the state's GHG emissions. In 2008, Senate Bill 375 established targets for metropolitan areas for reducing GHG emissions in part by reducing vehicle miles of travel (VMT) through coordinated land use and transportation planning at the regional level. Metropolitan Planning Organizations (MPOs) in California must demonstrate that their federally-required regional transportation plans and state-required sustainable communities strategies will meet regional targets for VMT and GHG reductions. Although the MPOs have primary authority over decisions about major transportation projects within the region, implementation of their sustainable communities strategies depends on land use and transportation planning and project approvals made by cities and counties.

[1] California Air Resources Board. 2017. California Greenhouse Gas Emission Inventory: 2000 – 2014. arb.ca.gov/cc/inventory/pubs/reports/2000_2014/ghg_inventory_trends_00-14_20160617.pdf

To encourage local land use and transportation plans and projects that support these regional plans, California has established several grant programs. Since 2006, the California Strategic Growth Council has administered several programs supporting greenhouse gas reductions through planning, capital project development, and acquisition of easements. These programs include:

- Sustainable Communities & Climate Change Reduction Programs (Proposition 84 funding): The SGC Sustainable Community Planning Grants and Incentives Program were made available to local and regional governments for planning activities – general plan updates, specific plans, corridor plans, zoning changes, public works policy changes, etc. – that support the planning and development of sustainable communities and lead to GHG reductions.[2]
- Affordable Housing and Sustainable Communities (AHSC) program: AHSC grants and affordable housing loans provide funding for transit-oriented developments and related infrastructure that reduce GHG emissions. Funding can be used for new housing, housing-related infrastructure, acquisition and substantial rehab, conversion of non-residential to residential uses, mixed-use developments, and connectivity projects to and by low-carbon transportation modes (increased transit service, transit ridership programs, bicycle and pedestrian facilities, vanpool programs). Such projects may reduce GHG emissions by decreasing travel distances and shifting travel modes to transit and active transportation.[3]
- Sustainable Agricultural Land Conservation (SALC) program: The SALC program is a component of the AHSC programs and funds planning and conservation management strategies to protect farm and ranch land. Preservation of agricultural land can reduce GHG emissions by preventing GHG-intensive urban sprawl and encouraging more compact development patterns. These measures can also preserve the carbon sequestration potential of land, by preventing the conversion of natural areas such as forests, wetlands, and riparian systems. Additionally, lower intensity agricultural uses with relatively low GHG emissions can be preserved from conversion to more carbon-intense higher-intensity agricultural uses.[4]

The legislature and governor have appropriated funding to the Strategic Growth Council for the AHSC and SALC programs from revenue collected from the State's Greenhouse Gas Reduction Fund. Because of their funding source, it is critical that AHSC and SALC grants contribute to the state's goals for reducing GHGs. This imperative creates a need for methods to estimate potential GHG reductions from the projects proposed for these grants, but also points to a need for methods for estimating potential GHG reductions throughout the planning process as local

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[2] California Natural Resources Agency. 2015. Bond Accountability: Proposition 84. bondaccountability.resources.ca.gov/p84.aspx

[3] California Strategic Growth Council. 2015. Affordable Housing and Sustainable Communities Program. http://www.sgc.ca.gov/Grant-Programs/AHSC-Program.html

[4] California Strategic Growth Council. 2015. Sustainable Agricultural Lands Conservation. http://www.sgc.ca.gov/Grant-Programs/AHSC-Program.html

governments and others weigh different planning scenarios. GHG quantification methods are needed for land development projects but also for the broader planning activities and implementation approaches that ultimately shape land development projects.

2. Existing Tools

Various agencies in the state have done significant work to estimate the GHG impacts of land use projects incentivized by current funding programs, and a number of different tools for estimating VMT impacts have been used in previous rounds of the SGC's grant programs. This report evaluates previously used as well as other potentially useful VMT estimation tools. Our focus is on sketch tools appropriate for local plans and projects and feasible for local jurisdictions, and we consider their usefulness in assessing the VMT impacts of area plans and land development projects. In this report we do not examine methods for assessing the VMT impacts of transportation investments, though tools for this purpose are also needed.

To build an inventory of existing tools, we conducted an extensive review of the literature and consulted with experts in the field. We convened a one-day meeting in May 2016 attended by nearly 20 representatives from metropolitan planning organizations, air districts, academia, the California Air Resources Board, the Governor's Office of Planning and Research, the Strategic Growth Council, and transportation consulting firms. This panel discussed the strengths and weaknesses of each tool and provided input on their unique attributes. The tools reviewed are list in Table 1; further information about the tools and their inputs and outputs are provided in Appendix A.

Overview of Different Approaches

In past rounds of the AHSC program, the California Air Resources Board (CARB) has required applicants to measure GHG reductions of proposed projects stemming from reduced VMT using the California Emissions Estimator Model (CalEEMod). ARB has published step-by-step guidelines for calculating VMT and GHG reductions for development projects with CalEEMod, and has outlined additional methods for calculating VMT and GHG reductions that may result from changes in transit service and transportation infrastructure projects.[5] The Governor's Office of Planning and Research (OPR) has suggested, with caveats, the use of CalEEMod for evaluating the transportation impacts of certain kinds of development projects in the California Environmental Quality Act (CEQA) process under new requirements established by California Senate Bill 743 (2013).

In addition to CalEEMod, many other models, methods, and tools are available that local jurisdictions and regional agencies could use to estimate VMT-related GHG impacts. A common way that VMT impacts are estimated is by multiplying the number of trips generated (the number of trips to and from a project site or area) by average trip lengths. Traditionally, trip generation is calculated with standard trip rates for various land uses published by the Institute of Transportation Engineers (ITE). These trip rates are based on studies of sites that are mostly in auto-oriented, suburban areas. Thus, these rates can greatly overestimate trip projections for

[5] California Air Resources Board. 2015. Greenhouse Gas Quantification Methodology for the Strategic Growth Council Affordable Housing and Sustainable Communities Program. Sacramento, CA. Available: http://www.arb.ca.gov/cc/capandtrade/auctionproceeds/sgc_ahsc_qm_15-16.pdf

infill, centrally-located, transit-oriented, or "smart growth" development[6] – types of development likely to be seen in AHSC grant applications. Different models take varying approaches to adjust for this overestimation. These approaches fall into four general categories, discussed in more detail below:

- Reduce trip generation estimates by removing trips that are not new.
- Use statistical models to derive reduced estimates for trips based on project and context characteristics.
- Use statistical models to derive reduced estimates for VMT based on project and context characteristics.
- Use separate elasticities for specific project or context characteristics to derive reduced estimates for VMT.

In this report, we do not discuss the use of regional travel demand models. Regional models are effective tools for evaluating the impact of major transportation investments; however, their use is likely infeasible or impractical for analyzing the kinds of smaller-scale projects that are generally proposed for these grant programs. A summary of all tools considered is in Table 1, below.

Method 1: Reduce trip generation projections by removing trips that are not new

One of the simpler approaches to adjusting trip generation estimates is to subtract trips to and from a project site that are not "new." Examples of non-new trips include "pass-by" trips, defined as trips to a site made by travelers who already had been passing by a site before a development, and "on-site" trips where travelers make multiple stops within a development. Projects in already-developed areas (i.e. infill projects) have a greater likelihood for pass-by trips, and on-site trips are more likely in mixed-use developments. The Urban Emissions (URBEMIS) model, a model that has historically been used in CEQA air quality analysis, uses this approach. VMT+, an online spreadsheet developed by the consulting firm Fehr & Peers, also calculates trip reductions in this way.

In both models, users must enter the percentages of trips that are not new. Resources that give guidance on this question include *NCHRP Special Report 684: Enhancing Internal Trip Capture Estimation for Mixed-Use Developments*.[7] Information from NCHRP 684 are incorporated into 3rd edition of the *ITE Trip Generation Handbook* (2014).[8]

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[6] Shavizadeh, K., R. Lee, D. Niemeier, T. Parker, and S. Handy. 2012. Evaluation of the Operation and Accuracy of Available Smart Growth Trip Generation Methodologies for Use in California. Transportation Research Record 2307: 120-131.

[7] National Cooperative Highway Research Program. 2011. NCHRP Report 684: Enhancing Internal Trip Capture Estimation for Mixed-Use Developments. Available: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_684.pdf

[8] Institute of Transportation Engineers. 2014. Trip Generation Handbook (3rd edition)

Method 2: Use statistical models to derive reduced estimates for trips

Other methods involve the use of statistical models to identify characteristics of projects and their surrounding areas that have strong statistical associations with trips. The California Smart-Growth Trip Generation (SGTG) Adjustment Tool developed by researchers affiliated with the Institute of Transportation Studies at UC Davis calculates an adjustment factor based on eight variables related to land use characteristics and transit availability. The adjustment factors are based on data collected at 50 project sites in California and were validated using data from another sample of California sites. The reduced trip projections from this tool, which should be used only for projects that meet certain "smart growth" criteria, can be multiplied by trip lengths to calculate VMT. In these case studies, trip lengths were obtained from the 2010 run of the California Statewide Travel Demand Model[9]. The average home-based trip length was used with the trip generation rates from the California Smart Growth Trip Generation Adjustment Tool to find project-generated VMT.

Similar to the California Smart-Growth Trip Generation Adjustment Tool is a method developed by Clifton, Currans, and Muhs[10] that calculates trip adjustment factors for projects in urban areas. They identified nine built environment characteristics that affect trip rates. Several of these built environment characteristics are similar to those used in the California Smart-Growth Trip Adjustment Tool but are defined slightly differently. A related paper by Currans and Clifton[11] discusses how household travel surveys could be used to adjust trip generation rates.

The Clifton, Currans, and Muhs method is based on data collected in Oregon. That said, smart growth elements appear to have a similar effect on travelers in Oregon as in California. An application of the SGTG tool to the Oregon sites used by Clifton, Currans, and Muhs found that that California-based SGTG model successfully predicted trips in Portland more accurately than standard ITE rates.[12]

Several tools are based on the US Environmental Protection Agency's MXD method developed by Fehr & Peers. The MXD model adjusts ITE trip generation rates based on several built environment characteristics. The original MXD model, in the form of a spreadsheet tool, is available from the US EPA. A second version of the MXD model and spreadsheet tool, updated with data for the San Diego region, is available from the San Diego Association of Governments. Similar to the California Smart Growth Trip Estimation Tool, MXD estimates trip generation

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[9] California Statewide Travel Demand Model data are available from Caltrans: www.dot.ca.gov/hq/tpp/offices/omsp/SB743.html

[10] Clifton, K., K. Currans, and C. Muhs. 2015. Adjusting ITE's Trip Generation Handbook for urban context. The Journal of Transport and Land Use. 8(1): 5-29.

[11] Currans, K. and K. Clifton. 2015. Using household travel surveys to adjust ITE trip generation rates. The Journal of Transport and Land Use. 8(1): 85-119.

[12] McFadden, A., R. Schneider, K.Shafizadeh, and S. Handy. 2013. Verification and Re-Estimation of the Smart Growth Trip Generation Model with Portland Data. Davis, CA. Available: http://downloads.ice.ucdavis.edu/ultrans/smartgrowthtripgen/SGTG_Portland_Report_final.pdf

rates. Trip generation rates are multiplied by user-entered trip lengths. Trip lengths for MXD can be obtained from the California Statewide Travel Demand Model.

The planning tool site Envision Tomorrow incorporates two models, one that calculates trip generation reductions for mixed-use project sites and one for mixed-use districts. The Envision Tomorrow site-level model is based on the EPA MXD method. The Envision Tomorrow district-level model is based on studies by Reid Ewing of the Center for Metropolitan Studies at the University of Utah.

Fehr & Peers also has developed a proprietary method, MXD+, which combines the MXD method and the aforementioned NCHRP 684 report. More information on MXD+ is available from in an American Planning Association Public Advisory Service memo by Walters, Bochner, and Ewing (2013).[13]

Method 3: Use statistical models to derive reduced estimates for VMT

Rather than identifying variables associated with trip generation, other models associate numerous land use and transportation characteristics for the project and the surrounding area directly with VMT. A working paper by Newmark and Haas[14] of the Center for Neighborhood Technology models how demographics, household income, regional context, and location efficiency are associated with VMT. The model from their paper is the basis for the web-based tool GreenTrip Connect, hosted by the advocacy group TransForm. GreenTrip Connect complements the GreenTrip certification system, a rating system for low-driving developments in the Bay Area (a similar rating concept as the LEED rating system for green buildings). Connect increases understanding of the potential impact of land use and transportation-related GHG reduction measures by comparing project-generated VMT to average household VMT in the project's city, county, and metropolitan region. The comparison to average city, county, or regional VMT makes GreenTrip Connect an efficient tool to use for comparing project VMT to thresholds and targets, as is required for environmental review under CEQA.

A report by Salon, then at UC Davis, prepared for the California Air Resources Board and the California Environmental Protection Agency, presents a model that correlates land use and transport system variables with VMT[15]. The model is based on empirical analysis of five California-based household travel surveys. The associated VMT Impact Tool spreadsheet allows users to select California jurisdictions and census tracts to view how VMT changes as a function of changes to eight land use and transportation system characteristics.

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[13] Walters, J., B. Bochner, and R. Ewing. 2013. Eliminating the Bias Against Mixed Use Development. American Planning Association – Planning Advisory Service Memo. Available: http://www.fehrandpeers.com/wp-content/uploads/2013/07/APA_PAS_May2013_GettingTripGenRight.pdf

[14] Newmark, G. and P. Haas. 2015. Income, Location Efficiency and VMT: Affordable Housing as a Climate Strategy. Center for Neighborhood Technology. Working Paper.

[15] Salon, D. 2014. Quantifying the effect of local government actions on VMT. Available: http://www.arb.ca.gov/research/apr/past/09-343.pdf

Sketch 7, another spreadsheet tool, estimates VMT based on seven land use and transportation characteristics. Sketch 7 was developed as a statewide tool but has been primarily used and maintained in the Sacramento region. Several versions were built, calibrated to the San Diego region, for small/medium MPOs, and for Bay Area rail corridors. Notably, Sketch7 projects VMT for several situations including a given project, the surrounding area (the context area) in a before-and-after project scenario, and compares the project scenarios to the regional VMT averages.

Similar to Sketch 7, Envision Tomorrow Plus (ET+) allows users to "paint" development scenarios onto parcels and compare scenario outcomes. ET+ is based on the aforementioned original Envision Tomorrow suite of tools. ET+ was developed for planning efforts in Utah, funded by a US Department of Housing and Urban Development Sustainable Communities Regional Planning Grant awarded to Salt Lake County, Wasatch Front Regional Council, and other agencies in the Salt Lake City region.

UrbanFootprint, an open-source downloadable software program, analyzes fiscal, environmental, public health, and transportation impacts of plans and policies. For transportation impacts, UrbanFootprint runs a sketch-level travel model based on land use and transportation system characteristics that outputs VMT. UrbanFootprint was funded by departments within the State of California, MPOs in California, as well as NGOs and other state and federal grants.

Method 4: Use separate elasticities for specific project or context characteristics to derive reduced estimates for VMT

A final method involves the use of elasticities for specific project characteristics such as density or land-use mix to adjust VMT estimates. CalEEMod, commonly used for CEQA air quality analyses, uses this method with elasticities taken from the *Quantifying GHG Mitigation Measures* report published by the California Air Pollution Control Officers Association (CAPCOA)[16]. By default, CalEEMod calculates transportation-related VMT using estimates of trips based on the traditional ITE trip generation rates multiplied by trip lengths. The tool includes default trip lengths based on the 1999 California Household Survey, but it allows users to input other trip lengths, a practice recommended by OPR given the obsolescence of the default values and the wide variation in trip lengths within the state. The user specifies which adjustments to make to the VMT estimates based on project characteristics. Given its focus on project rather than area characteristics, the tool may not be not well suited to the analysis of plans.

[16] California Air Pollution Control Officers Association. 2010. Quantifying Greenhouse Gas Mitigation Measures. Sacramento, CA. Available: http://www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf

GHG reductions for transportation projects

The methods discussed above are potentially useful for estimating the GHG impacts of development projects and area plans. Given that their starting point is the trip-generation potential of land development, they are not useful for estimating the GHG impacts of transportation investments. Transportation investments do not directly generate travel in the way that development projects do, though they may induce additional travel through a variety of mechanisms[17].

As previously mentioned, the ARB guide for quantifying GHGs for the AHSC program recommends methods applicable for transportation projects, referred to as transit and connectivity (TAC) methods. The types of projects for which TAC methods are available are: operation of new bus, train, vanpool or shuttle service; operation of new ferry service; bicycle paths or lanes; and pedestrian facilities. For each of the TAC methods, ARB identifies data required and a series of equations to calculate GHG reductions. It is important to note that the methods approved for these grant programs are not held to the same legal defensibility standards as those used in CEQA analysis. Analysis used for CEQA must be based on "substantial evidence" and "best available" data. Analysis for grant programs requires the rigor requested by the granting agency.

[17] Handy, S. 2015. Increasing Highway Capacity Unlikely to Relieve Traffic Congestion. Policy Brief. National Center for Sustainable Transportation.

Table 1: Sketch-Level VMT Quantification Models		
Tool	Outputs (trips or VMT)	Key variables for determining reduced trip/VMT rates for smart growth-type development
URBEMIS	Trips	Diverted trips/ Pass-by trips
VMT+	Trips (and VMT)	Pass-by trips/ On-site trips
California Smart-Growth Trip Generation Adjustment Tool	Trips	Eight smart growth factors (population, location, urban form, parking, and transit-related characteristics)
Clifton, Currans, and Muhs (2015)/ Adjusting ITE Trip Gen. for Urban Context	Trips	Nine built environment factors (population, employment, urban form, and alternative transportation-related characteristics)
Envision Tomorrow Site-Level Model	Trips	Six factors (intersection density, transit presence, central location, nearby employment, employment accessible by transit, vehicle ownership)
Envision Tomorrow District-Scale Model	Trips	11 factors covering five topics (employment, intersections, transit availability, travel speed, district area)
MXD	Trips	Multiple characteristics including project and surrounding area characteristics.
Envision Tomorrow+	VMT	Multiple characteristics including project land use characteristics, surrounding land use characteristics, street network, land values, population and economic data
Sketch 7	VMT	Seven D's of land use and transportation (auto/ transit accessibility, jobs/housing balance, residential density/diversity, street pattern, demographics)
Urban Footprint	VMT	Land use, road network, transit data demographic and economic data
CNT (2015)/Green Trip Connect	VMT	Location (surrounding land use and transportation characteristics, parking spaces/charges, presence of affordable housing/rents, offers of residential transit passes/carshare/bikeshare
VMT Impact Tool/Salon (2014)	VMT	Eight land use and transportation variables (% transit commuters, % non-motorized commuters, gas prices, % single-family homes, road density, activity mix, regional job access, local job access
CalEEMod	VMT	Measures in CAPCOA Quantifying GHG Mitigations Report

3. Selection of Tools

With input from the expert panel, we selected six tools were for application in a series of case studies. The selected tools span the range of analytical methods identified earlier. The tools selected for this analysis and their applicability for certain types of projects and context areas are summarized in Table 2.

Table 2: VMT Quantification Tools Selected

Tools	Methodology	Applicability
CalEEMod 2013 & 2016	Adjustment to VMT based on elasticities	• Commercial (subset), educational, industrial, recreational, residential, retail (subset). • Any context area
California Smart Growth Trip Generation Adjustment Tool	Statistically-based reduction in trips	• Mid- to high-density residential, office, restaurant, coffee shop, retail. • "Smart growth" project location
GreenTrip Connect	Statistically-based reduction in VMT	• Residential. • Any context area
MXD	Statistically-based reduction in trips	• Residential, retail, office, industrial (subset), commercial (subset), educational, other. • Any context area
Sketch 7	Statistically-based reduction in VMT	• Mixed use, residential, office, retail, industrial, public, civic, medical, educational, military, airport. • Any context area

4. Case Studies

We used the six selected tools to assess VMT impacts for a variety of case study projects. We selected a diverse mix of land use projects and context areas to compare each tool's strengths and weaknesses. Case study projects are located in the San Francisco Bay Area and the Sacramento region and represent actual projects proposed to local jurisdictions. Some projects had been built at the time of the analysis and nearly all had gone through some form of environmental review. A summary of the case studies and their characteristics is presented in Table 4. We describe the case study projects and discuss the VMT estimates in this section.

In addition to estimating VMT impacts for actual proposed projects, we used a series of hypothetical projects to test the ability of the tools to account for contextual factors (central business district, high-quality transit, urban neighborhood, exurban, etc.). The sensitivity test gives insight into each tool's analytical capacity in a way that is obscured when both land uses and context areas are varied across case studies. The sensitivity analysis is discussed in Section 5.

Application of Tools

Not every tool is suitable for every case study project, as some of the tools have built-in constraints. For example, the California Smart Growth Trip Adjustment Tool should only be applied to projects that meet certain smart growth criteria: population density, employment density, distance to central business district, bicycle and walking infrastructure, etc. must be present around the modeled project for the results to be valid. The completed analyses are listed in Table 3.

GreenTrip Connect exclusively estimates VMT for residential projects, so we used it to evaluate all projects with a residential component but did not use it to evaluate the El Camino Real Corridor plan nor the Second Street Crossing project in Davis, both of which are entirely retail and commercial projects. Similarly, GreenTrip Connect's estimates of VMT are solely estimated based on the residential components of mixed-use projects. For example, it does not account for the VMT generated from the research & development component of the Nishi Gateway. Thus, GreenTrip Connect produces only a partial estimate of VMT impacts for mixed-use projects.

Although Sketch7 was built and calibrated for multiple regions and contexts, the Sacramento Area Council of Governments has been the primary user, and the agency has maintained a database for inputs. As such, its use is limited to the Sacramento region without investment from other regional planning agencies to develop the needed inputs. We thus applied Sketch7 only for case studies in the Sacramento region.

The use of tools for each case study is summarized in Table 3 and discussed below. It is important to note that the results reported depend on the assumptions we made in applying the methods and the values we used as inputs. These tools are highly sensitive to assumptions and inputs, and other analysts applying these methods to these projects might generate very

different results. Our goal is not to produce the most realistic estimate but to illustrate what goes into the use of these tools and the range of results they can produce.

Table 3: VMT quantification tools applied to each case study

Case Study	CalEEMod 2013 & 2016	CA Smart Growth Trip Adj. Tool	GreenTrip Connect	MXD	Sketch7
El Camino Real Corridor	●	●		●	
The Cannery	●		●	●	●
The Crossings/ Marea Alta	●	●	●	●	
Nishi Gateway	●		●	●	●
Second Street Crossing	●			●	●

Table 4: Summary of Case Study Characteristics			
Case Study	Second Street Crossing	Nishi Gateway	The Cannery
Location	Davis	Davis	Davis
Geographical context	Urban edge	Adjacent to downtown	Urban edge
Prior Land Use	Undeveloped	Undeveloped	Industrial (tomato cannery)
Site Area	19 acres	50 acres	100 acres
Project Land Use Characteristics	173,000 square feet community-oriented retail, including a Target store, 14.9 acres surface parking	Mixed use: 325,000 square feet research & development, 650 units of multi-family residential, 20,000 square feet retail, 13.1 acres surface parking	Mixed use: 610 residential units (high-, medium-, and low-densities, including 110 affordable units), up to 236,000 square feet mixed-use commercial, office, open space, urban farm
Transit within ¼ mile	Bus, < ½ hr. headways: 4 lines Bus, Commute: 3 lines Rail: None	Bus, < ½ hr. headways: 6 lines Bus, Commute: 4 lines Rail: Amtrak Capitol Corridor, California Zephyr, Coast Starlight	Bus, < ½ hr. headways: 3 lines Bus, Commute: 3 lines Rail: None
Adjacent Land Uses	Multi-family residential, single-family residential, commercial, industrial	Central business district, multi-family residential, university, retail (including restaurant and supermarket), commercial, light industrial	Agricultural, single-family residential, multi-family residential, commercial, retail, office, park
Adjacent Transportation Network	Major arterial, minor arterial, Interstate 80	Local streets (historical downtown grid), major arterial, Interstate 80	Local streets, major arterial, Union Pacific Railroad
Adjacent Bicycle Infrastructure	On-street bicycle lanes, off-street path, bicycle parking	On-street bicycle lanes, off-street paths, bicycle parking	On-street bicycle lanes, off-street paths
Project Status	Approved by City Council and public vote in 2006; built; opened for business in 2009	Approved by City Council and rejected by public vote in 2016; not built	Approved by City Council in 2013; construction began 2014

Project	The Crossings / Marea Alta	El Camino Real Corridor
Location	San Leandro	Mountain View
Geographical context	Suburban center, adjacent to downtown	Suburban center, adjacent to downtown
Prior Land Use	Surface parking lot	Mix of mostly strip commercial and some residential uses on corridor
Site Area	2 acres	21 acres
Project Land Use Characteristics	200 units of affordable multi-family residential, including 85 senior apartments	Mixed use: 500 residential units, 1,000,000 square feet office, 250,000 square feet retail, 250,000 square feet restaurant
Transit within ¼ mile	Bus, < ½ hr. headways: 4 lines Bus, Commute: 6 lines Rail: Bay Area Rapid Transit (BART)	Bus, < ½ hr. headways: 2 lines Bus, Commute: 4 lines Rail: None
Adjacent Land Uses	Central business district, multi-family residential, single-family residential	Central business district, multi-family residential, single-family residential
Adjacent Transportation Network	Major arterial, local streets (downtown grid)	Major arterial, local streets
Adjacent Bicycle Infrastructure	None	None
Project Status	Approved by City Council in 2014; under construction	Hypothetical scenario

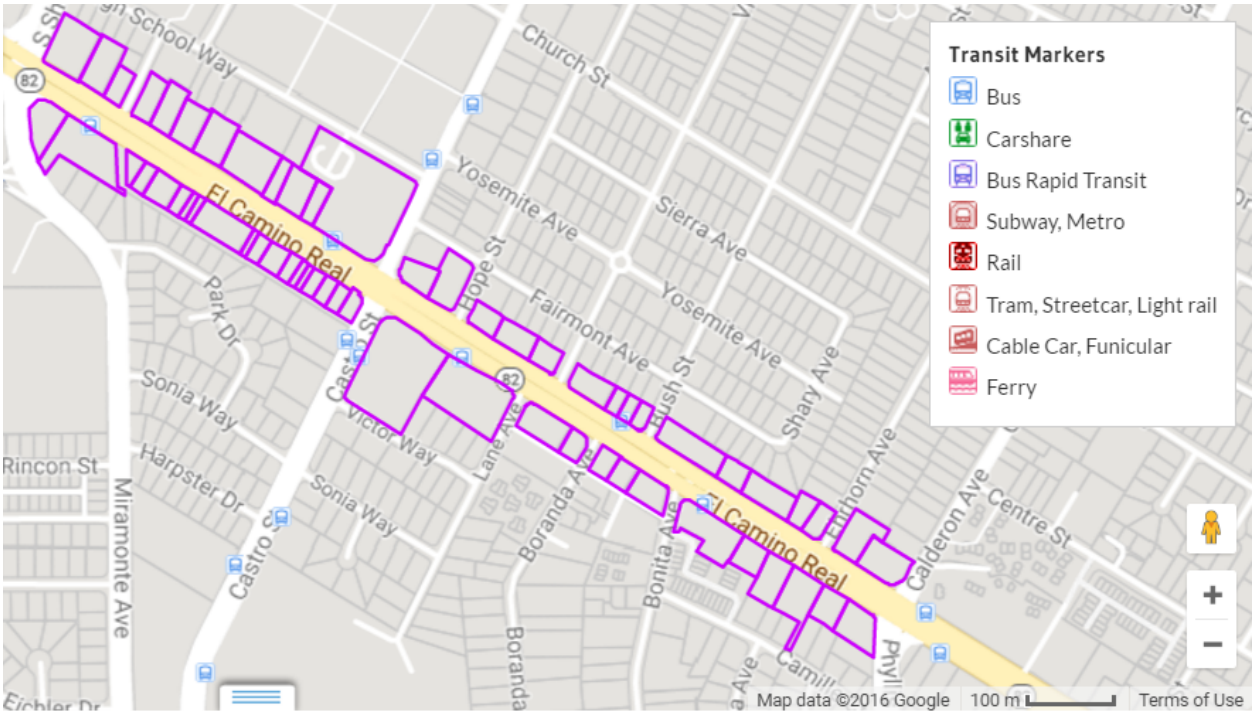
El Camino Real Corridor – Mountain View

El Camino Real (California Route 82) is a state highway that takes the form of a major arterial through several suburban cities in the Peninsula and South Bay Area. Along much of the route, El Camino Real is surrounded by low-density, strip commercial, auto-oriented development; however, many jurisdictions have targeted El Camino Real as a major redevelopment opportunity. The "Grand Boulevard Initiative" seeks to convert El Camino Real into a more vibrant, mixed-use, pedestrian and transit-oriented corridor. Several cities, including Mountain View, have created specific plans for the El Camino Real corridor to reflect this vision.

Modeling the VMT implications of a specific plan is somewhat difficult. Unlike a development proposal which proposes an exact amount of development, specific plans outline more general parameters of development, with varying uses and amounts of development along an amorphous geography. Thus, in this case we illustrate a theoretical buildout scenario for a portion of El Camino Real in Mountain View. Real development will not be built exactly to the specifications of the scenario, but the scenario is in the spirit of the applicable policies of the area.

The modeled scenario includes parcels that are adjacent to El Camino Real between Shoreline Boulevard and Calderon/Phyllis Avenues. Using the area measure tool on an online mapping tool, we calculated the land area of the parcels in this scenario to be approximately 21 acres, just under one million square feet.

Figure 1. El Camino Real - Mountain View scenario corridor



Key scenario assumptions include an overall floor area ratio (FAR) along the corridor of 2.0, which is typical of two-story buildings using nearly all of the parcel (minimal setback). This

results in a projected total building area of approximately two million square feet. In multi-story, mixed-use buildings, ground floors are typically a mix of retail, service, and office uses, and upper floors are a mix of office and residential. Thus this scenario thus assumes a 25% residential mix, 50% office mix, and 25% retail/service mix. Using specific ITE Trip Generation codes – required by some models – the scenario assumes 25% low-rise apartments, 50% general office, 12.5% retail, and 12.5% quality restaurant (a distribution of land uses that may or may not be realistic given the market in the area). The 25% of building area for low-rise apartments extrapolates to 500,000 square feet. Assuming an average unit size of 1,000 square feet, the scenario assumes 500 housing units.

Inputs about the surrounding area were gathered by visual inspection of Google Maps and statistics produced by web-based GIS mapping services, including the US Census Longitudinal Housing and Employment Dynamics (LEHD) On The Map tool and ESRI Community Analyst.

GreenTrip Connect was only used to model VMT from the residential development portion of the scenario. The mixed uses also necessitated multiple runs of the California Smart Growth Trip Generation Model: one run for each of the five different land use codes incorporated in the scenario. This project is based in the San Francisco Bay Area, thus Sketch7 does not have the requisite base data and was not used.

Table 5: VMT Estimates – El Camino Real Corridor

	Output from Tool	Standardized Estimate (VMT per day)
California Smart Growth Trip Generation Tool[1]	914 AM Peak Hour Trips 2,611 PM Peak Hour Trips	160,968
CalEEMod 2013	Mitigated: 65,580,664 VMT per year Unmitigated: 69,032,278 VMT per year	Mitigated: 179,673 Unmitigated: 189,130
CalEEMod 2016	Mitigated: 65,907,035 VMT per year Unmitigated: 69,375,826 VMT per year	Mitigated: 180,567 Unmitigated: 190,071
GreenTrip Connect[2]	16 VMT per HH per day	7,979 (household)
EPA MXD Tool[1]	313,238 VMT per day	313,238
Sketch7	Not applicable	Not applicable

[1] Trip lengths from California Statewide Travel Demand Model

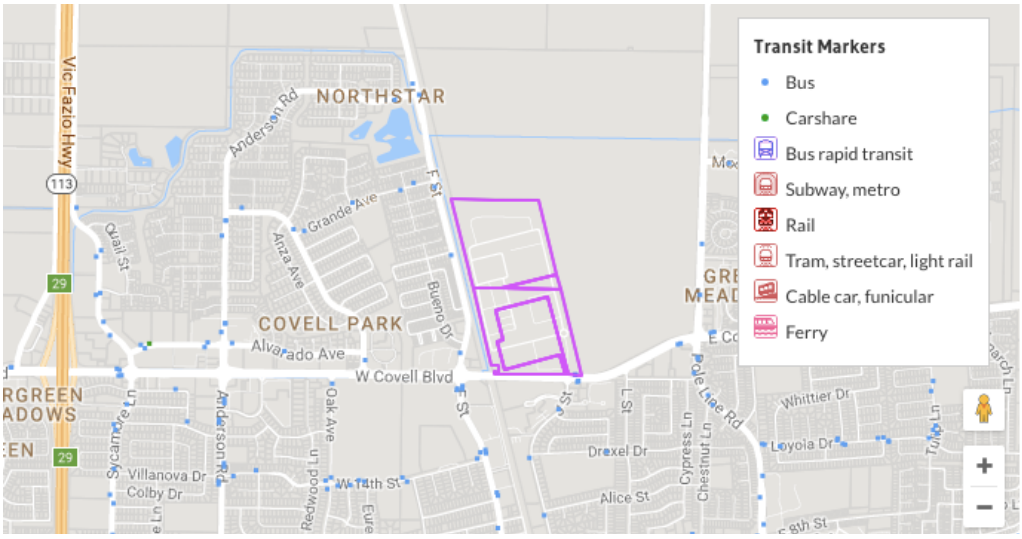
[2] GreenTrip Connect estimates only VMT from residential component of corridor plan

Table 6: Greenhouse Gas Estimates – El Camino Real Corridor		
	Transportation GHG Output	Standardized Estimate (MT CO_2e per year)
California Smart Growth Trip Generation Tool	None	None
CalEEMod 2013	Mitigated: 28,636 MT CO_2e per year Unmitigated: 30,060 MT CO_2e per year	Mitigated: 28,636 Unmitigated: 30,060
CalEEMod 2016	Mitigated: 24,731 MT CO_2e per year Unmitigated: 25,950 MT CO_2e per year	Mitigated: 24,731 Unmitigated: 25,950
GreenTrip Connect	8.06 kg CO_2 per unit per day	1,473
EPA MXD Tool	None	None
Sketch 7	Not applicable	Not applicable

The Cannery – Davis, California

The Cannery is a 100-acre grayfield development adjacent to the northern-most residential neighborhoods in Davis, California. The site was previously a Hunt-Wesson tomato cannery and is surrounded on two sides by actively farmed agricultural land. It is a predominantly residential mixed-use development with multiple housing densities and 240,000 square feet of retail, research and development, and/or commercial land use potential. It proposes approximately 600 dwelling units – 120 of which are affordable housing units – and employment between 600 and 850 jobs.

Figure 2. The Cannery Project Site – Davis



The Cannery is illustrative of residential developments in many parts of California. It is located at the edge of an established community, and has housing densities typical for new semi-suburban housing. Davis is a community with a major employment center (University of California, Davis), is 20 miles west of the major employment center in Downtown Sacramento, and is located on the Interstate 80 corridor approximately 75 miles east the San Francisco Bay

Area. Residential developments in this area would likely generate travel to a mixture of these various employment centers. The immediate and regional land use contexts, as well as the land use mix per se, provide a useful case study to quantify residential VMT.

Project information was gathered from the Notice of Preparation, the preliminary scoping document for an environmental impact report required by the CEQA. Inputs about the surrounding areas were gathered by visual inspection of Google Maps, Google Earth, and from the local transit agencies, Unitrans and Yolobus. Employment and residential data for the surrounding area was gathered from web-based mapping services, including the US Census Longitudinal Housing and Employment Dynamics (LEHD) OnTheMap tool.

Table 7: VMT Estimates – The Cannery

	Output from Tool	Standardized Estimate (VMT per day)
California Smart Growth Trip Generation Tool	Not Applicable	Not Applicable
CalEEMod 2013	Mitigated: 14,302,153 VMT per year Unmitigated: 16,779,964 VMT per year	Mitigated: 41,622 Unmitigated: 47,190
CalEEMod 2016	Mitigated: 11,873,705 VMT per year Unmitigated: 13,825,047 VMT per year	Mitigated: 32,397 Unmitigated: 38,010
GreenTrip Connect	32.73 VMT per HH per day	19,965
EPA MXD Tool	54,139VMT per day	54,139

Table 8: Sketch 7 Estimates– The Cannery

	Regional Average	Context Area	Adj. Context + Project	Project
HH VMT per Capita per Day	19.3	17.33	18.16	19.33
HH VMT Total per Day		130,492	136,742	31,149
Transit Trips per Capita per Day	0.05	0.04	0.02	0.04
Bike or Walk Trips Per Capita per Day	0.35	0.66	0.49	0.60

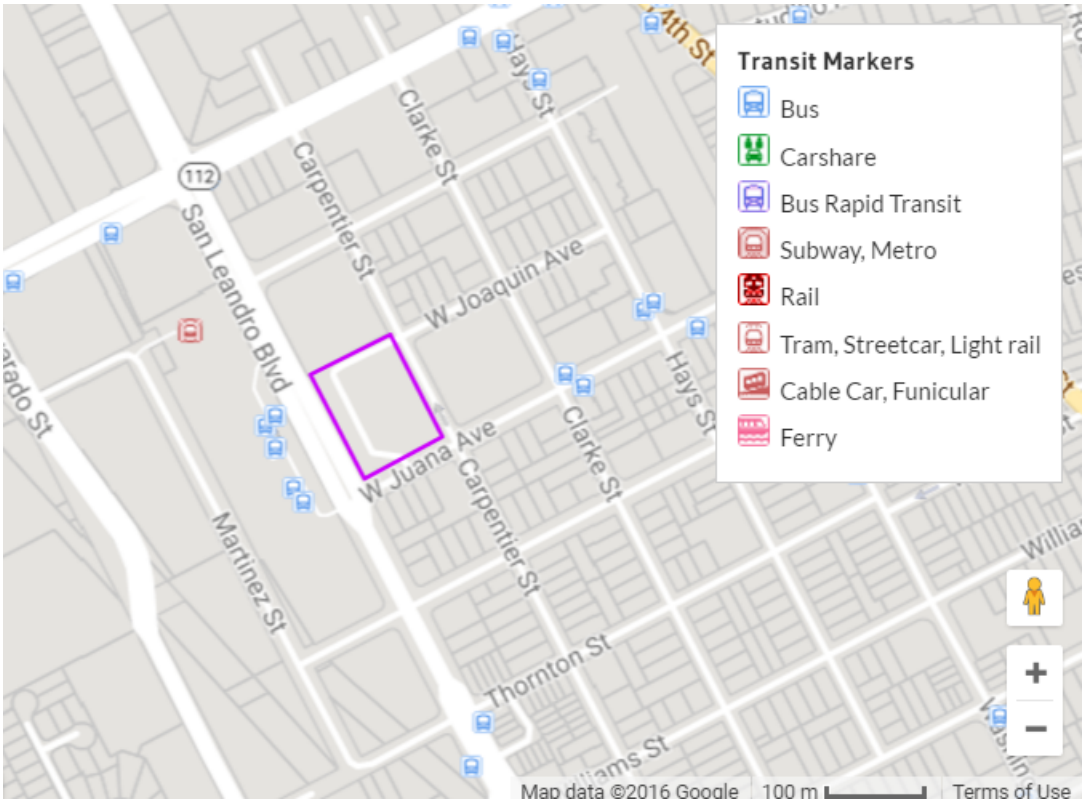
Table 9: Greenhouse Gas Estimates – The Cannery

	Transportation GHG Output	Standardized Estimate (MT CO_2e per year)
California Smart Growth Trip Generation Tool	Not applicable	Not applicable
CalEEMod 2013	Mitigated: 7,039 MT CO_2 per year Unmitigated: 7,943 MT CO_2 per yea	Mitigated: 7,039 Unmitigated: 7,943
CalEEMod 2016	Mitigated: 6,344 MT CO_2 per year Unmitigated: 7,154 MT CO_2 per year	Mitigated: 6,344 Unmitigated: 7,154
GreenTrip Connect	38.9 lbs. CO_2 per HH per day	3,929
EPA MXD Tool	None	None
Sketch 7	None	None

The Crossings/Marea Alta

The Crossings/Marea Alta project is located in San Leandro, California adjacent to the San Leandro BART station in the East Bay Area. It is an example of a residential transit-oriented development as well as an affordable housing project. The project consists of 200 units total – 115 affordable apartments and 85 affordable senior apartments.

Figure 3. The Crossings/Marea Alta Project Site – San Leandro



This case study was selected because the project received "GreenTrip Certification" from the land use and transportation advocacy group TransForm, based in the San Francisco Bay Area. GreenTrip Certification is a program to encourage GHG-reducing planning and design elements by providing the reward of certification. This project being GreenTrip-certified indicates that it should generate a relatively low amount of VMT, and is thus interesting to evaluate with a range of methodological platforms.

Inputs for the models for this project were gathered through project descriptions published by the City of San Leandro and information published by the developer. Inputs about the surrounding area were gathered by visual inspection of Google Map and Google Street View imagery. Context area statistics were pulled from web-based GIS mapping services, including the US Census Longitudinal Housing and Employment Dynamics (LEHD) On The Map tool and ESRI Community Analyst (requires an organizational ESRI subscription).

Uncertainty of project inputs arose regarding land use categories and pricing strategies. For example, CalEEMod allows users to select low-rise apartments or medium-rise apartments;

however, specifications of these two housing types are not apparent within the CalEEMod platform per se. Specifications of these land use types can be compared in the CalEEMod User's Guide, available online. Additionally, GreenTrip Connect allows users to input the price of unbundled parking if included in the project. Parking pricing – a policy decision usually made later in the development process – was often unavailable in the NOPs published per CEQA requirements. Uncertainty around parking pricing, transit pass subsidy, and other GreenTrip strategies arose for every case study in this evaluation. Users of Connect could create a range of pricing scenarios for proposed projects, which could help guide discussion between local jurisdictions and developers to align with local planning policy and climate goals.

The California Smart Growth Trip Generation Tool and GreenTrip Connect produced VMT estimates that were relatively similar, between 2,000 and 4,000 VMT per day. The VMT estimates from the EPA MXD model and the two versions of CalEEMod were much higher, greater than 6,000 VMT per day.

Table 10: VMT Estimates – The Crossings/Marea Alta

	Output from Tool	Standardized Estimate (VMT per day)
California Smart Growth Trip Generation Tool[1]	47 AM Peak Hour Trips 53 PM Peak Hour Trips	3,690
CalEEMod 2013	Mitigated: 2,503,630 VMT per year Unmitigated: 2,945,488	Mitigated: 6,859 Unmitigated: 8,070
CalEEMod 2016	Mitigated: 2,702,241 VMT per year Unmitigated: 3,002,489 VMT per year	Mitigated: 7,403 Unmitigated: 8,226
GreenTrip Connect	2,335 VMT per day	2,335
EPA MXD Tool[1]	6,699 VMT per day	6,699
Sketch 7	Not applicable	Not applicable

[1] Trip lengths from 2010 California Statewide Travel Demand Model

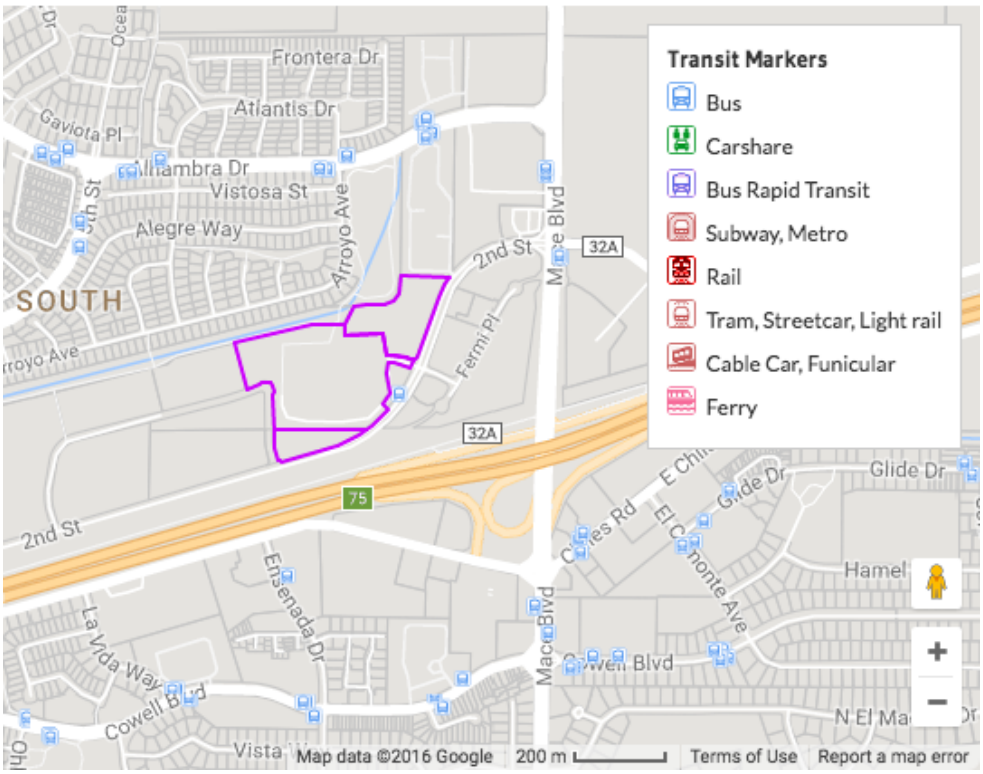
Table 11: Greenhouse Gas Estimates– The Crossings/Marea Alta

	Transportation GHG Output	Standardized Estimate (MT CO_2e per year)
California Smart Growth Trip Generation Tool	None	None
CalEEMod 2013	Mitigated: 1,281 MT CO_2e per year Unmitigated: 1,417 MT CO_2e per year	Mitigated: 1,281 Unmitigated: 1,417
CalEEMod 2016	Mitigated: 1,089 MT CO_2e per year Unmitigated: 1,203 MT CO_2e per year	Mitigated: 1,089 Unmitigated: 1,203
GreenTrip Connect	1.22 MT CO_2e per day	445
EPA MXD Tool	None	None
Sketch 7	Not applicable	Not applicable

Second Street Crossing

Second Street Crossing is located in Davis, California at the eastern-most edge of city limits. It is a commercial development in a community with relatively little retail compared to housing, and was the first "big box" retail store in Davis. The site is 19 acres consisting of 173,000 square feet of retail, including a Target store, and 14.9 acres of surface parking.

Figure 4. Second Street Crossing Project Site – Davis



This case study was selected for several reasons. It is a retail land use development that is commonly seen in suburban areas of California, as shopping centers provide sales tax revenues commonly sought by local governments. It is the first of its kind in Davis but is similar to a shopping center in the City of Woodland, a city approximately 10 miles to the north. Davis features a relatively high non-motorized mode share for the United States; approximately 20% of Davis residents arrive to work by bicycle. This project is on the urban edge – land uses east of Mace Boulevard are almost exclusively agricultural – thus this project site has lower accessibility than other parts of the city. Further, travel patterns of Davis residents were studied before and after the development of this shopping center. Study results showed an overall decrease in per capita shopping-related VMT of about 19 percent after Target opened. This allows understanding of project-based change in VMT within a broader context of regional travel, which most of these sketch models are unable to capture.

Input data were gathered from project descriptions in the Notice of Preparation. Inputs about the surrounding areas were gathered by visual inspection of Google Maps, Google Earth, and

the local transit agencies, Unitrans and Yolobus. Employment and residential data for the surrounding area were gathered from web-based mapping services including the US Census Longitudinal Housing and Employment Dynamics (LEHD) tool.

Some inputs are subject to analyst judgement. For example, land use types are selected from a limited set of options in CalEEMod, Sketch7, and MXD. A retail project such as Second Street Crossing could fall within several land use subtypes: free-standing discount store, free-standing discount superstore, regional shopping center, and strip mall could all ostensibly describe the Target store and its adjacent retail chain stores. Sketch7 and MXD have different land use types than CalEEMod, but pose a similar judgement call.

Table 12: VMT Estimates – Second Street Crossing

	Output from Model	Standardized Estimate (VMT per day)
California Smart Growth Trip Generation Tool	Not applicable	Not applicable
CalEEMod 2013	Mitigated: 14,428,253 VMT per year Unmitigated: 15,497,587 VMT per year	Mitigated: 39,529 Unmitigated: 42,459
CalEEMod 2016	Mitigated: 11,480,817 VMT per year Unmitigated: 12,331,704 VMT per year	Mitigated: 31,454 Unmitigated: 33,786
GreenTrip Connect	Not applicable	Not applicable
EPA MXD Tool	59,205 VMT per day	59,205

GreenTrip Connect and California Smart Growth Trip Generation Tool were not applicable for this project. GreenTrip Connect models only residential development, and the Smart Growth Trip Generation Tool deemed itself inapplicable to the project because of the lack of residential and employment density surrounding the project location, as well as its low transit accessibility.

Sketch7 is unique in its VMT outputs. It estimates the change in daily household VMT from a baseline for its half-mile radius context area. Its outputs report the daily household VMT for the context area (all parcels in the half-mile context area, excluding the project site), the adjusted VMT of the context area including the new land use project, and the VMT of just the project site. When a project site has no residential land uses as is the case of Second Street Crossing, Sketch7 outputs 0 project-based VMT because there are 0 households.

Both of Sketch7's VMT metrics are important to consider. The amount of VMT going to and from a parcel – as shown by CalEEMod and MXD – can be useful for understanding the location efficiency of a project. The analysis is particularly useful when that project is mostly residential. The change in travel behavior in a neighborhood (or context area) that results from a land development project gives a more useful metric for evaluating the efficiency of the land use and transportation network.

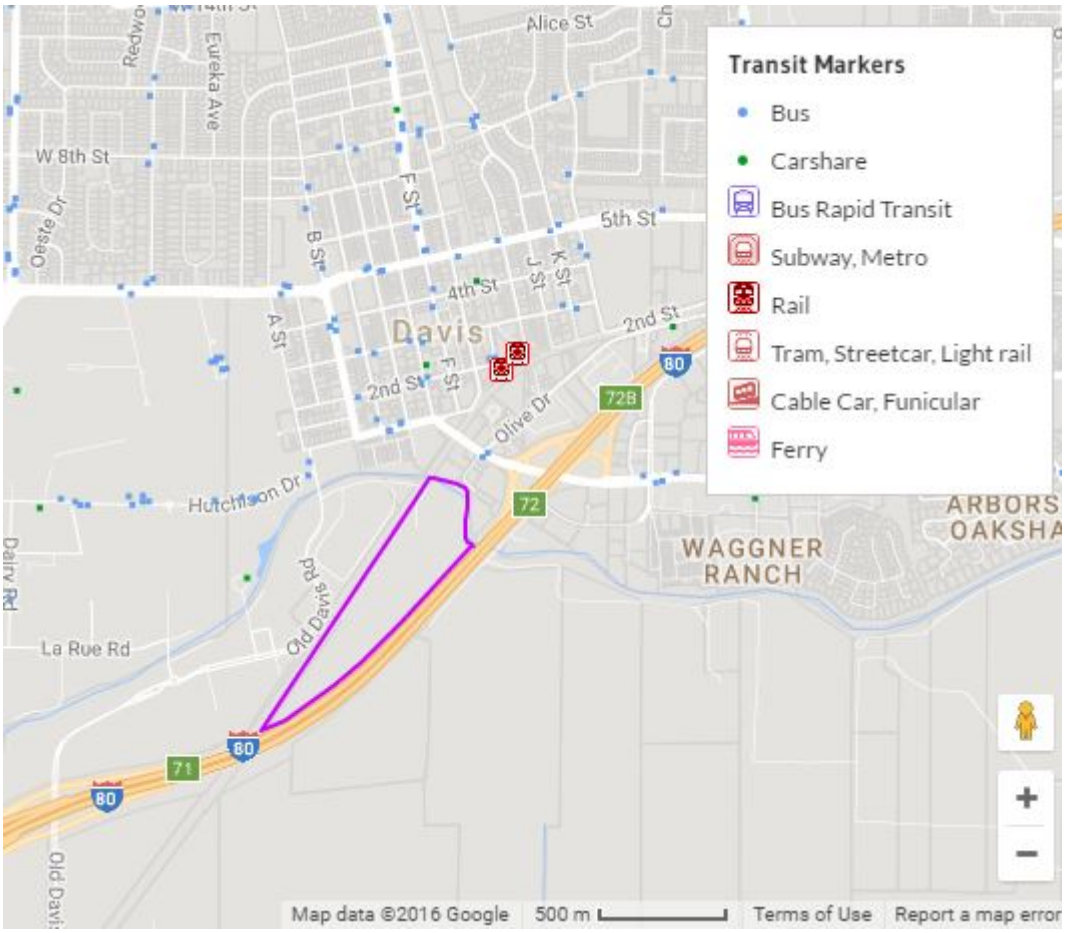
Table 13: Sketch7 Estimates – Second Street Crossing				
	Regional Average	Context Area	Adj. Context + Project	Project
HH VMT per Capita per Day	19.30	16.74	18.06	17.96
HH VMT Total per Day	--	79,881	86,180	0
Transit Trips per Capita per Day	0.05	0.04	0.02	0.04
Bike or Walk Trips Per Capita per Day	0.35	0.63	0.45	0.63

Table 14: Greenhouse Gas Estimates – Second Street Crossing		
	Transportation GHG Output	Standardized Estimate (MT CO_2e per year)
California Smart Growth Trip Generation Tool	Not applicable	Not applicable
CalEEMod 2013	Mitigated: 7,575 MT CO_2e per year Unmitigated: 8,104 MT CO_2e per year	Mitigated: 7,575 Unmitigated: 8,104
CalEEMod 2016	Mitigated: 5,688 MT CO_2e per year Unmitigated: 6,097 MT CO2e per year	Mitigated: 5,688 Unmitigated: 6,079
GreenTrip Connect	Not applicable	Not applicable
EPA MXD Tool	None	None
Sketch 7	None	None

Nishi Gateway – Davis, California

The Nishi Gateway is also located in Davis, California and is a proposed project that has not been built. It is located on the southern edge of downtown Davis, adjacent to the University of California and north of Interstate 80. It is a 50-acre mixed-use development with 325,000 square feet of research and development, 650 units of multi-family residential, 20,000 square feet of retail, and 13.1 acres of surface parking.

Figure 5. Nishi Gateway Project Site – Davis



This case study illustrates a large-scale infill development with mixed land uses. Employment centers of this scale are often located in suburban or exurban locations with poor accessibility by modes other than automobile; the proposed Nishi Gateway is in a location easily accessed by transit, walking, and bicycling.

Extensive transportation analyses of the Nishi Gateway were conducted as part of the CEQA process; however, sketch model input data were gathered from project descriptions in the Notice of Preparation document, which preceded the full environmental impact report. This was to simulate a project impact assessment process in the early stages of planning. Inputs for the surrounding areas were gathered by visual inspection of Google Maps and Google Earth, as well as from the local transit agencies. Employment and residential data for the surrounding

area was gathered from web-based mapping services including the US Census Longitudinal Housing and Employment Dynamics (LEHD) OnTheMap tool.

Table 15: VMT Estimates – Nishi Gateway		
	Output from Tool	Standardized Estimates (VMT per day)
California Smart Growth Trip Generation Tool	Not applicable	Not applicable
CalEEMod 2013	Mitigated: 16,461,038 VMT per year Unmitigated: 18,663,308 VMT per year	Mitigated: 39,529 Unmitigated: 51,132
CalEEMod 2016	Mitigated: 14,796,696 VMT per year Unmitigated: 16,776,299	Mitigated: 31,454 Unmitigated: 45,962
GreenTrip Connect[1]	27.02 VMT per HH per day	19,614
EPA MXD Tool[2]	43,745 VMT per day	43,745

[1] GreenTrip Connect calculates only residential portion of project.
[2] Trip lengths from California Statewide Travel Demand Model

Table 16: Sketch 7 Estimates – Nishi Gateway				
	Regional Average	Context Area	Adj. Context + Project	Project
HH VMT per Capita per Day	19.30	14.47	14.25	13.9
HH VMT Total per Day	--	89,076	87,722	18,404
Transit Trips per Capita per Day	0.05	0.11	0.12	0.20
Bike or Walk Trips Per Capita per Day	0.35	1.24	1.29	1.38

Table 17: Greenhouse Gas Estimates – Nishi Gateway		
	Transportation GHG Output	Standardized Estimates (MT CO_2e per year)
California Smart Growth Trip Generation Tool	Not applicable	Not applicable
CalEEMod 2013	Mitigated: 6,709 MT CO_2e per year Unmitigated: 7,571 MT CO_2e per year	Mitigated: 6,709 Unmitigated: 7,571
CalEEMod 2016	6,484 MT CO_2e per year	6,484
GreenTrip Connect[1]	32.11 lbs per HH per day	3,456
EPA MXD Tool	None	None
Sketch 7	None	None

[1] GreenTrip Connect calculates only residential portion of project.

5. Sensitivity Testing

We tested the selected methods for their sensitivity to a range of land use context areas by crafting a hypothetical project – ten acres with 100 housing units – and locating it in different places throughout a metropolitan region. The hypothetical project was modeled at several places along the urban-to-rural spectrum, using land use and transportation characteristics from the Sacramento, California metropolitan region as inputs. Although this analysis does not have a real-world equivalent, in that projects are rarely proposed independently of a specific location, it does add to our understanding of the performance of these tools.

This analysis highlights strengths, weaknesses, irregularities, and general practical considerations for the tools tested. It provides greater clarity to the nuances of the VMT estimates as it holds land use variables constant while changing the project's context characteristics. This analysis also indicates the degree to which the tools are consistent with theory as well as empirical observations that VMT per capita is lower in urban cores and higher in suburban and exurban areas. Numerous studies have shown that built environment characteristics such as mix of land uses, grid-like street patterns, transit accessibility, and compact development are associated with lower VMT per household and per person[18]. As this hypothetical project moves from the urban core to an exurb, characteristics associated with low VMT decrease and VMT per household should increase.

Table 18: Hypothetical Land Use Project Characteristics	
Acres	10
Land Use	Medium-density residential
Density	10 dwelling units per acre
Dwelling Units	100 units
Project Characteristics	60 2-bedroom 40 3-bedroom 10 affordable units 50 parking spaces
Distance to Transit (miles)	0.1 – Urban core 0.2 – Urban neighborhood with high-quality transit 1.0 – Urban neighborhood without high-quality transit 0.1 – Suburb with high-quality transit 5.0 – Suburb without high-quality transit 5.0 – Outer suburb without high-quality transit 15 – Exurb

We used CalEEMod 2016, GreenTrip Connect, and Sketch7 for this analysis as these tools can evaluate a single-use residential development at a variety of locations. CalEEMod 2016 was revised to improve measurement at infill-type developments, thus it was chosen over the 2013 version. MXD is designed for mixed-use developments and the California Smart Growth Trip

[18] Ewing & Cervero. 2010. Travel and the Built Environment. Journal of the American Planning Association 76(3).

Estimation Tool estimates trips from only "smart" locations, and would be applicable to only the urban core scenario. These tools were therefore not used in this analysis.

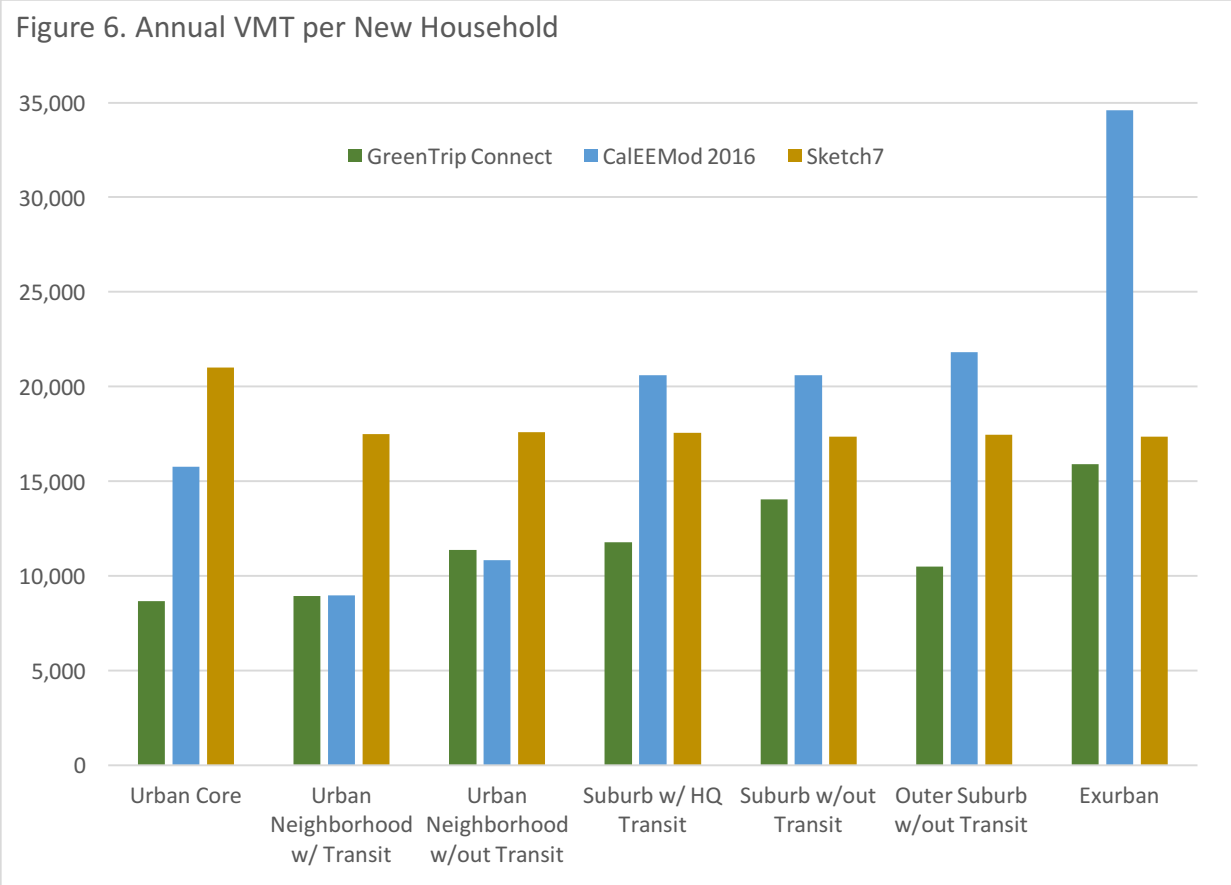
Table 19 and Figure 1 show the absolute VMT forecasted by each of the three tools at the range of locations. Absolute VMT forecasts are shown, rather than VMT per capita or per household, because the analysis maintains 100 households across all scenarios and tools. Patterns emerge among the three VMT estimation tools, demonstrating the sensitivity of each method to land use type and context area characteristics.

Table 19: Sensitivity Test – Annual Household VMT

	CalEEMod 2016	GreenTrip Connect	Sketch7
Urban core: Downtown/Midtown Sacramento – 15th & Q Streets	15,758	8,645	21,011
Urban neighborhood with high-quality transit: Curtis Park Village – Portola Way & 21st Street	8,978	8,923	17,479
Urban neighborhood without high-quality transit: The Mill – 5th Street & Broadway	10,818	11,354	17,573
Suburb with high-quality transit: Folsom Boulevard at Mather Field Road	20,606	11,785	17,566
Suburb without high-quality transit: Arden Arcade – McClaren Drive & Shelato Way	20,606	14,031	17,338
Outer suburb without high-quality transit: Roseville – Dana Way & Parkview Drive	21,818	10,491	17,445
Outer suburb / exurban: Loomis – Sierra College Boulevard & Brace Road	34,592	15,884	17,357

Table 20: Sensitivity Test – Daily Household VMT

	CalEEMod 2016	GreenTrip Connect	Sketch7
Urban core: Downtown/Midtown Sacramento – 15th & Q Streets	43	24	58
Urban neighborhood with high-quality transit: Curtis Park Village – Portola Way & 21st Street	25	24	48
Urban neighborhood without high-quality transit: The Mill – 5th Street & Broadway	30	31	48
Suburb with high-quality transit: Folsom Boulevard at Mather Field Road	56	32	48
Suburb without high-quality transit: Arden Arcade – McClaren Drive & Shelato Way	56	38	48
Outer suburb without high-quality transit: Roseville – Dana Way & Parkview Drive	60	29	48
Outer suburb / exurban: Loomis – Sierra College Boulevard & Brace Road	95	44	48



The differences in output between the three methods are notable. Variation in Sketch7's project-generated outputs is small; variation in CalEEMod's outputs is much larger and follows an expected upward trend along the urban-to-exurban spectrum, similar to GreenTrip Connect's smaller but upward trend. In exurban areas, GreenTrip Connect and Sketch7 produce similar results, though with GreenTrip Connect forecasting smaller magnitudes of VMT for every project location.

This sensitivity test produces both intuitive and non-intuitive results. It highlights each tool's ability to capture (or not) the characteristics of the built environment and transportation options along the urban-to-exurban gradient:

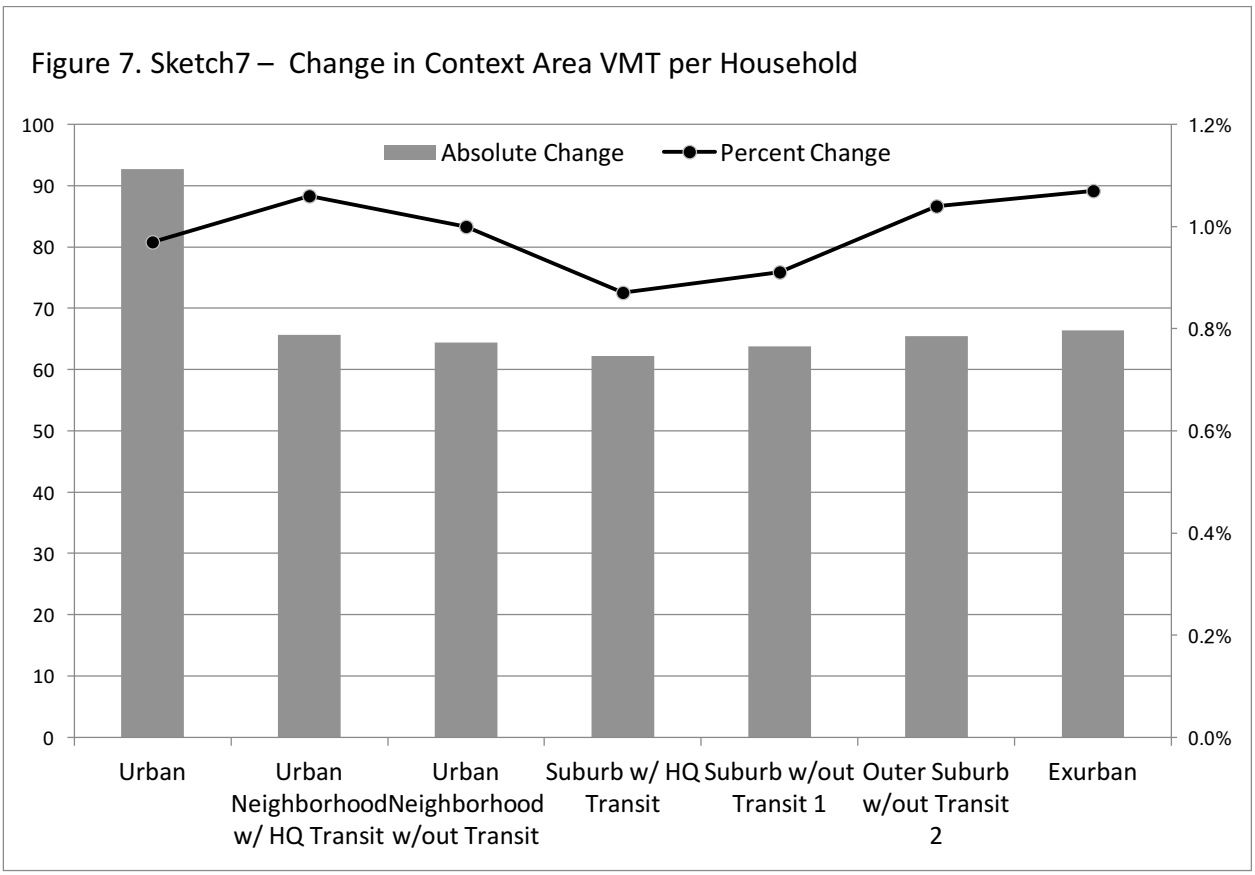
- The urban core scenario demonstrates higher VMT than several of its urban neighborhood and suburban counterparts across all three tools. CalEEMod and Sketch7 use land use type and relative density (among other variables) to forecast the proposed project's VMT. A 10-unit-per-acre development is a low-density land use-type for the urban core in Sacramento, so it effectively decreases the housing density of the area, which may affect these higher-than-expected VMT forecasts.
- GreenTrip Connect forecasts mostly linearly increasing VMT moving from the urban core to the exurban locations, as planners would generally expect. It shows lower VMT generation for the outer suburban location, counter to expectations. GreenTrip Connect

uses demographic factors to estimate VMT generation, which may be at play in the exurban site.

- Sketch7 forecasts little variation in project household-based VMT between the different context areas. Sketch7 uses the land use type of the project (medium-density residential, in this case) as a major factor in calculating VMT generated from the project. It showed more variation in how the project affected its context area than VMT from the project itself, as shown in the tables and charts below.
- CalEEMod's outputs are highly dependent on the specified land use setting (urban or rural), and the amount of VMT "mitigation" (reduction based on project context) is capped for different project settings (75% for urban centers, 40% for compact infill, 20% for suburban centers, and 15% for suburban). The lack of variation in VMT for the project located in a low-density suburban area with transit versus without transit can likely be explained by this "cap" – other project characteristics sum to the allowable 15% reduction in VMT, regardless of the presence of transit. Sketch7 is designed to estimate change in VMT at the level of the context area, as well as at the project level. It shows the change in VMT within a 1/2-mile radius as a result of the project (Table 20). Figure 3, below, illustrates the absolute and percent change in context area VMT as a result of the housing project. In locations with the most driving – the suburban areas where households are likely to have fewer transportation options and longer distances to jobs, goods, and services– the absolute change in VMT is larger while the percent change in driving is smaller, likely because there is already more driving in general.

Table 21: Sensitivity Test – Sketch7: Change in VMT in ½-Mile Context Area (annual)

	VMT per HH	Percent Change
Urban core: Downtown/Midtown Sacramento – 15th & Q Streets	+ 93	0.97%
Urban neighborhood with high-quality transit: Curtis Park Village – Portola Way & 21st Street	+ 66	1.06%
Urban neighborhood without high-quality transit: The Mill – 5th Street & Broadway	+ 64	1.00%
Suburb with high-quality transit: Folsom Boulevard at Mather Field Road	+ 62	0.87%
Suburb without high-quality transit: Arden Arcade – McClaren Drive & Shelato Way	+ 64	0.91%
Outer suburb without high-quality transit: Roseville – Dana Way & Parkview Drive	+ 65	1.04%
Outer suburb / exurban: Loomis – Sierra College Boulevard & Brace Road	+ 66	1.07%



The variation in estimates between these three tools illustrates that meaningful VMT analysis requires evaluation of a range of scenarios by a single tool. A single project will produce a range of results depending on which tool is used, but the magnitude and direction of VMT estimates between several scenarios will illustrate a project's efficient (or not) transportation performance. For example, a project sponsor could use GreenTrip Connect to evaluate a housing development in several locations throughout its jurisdiction, demonstrating which location promotes the most efficient land use and transportation choices. A single run of GreenTrip Connect, or any of these tools, provides limited insight into the efficiency of the project or project location.

Further, this analysis shows that comparing outputs from two different tools would be deceptive; outputs from CalEEMod, GreenTrip Connect, and Sketch7 are best compared to other results from CalEEMod, GreenTrip Connect, and Sketch7, respectively. In short, the accuracy of the absolute VMT estimate from each tool is uncertain; sketch tools are better suited to illustrate and compare differences between scenarios.

6. User Experience

An important objective of this study was to assess the ease of use of each tool, in addition to its analytical capabilities. Each tool was evaluated from the perspective of a new user.

CalEEMod (2013 and 2016 versions)

CalEEMod is a self-contained software program that is downloaded and installed on a user's computer. We tested both 2013 and 2016 versions, and they operate essentially identically from a user standpoint. The versions differ in some default values that users would likely use, as well as under-the-hood programming.

Using the tool

On the first window, users enter a several basic project characteristics including project location, which can be specified in different geographic units (air district, county, et cetera). The most specific geographic unit that can be entered is the county level. Users also must define whether the project is urban and rural, the start date of construction, the year the project becomes operational, and the California Energy Commission (CEC) Forecasting Climate Zone of the project site. This can be looked up on the CEC website [energy.ca.gov/maps/renewable/building_climate_zones.html]. Finally, users select the utility provider serving the project. The energy zone and utility factor do not factor into CalEEMod's VMT or transportation GHG calculations, but because the primary purpose of CalEEMod is to model GHG and criteria pollutants from transportation and non-transportation sources, these are required entries.

On the following window, users enter the land use(s) of the project. Users select a primary land use type (e.g. residential, commercial, industrial) and land use subtype (e.g. single-family home, mid-rise apartment, condominium/townhouse). Possible land use subtypes replicate a subset of ITE land uses categories. Based on the land uses selected, users then enter the number of units or square footage of that use. CalEEMod automatically generates values for lot acreage, building square footage, and population based on user inputs, which likely differ from the actual project. However, users should not change the values on this screen. Users can enter the actual density of the project as a mitigation measure on a later window.

Users interested only in VMT can next skip several windows for the construction phase of the project as these do not factor into operational VMT. Following the construction section, users next encounter several windows covering the operational phase of the project. The first of these windows includes inputs about vehicle trips. The window includes several columns for trip rates for various types of trips, for which CalEEMod provides default values; however, users can change them if they have more locally relevant data (such as from a regional travel demand model). CalEEMod also includes default values for average trip lengths that users can change. These default values come from the 1999 California Household Travel Survey (CHTS); trip lengths from the 2012 CHTS are likely to be more accurate, and other more recent and more local sources of data on trip lengths may also produce better VMT estimates. The following windows cover vehicle emissions factors for various pollutants and vehicle types, fleet mix of

vehicles, and road dust. Again, CalEEMod provides default values that need not be edited for VMT estimation purposes. After the operational section are two windows on vegetation. Again, users can skip this section as it is not relevant to VMT estimation.

Next, users reach the emissions mitigation section. There are six mitigation sub-sections, with users only needing to enter information (if applicable) in the traffic sub-section, which spans two windows. In the "land use and site enhancement" setting, users can enter more detailed project settings (low density suburban, suburban center, urban, and urban center) than specified on CalEEMod's first window. Other types of mitigation under "land use and site enhancement" include several land use, neighborhood design, parking, and transit measures.

Under land use mitigation, users enter the project household density, intersections per square mile, distance to job centers, and the distance to transit. These inputs are used to "mitigate" the project's VMT in comparison to a project of the same size and land use mix but with "typical suburban" characteristics (accessibility, density, transit, etc.).

There are at least two ways that users can account for a project's context area in CalEEMod. The built-in mitigation measures are one option, and use academic research to inform the type and amount of VMT mitigation. These mitigation measures are discussed at length in "Quantifying Greenhouse Gas Mitigation Measures", authored by the California Air Pollution Control Officers Association. Alternately, users can adjust CalEEMod's trip lengths to reflect conditions for the project's region, county, city, or TAZ. Trip length data is available by county and TAZ from the California Statewide Travel Demand Model[19]. Should users manually adjust trip lengths, they should exercise caution when also using built-in mitigation measures as they could double count the contextual characteristics that would reduce project VMT.

On the next window, users can enter commute trip-related mitigation measures, if applicable. From here, users advance to the final input window and click on "recalculate all emissions and run report" to generate the outputs.

Interpreting the outputs

CalEEMod generates a long string of outputs, mostly relating to GHG and criteria air pollutant emissions. Operational VMT projections can be found under Section 4.2 Trip Summary Information. The "mitigated annual VMT" is the output that reflect the project with associated land use and transportation mitigation measures. Annual VMT can be normalized to VMT per day, per household, per employee, et cetera. VMT projections are made for each land use in a project as well as the entire projects. The outputs can be downloaded as a PDF or spreadsheet file.

[19] California Statewide Travel Demand Model data is available from Caltrans to assist SB 743 implementation. It is available in an Excel spreadsheet from dot.ca.gov/hq/tpp/offices/omsp/SB743.html.

California Smart Growth Trip Generation Tool

The California Smart Growth Trip Generation Tool operates on an Excel spreadsheet. Users interact with the first two worksheets.

Using the tool

The first worksheet contains a series of questions that ascertain whether the tool is appropriate for a given project. Key determinants of whether the tool can be used include: projects being comprised of a select sub-set of ITE land uses, presence of mixed-uses in the project vicinity, a lack of special attractor land uses in the project vicinity, and sufficient land use density and transit service. The tool can model only one land use at a time. Thus, for a mixed-use project, the tool would need to be run several times for each land use.

Table 22: ITE Land Use Codes included in California Smart Growth Trip Generation Tool

Land Use	ITE Land Use Code
Apartment	220
High-Rise Apartment	222
Mid-Rise Apartment	223
Residential Condominium/Townhouse	230
High-Rise Residential Condominium/Townhouse	232
General Office Building	710
Free-Standing Discount Superstore	813
Variety Store	814
Free-Standing Discount Store	815
Shopping Center	820
Office Supply Superstore	867
Pharmacy/Drugstore without Drive-Through Window	880
Drinking Place	925
Quality Restaurant	931
Coffee/Donut Shop without Drive-Through Window	936

If project is deemed appropriate for analysis, users progress to the second worksheet. Here, users enter the size of the entire project, including number of residential dwelling units and gross square feet of retail or office space. Users then enter the ITE-estimated morning and afternoon peak hour trips of the analyzed land use. The tool does not calculate the peak hour trips for uses. This must be calculated by the user based on the size (e.g. units, square footage) of a given land use multiplied by the ITE trip rate, which users must look up.

On the second worksheet, users provide inputs such as distance to the center of a central business district, building setbacks of the proposed project, presence of metered parking in the project vicinity, and the proportion of the site area covered by a surface parking lot.

Interpreting the outputs

The tool outputs morning and afternoon peak hour trips. If a project is mixed-use, users will need to add the results of multiple runs of the tool to calculate overall AM and PM peak hour trips associated with the project. To convert trips to VMT per day, users must go through a few

additional steps. First, peak hour trips must be converted to trips per day. In these case studies, we assumed 20 percent of trips were made at peak times. Once the number of trips per day is calculated, that figure can then be multiplied by average trip distance to calculate VMT per day. Users have multiple choices for average trip distance. One option is to use an average trip length for the region as provided by the metropolitan planning organization in its regional transportation plan or other documents. Another option is to use the 5.8-mile average distance for automobile trips from the California Household Travel Survey (2012). The former method will generate a more contextually-sensitive VMT estimate.

GreenTRIP Connect

GreenTrip Connect is a web-based tool that uses user inputs from a map interface and underlying data to calculate household-based VMT from housing projects. It does not currently have the ability to calculate VMT from non-residential land uses.

Using the tool

Users navigate to connect.greentrip.org and begin by entering the address, city, ZIP code, or transit station at which residential development will be modeled. It navigates users to a robust Google Map interface. Users can toggle between a parcel map and satellite imagery map – which converts to Google Street View at high-resolution zoom. Users can overlay parcel-level transit data, commute distances, employment density, and other characteristics that affect travel demand. Parcels targeted for development are selected and project characteristics are described. Project characteristics include number of housing units, types of housing units (studio, 1 bedroom, et cetera), number and type of parking spaces (surface, garage/structure, bicycle, et cetera), place type (regional center, urban center, et cetera), number of affordable housing units, and GreenTrip strategies. These strategies include charges for parking, provision of transit passes, provision of car sharing memberships, and provision of bike sharing memberships. Details such as cost of parking spaces, value of transit passes, and number of transit passes provided per unit are also customizable. A final input is the municipal parking requirement per housing unit, as this tool analyzes the cost and amount of space used by parking compared to that required by municipal code.

User inputs are used with four underlying variables – household income, location efficiency (employment density, transit availability, neighborhood commute distance), household makeup, and regional context – to calculate predicted household travel.

Interpreting the Outputs

The tool produces several outputs related to driving and transportation emissions and provides several summary statistics about the built project. These outputs are compared to averages of various geographies (city, county, region). Daily VMT and average daily greenhouse gas emissions (pounds per day) are calculated per housing unit for several iterations of the project: if built on an average location in the jurisdiction, on the selected parcel, with affordable housing, and with GreenTRIP strategies. It then aggregates those factors into the project scenario, so users can see the VMT impacts of individual project characteristics. If the analyzed

project is located in the San Francisco Bay Area, the tool also outputs predicted use of the provided parking spaces.

The tool provides three comparison scenarios of the selected project compared to an average project in the selected county. It shows the percent increase or decrease in driving compared to a county average, as well as the absolute miles difference from a county average. These comparisons are also shown for greenhouse gas emissions from the project's travel demand.

The outputs of Connect are somewhat unique from those of CalEEMod and MXD. It reports household VMT per day, which can be aggregated to the project and year levels within the web interface. Daily household VMT is similar to many activity-based travel models' forecast of regional travel patterns, and allows for comparison of household VMT through scenario planning exercises. The scenario outputs it provides allow for an indication of the project's performance with a single run of the tool.

Sketch7

Sketch7 is a spreadsheet-based tool that also uses a web-based mapping interface for users to select the project location and land use characteristics. It calculates the change in VMT from the addition of the project to the surrounding land use mix.

Several versions of Sketch7 were originally developed and calibrated for regions in California; however, the proper functioning of Sketch7 requires development maintenance of a parcel database to use as baseline data. During this evaluation, the Sacramento region was the only region to have this database available.

Using the tool

The spreadsheet contains macros to automate the processes of importing data and navigation through the tool, so users must enable macros at the start of their session for proper functioning of Sketch7. Users open a Sketch7 spreadsheet and are prompted to a web-based map interface to choose the project parcels, project land uses, number of dwellings, and amount of employment. The map interface also pulls land use and density data for a half-mile context area around the selected parcels. The data are base year data from the metropolitan planning organizations' parcel inventory, with which user-input changes in land use patterns are analyzed. The interactive map runs on Microsoft Silverlight, which requires users to have a free plug-in but is only compatible with certain internet browsers (e.g. not available for Google Chrome on MacOS). Most Windows-based browsers are supported.

Users save the land use data from the interactive map locally into an XML file and navigate back to the spreadsheet tool to "import data from the map". The project and context data from the XML file are imported into the spreadsheet and used in analysis. Users can change land use inputs, dwellings, and employment on the "input" sheet, or continue by indicating the level of transit service, street design, and demographic mix for the project. Users then progress to the final worksheet, which reports the assessment of the project and its impact on the project context area.

The workflow of the Sketch7 simulates a web-based interface. Being Excel-based, the automations inherent to web-based tools (such as GreenTrip Connect) are simulated with macros; however, individual operating systems and user settings can interfere with the smooth transition between steps, and macros can become "broken" with updates to Microsoft Office or other technical issues.

Further, being a spread-sheet based tool makes Sketch7 susceptible to "breaking" from the alteration of values on the computational worksheets. During the sensitivity analysis, it became apparent that different versions of Sketch7 produced different VMT results, likely because of errors entered "under the hood" of the tool. A clean version of Sketch7 is crucial for appropriate results, yet it would be very difficult for an unfamiliar user to diagnose these issues without several similar land use scenarios. Program- and web-based models like CalEEMod and GreenTrip Connect are more resilient to these kinds of introduced errors.

Interpreting the Outputs

The final report in Sketch7 quantitatively and qualitatively assesses the project's impact on eight factors: auto accessibility, transit accessibility, jobs/housing balance, land use diversity or mix, residential density, street pattern, household income, and household age. These are generally called the "Ds" factors that affect travel demand. The report also includes travel metrics such as household VMT per capita, total household VMT, transit trips per capita, and bike or walk trips per capita. These are reported in a table for the region, the context area, the context area including adjustments from the user's project, and the project itself.

The comparison of travel metrics between the regional average, the existing context area, and the adjusted context area best shows the percent change in driving, transit, and walking and bicycling as a result of the proposed change in land use. Where GreenTrip Connect can be aggregated to the project or year level automatically, thus making its outputs comparable to tools like CalEEMod, this must be done manually in Sketch7. Its outputs would best be used in multiples as a result of a scenario planning exercise, where users compare the change in travel patterns as a result of various project types and locations.

MXD

The Mixed-Use Trip Generation Model, or MXD, is a spreadsheet-based tool built by the transportation consulting firm Fehr & Peers and hosted by the Environmental Protection Agency. It adjusts a project's net external vehicle trip generation estimates produced using trip rates from the Institute of Transportation Engineers to account for built environment variables within the project and its surroundings.

Using the Tool

There are relatively few user inputs in the MXD tool. Users open a spreadsheet and provide simple project information, such as presence of nearby transit and distance to a central business district. More intensive inputs are the magnitude of employment in the area surrounding the project; these data can be found at external sources, such as the OnTheMap

website hosted by the US Census Bureau. Users then input a simplified land use mix and can change modeling parameters (e.g. logarithmic or linear), if they choose.

As is the case with many of these tools, the simplified land use choices create the potential for unintentional analyst bias. Multiple case studies in this study include Research & Development, which is not a land use choice in MXD. Based on the narrative in the planning and environmental documents, users could categorize Research & Development as Light Industrial, Manufacturing, or potentially Non-Medical Office. All of these land uses generate different trip rates. Fewer land use categories make inputs more streamlined, but can increase the incidence of user interpretation.

The final user input to estimate VMT is trip length data as the MXD model does not include this information. MXD produces vehicle trip estimates by trip purposes for internal and external trips. As such, the user should obtain trip lengths by trip purpose from travel surveys or the best available data from other sources such as the regional travel forecasting model (specific to the project area) or big data sources relying on mobile device movements. These data may be available from the metropolitan planning organizations, the MPO's regional transportation plans, or the regional transportation planning agencies. These data may be difficult to find without contacting staff at these planning agencies.

Interpreting the Outputs

MXD produces a large string of outputs. It shows the percent and absolute trip rate reduction by mode and trip type, as well as trip rate reduction broken out by morning and afternoon peak times. It also calculates daily VMT by trip type, indicating MXD's downward adjustment from standard ITE trip generation rates. Calculated VMT is a result of MXD's adjusted trip generation rates multiplied by the average trip length by trip purpose. The trip length input source is important and can drastically influence the results. The result is project-based VMT with several illustrative comparisons, such as the VMT reduced from siting the project in a low-VMT TAZ compared to the region.

Table 23: Summary of Practical User Experience

	Benefits	Drawbacks
California Smart Growth Tool	• Few, intuitive inputs with direction of where to find them	• Calculates trips one land use at a time, and in limited context areas • Calculates trips, not VMT
CalEEMod 2013 & 2016	• Many, customizable inputs • Program interface reduces back-end error	• Many, customizable inputs • Defaults and land use categories may misrepresent project and/or context area
GreenTrip Connect	• Simple user interface • Straightforward outputs	• Measures only residential travel, even in mixed-use projects
MXD	• Simple inputs categories • Straightforward outputs	• Important input data may be difficult to find
Sketch7	• Straightforward inputs & interface • System-level outputs • Outputs include walk, bike, and transit trips	• Spreadsheet interface can become "buggy", break • Regional TAZ data used to calibrate tool may be difficult to obtain

7. Conclusions

Under California policy, the impact of plans and proposed projects on VMT is an important consideration for local decision makers. The available VMT quantification tools have notable strengths and weaknesses, and analysts should keep several caveats in mind when implementing these tools to evaluate policy and investment decisions. One of the most important limitations is that they are generally designed to produce estimates of the VMT flowing two and from a project but do not assess the effect of the project on overall VMT for the area, especially for the long-term and in light of the cumulative effects of development in the area.

Each of the six tools evaluated have both benefits and drawbacks of the analytical and practical kind. Some of the tools are easier to implement "off-the-shelf", such as GreenTrip Connect and CalEEMod. Others, like the Smart Growth Trip Tool, MXD, and Sketch7 require more input data from users, but can be run efficiently once those data are acquired. Further, some tools allow for customization of default parameters and calculations. For operational VMT calculations, CalEEMod offers a platform for entirely customizable travel parameters such as trip lengths by trip purpose and trip generation rates (new, diverted, pass-by) allowing customization to reflect the local travel patterns in the area of a project. Sketch7 allows adjustment to baseline data and the elasticities it uses to forecast travel behavior. MXD allows users to choose the function used to calculate VMT. These customization is should be used to account for the context of a specific project. However, it increases the burden on the analyst, who must find the best possible sources of input data, carefully consider potential biases, and thoroughly document assumptions. Simply using these tools "off the shelf" with default values is not likely to produce robust and defensible estimates. .

The five case studies presented here clearly shows that there is no "one-size-fits-all" VMT quantification tool. Each tool has a different set of land uses built into it, usually defined by a specific list of ITE codes. Further, each tool is unique in its sensitivity to the project context area as shown in Section 5. For these reasons, practitioners may want to consider each of these methods in searching for the tool that best fits their particular need. .

The available VMT estimation methods have not been validated as to their accuracy, owing to a lack of data against which to validate them. Actual changes in VMT resulting from land use projects are best measured through before-and-after surveys of residents, employees, and/or customers, but such surveys are rarely done. Without such data, we cannot say which of these quantification methods is most accurate. The lack of validation and uncertainties around accuracy may pose challenges for CEQA practitioners when analyzing VMT impacts and their significance. A concerted data collection effort would enable validation of these tools for different types of projects in different kinds of contexts, information that local planners and projects sponsors could use to choose the best tool for their case. Even without validation, however, the existing VMT quantification tools are still useful. The internal consistency of each tool allows for insightful comparison between scenarios that differ with respect to project characteristics and/or location, even if their ability to accurately forecast VMT or GHG emissions for a given land use project in a given situation is uncertain.

Users should take care on a number of conceptual points. VMT per capita or per household is a better metric for comparing the impact of different types of residential development, as the absolute value of VMT can be deceiving when scenarios vary in density and number of households. Assigning VMT to households, jobs, or retail units can be complicated for mixed-use projects. Whose VMT the sketch tool is quantifying is another consideration. Most tools quantify the VMT associated with the project itself, but Sketch 7 adjust the total VMT of an area based on changes stemming from the project. The latter can better represent the overall adjustment of daily travel – the adjustment of "tours" – than a tool that quantifies project-based VMT. Sketch7's system-level approach (also possible to some degree using CalEEMod's mitigation measures and MXD's context sensitivity) can be useful for testing the transportation impacts of polices and plans.

Like any tool, these sketch tools can be useful when implemented properly. Rather than simply running the tool "off the shelf," analysts should consider appropriate adjustments to parameters, in addition to taking care to ensure accurate inputs. These tools cannot replace the expertise of planners nor solve complex policy dilemmas, but they can offer important insight when used to compare project scenarios and to compare project impacts to threshold values, as long as common data sources and consistent assumptions are used throughout.

Appendix: Summary of Tools

California Emissions Estimator Model (CalEEMod)

Developer: California Air Pollution Control Officers Association (CAPCOA)
Measures: GHG and VMT

Year: 2013

Cost: Free

Format: Downloadable program

URL: http://www.caleemod.com

Documentation: http://www.aqmd.gov/caleemod/user's-guide

The CalEEMod model by the California Air Pollution Control Officers Association (CAPCOA) projects criteria pollutant and GHG emissions associated with construction and operation of projects. VMT and associated transportation-related emissions are calculated as a component of the operational and total emissions. CalEEMod also has the ability to model the effects of various mitigation measures identified in the CAPCOA Quantifying GHG Mitigations Report. Other, non-transportation-related factors influencing GHG that are captured in the model include construction-related activities (e.g. demolition, grading, construction time, types of materials used), equipment used in the project (e.g. wood stoves, generators, forklifts/cranes, landscaping equipment), energy use of buildings, water use, solid waste, and vegation.

Primary Inputs

Land use types (dwelling units/floor space)

Other adjustable inputs (transportation)

Trip rates (ITE default. Separate rates for weekdays, Saturdays, Sundays)
Trip lengths (H-W, H-S, H-O)

Outputs

CO2e (MT/year)
VMT (annual)

Transportation-related mitigation measures which can be modeled (from CAPCOA Quantifying GHG Mitigation Document)

Land use

- Increase density (dwelling units, jobs/acre)
- Increase diversity

- Improve walkability/design (intersections/sq. miles)
- Improve destination accessibility (distance to downtown, job center)
- Increase transit accessibility (distance to transit)
- Integrate below market rate housing (# dwelling units below market rate)

Neighborhood enhancements

- Improve pedestrian network
- Traffic calming measures (% streets, % intersections with improvement)
- Implement NEV network

Parking policy/pricing

- Limit parking supply (% reduction in spaces)
- Unbundle parking costs (monthly parking cost)
- On-street market pricing (% increase in price)

Transit improvements

- Provide BRT system (% lines BRT)
- Expand transit network (% increase transit coverage)
- Increase transit frequency (% reduction in headways)

Commute trips

- Implement trip reduction program (% employee eligible)
- Transit subsidy (% employee eligible)
- Employee parking “cash-out” (% employee eligible)
- Workplace parking charge (% employee eligible)
- Encourage telecommuting/alternative work schedule (% employees using)
- Market commute trip reduction option (% employee eligible)
- Employee vanpool/shuttle (% employee eligible or % vanpool mode share)
- Provide ride sharing (% employee eligible)

Urban Emissions Model (URBEMIS)

Developer: California Air Resources Board (CARB)

Measures: GHG and VMT

Year: 2007

Cost: Free

Format: Downloadable program

URL: http://www.urbemis.com

Documentation: http://www.urbemis.com/support/manual.html

Like CalEEMod, URBEMIS projects criteria pollutant and GHG emissions associated with construction and operation of projects, with VMT and transportation-related emissions being one component. URBEMIS, which has been used frequently for CEQA air quality analyses, appears to have been supplanted by CalEEMod (The South Coast Air District calls URBEMIS outdated and outline several benefits of the newer CalEEMod here [http://www.aqmd.gov/caleemod/faqs]). Transportation-related VMT is based on ITE trip generation rates multiplied by trip lengths. To reduce ITE-based trip projects, users can adjust the primary trip percentage, diverted trip percentage, and pass-by trip percentage. Additionally, URBEMIS provides for trip reductions for several land use and transportation mitigation measures including: mixed uses, presence of local serving retail, presence of affordable housing, higher rates of transit and non-motorized modes, application of transportation demand management measures, and reduced parking supply. For each potential mitigations, URBEMIS asks several questions about the nature of a mitigation measure for a given project (e.g. number of bus stops, percent of road lengths with bike lanes) to calculate the amount of trip reduction.

Primary inputs

Land use types (dwelling units/floor space)

Other adjustable inputs (transportation)

Trip generation rate (ITE default – adjustable)

Worker commute trip % (percent of trips to a given land use in project that are generated by workers)

Primary trip %

Diverted trip %

Pass-by trip %

Trip speeds

Percentages of trip types (HBW, HBS, HBO)

Trip lengths (separate lengths for rural and urban)

Outputs

CO2 (pounds/day)

VMT (miles/day)

Transportation-related mitigation measures (suggested trip reductions in manual)

Mix of uses

Local serving retail

Transit use

Bike and pedestrian

Affordable housing

Transportation demand management

Parking supply

VMT+

Developer: Fehr & Peers

Measures: VMT and Transportation-related GHG

Year: 2013

Cost: Free

Format: Calculator on website

URL: http://www.fehrandpeers.com/vmt

The VMT+ tool by Fehr & Peers estimates VMT to and from a project or plan areas, off-site VMT generated by project/plan-area households and associated GHG emissions. The tool was developed as an educational tool for climate action planning and is hosted on a website on the Fehr & Peers website. VMT is estimated by a multiplication of trips generated multiplied by trip lengths. The tool uses ITE trip generation rates as a default, but these are adjustable. Trip lengths are also adjustable, but values are provided for an "average western US city" and several California regions: Los Angeles-Riverside-Orange, Sacramento-Yolo, San Diego, and San Francisco-Oakland-San Jose.

Primary Inputs

Land Use type (dwelling units, floor space)

Other adjustable inputs

Trip generation rates (ITE default)

On-site capture (%)

Pass-by capture (%)

Proportion of trip purposes (HBW, HBO, HBS, NHB)

Average trip lengths (HBW, HBO, NHB for internal, internal-external, and external trips)

Outputs

VMT (per household per day)

CO2e (MT per day)

ASAP (Plan+, MXD+, TDM+)

Developer: Fehr & Peers

Measures: VMT and Transportation-related GHG

Year: 2013

Cost: Paid

URL: http://asap.fehrandpeers.com/tools/sustainable-development/plan

The previously discussed free VMT+ tool is one of several tools that are a part of Fehr & Peers' ASAP platform. Additional proprietary tools on the ASAP platform allow for alternative VMT and GHG projections that take into account additional factors. For instance, projections from the VMT+ tool assume ITE trip generation rates, which can overestimates trips for Smart Growth projects. While the trip generation rates are manually adjustable, the MXD+ tool calculates reduced trip generation rates. The Plan+ tool takes into account built environment and transit characteristics that reduce VMT. The TDM+ tool models reductions possible from enactment of measures from the CAPCOA Quantifying GHG Mitigations Report.

Some inputs (as gathered from ASAP promotional videos)

Area developed (acres)

Number of intersections

Transit present (yes/no)

Percentage of households within ¼ miles of transit

Location within a CBD

Average household size

Land uses types and amounts (dwelling units, square footage)

Outputs

VMT (Daily, AM, PM)

Trips (Daily, AM, PM)

CO2e (Metric tons per day)

GreenTrip Connect

Developer: Center for Neighborhood Technology

Measures: Trip Generation Rate Adjustments

Year: 2016

Cost: Free

Format: Web tool

URL: http://connect.greentrip.org/

GreenTrip Connect is a web-based tool that can estimate household VMT, among other characteristics. In the tool, users enter the location of a project on a map, the size of a development, the amount of parking provided, rents and whether there will be affordable housing, and whether "GreenTrip strategies" will be implemented. There are four GreenTrip strategies: parking charges and the offering of residential transit passes, carshare memberships, and bikeshare memberships. The reductions in GreenTrip Connect are based on a working paper by Newmark and Haas of the Center for Neighborhood Technology. Their paper includes a model which correlates VMT to several variables related to income (categories), regional context (categories), location efficiency, and household demographics.

Tool Inputs

Project site location (on map)
Housing units (by type, number, square footage, estimated rent)
Parking spaces
Presence of affordable housing (number, income group)
Presence of parking charges
Offering of residential transit passes
Offering of car sharing memberships
Offering of bike sharing memberships

Tool outputs

Household VMT (miles/day)

Model Variables

Income (extremely low, very low, low, moderate, middle high)
Regional context (rural area, metro region, small city)
Employment density
Transit availability
Neighborhood commute distance
Disability in household
Number of adult students, workers , schoolchildren, adults, senior in household

VMT Impact Tool

Developer: Deborah Salon/UC Davis

Measures: Trip Generation Rate Adjustments

Year: 2014

Cost: Free

Format: Spreadsheet

URL: http://www.envisiontomorrow.org/district-level-travel-model/

The VMT Impact Tool is a free spreadsheet that shows how VMT could change as a result of land use and transportation system changes. Unlike other tools discussed here, the VMT Impact Tool does not calculate absolute numbers of trips or miles traveled, rather it presents VMT changes in terms of marginal effects (e.g. change in VMT if gas prices increased by $1) and elasticities (e.g. change in VMT if gas prices increased 1%). The land use and transportation system changes the VMT Impact Tool includes are: transit and non-motorized commute mode share, share of single family homes, road density, activity mix, regional and local job access, and gasoline price. The VMT changes were calculated from a model based on data from five California-based household travel surveys conducted from 2000 to 2009. Users can select results for individual cities or census tract as the model found VMT reductions vary by neighborhood type.

User selects:

Geography (city/census tract)

Models impact of:

Transit commute mode share
Non-motorized commute mode share
Percent single family homes
Road density
Activity mix
Regional job access (gravity formulation between 5-50 miles)
Local job access (gravity formulation between 0-5 miles)
Average gasoline price

Output:

VMT Marginal Effect
VMT Elasticity

California Smart-Growth Trip Generation Adjustment Tool

Developer: UC Davis ULTRANS

Measures: Trips Generated

Year: 2012

Cost: Free

Format: Spreadsheet

URL: http://ultrans.its.ucdavis.edu/projects/smart-growth-trip-generation

This tool provides adjusted estimates for trips generated by smart growth projects. The adjustments were based on a sampling of trips at 50 smart growth sites throughout California and the characteristics of that site. Eight smart growth factors were identified that have strong statistical associations to trips at the sites. The smart growth factors include housing, employment, transit, and parking characteristics. There are coefficients for each of the smart growth factors. Using these coefficients and the characteristics of the project site, an adjustment factor is calculated which can be applied to traditional ITE trip generation rates to come up with an adjusted trip projection. The Smart Growth Trip Generation Adjustment Tool is a spreadsheet that allows users to enter the project characteristics and performs the trip projection. The resulting adjusted trip estimate could then be multiplied by average trip distances associated with projects to calculate VMT. Since the tool is for smart growth projects, the development being analyzed must qualify as smart growth. The first step of the spreadsheet tool is to check whether a given project qualifies as smart growth.

Primary Inputs (Smart growth factors)

Residential population within a ½ mile straight line radius

Jobs within a ½ mile straight line radius

Straight-line distance to center of central business district (miles)

Average building setback distance from sidewalk (feet)

Metered on-street parking within a 0.1 mile, straight line radius (1 = yes, 0 = no)

Individual PM peak-hour bus line stops passing within a ¼ mile, straight-line radius

Individual PM peak-hour train line stops passing within a ½ mile, straight-line radius

Proportion of site area covered by surface parking lots (0 to 1)

Outputs

Smart Growth Adjustment Factor

AM and PM Peak Trips (using ITE trip rates)

Adjust AM and PM Peak Trips

Adjusting ITE's Trip Generation Handbook for Urban Context

Developer: Clifton, Currans, and Muhs

Measures: Trip Generation Rate Adjustments

Year: 2015

Cost: Free

Format: Paper with trip adjustment coefficients

URL: http://dx.doi.org/10.5198/jtlu.2015.378 (Clifton, Currans, and Muhs, 2015)

http://dx.doi.org/10.5198/jtlu.2015.470 (Currans and Clifton, 2015 – related paper)

This paper follows a similar procedure to the California Smart Growth Trip Generation Adjustment Tool by calculating coefficients to adjust trip rates based on built environment factors. The nine factors included in the model relate to population, employment, urban form, and alternative transportation characteristics. Many of these are similar to the California smart growth tool, with slightly different definitions. The coefficients in the paper could be used to calculate a reduced trip projection compared to raw ITE trip rates, which in turn can be multiplied by average trip distances to calculate VMT. Unlike the California smart growth tool, there is no associated spreadsheet tool which performs the trip projections. The calculations would have to be done by users, although a similar spreadsheet tool could be developed. The Clifton, Currans, and Muhs paper and resulting coefficients are based on sites in the Portland, Oregon region, which may or may not appropriate for use in California. A related paper by Currans and Clifton (2015) discuss how household travel surveys could be used to adjust trip generation rates.

Primary Inputs (Built environment factors)

Number of transit corridors (count)
Activity density (residents and employees per acre)
Number of high-frequency bus routes (count)
Employment density (employees per acre)
Lot coverage (%)
Length of bike facilities (miles)
Retail and service employment index (count)
Rail access (yes or no)
Intersection density (number per acre)

Outputs

Trip reduction

Envision Tomorrow Site-Scale MXD-Model

Developer: Envision Tomorrow/Fregonese Associates
Year: 2014
Cost: Free
Format: Spreadsheet
URL: http://www.envisiontomorrow.org/site-mxd/

The Envision Tomorrow site-scale model is a free spreadsheet that estimates reductions to ITE trip generation for mixed-use projects. The tool is based on the MXD method developed by Fehr & Peers and the US Environmental Protection Agency. The model is sensitive to the following characteristics: types of land uses, local employment (within 30-minute transit trip and within one mile), number of intersections, presence of transit, and average household size. There is also an input for average trip lengths to convert projected trips to VMT.

Primary inputs

Average trip lengths for HBW, NHB, and HBO trips in the region/city
Specific uses within proposed development (restaurant, retail, medical office, etc.)
Employment accessible within a 30 minute transit trip
Employment located within 1 mile of the site
Number of intersections within and on the perimeter of the site
Presence of transit
Average household sizes for residents

Outputs

Trips

Envision Tomorrow District Scale MXD-Model

Developer: Envision Tomorrow

Measures: Trip Generation Rate Adjustments

Year: 2014

Cost: Free

Format: Spreadsheet

URL**:** http://www.envisiontomorrow.org/district-level-travel-model/

The Envision Tomorrow district-scale model is a free spreadsheet that estimates reductions to ITE trip generation for projects for mixed-use areas less than one square miles. Reductions are based on several variables related to employment, intersections, transit availability, travel speed, and district area. Research by Reid Ewing and the University of Utah Center Metropolitan Studies informed the model, including a study of six mixed-use areas nationwide.

Primary inputs

Regional employment count (based on a reasonable commute shed)
Number of intersections in the district
Number of 4-way intersections
Intersections within a 1-mile buffer of the study area boundary
Transit stops within the district
Proportion of the district boundary covered by a quarter mile buffer around the transit stops
The area of both a quarter and 1-mile buffer around the study area
Assumed average vehicle travel speed within district
Employment within 1 mile of the district boundary
Employment within 20 and 30 minutes by auto
Employment within 30 minutes by transit

Outputs

Trips (ITE vs. reduced)

VMT Reduction (%)

Envision Tomorrow Plus (ET+)

Developer: Fregonese Associates / University of Utah
Year: 2013
Cost: Free
Format: Spreadsheet and ArcGIS extension
URL 1: http://www.arch.utah.edu/cgi-bin/wordpress-etplus/
URL 2: http://www.envisionutah.org/wasatch-choice-toolbox/tool-et

The Envision Tomorrow Plus (ET+) is an open-access land-use scenario planning package that allows users to "paint" development scenarios on the urban landscape within ArcGIS and compare scenario outcomes. The development of ET+ was funded by a HUD Sustainable Communities Regional Planning Grant awarded to Salt Lake County and a consortium of agencies in the Wasatch Front Regional Council region. It is based on the original Envision Tomorrow tool developed by Fregonese Associates, Inc. but includes approximately 20 (and ever-growing) "apps" developed by researchers at the Metropolitan Research Center at the University of Utah. It can be applied at scales from a single parcel to a metropolitan region. Transportation analysis uses the 7D analytical framework – separate apps for household travel (the HH Travel Standalone App Tool) and mixed-use development travel (MXD Travel Standalone App Tool). Both apps estimate VMT, trips by different modes, and change in pollutant emission by housing types and unit.

Primary inputs

Household/population assumptions
Household income by housing types
Workers per household
Wage estimates by industry
Housing cost by housing type
Parcel sizes
Students per housing type
Capital costs estimates
Energy grid mix and energy costs
Water consumption (internal and landscape, including waste water production)
Building and site characteristics (parcel size, unit size, parking, floor-area ratio, etc.)
Building square footage mix (%) by building uses
Residential physical and financial inputs and outputs (# of units, housing type, square footages, sales prices, etc.)
Employment (jobs per acre)
Non-residential physical and financial inputs and outputs
Commercial parking/parking inputs and outputs (parking spaces, parking square foot, parking space construction cost, etc.)
Land cost
Total project value
Subsidy

Block and street characteristics (block width, street density, street miles, lane miles, intersection density)

Outputs (called indicators)

Vehicle miles traveled (VMT)
Vehicle trips
Walk trips
Bike trips
Transit trips
Greenhouse gas and pollutant emissions

Additional Ouputs

Developed/vacant area
Built environment – buildings, streets, civic and parks
Housing mix – single family, townhome, multifamily, mobile home
Employment mix – retail, office, industrial
Parking requirements – standard and with shared parking reductions
Impervious surface
Building energy use – annualized for residential and commercial buildings
Water use – annualized for building and landscaping
Waste generation
Transportation safety
Jobs-housing balance – includes both jobs/housing and wages/income balance within a 3-mile radius
Cost of living (housing + transportation + energy)
Rents, sales prices
Project feasibility, potential for public-private partnerships
Fiscal revenues and costs
Redevelopment candidates – identifies parcels/areas with potential for redevelopment

UrbanFootprint

Developer: Calthorpe Associates/Calthorpe Analytics
Year: 2012
Cost: Free
Format: Browser-based downloadable program
URL: http://www.scag.ca.gov/Documents/UrbanFootprintTechnicalSummary.pdf

UrbanFootprint is a land use planning, modeling and data organization framework designed for scenario analysis of fiscal, environmental, transportation, and public health impacts of plans and policies. Its development was funded by departments within the State of California, MPOs in California, as well as NGOs and other state and federal grants. Unlike spreadsheet- and GIS-based tools, it is based on open source software. It includes a sketch-level travel model that is based on the Ds variables (now up to eight). It uses statistical methods to quantify relationships among the Ds variables, known as the 8D MXD method.

Inputs

Parcel-level land uses (i.e. Assessor's tax parcel data)
TAZ-level population, housing, employment data
Land cover (urban, constrained, greenfield)
Census data (population, housing, jobs characteristics)
Transit data
Street intersection/density data
Building data

Outputs

Land consumption
Vehicle miles traveled, travel mode, fuel consumption
Transportation greenhouse gas and air pollutant emissions
Building energy and water consumption, costs, and related GHG emissions
Household costs for housing, transportation and utilities
Public health impacts and costs (physical activity, respiratory health, pedestrian safety)
Local fiscal impacts

Sketch7

Developer: Fehr & Peers, Sacramento Area Council of Governments, UC Davis Urban Land Use and Transportation Center (ULTRANS)
Measures: Change in VMT, transit trips per capita, bicycle and walk trips per capita
Year: 2012
Cost: Free
Format: Spreadsheet and Web-based GIS Application
URL**:** http://ultrans.its.ucdavis.edu/projects/improved-data-and-tools-integrated-land-use-transportation-planning-california

Sketch7 is a spreadsheet tool that provides a sketch-level projection of VMT for two scenarios: (1) the project's context area prior to development of the project and (2) the project's context area with the project. It also estimates travel statistics of the project. VMT projections are sensitive to the 7 "Ds" of land and use transportation characteristics (density, diversity, distance, design, destination, demographics, and development scale). Generally, these are characteristics of the built environment such as mix of land use (diversity), distance to employment, goods, and services (distance), street connectivity (design), transit accessibility (destination), et cetera. The spreadsheet directs users to a web-based map application, built in Microsoft Silverlight, that allows users to select individual parcels and make land use changes on a map, and then import those land use data to the spreadsheet. Sketch 7 has been utilized and maintained primarily in the Sacramento region; however, additional locally-calibrated equations were also derived for use in the San Diego region, for small/medium MPOs, and for Bay Area rail corridors. Notably, Sketch7 projects VMT for several situations: the project parcel(s), the surrounding area (the parcels' context area) before the project and as adjusted by the project, and the regional average.

Inputs

Land uses
Employment
Transit service
Street design
Demographics

Outputs

Household VMT per capita
Household VMT total
Transit trips per capita
Bike/walk trips for capita

*All outputs presented in terms of regional average, context area, adjusted context area, and project site