Implementation of Ds Analysis Modules with Regional Travel Demand Models

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2. Test Plans for Regional Travel Demand Forecasting Models
3. Documentation of Statistically Calibrated Post-Processor Modules
4. Guidelines for Validation Testing
5. User Guidance on Analysis Module Applications
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1. TECHNICAL ASSISTANCE PROVIDED to SELECTED MPOs

A. Travel Demand Forecasting (TDF) Model Intervention: Rationale and Approach

As described in the Overview Report and other Appendices, the “Improved Data & Tools for Integrated Land Use-Transportation Planning” study has provided locally-derived and up-to-date quantitative data regarding land use/travel relationships in California. And, it has made these relationships available for practical use in “sketch-planning” analysis tools, GIS-based “visioning” software, and in travel demand modeling.

Such data and tools are necessary to conduct integrated regional Blueprint scenario planning, preparing Sustainable Communities Strategies and Regional Transportation Plans, as well as for local land use General and Specific Community planning and smart growth project implementation in California.

The project was devoted to the collection, synthesis and statistical analysis of recent California travel survey data linked to fine-grain built environment data. This resulted in the creation of a variety of new “Ds Analysis Modules” capable of assessing and predicting the effects of the built environment and demographic factors on the generation of vehicle trips and VMT in different regions in California. The data collection and analyses conducted for this effort are important steps toward advancing the state-of-practice.

To demonstrate the applicability and use of the Ds Analysis Modules, the study team has incorporated the modules as “post-processors” to a selection of Travel Demand Forecast (TDF) models in use by several California metropolitan planning organizations (MPOs). Eight MPOs were selected for pilot implementation of post-processors based on their: willingness to participate, possession of a complete and calibrated regional travel model, and being able to devote staff time to participate in model testing and training.

These regions were:

- Six MPOs in the San Joaquin Valley: Fresno COG; Tulare CAG; Kern COG; San Joaquin COG, Merced and Stanislaus COGs (which share a three-county model)
- Butte County Association of Governments (CAG)
- San Luis Obispo Council of Governments (COG)

The Shasta Regional Transportation Agency was also represented; however, because of the relatively unique activity based travel model being implementing, only a general adjustment framework was developed and no post-processor calibration was performed.

The development of these TDF model post-processors is described in the following sections.
B. Information Exchange with MPOs

During May and June of 2012, Fehr & Peers Consultants provided technical assistance to the selected MPOs on implementation of the Ds Analysis Modules in conjunction with their regional travel demand forecasting (TDF) models. This process involved the following coordination efforts and information exchanges:

1. **Initial data request**

Fehr & Peers itemized the specific travel model data each MPO needed to provide, which included the following from both the MPO base year and RTP forecast year: TAZ mapping and GIS files, socio-economic and demographic data, transportation networks and skim matrices, trip tables, model operating directory, parameters and subroutine modules. (For those MPOs for which Fehr & Peers already had the necessary files, requests were confined to confirmation of the currency of these files and any additional data not already in hand.)

   - MPOs’ responsibility: Transmitted requested data to Fehr & Peers

2. **Specify model diagnostic runs**

Fehr & Peers contacted the MPO modelers to discuss land use/transportation scenarios the MPO already had available for base year and forecast year analysis. With each MPO, they identified scenarios to be used for model diagnostic runs. If the MPO already had setups for two substantially different land use scenarios in a single year with the same transportation network, those scenarios were selected as the diagnostic test cases. If not, Fehr & Peers specified the means through which the MPO should pivot from a single scenario to generate a hypothetical alternative scenario (usually by swapping land use among multiple zone pairs) for testing purposes. Then either Fehr & Peers or the MPO performed complete model runs for the two comparison scenarios.

   - MPOs’ responsibility: Transmit test run results to Fehr & Peers matching the technical specifications of the two land use cases.

3. **Perform statistical analysis of model test results**

Fehr & Peers performed statistical analysis of model test results in comparison with tests that Fehr & Peers performed on the same cases using the Ds Analysis Modules. The analysis ascertained the degree of land use sensitivity already captured in the MPO model, and any need for further model post-process adjustment to match the research-based, regionally specific sensitivities. Fehr & Peers provided the results and proposed post-process algorithms to the MPO modelers for review.

   - MPOs’ responsibility: Review findings on TDF model sensitivity and the proposed
4. **Perform post-processor validation runs**

Fehr & Peers applied the post-process module to original model test cases to demonstrate that the post-processor accurately adjusts model-generated regional VMT estimates in a manner consistent with the regionally specific findings on land use “D” sensitivities.

- MPOs’ responsibility: Review results and comment to Fehr & Peers

5. **Document tests, tool performance and application procedures**

Fehr & Peers documented the tests, test results and post-processor application procedures for use by MPO modelers in analyses they will perform in support of their regional transportation planning beyond the end of this study’s technical assistance.

- MPOs’ responsibility: Review and comment to Fehr & Peers.

6. **Training workshop**

Fehr & Peers hosted a training webinar (on June 26, 2012) with staff of the “demo” MPOs to review the testing process, post-processor module formulation and application process, including a “live” demonstration of post-processor application and reporting of before-and-after results. Example modules were presented during the webinar to generate questions for group discussion. The webinar was recorded for referral by MPO modelers when applying the post process module beyond completion of this project.

MPOs’ responsibility: Attend webinar, participate in question/answer and discussion.

Assistance provided to end-users also included the processes and guidance described in the following sections:

2: Test Plans for Regional TDM Models

3: Documentation of Statistically Calibrated Post-Processor Modules

4: Guidelines for Validation Testing

5: User Guidance on Analysis Module Applications
2. TRAVEL MODEL TEST PLANS and RESULTS

This section describes the process that was used to evaluate the built environment sensitivities of TDF models and the results of those analyses.

A. Examination and Evaluation of TDF Model Sensitivities

Prior to applying the Ds Analysis Modules developed for this study, a model sensitivity analysis was conducted for TDF models in each of the eight “demonstration” MPO regions. This analysis determined each regional TDF model’s existing sensitivity to local built environment variables (as of May/June 2012).

The initial step of this analysis was inspection of each step of the TDF model, with a particular focus on trip generation modules within each of the models. Specifically, these were examined for any explicit sensitivity to the following “D” variables:

1. Density: dwellings, jobs per acre
2. Diversity: mix of housing, jobs, retail
3. Design: connectivity, walkability, network density
4. Destinations: regional accessibility
5. Development Scale: residents, jobs
6. Demographics: household size, income
7. Distance to Transit: rail or bus proximity

None of the demonstration MPOs’ TDF models was found to have any explicit sensitivity to the first three built environment “D” variables (density, diversity and design). With respect to the next three “D” variables (Destinations, Development and Demographics), each of the models proved itself sensitive; indeed distance or impedance to potential destinations is a key variable in the trip distribution component of all TDF models, and development quantities and demographic variables are key determinants of trip generation estimates.

With respect to the final “D”, Distance to Transit, there were a variety of sensitivities across the six models. The Butte CAG model predicts only auto trips; transit and non-motorized travel are not included. Three of the models, (Fresno, Kern and the three-county model covering San Joaquin, Stanislaus, and Merced COGs) have full mode choice models, while Tulare and San Luis Obispo have simplified mode split algorithms. In total, the Ds Analysis Modules were implemented for six regional TDF models, and technical assistance offered to all eight MPOs that use those models.

The preliminary examination of the six demonstration TDF models’ structure and sub-modules suggested that while some Ds are well represented in the models, each model lacked sensitivity to the full range of "D" variables, especially the first three built-
environment “D” variables (listed and described in the Overview report).

By comparison, the Ds Analysis Modules developed for this study are sensitive to Density, Diversity and Design as well as other “D” variables, and have been shown to produce results consistent with national research on travel behavior and the built environment. Thus it was concluded that a TDF model adjustment process was warranted using the observed relationships between “D” variables and travel behavior found in the Ds Analysis Modules.

A process was developed that would combine the TDF models’ sensitivity to “D” variables with the greater and broader sensitivity of the Ds Analysis Module. This TDF model calibration procedure has a useful side benefit: it effectively determines the degree to which each agency’s TDF model accounts for various built environment factors. Thus it became possible to document the effective sensitivity to the “Ds” already present in each TDF model, and to adjust each model only to the degree warranted.

B. Model Testing Using Alternative Land Uses: The “Swap” Approach

To determine the degree to which particular TDF models are sensitive to detailed built environment and socio-demographic changes, an alternative – or “sustainable swap” - land use scenario was developed based on each model’s base year TDF model land use. To simplify the development of this alternative land use scenario, a “swap” methodology was devised that rearranges land uses and urban form in the TDF model’s base year land use. Its purpose is not to develop a plausible land use scenario, but to test the TDF model’s sensitivity to changing input values relative to the Ds Analysis Module’s sensitivity.

The following guidelines were applied in developing each of the “swap” scenarios:

1. Land-Use “Swap” Tests. These tests change the predominant land uses within selected transportation analysis zones (TAZs) used in the TDF model. In effect, the developed area of a TAZ is converted from one predominant urban form to another. Such “swaps” were typically performed on 15-20 TAZs for each TDF model, geographically spread across the model area. Several involved changing land-use types near urban centers, while the other changes were spread out across the TDF model area (please see note on TAZ size limits below). In changing land-use types, the intent was to obtain diversity across the relevant factors, and to compare substantial change compared to the “base” land uses.

An important rule regarding these swaps is the requirement that all changed TAZs must contain at least some residential land uses. For example, it is not feasible to convert an entirely industrial TAZ from “Industrial Focus” to “Town Mixed Use” because the VMT calculation will not work properly, as the Ds Analysis modules only compute Home-Based VMT and Average Household VMT by TAZ.
The table below shows examples of such swaps for the Fresno COG TDF model:

<table>
<thead>
<tr>
<th>Original (&quot;Base&quot;) Land-Uses</th>
<th>Changed (&quot;Swap&quot;) Land-Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail: Strip Mall/ Big Box</td>
<td>Office Focus</td>
</tr>
<tr>
<td>Town Mixed Use</td>
<td>Retail: Strip Mall/ Big Box</td>
</tr>
<tr>
<td>Rural Residential</td>
<td>City Mixed Use</td>
</tr>
<tr>
<td>Large Lot Residential Area</td>
<td>Town Mixed Use</td>
</tr>
<tr>
<td>Town Mixed Use</td>
<td>Office Focus</td>
</tr>
<tr>
<td>Office Focus</td>
<td>City Mixed Use</td>
</tr>
<tr>
<td>Office/Industrial</td>
<td>City Mixed Use</td>
</tr>
<tr>
<td>Office/Industrial</td>
<td>City Mixed Use</td>
</tr>
<tr>
<td>Office/Industrial</td>
<td>Village Mixed Use</td>
</tr>
<tr>
<td>Large Lot Residential Area</td>
<td>City Mixed Use</td>
</tr>
<tr>
<td>Town Mixed Use</td>
<td>Large Lot Residential Area</td>
</tr>
<tr>
<td>High Intensity Activity Center</td>
<td>Mixed Office and R&amp;D</td>
</tr>
<tr>
<td>Urban Mixed Use</td>
<td>City Mixed Use</td>
</tr>
</tbody>
</table>

2. **Geographic Tests.** These tests are similar to the land-use swap tests, except that the entire TAZ contents are shifted as opposed to simply re-characterizing the developed area by changing land-use types. Such geographic swaps were performed on about 5-10 TAZs per region, with a similar mix of near and far locations (as described in 1 above). All TAZs used in these tests contained households.

3. **Density/Intensity Change Tests.** The goal of this test was to provide at least 10 measurable changes of household density and 10 of employment intensity for each modeling region (covering a range of area-types). Residential density within at least ten selected TAZs was increased by factors ranging from 0.75 to 1.25 times the original density (two TAZs were selected for each 0.1 increment of density increase). This change was generally achieved by scaling up the number of housing/dwelling units in a TAZ. Similarly, approximately 10 other TAZs were selected in each MPO area to change the employment intensities (as noted above each of these TAZs included households). The change in employment intensities was the same: intensities were increased by factors ranging from .075 to 1.25 times.
the original intensities (e.g., two TAZs for each change amount).

Note: Large TAZs complicate the estimation of developed acreage and can skew results. For these reasons, these tests were limited to TAZs less than 750 acres in size. Smaller TAZs also tend to be in the more built-up portions of a region, where transportation alternatives are often also the greatest.

C. Calibration Tool Development: Step-by-Step Methodology

Once the alternative “Swap” land use scenario was developed (as described above) for each region, sensitivity testing was conducted using the MPO’s most up-to-date Travel Demand Forecasting Model (TDF). Each TDF model was first deemed by the regional MPO to be reasonably well-calibrated, and had a recent and complete set of associated base year land use data.

To develop the “Ds Adjustment Equation” post-processor tools, the following steps were followed for each region:

Step 1: As described above, an alternative sustainable (or smart) “land-use swap” derivative of the model’s “base” year land use was developed. Each TAZ land-use-swap can be described in terms of changes to density, diversity, design, destination, and distance to transit in the region.

Step 2: Both models were run - Ds Analysis Module and the TDF model - with same land use data assumptions and computed average household-based VMT at the TAZ level for both the existing “base” and sustainable (or smart) “swap” land-use scenarios.

The “D” variables were computed at the smallest scale feasible – generally at the parcel or grid cell level for those regions that have such disaggregate data. The sequential Ds Analysis Module equations use half-mile land-use buffers around the household as a unit of analysis; thus, in order to link the Ds Analysis Modules to the TDF models, half-mile buffers were computed around TAZ centroids. Using the TAZ centroid to compute the land-use buffer is a simplified approach, but this approach still required detailed land-use data across each demonstration region.

The Ds Analysis Modules have two forms, 2-Step and 3-Step (as described in Appendix D). The advantage of using one or the other depends on the confidence that each MPO has on its TDF model’s Trip Distribution process. The 3-Step Module relies on the Trip

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1 The required needed to be sufficient to calculate basic household demographic estimates (such as average # of workers, average # of drivers, percentage of households with children, household income groups, average household size, and average # of vehicles in the household) either at the TAZ level or census tract/block levels; density data (such as household density, employment aacres, populations/residential acres, developed acres, commercial acres, etc.); diversity data (jobs per household ratios, employment types, etc.); design data (such as, street intersection densities, roadway densities, etc.); destination data (transit accessibility, distance-based accessibility, etc); and distance to transit data (distance to the nearest or rail line).
Table information to estimate average Origin-Destination (O-D) pairs from one TAZ to another. The O-D information used in the Ds Analysis Modules is trip destination and related land use metrics. Using the 3-Step Module adds additional data processing time. The 2-Step Module is a more computationally efficient approach and was therefore used in developing the post-processors for the eight “demonstration” MPOs in the following way:

- **Computing VMT per Household using the 2-Step Ds Analysis Module:** The Ds Analysis Modules use demographic information at the household level. Therefore, a quasi population-synthesizer was used to disaggregate TAZ demographic information into the Ds Analysis Modules household-types. Then, half-mile land use buffers are calculated (from each TAZ centroid) either with parcel data or TAZ-level data. The 2-Step Ds Analysis Module requires estimating the probability of a vehicle trip and then estimating VMT per household. The 2-Step Module is used to estimate VMT per household-type, and the results are aggregated back again (using a weighted average approach) to estimate average VMT per Household by TAZ. In other words, the Ds Analysis Module is applied at the individual household level, and the results are multiplied by the appropriate number of households to obtain average VMT per household (VMT/HH) by TAZ. It should be noted that only household-based VMT is estimated (i.e., travel in which the household’s residence is one trip end -- non-home based travel is excluded). This means that the adjustments made by the 2-Step Ds Analysis Module affect only households’ home-based trips, which theory suggests are the trips most likely to be affected by the built environment surrounding the residence.

- **Computing VMT per Household using the 3-Step Ds Analysis Module:** As with the 2-Step Ds Analysis Module, a quasi population-synthesizer is used to disaggregate TAZ demographic information into the Ds Analysis Modules’ household-types and trip-agent types (e.g., age, gender, and trip-purpose). Then, half-mile land use buffers are calculated (from each TAZ centroid) either with parcel data (preferred) or TAZ-level data (if parcel-level data is not available). Since the 3-Step Ds Analysis Module requires Non-Home-End land use information to estimate trip lengths, the TDF model’s Production-Attraction (PA) tables are used to estimate the home-end and non-home-end trip pairs (P-A) land-use metrics. Subsequently, a weighted average trip length would be computed for each TAZ. The 3-Step Ds Analysis Module can then be applied, by looking first into the household probability of making a vehicle trip, and then by multiplying the vehicle trip generation obtained with the Ds Analysis Module
by the average trip length for a given synthesized household. Then, VMT per household-type estimates are produced, and the results can be aggregated back again (using a weighted average approach) to estimate average Household VMT by TAZ. As with the 2-Step Ds Module, the 3-Step Ds Analysis Module is applied at the household level, then results are multiplied by the appropriate number of households to obtain average VMT per Household (HH) by TAZ.

- **Computing VMT per Household using TDF Models:** In order to properly link the VMT estimates between the Ds Analysis Modules and each of the TDF models, “VMT per Household” should be estimated. For *trip-based travel models*, VMT/HH will be estimated by tracking VMT by the home-based trip-type stratifications used by the model and adding together all home-based VMT, which includes only trips that start or end at home and that can be calculated within the 4-step modeling framework. Then, home-based (production generated) VMT is divided over the Household population for each TAZ to estimate an average VMT per household (VMT/HH) by TAZ. For *activity-based travel models*, household VMT would include all vehicle travel generated by the household, and with this more disaggregate modeling framework a more direct average VMT per household can be calculated.

- **Comparing VMT/HH estimated by Ds Analysis Modules and TDF models:** The average VMT/HH estimates should be computed for both land-use data sets: the “base” and the sustainable (or smart) “swap.” In each of these tools, VMT estimates are compared for the “base” and the “swap” to determine the level of VMT reduction predicted due to the sustainable (smart) land use swaps.

**Step 3:** This step entails regressing the *percentage difference between the VMT differences* found for the sustainable swap by the two models – the Ds Analysis Module vs. TDF model - against the changes in the "D" variables. The dependent variable for this regression is the percentage difference between the reductions determined by each the average VMT/HH by TAZ for the Sustainable (smart) land use “swap” from the “Base” land use. The independent variables for the regression are the changes (in either percentage or absolute terms) in the D-variables from the Base and the Sustainable (smart) land uses.
The regression procedure is outlined in this table:

<table>
<thead>
<tr>
<th>Model</th>
<th>Base LU</th>
<th>Sustainable LU Swap</th>
<th>Percent Difference</th>
<th>Ds Adjust. Regression Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ds Analysis Module</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1/2 - mile buffer)</td>
<td>VMT/HH Base</td>
<td>VMT/HH Smart</td>
<td>Y_{dsM} = VMT/HH _{(Smart-Base)%}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LU Buffer Ds</td>
<td>LU Buffer Ds Smart</td>
<td>X_{di} _{dsM} = LU Buffer _{(Smart-Base) %}</td>
<td></td>
</tr>
<tr>
<td><strong>MPO TDF Model</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(TAZ level)</td>
<td>VMT/HH Base</td>
<td>VMT/HH Smart</td>
<td>Y_{TDF} = VMT/HH _{(Smart-Base)%}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LU Ds by TAZ</td>
<td>LU Ds by TAZ Smart</td>
<td>X_{di} _{TDF} = LU by TAZ _{(Smart-Base)%}</td>
<td></td>
</tr>
</tbody>
</table>

Ds Adjustment Equation: \{ Y _{VMT Change} = \alpha + \beta _{d1} (X_{d1}) + \beta _{d2} (X_{d2}) + \beta _{d3} (X_{d3}) + \beta _{d4} (X_{d4}) + \ldots \} 

The resulting equation can then be used to devise adjustment factors (which constitute the Ds adjustment equation or “calibration tool”) for the analyzed TDF modeling region as a whole or for subareas within the region. Note: the constant (\alpha) found in this regression equation needs to be included and carefully examined, as it represents in part the effect of “D” variables that are not present or are only partially represented in the regional TDF model.

**Step 4:** Finally, using the Ds adjustment equation, the regional models are adjusted either at the aggregate macro level, or at the more refined TAZ level. It is also potentially possible to develop regression equations in which the vehicle trip table will be adjusted prior to the trip assignment step.

The model calibration process is illustrated schematically in Figure 1. In the figure, the term “MPO model” refers to the regional TDF model, while “Sequential D Model” refers to the Ds Analysis Modules.
The following sections describe the implementation of the post-processors for the selected demonstration MPO TDF models. A detailed description the Fresno implementation process is followed by more succinct summaries for the other MPOs; these shorter summaries focus on the results and other unique aspects of implementation process for these models.

3. DOCUMENTATION of STATISTICALLY CALIBRATED POST-PROCESSOR MODULES

Please note: The post-processors described below were tailored specifically to the TDF models provided by the eight demonstration MPOs as representing their regions’ valid TDF for use in RTP analysis as of June 2012. MPOs are advised that recalibration of their TDF model should be accompanied by re-estimation and calibration of the Ds Analysis Module post-processor equations as well.
Model Testing and Ds Post-processor Development:

A. Fresno Council of Government (COG) Case Study

The process outlined in the previous sections can perhaps best be understood by describing its application to Fresno COG TDF model.

A sustainable swap land use was devised based on Fresno COG’s 2008 base year land use. A total of 50 TAZs were modified, as shown in Figure 2:

Figure 2 - TAZ Swap Scenario

The Base and the Swap land uses were analyzed with both the Fresno COG TDF model and the small region Ds Analysis Module. While the land uses were the same for both, the Ds Analysis Module considered several half-mile buffer variables that the TDF model does not include.

The Fresno COG TDF analysis indicates total household-based VMT of 38.7 per household for the Base scenario, and 33.6 per household for the Swap Scenario – a reduction of 13.2%. This reduction shows that the Fresno COG TDF has some sensitivity
to the “Ds” variable changes that the Swap land use entails. The 2-step Ds Analysis Module on the other hand, indicates a reduction of 17.9% in per household VMT between the Base and Swap scenarios. In addition, the average Home-Based VMT per TAZ in the TDF analysis was 5,520 in the Base and 6,027 Swap, whereas in the Ds Analysis Module, the home-based VMT was of 5,417 in the Base, and 5,614 in the Swap scenario. The TDF growth in VMT was of 9.3%, while the Ds Analysis Module’s average home-based VMT per TAZ growth was only of 3.6%.

The tool was developed by regressing the “difference of the percent differences” TAZ by TAZ against the changes in the independent variable present in the Ds Analysis Module. In other words, it is hypothesized that zone by zone changes in the “D” variables that the Ds Analysis Module is sensitive to (and which the TDF is not) can explain the additional 5.7% reduction in VMT found by the Ds Analysis Module.

Figure 3 (below) illustrates the process used to develop the calibration via linear regression. Note that only TAZs that had land use swaps or were adjacent to swap TAZs were included in the development of the calibration tool. (Adjacent zones are included because change in adjacent zones affects the half-mile buffered land use variables).

Figure 3 - Calibration Tool Building
Table 1 (below) illustrates the best fitting regression equation developed for explaining the additional reduction in VMT found by the Ds Analysis Module in Fresno. The equation has an adjusted $R^2$ of 0.61 which means that the independent variables in the equation collectively explain about three-fifths of the VMT reduction in the Swap zones. (Note: variables in light blue type were tested, but did not prove to have a significant influence in the final equation).

Two density variables and one diversity variable are included in the final equation. One density variable has a negative coefficient, indicating that increases in nearby minor (neighborhood) commercial serves to reduce VMT. The other density variable, sum of developed acres within the one-half mile, has a positive effect on VMT, suggesting that vehicular travel is higher in fully built up areas compared to rural or semi-rural areas. Five demographic variables are included in the equation. The seemingly anomalous negative coefficient on income suggests that income in the TDF is too positive, and that VMT does not increase with income as much when built environment Ds are considered. In sum, the equation appears to be a good corrective to the raw TDF results, and was used to develop a spreadsheet calibration tool for adjusting TDF VMT forecasts.

**Table 1 - Fresno COG Calibration Equation**

<table>
<thead>
<tr>
<th>D Variables</th>
<th>Description</th>
<th>Variables in terms of differences: (Scenario - Base)</th>
<th>Calibration Model B</th>
<th>sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td></td>
<td></td>
<td>1.773</td>
<td>0.038</td>
</tr>
<tr>
<td>TOTHH</td>
<td>Total Households per TAZ</td>
<td></td>
<td>-0.045</td>
<td>0.000</td>
</tr>
<tr>
<td>HHVEH_CAT_0</td>
<td>Household Size</td>
<td></td>
<td>-54.796</td>
<td>0.099</td>
</tr>
<tr>
<td>HHSIZE_CAT_1</td>
<td>Household Size</td>
<td></td>
<td>-146.894</td>
<td>0.000</td>
</tr>
<tr>
<td>DEN_NetRes</td>
<td>Household population/residential acres within buffer</td>
<td></td>
<td>0.231</td>
<td>0.000</td>
</tr>
<tr>
<td>DEN_DevAcres</td>
<td>Sum of developed acres within half mile</td>
<td></td>
<td>-1.488</td>
<td>0.029</td>
</tr>
<tr>
<td>DEN_EmpAcre</td>
<td>Total jobs in 1/2 mile buffer</td>
<td></td>
<td>-33.326</td>
<td>0.068</td>
</tr>
<tr>
<td>DEN_mi_acres</td>
<td>Minor commercial acres within buffer</td>
<td></td>
<td>-1.488</td>
<td>0.029</td>
</tr>
<tr>
<td>DEN_inUrban</td>
<td>Record in Urban Area</td>
<td></td>
<td>-33.326</td>
<td>0.068</td>
</tr>
<tr>
<td>DIV_JobsHH</td>
<td>Number of jobs/hh within buffer</td>
<td></td>
<td>-33.326</td>
<td>0.068</td>
</tr>
<tr>
<td>DIV_LUEntropy</td>
<td>Land Use Mix within buffer (Entropy Index)</td>
<td></td>
<td>-33.326</td>
<td>0.068</td>
</tr>
<tr>
<td>DSG_Street</td>
<td>Roadway density</td>
<td></td>
<td>2020 Concept Scenario VMT Reduction</td>
<td>8</td>
</tr>
<tr>
<td>DistT_RRStop</td>
<td>Nearest railroad station (converted to miles)</td>
<td></td>
<td>Number of “D” variables</td>
<td>-1.98%</td>
</tr>
</tbody>
</table>

**R2**

2020 Concept Scenario VMT Reduction

- 0.625

- Adj R2

- 0.610
Future Scenario Analysis – Fresno COG

As test case for the new Fresno calibration tool, a 2020 scenario based on Fresno’s 2011 RTP 2020 land use and transportation network was developed. For this hypothetical scenario, the RTP 2020 population and employment totals were used, but all development was assumed to be infill (i.e., there was no increase in developed acres). The resulting scenario has increased residential and employment density in all TAZs where new development was expected (a few zones showed reductions in land use). The transportation network was kept unchanged. As with the sustainable Swap land use scenario developed in the base year, the all-infill 2020 scenario was not intended as a realistic land use plan, but rather as one that results in significant changes in density and other built environment variables to test the response of the Ds calibration tool.

Figure 4 illustrates how the Calibration Tool was applied to the future land use scenario. The TDF was first run for the unadjusted 2020 land use and per household VMT was calculated in the same way as described for the Base year land use. Then adjustment factors derived from the calibration equation are applied by the spreadsheet tool on a TAZ-by-TAZ basis based on the changes in the “D” variables in the 2020 infill-only scenario (i.e., changes in “D” variable used in the calibration regression equation). The spreadsheet then calculates and sums the adjusted VMT for the alternative scenario.

Figure 4 - Calibration Equation Implementation

TDF Base LU → Ds Base LU

TDF Scenario LU → Ds Scenario LU

Apply calibration equation to obtain VMT DoFD and generate factors

Base ½ Mile Ds Buffers

Scen.½ Mile Ds Buffers

VMT (Change) = β (Ds Delta) + β (Ds Delta) + ...

TAZ Ds Factors

Scenario VMT Adjusted
An important feature of this VMT calibration tool is that it responds to both increases and decreases in “D” factors. Figure 5 (below) shows the TAZ-by-TAZ adjustment factors for central Fresno and areas to the west. Shades of green indicate zones where the land use changes in the infill-only scenario result in reductions in home-based VMT. The smaller number of orange shaded TAZs sees increases home-based VMT due to reductions in density or a reduction in the degree of diversity within and around the TAZ. The histogram in Figure 6 (below) shows that more TAZs see VMT reductions than increases. The histogram also shows that the majority TAZs do not see any changes in the VMT estimation; these are zones where no significant changes in development quantities are anticipated under the 2020 scenario. In aggregate, the VMT change for all TAZs under the infill-only 2020 scenario is -1.98%. Figure 7 shows the anticipated change in VMT for each of the three major purposes. As shown, the Ds Analysis Module cannot forecast changes in non-home-based VMT.

Figure 5 - Fresno Ds Analysis Module Adjustment Factor by TAZ
Figure 6 - Ds Analysis Module Reduction Factors

Adjustment Factor Distribution

Figure 7 - Adjusted VMT for 2020 Conceptual Scenario

Base 2020 Scenario vs. Adjusted Scenario
B. Tulare County Association of Governments (CAG) Calibration Tool Development Summary

A sustainable “swap” land use was devised based on Tulare CAG’s 2008 base year land use. A total of 50 TAZs were modified, as shown in Figure 8.

Figure 8 - Tulare CAG Land Use Swaps

Table 2 (below) illustrates the best fitting regression equation developed for explaining the additional reduction in VMT found by Ds Analysis Module in Tulare County. The equation has an adjusted R² of 0.48 which means that the independent variables in the equation collectively explain about half of the VMT reduction in the swap zones. (Note: variables in light blue type were tested, but did not prove to have a significant influence in the final equation).

Four density variables are included in the final equation. Three have negative coefficients, indicating that increases in household population density, nearby retail, and total development within the one-half mile all have a negative effect on VMT. It should be noted that the coefficient on household population density is not highly significant; there is a 40% chance that the coefficient is zero.

Three demographic or household variables are included in the equation: Total households...
per TAZ (which is also a quasi-density variable) has a negative effect on VMT, which is logical. A second demographic variable, number of zero vehicle households has an anomalous positive effect on VMT, indicating that the TDF exaggerates the negative effect of having no vehicles on VMT generation. The third demographic variable, the number of household vehicles, has a positive effect on VMT, which is reasonable.

In sum, the equation appears to be a good corrective to the raw TDF results, and was used to develop a spreadsheet calibration tool for adjusting TDF VMT forecasts.

### Table 2 - Tulare CAG Calibration Equation

<table>
<thead>
<tr>
<th>D Variables</th>
<th>Description</th>
<th>Calibration Model B</th>
<th>t (sig.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTHH</td>
<td>Total Households per TAZ</td>
<td>0.017</td>
<td>0.994</td>
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<tr>
<td>HHVEH_CAT_0</td>
<td>Household Size</td>
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<td>0.000</td>
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<tr>
<td>HHSIZE_CAT_1</td>
<td>Household Size</td>
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<td>0.014</td>
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<tr>
<td>HHSIZE_CAT_2</td>
<td>Household Size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income10K</td>
<td>Income by $10K increments</td>
<td>38.435</td>
<td>0.000</td>
</tr>
<tr>
<td>HHVEHCNT</td>
<td>Household Vehicle Count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEN_NetRes</td>
<td>Household population/residential acres within buffer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEN_DevAcres</td>
<td>Sum of developed acres within half mile</td>
<td>-0.320</td>
<td>0.414</td>
</tr>
<tr>
<td>DEN_EmpAcre</td>
<td>Total jobs in 1/2 mile buffer</td>
<td>-0.749</td>
<td>0.007</td>
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<tr>
<td>DEN_mi_acres</td>
<td>Minor commercial acres within buffer</td>
<td>14.709</td>
<td>0.062</td>
</tr>
<tr>
<td>DEN_inUrban</td>
<td>Record in Urban Area</td>
<td>-1.118</td>
<td>0.009</td>
</tr>
<tr>
<td>DIV_JobsHH</td>
<td>Number of jobs/hh within buffer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIV_LUEntropy</td>
<td>Land Use Mix within buffer (Entropy Index)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSG_Sreet</td>
<td>Roadway density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dist. to Transit</td>
<td>Nearest railroad station (converted to miles)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Number of “D” variables</th>
<th>2020 Concept Scenario VMT Reduction</th>
<th>-1.24%</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2</td>
<td>0.497</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adj R2</td>
<td>0.481</td>
<td></td>
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</tr>
</tbody>
</table>

### Future Scenario Analysis - Tulare CAG

As test case for the new Tulare CAG Calibration Tool, a 2020 scenario based on Tulare CAG’s 2011 RTP 2020 land use and transportation network was developed. As was the case in Fresno County, the RTP 2020 population and employment totals were used, but all development was assumed to be infill (i.e., there was no increase in developed acres). The resulting scenario has increased residential and employment density in all TAZs where new development was expected (a few zones showed reductions in land use). The
transportation network was kept unchanged.

The TDF model was first run for the unadjusted 2020 land use and per household VMT was calculated in the same way as described for the Base year land use. Then adjustment factors derived from the calibration equation are applied by the spreadsheet tool on a TAZ-by-TAZ level based on the changes in the “D” variables in the 2020 infill-only scenario. The infill-only scenario results in a -1.24% reduction in regional VMT.

**Figure 9 - Ds Adjustment Module Reduction Factors Tulare CAG**

**Figure 10 - Adjusted VMT for 2020 Conceptual Scenario for Tulare CAG**

**Base 2020 Scenario vs. Adjusted Scenario**

<table>
<thead>
<tr>
<th></th>
<th>HBW</th>
<th>HBO</th>
<th>NHB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario</td>
<td>4,176,456</td>
<td>4,765,847</td>
<td>2,244,998</td>
</tr>
<tr>
<td>Scenario (Adj)</td>
<td>4,103,122</td>
<td>4,700,933</td>
<td>2,244,998</td>
</tr>
</tbody>
</table>
C. Kern COG Calibration Tool Development Summary

A sustainable swap land use was devised based on Kern COG 2008 base year land use. A total of 50 TAZs were modified, an example of the swaps is shown in Figure 11.

Figure 11- Kern COG Land Use Swaps

Table 3 (below) illustrates the best fitting regression equation developed for explaining the additional reduction in VMT found by Ds Analysis Module in Kern County. The equation has an adjusted $R^2$ of 0.59 which means that the independent variables in the equation collectively explain about three-fifths of the VMT reduction in the swap zones. (Note: variables in light blue type were tested, but did not prove to have a significant influence in the final equation).

Two density variables and one design variable are included in the final equation; all have negative coefficients, indicating that increases in household population density, nearby employment, and an increase in street density within the one-half mile all have a negative effect on VMT.

Two demographic or household variables are included in the equation: number of zero
vehicle households, where it was found that the Kern TDF model slightly over-predicts VMT at TAZs where there are zero vehicle households. The third demographic variable, the number of household vehicles, has a positive effect on VMT, which is reasonable.

In sum, the equation appears to be a good corrective to the raw TDF results, and was used to develop a spreadsheet calibration tool for adjusting TDF VMT forecasts.

Table 3 - Kern COG Calibration Equation

<table>
<thead>
<tr>
<th>D Variables</th>
<th>Description</th>
<th>Calibration Model B</th>
<th>t (sig.)</th>
</tr>
</thead>
<tbody>
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<td>Demographics</td>
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<td></td>
</tr>
<tr>
<td>TOTHH</td>
<td>Total Households per TAZ</td>
<td>-397.062</td>
<td>0.000</td>
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<tr>
<td>HHVEH_CAT_0</td>
<td>Household Size</td>
<td>-397.062</td>
<td>0.000</td>
</tr>
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<td>HHSIZE_CAT_1</td>
<td>Household Size</td>
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<td>HHSIZE_CAT_2</td>
<td>Household Size</td>
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<td>0.000</td>
</tr>
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<td>Income10K</td>
<td>Income by $10K increments</td>
<td>34.702</td>
<td>0.000</td>
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<td>HHVEHCNT</td>
<td>Household Vehicle Count</td>
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<td>0.000</td>
</tr>
<tr>
<td>Density</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEN_NetRes</td>
<td>Household population/residential acres within buffer</td>
<td>-0.194</td>
<td>0.054</td>
</tr>
<tr>
<td>DEN_DevAcres</td>
<td>Sum of developed acres within half mile</td>
<td>-0.194</td>
<td>0.054</td>
</tr>
<tr>
<td>DEN_EmpAcre</td>
<td>Total jobs in 1/2 mile buffer</td>
<td>-0.194</td>
<td>0.054</td>
</tr>
<tr>
<td>DEN_mi_acres</td>
<td>Minor commercial acres within buffer</td>
<td>-0.194</td>
<td>0.054</td>
</tr>
<tr>
<td>DEN_inUrban</td>
<td>Record in Urban Area</td>
<td>-0.194</td>
<td>0.054</td>
</tr>
<tr>
<td>Diversity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIV_JobsHH</td>
<td>Number of jobs/hh within buffer</td>
<td>-2.566</td>
<td>0.001</td>
</tr>
<tr>
<td>DIV_LUEntropy</td>
<td>Land Use Mix within buffer (Entropy Index)</td>
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<td>0.001</td>
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<tr>
<td>Design</td>
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</tr>
<tr>
<td>DSG_Street</td>
<td>Roadway density</td>
<td>-3.778</td>
<td>0.000</td>
</tr>
<tr>
<td>Dist. to Transit</td>
<td>Nearest railroad station (converted to miles)</td>
<td>-3.778</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Number of “D” variables 5
2020 Concept Scenario VMT Reduction -2.12%

R2 0.601
Adj R2 0.591

Future Scenario Analysis – Kern COG

As a test case for the new Kern COG Calibration Tool, a 2020 scenario based on Kern COG’s 2011 RTP 2020 land use and transportation network was developed. This test case was developed in the same way as described for the MPOs above. The TDF model was first run for the unadjusted 2020 land use and per household VMT was calculated in
the same way as described for the Base year land use. Then adjustment factors derived from the calibration equation are applied by the spreadsheet tool on a TAZ-by-TAZ level based on the changes in the “D” variables in the 2020 infill-only scenario. The infill-only scenario results in a -2.12% reduction in regional VMT.

**Figure 12 - Ds Analysis Module Reduction Factors Kern COG**

**Figure 13 - Adjusted VMT for 2020 Conceptual Scenario for Kern COG**

**Base 2020 Scenario vs. Adjusted Scenario**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Scenario (Adj)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBW</td>
<td>9,170,121</td>
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<td>HBO</td>
<td>14,217,703</td>
</tr>
<tr>
<td>NHB</td>
<td>5,529,457</td>
</tr>
</tbody>
</table>

**D. Three-County Model Calibration Tool Development Summaries**

A sustainable swap land use was devised based on the 2008 base year version of the Three-County Model, which contains San Joaquin COG, Stanislaus COG, and Merced CAG. A total of 50 TAZs were modified—Figure 14 shows an example of the swaps in the
Table 4 (below) illustrates the best fitting regression equation developed for explaining the additional reduction in VMT found by Ds Analysis Module for the Three-County Model. The equation has an adjusted $R^2$ of 0.50 which means that the independent variables in the equation collectively explain about half of the VMT reduction in the swap zones. (Note: variables in light blue type were tested, but did not prove to have a significant influence in the final equation).

Two density variables are included in the final equation; both have negative coefficients, indicating that increases in household population density, and nearby employment within the one-half mile all have a negative effect on VMT. In addition, two land use diversity variables were found statistically significant: jobs per household ratio, and the land use entropy index. Both of the land use diversity variables are negatively correlated with VMT.

One demographic variable proved statistically significant; zero vehicle households. Zero vehicle households were found to be negatively correlated with VMT. In sum, the equation appears to be a good corrective to the raw TDF results, and was used to develop a
A spreadsheet calibration tool for adjusting TDF VMT forecasts.

### Table 4 – Three-County Calibration Equation

<table>
<thead>
<tr>
<th>D Variables</th>
<th>Description Variables in terms of differences: (Scenario - Base)</th>
<th>Calibration Model B</th>
<th>t (sig.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demographics</strong></td>
<td>(Constant)</td>
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<td>TOTHH</td>
<td>Total Households per TAZ</td>
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<td></td>
</tr>
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<td>HHVEH_CAT_0</td>
<td>Household Size</td>
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<td>0.000</td>
</tr>
<tr>
<td>HHSIZE_CAT_1</td>
<td>Household Size</td>
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<td></td>
</tr>
<tr>
<td>HHSIZE_CAT_2</td>
<td>Household Size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income10K</td>
<td>Income by $10K increments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHVEHCNT</td>
<td>Household Vehicle Count</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td>DEN_NetRes</td>
<td>-0.349</td>
<td>0.060</td>
</tr>
<tr>
<td>DEN_DevAcres</td>
<td>Sum of developed acres within half mile buffer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEN_EmpAcre</td>
<td>Total jobs in 1/2 mile buffer</td>
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<td>0.000</td>
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<tr>
<td>DEN_mi_acres</td>
<td>Minor commercial acres within buffer</td>
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<td></td>
</tr>
<tr>
<td>DEN_inUrban</td>
<td>Record in Urban Area</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Diversity</strong></td>
<td>DIV_JobsHH</td>
<td>0.943</td>
<td>0.127</td>
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<tr>
<td>DIV_LUEntropy</td>
<td>Land Use Mix within buffer (Entropy Index)</td>
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<td>0.001</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>DSG_Street</td>
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<td></td>
</tr>
<tr>
<td><strong>Dist. to Transit</strong></td>
<td>DisT_RRstop</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nearest railroad station (converted to miles)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Number of “D” variables: 5
2020 Concept Scenario VMT Reduction: -2.97%

R2: 0.511
Adj R2: 0.500

### Future Scenario Analysis - Three-County Model

As a test case for the new Three-County TDF Model Calibration Tool, a 2020 scenario was developed based on the regional MPOs’ forecasts of future land use and transportation network conditions. The general procedure for developing this illustrative land use/transportation scenario is the same as for the other MPOs described above.

The TDF model was first run for the unadjusted 2020 scenario and per household VMT was calculated in the same way as described for the Base year land use. Then adjustment factors derived from the calibration equation are applied by the spreadsheet tool on a TAZ-by-TAZ level based on the changes in the “D” variables in the 2020 infill-
only scenario. The infill-only scenario results in a -2.97% reduction in regional VMT.

Figure 15 - Ds Adjustment Module Reduction Factors Three-County Model

![Adjustment Factor Distribution](image)

Figure 16 - Adjusted VMT for 2020 Conceptual Scenario for Three-County Model

![Base 2020 Scenario vs. Adjusted Scenario](image)
E. San Luis Obispo COG (SLOCOG) Calibration Tool Development Summary

A sustainable swap land use was devised based on SLOCOG’s 2008 base year land use. A total of 50 TAZs were modified. Examples of the swaps are shown in Figure 17.

**Figure 17 - SLOCOG Land Use Swaps**

Table 5 illustrates the best fitting regression equation developed for explaining the additional reduction in VMT found by Ds Analysis Module in the SLOCOG area. The equation has an adjusted $R^2$ of 0.61 which means that the independent variables in the equation collectively explain about three-fifths of the VMT reduction in the swap zones. (Note: variables in light blue type were tested, but did not prove to have a significant influence in the final equation).

One density variable is included in the final equation—population density—which has a negative coefficient indicating that it is negatively correlated with household VMT. In addition, one land use diversity variable was found to be statistically significant. In this case, the land use entropy index is negatively correlated with VMT. Finally, a street design variable was found statistically significant, where more roadway density is also correlated
with less VMT.

Two demographic or household variables are included in the equation: Total households per TAZ (which is also a quasi-density variable) has a positive effect on VMT. A second demographic variable, the average household income, also has a positive effect on VMT; both variables are reasonable based on how the SLOCOG TDF model was developed.

Overall, the calibration equation represents a reasonable correction to the raw TDF results.

**Table 5 - SLOCOG Calibration Equation**

<table>
<thead>
<tr>
<th>D Variables</th>
<th>Description Variables in terms of differences: (Scenario - Base)</th>
<th>Calibration Model B</th>
<th>t (sig.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
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<td>-4.985</td>
<td>0.000</td>
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<tr>
<td><strong>Demographics</strong></td>
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<td>0.000</td>
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<tr>
<td>HHSIZE_CAT_1</td>
<td>Household Size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHSIZE_CAT_2</td>
<td>Household Size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income10K</td>
<td>Income by $10K increments</td>
<td>0.507</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td>Household population/residential acres within buffer (DEN_NetRes)</td>
<td>-0.640</td>
<td>0.115</td>
</tr>
<tr>
<td>DEN_DevAcres</td>
<td>Sum of developed acres within half mile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEN_EmpAcre</td>
<td>Total jobs in 1/2 mile buffer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEN_mi_acres</td>
<td>Minor commercial acres within buffer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEN_inUrban</td>
<td>Record in Urban Area</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Diversity</strong></td>
<td>Number of jobs/hh within buffer (DIV_JobsHH)</td>
<td>-36.480</td>
<td>0.000</td>
</tr>
<tr>
<td>DIV_LUEntropy</td>
<td>Land Use Mix within buffer (Entropy Index)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>Roadway density (DSG_Street)</td>
<td>-6.890</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Dist. to Transit</strong></td>
<td>Nearest railroad station (converted to miles) (DisT_RRstop)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Number of “D” variables | 5 |
| 2020 Concept Scenario VMT Reduction | -2.72% |

R2 | 0.628 |
Adj R2 | 0.612 |

**Future Scenario Analysis - SLOCOG**

A 2020 scenario based on SLOCOG’s 2020 RTP population and employment totals was developed as a test case for the Ds Calibration Tool. The process to develop this scenario is similar to what was described for the other MPOs above. The TDF model was first run
for the unadjusted 2020 land use and per household VMT was calculated in the same way as described for the Base year land use. Then adjustment factors derived from the calibration equation are applied by the spreadsheet tool on a TAZ-by-TAZ level based on the changes in the “D” variables in the 2020 infill-only scenario. The infill-only scenario results in a -2.72% reduction in regional VMT.

**Figure 18 - Ds Analysis Module Reduction Factors for SLOCOG**

![Adjustment Factor Distribution](image)

**Figure 19 - Adjusted VMT for 2020 Conceptual Scenario for SLOCOG**

![Base 2020 Scenario vs. Adjusted Scenario](image)
F. Butte CAG (BCAG) Calibration Tool Development Summary

A sustainable swap land use was devised based on BCAG’s 2010 base year land use. A total of 59 TAZs were modified—Figure 20 shows a sampling of the swapped TAZs in the Chico area.

Table 6 (below) illustrates the best fitting regression equation developed for explaining the additional reduction in VMT found by Ds Analysis Module in the BCAG area. The equation has an adjusted $R^2$ of 0.12 which means that the independent variables in the equation collectively explain just over one-tenth of the VMT variation in the swap zones. (Note: variables in light blue type were tested, but did not prove to have a significant influence in the final equation).

Two density variables are included in the final equation—residential density and total developed acreage within a half-mile buffer of the TAZ. Residential density has a slight positive effect on VMT, indicating that the TDF model is overly-sensitive to this variable, while there is a slight negative effect on VMT associated with overall developed acreage, indicating that the TDF model is not sensitive enough with respect to non-residential development intensity.

One diversity variable, land use mix, also was significant in our tests. The coefficient is negative, indicating that there the TDF model is not sensitive enough at reducing VMT when there is a better mix of land uses nearby households.

One demographic variable included in the equation—income. The coefficient on the income variable is negative, indicating that the TDF model may be over-predicting the VMT of higher income households.

Overall, the BCAG Calibration Tool had a lower adjusted $R^2$ statistic than other TDF models described in this appendix. While it was not an explicit goal of the Ds Analysis Module to obtain high $R^2$ statistics, the project team explored several potential reasons for this discrepancy. One item that stands out as a potential cause is the highly customized trip generation rates in the BCAG TDF model. In order for the TDF model to validate well to observed conditions, a variety of trip generation rates had to be incorporated into the TDF model. These trip generation rate variations reflect differences in residential occupancy patterns (some areas in Butte County have a high proportion of vacation homes) and non-residential uses (rural areas have lower commercial trip generation rates and areas outside of Chico have relatively high vacancy rates). Considering that the Ds Analysis Module does not have these geographically specific trip generation inputs, it is less surprising that the $R^2$ statistic is relatively low in the BCAG area.
Figure 20 – Butte CAG Land Use Swaps
Table 6 - Butte CAG Calibration Equation

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
<th>Calibration Model</th>
<th>B (sig.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td></td>
<td>-3.694 0.061</td>
<td></td>
</tr>
<tr>
<td><strong>Demographics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTHH</td>
<td>Total Household</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHSIZE_CAT_1</td>
<td>Household Size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHSIZE_CAT_2</td>
<td>Household Size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income10K</td>
<td>Income by $10K increments</td>
<td>-1.135 0.019</td>
<td></td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEN_NetRes</td>
<td>Household population/residential acres within buffer</td>
<td>0.220 0.158</td>
<td></td>
</tr>
<tr>
<td>DEN_DevAcres</td>
<td>Sum of developed acres within half mile</td>
<td>-0.248 0.001</td>
<td></td>
</tr>
<tr>
<td>DEN_EmpAcre</td>
<td>Total jobs in 1/2 mile buffer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEN_mi_acres</td>
<td>Minor commercial acres within buffer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEN_inUrban</td>
<td>Record in Urban Area</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Diversity</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>DIV_JobsHH</td>
<td>Number of jobs/hh within buffer</td>
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<td></td>
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<tr>
<td>DIV_LUEntropy</td>
<td>Land Use Mix within buffer (Entropy Index)</td>
<td>-172.54 0.002</td>
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<td><strong>Design</strong></td>
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<td></td>
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</tr>
<tr>
<td>DSG_Street</td>
<td>Roadway density</td>
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<td></td>
</tr>
<tr>
<td><strong>Dist. to Transit</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DisT_RRstop</td>
<td>Nearest railroad station (converted to miles)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Number of “D” variables: 4
2035 Concept Scenario VMT Reduction: -0.46%

R2: 0.140
Adj R2: 0.120

Future Scenario Analysis - Butte CAG

Similar to the other MPO areas evaluated in this document, the Ds Analysis Module was applied to a future land use scenario as a proof of concept. For this effort, BCAG provided a sample 2035 land use file that is based on preliminary land use sketch planning efforts and their current 2035 RTP.

The BCAG TDF model was first run and VMT adjustment factors were developed using the same methods as described for the other MPO areas. The infill-only 2035 scenario results in a -0.46% reduction in regional VMT when compared to the raw TDF model run. This result is lower than the other MPO models described in this appendix, but this is in part due to the lower number of "D" variables identified. In addition, one of the variables, land use entropy, was not calculated as part of the sample 2035 scenario. Considering the...
nature of the 2035 scenario, these results are quite reasonable.

Figure 21 - Ds Analysis Module Reduction Factors for Butte CAG

![Adjustment Factor Distribution](image)

Figure 22 - Adjusted VMT for 2020 Conceptual Scenario for Butte CAG

![Base 2035 Scenario vs. Adjusted Scenario](image)
G. Shasta Regional Transportation Agency (SRTA)

As part of the implementation of the Ds Analysis Module, Fehr & Peers worked with SRTA staff to develop an implementation framework for Shasta County. SRTA is unique among the MPOs described in this document since it has an “activity based” TDF model (all the other MPOs have more traditional “trip based” TDF models). Activity based TDF models are a more recent development in the travel forecasting profession and there are only a handful of these models in California.

The unique characteristics of an activity based TDF model provide for the potential for a “truer” application of the Ds Analysis Module than traditional trip based TDF models, since activity based TDF models emulate the travel records found in household travel surveys. As described above, when applying the Ds Analysis Module to the trip based TDF models, only the home-based trips can be adjusted since the TDF models do not keep track of who made non-home-based trips. Activity based TDF models do track the non-home-based trips generated by households and therefore provide the opportunity to adjust the entire household VMT (as opposed to just home-based VMT), which is how the Ds Analysis Modules were originally estimated.

While the additional detail provided by the activity based TDF models provide for a potentially more accurate adjustment to VMT, the additional complexity prevented us from calibrating and implementing the Ds Analysis Module for SRTA. However, we did develop an implementation framework, which is outlined below.

**Step 1 –** Sustainable Swaps. This step is the same as described above.

**Step 2 –** Run Both Models (Ds Analysis Module and TDF model). This step is the same for running the Ds Analysis Modules on the base and swapped land use scenario. For the activity based TDF model, the lengths (distance) of all auto trip tours generated by a household should be aggregated and summed by TAZ. These trip tours would include both home-based trips that begin or end at the household and non-home-based trips that occur outside away from the home (e.g., trip between workplace and the grocery store). The trip tour lengths per household should be calculated for both the base and the sustainable swap land use scenarios.

**Step 3 –** Regression. This step is the same as was described above.

**Step 4 –** Adjustment Equation. Aggregate macro-level and TAZ level adjustments to VMT could be made to the activity based TDF model in the same way that was demonstrated above. Additional investigation would be required to determine the feasibility of an “in stream” processor that could impact either the activity generation or mode choice elements of the activity based TDF model.
4. GUIDELINES for VALIDATION TESTING

The following guidelines apply both to validating regional travel models to which a Ds post-processor is added and to validating GIS planning tools being used for sketch level emulation of a regional travel model.

An important step in applying the Ds Analysis Modules as a post-processor to a travel model is to be sure that the application does not affect the validation of the model. Travel models used for Regional Transportation Plans (RTP) and air quality conformity analysis are validated to demonstrate that they replicate empirical traffic count data. The primary source of data for validating regional models is Caltrans Highway Performance Monitoring System (HPMS), which provides statistics on daily vehicle miles travel (VMT) for MPOs, counties, and urban areas throughout the state. MPO travel models used for RTPs and other official purposes need to demonstrate that, when applied to information on the base year land use and transportation system, they produce VMT estimates that match the HPMS data for the same year within 3%.

To assess whether an MPO model with a Ds Analysis Module post-processor still adheres to these validation standards, two situations are considered:

1. Cases where the Ds Analysis Module is used to forecast future VMT directly from a base year travel model.

2. Cases where the Ds Analysis Module is used to pivot from a future baseline forecast produced by the MPO model to estimate incremental change in VMT between the future baseline and an alternative future land use scenario, such as a Sustainable Communities Strategy (SCS). GIS scenario planning tools will almost always be applied in this manner.

In case #1, the validation process is as follows.

a) Develop the calibrated Ds Analysis Module in the manner described in earlier sections of this report, through regression analysis that compares the difference between: the response of the travel model to measured changes in the built environment "D" variables, and the empirical evidence on the effects of those variables from NHTS and other survey data. The resulting module adjusts only to compensate for the empirical "D" effects not captured in the model.

b) Apply the regionally calibrated Ds Analysis Module to the MPO’s base year land use and travel model. Compare the resulting estimate of base year regional VMT to the HPMS regional VMT for the same year. If the Ds-adjusted model VMT is within the 3% permissible range from HPMS data, consider the Ds-adjusted travel model to be valid. If not, continue to Step c.

c) If the Ds-adjusted travel model produces volume and VMT estimates outside a 3%
variation from HPMS data, apply a calibration factor to the Ds Analysis Module to correct the resulting estimate to within the +/-3% of HPMS VMT. Rerun the base-year travel model with the Ds Analysis Module applied to insure that the calibrated, post-processed model results are within acceptable HPMS range.

d) Apply the same HPMS-calibrated version of the Ds Analysis Module in all forecasts performed with the module.

e) If a GIS planning tool is applied to forecast future VMT directly from a base year travel model, then steps a – d should be performed to test and calibrate the Ds Analysis Module to produce VMT within the acceptable HPMS range when applied with the regional base year travel model. The resulting calibrated version of the Ds Analysis Module should be used in the GIS planning tool applied in that region.

In case #2, the Ds Analysis Module is not used in a manner that would bias the model’s base validation. It is used to enhance the degree of precision with which the future forecast scenario is presented to the validated model. The module refines the means through which the model recognizes the detailed attributes of the land use and local access in much the same manner that the models themselves are customarily refined through, for example: disaggregating large rural traffic zones when future urbanization increases land use allocations in a future scenario to provide a finer grained recognition of the land pattern; and/or by refining the network definition of a bus line to add more frequent spacing of bus stops to serve the more urbanized land use.

The Ds Analysis Module pivots from a forecast application of the validated travel model to introduce the effects of fine grained urban form and local accessibility in manners that already exist in downtown areas of the same model. It performs the refinements drawing upon the validated model itself for all of the effects found to be contained within the valid model and the travel surveys and related empirical evidence upon which the validated model was originally developed. The 3-step Ds Analysis Module also uses trip length, time, and travel cost skims by travel mode, transit network accessibility and socio-demographic data from a validated regional model. As a consequence, further validation or calibration of the Ds Analysis Module is not necessary.

GIS tools are almost always applied in this manner and, for the same reasons; in those cases, they do not require further validation or calibration on a regional basis.
5. USER GUIDANCE ON ANALYSIS MODULE APPLICATIONS

Note: The post-processors described above are tailored to the particular TDF models provided by the MPOs as representing their regions’ valid TDF models for use in RTP analysis beginning in June 2012. MPOs are advised that any future recalibration of their TDF models should be accompanied by re-estimation and calibration of the Ds Analysis Module post-processor equations as well.

A. Guidance in Application of Regionally–Calibrated Ds Post-Process Modules

Accompanying this report, each MPO that received technical assistance also received a fully coded Microsoft Excel spreadsheet set containing the coded Ds Analysis Module for post-processing the output of its June 2012 regional TDF model. Instructions on spreadsheet use are coded into the spreadsheet. In general terms, the process is illustrated on the following page. (Note: The Butte CAG implementation spreadsheet is slightly different since BCAG’s TransCAD model has a different data structure than the other MPOs’ models.)

The spreadsheet is applied to data from two sources:

- The same land use data as input to the TDF for the given regional analysis scenario, but buffered to capture built-environment “D” effects (as described in Appendix “C” to this Final Study Report).

- The TDF model forecast of region-wide vehicle miles traveled (VMT) by trip purpose, to be adjusted by a separate data preparation script and the post-processor spreadsheet to take into account the effects of the built environment “D” variables.

The Ds Analysis Module spreadsheet produces an estimate of the adjusted regional VMT accounting for effects of the land use scenario’s built environment strategies.

These concepts are illustrated in Figures 23 and 24 (below).
Define input file names from the regional model and run the import macros (located in the Macro Button on the View tab in the Ribbon) to populate the spreadsheet.

Review the process and define the inputs on the “TxD Implementation” tab.
Figure 24 - Output Worksheet for Ds Adjustment Module

Review the summary of VMT and resulting reductions on the "VMT_Adjustment" tab.

Input data are automatically pasted into the appropriate tabs for calculations.

Percentage change in model VMT based on TxD equation.
B. Guidelines for Selecting Ds Analysis Module Appropriate to a Region

In almost all cases, the appropriate Ds Analysis Module for analysis in a region is the one specifically developed for that area:

- Sacramento region – use the SACOG Ds Analysis Modules
- San Diego region – use the SANDAG Ds Analysis Modules
- San Joaquin Valley -- the eight MPOs in the San Joaquin Valley use the Small MPOs Modules, with the San Joaquin Valley variable set to 1.
- MPOs in the Northern Sacramento Valley, Central Coast, and Inland Empire use the Small MPOs Modules with the San Joaquin Valley variable set to 0.
- Development in the rail corridors of the San Francisco Bay Area, including designated Priority Development Areas – use the Bay Area rail corridors analytical methods.

In all of the above cases, when applying any of the Ds Analysis Modules in the form of a post-process or in-stream adjustment to an MPO travel model, the module must be calibrated to prevent double-counting effects already contained within the MPO model and overstating the potential smart growth benefits. This is accomplished using the model diagnostic testing and calibration process described in Appendix E1 of this document.

In some situations, a regional planning process may anticipate substantial changes over time in a given region’s transportation infrastructure and services and in supporting travel incentives and demand management programs, placing the region in a different planning context. Such changes may subject travelers in the region to different options, incentives and disincentives than were present when the surveys upon which the Ds Analysis Modules were based were conducted. For example, San Joaquin COG may anticipate that year 2035 conditions in its region will include light rail transit network and downtown densities similar to those that presently exist in Sacramento. Or San Diego may foresee 2040 conditions in which its rail system becomes as comprehensive as those presently serving the Bay Area and downtown densities, cordon tolls and parking pricing that are similar to San Francisco today. In these cases, a region may adopt Ds Analysis Module based on research in the region it anticipates resembling in the future. SJCOG may elect to use the SACOG module, or SANDAG may opt to use the Bay Area rail corridors equations.

However, module adoption from another region should only occur if the borrowing region can demonstrate that its future characteristics will be more similar to the present (approximately 2010) characteristics of the donor region than to the present characteristics found in its own region:
• Average region-wide development density, and
• Downtown core development density, and
• Downtown core parking prices, and
• Roadway pricing per freeway mile, and
• Region-wide rail miles per capita

If these conditions are not met, the region should continue to use the Ds Analysis Module developed specifically for its region based on its region’s 2000-to-2009 travel survey.

C. Distinction between Ds Analysis Modules and Project-Scale Tools

The built environment relationships developed in this project are intended for regional or large scale scenario planning processes, such as development or evaluation of a regional Sustainable Communities Strategies plan, jurisdiction General Plan or large specific community plan (at least 200 acres in size). Application of the Ds equations at a site project level should be undertaken only with considerable caution. Considerations in testing/comparing the Ds Analysis Modules to project-scale analysis tools (such as CalEEMod, MXD, Urbemis, ITE trip-generation rates, etc.) should recognize that:

• The Ds Analysis Modules are tailored for accurate prediction of impacts of regional concern, including regional VMT and total regional linked vehicle trips and tours by mode, rather than the number of vehicle trips entering and exiting a specific development site and affecting local street intersections.
• The Ds Analysis Modules focus on households as the primary generator of travel and account for all travel conducted by the household, including non-home-based (NHB) trips and VMT.
• The Ds Analysis Modules are designed to adjust regional travel model estimates by accounting for effects not well-captured in the models, and they move trip generation up or down from the generic average regional conditions represented in the model’s trip rates. (CalEEMod, Urbemis and MXD are designed to adjust ITE trip generation rates, which generally reflect suburban conditions.) The quantification of discounts operates on a different assumption of the source of the base estimate and therefore the factors and quantities are not directly transferrable.
• The Ds Analysis Modules focus on broader measurements of land use type and context, such as population and employment, over a larger sampling area that accounts both for the “project” and its context. Depending on Ds Analysis Module, this is a minimum of a quarter-mile (125 acres) or half-mile radius (500 acres), with
a travel shed that relates directly to trip-making relationships (walking distance, biking distance, transit access distance, school-shed distance) when examined from a regional perspective. This contrasts with highly variable project size used for site-specific traffic analysis, with an artificial cut-off point (the project boundary) defining what represents a trip and a measureable VMT.

- The Ds Analysis Modules consider the regional or sub-regional balances of jobs/housing, shopping, and recreational opportunities and account for the impacts of imbalances explicitly, while tools like Urbemis and CalEEMod do not account for broad scale imbalances. The Ds research and resulting analysis modules take such balances into consideration, and are therefore most attuned to performing analysis of regional plans, such as SCS; or citywide plans, including General Plans; or large specific plans where sub-regional and regional balances can be checked and maintained.

- The Ds Analysis Modules account for more household demographic factors than most project-specific analysis, including: family size, income, and vehicle ownership, but in less detail on characteristics of non-residential land uses of individual projects. ITE-based tools such as CalEEMod and Urbemis distinguish fast food restaurants from quality restaurants, discount retail from life-style shopping, company headquarters offices from multi-tenant or medical offices, and they account for specific numbers of movie theater screens, hospital beds, hotel rooms, etc. They are designed to conduct as detailed accounting as possible of the number of vehicle trips entering a discrete project boundary based on a precise accounting of over 150 specific land use types.

- The Ds Analysis Modules do not directly account for project-specific TDM measures such as employer commute reduction programs, parking pricing, telecommute, regional pricing, and other traveler incentives and disincentives in the explicit terms employed in CalEEMod and Urbemis.

- The Ds Analysis Modules interact with a regional travel model to account for project-specific changes in regional accessibility and the quality of transit availability. And, they account for regionally-specific trip lengths for VMT calculation rather than using generic values for trip length or no accounting for trip length and VMT at all.

D. Relationship between Ds Analysis Modules and Elasticities

The statistical relationships identified in this study are intended to be used in the form described in this report, as two-step or three-step sequences of logistic or regression equations. Elasticities are presented for the purpose of comparing this study’s findings to the findings of other published research on the effects of "D" variables on vehicle travel,
not as a recommended method of applying this study’s results. In cases where elasticities are the only feasible means of implementing built environment sensitivities in a planning process, the following should be taken into consideration before applying “D” elasticities presented in this report in place of the recommended several-step equation modules:

- Elasticities derived from the “D” equations were used to show that they are consistent with the results other research, but tailored for California regions. They can also be used to show how elasticities computed from testing MPO models compare with the research-based elasticities for the region. However, the most reliable means of operationalizing the “D” equations is as several-step multi-variable equations rather than a series of elasticity applications.

- Application of elasticities requires application of boundary controls to prevent large changes in independent variations from producing exorbitant changes in dependent variables. The well-populated difference ranges in independent variable over which the elasticity values were derived do not allow for stable application over increases in a variable by a substantial percentage (say a 400% increase in density). Testing is needed to determine reasonable maximum and minimum elasticity effects and reasonable floor and ceiling constraints on net changes in independent variables and/or floor and ceiling values on dependent variables (such as the minimum and maximum VMT per household presently found in the region).

- Applying a series of elasticities requires controlling for compounding effects. Using the elasticities in isolation creates the potential for sequential factoring of the dependent variable by relatively large effects, even though the individual “D” variables naturally work in concert with one another as in the comparisons among different “place or area types”, rather than as independent “levers.” Floor and ceiling effects need to be used to control the lower and upper bounds of adjusted VMT generation once all elasticities have been applied to be sure they are within the range expected of the new built environment “place or area type” based on evidence from the lowest and highest VMT generating examples of each place or area type presently found in the region.

6. CONCLUSIONS and FURTHER RESEARCH

The data, findings, and tools developed through this study provide California MPOs the ability to capture the effects of smart growth strategies in the travel modeling they employ regional scenario evaluation and planning. The research discovered statistically valid relationships between the amount of travel generated by California households and the
built environment within their neighborhoods and the context of their travel destinations.

Development density, diversity, design and other “D” variables were found to measurably influence vehicle trip making and VMT in each of the MPO regions studied:

- San Joaquin Valley
- Northern Sacramento Valley
- Central Coast
- Inland Empire
- Sacramento
- San Diego
- Rail corridors of the San Francisco Bay Area

The empirical relationships were captured in Ds Analysis Modules for use in a spreadsheet post-processor for MPO travel models and in other planning tools. Testing of six regional travel demand forecasting (TDF) models representing eight MPOs found that even the most recently developed models were not fully sensitive to the “D” variables. Calibrated versions of the Ds Analysis Modules were developed for each TDF to capture those effects not present in the latest MPO models. These spreadsheet modules were provided to the MPOs, along with information on the model testing and application guidance, as tools to allow them to capture built environment effects in regional modeling performed in support of development of Sustainable Communities Strategies called for under SB 375.

The study represents a major milestone in equipping California MPOs with the tools they need to more responsibly inform decision-makers on the benefits of sustainable land use and transportation plans in reducing VMT and related impacts.

Recommended follow-up efforts and research topics include:

1) Equipping the models used by other MPOs, i.e., beyond those that could be included in this study;
2) Applying the post-process modules to activity-based travel demand forecasting (TDF) models (in addition to trip-based travel models);
3) Implementing the more sophisticated 3-step Ds Analysis Modules in conjunction with regional travel models and other tools;
4) Implementing the Ds Analysis Modules within the TDF model streams, rather than as post-processors, to allow the models to reflect the VMT adjustments in traffic volume assignments and highway congestion forecasts;
5) Additional research on attraction-end “D” effects for inclusion in the more sophisticated Ds Analysis Modules including, potentially, hierarchical or structural equations modeling;
6) Capturing more explicitly the effects of parking availability and cost as well as roadway
congestion and related pricing;
7) Capturing the effects of other travel demand management strategies;
8) Inter-agency sharing of validation test and performance results to collaboratively advance further model enhancements;
9) Providing further assistance to developers of scenario planning tools used in California planning (such as Envision Tomorrow+ and Urban Footprint, for example) to ensure consistent application of the Ds Analysis Modules in such tools to help ensure consistency in scenario sketch planning and travel model post-processing;
10) Improving the land use databases used to correlate travel from the 2009 National Household Travel Survey (NHTS) with built-environment variables, particularly in regions with limited parcel and land coverage data;
11) Updating the statistical research on “D” relationships once the new California Statewide Travel Survey and full 2010 US Census results are available; and
12) Extending the research and analysis methods employed in this study and the tools produced to state-level use and to use in regions outside of California.

With each of these advances, transportation models and related scenario planning tools will become progressively more powerful and accurate in their ability to capture the effects of smart growth development patterns and sustainable communities strategies.