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16. ABSTRACT

This project was initiated in 2009 to address a long-standing need for information and tools on land use-transportation relationships in California. Effective planning requires the ability to estimate potential benefits and impacts of land use-transportation choices, including those regarding “smart growth” and “sustainable communities” strategies (such as urban infill, mixed-use, transit-oriented development, complete streets, etc.). Providing up-to-date, California-specific data allows decision-makers to more effectively consider the potential benefits and impacts of choices regarding transportation infrastructure and land use planning in a consistent and supportable way. This enhances the ability of local, regional, and State agencies, community groups, and others to identify optimal and effective solutions. It also assists them in complying with various requirements, including California’s climate change laws – especially SB 375.

The project has advanced the state-of-practice for planning in California by providing locally-derived quantitative data on land use-travel relationships for most of California’s urban and urbanizing areas, as well as a selection of ex-urban and rural locations. It has also provided these results for practical use in ”sketch”-planning tools that assist in developing scenarios, as well as with travel demand forecasting models that are used to analyze resulting scenarios. This project is an important step toward an ongoing process of systematized analysis of transportation and land use interactions as updated data becomes available in the future.

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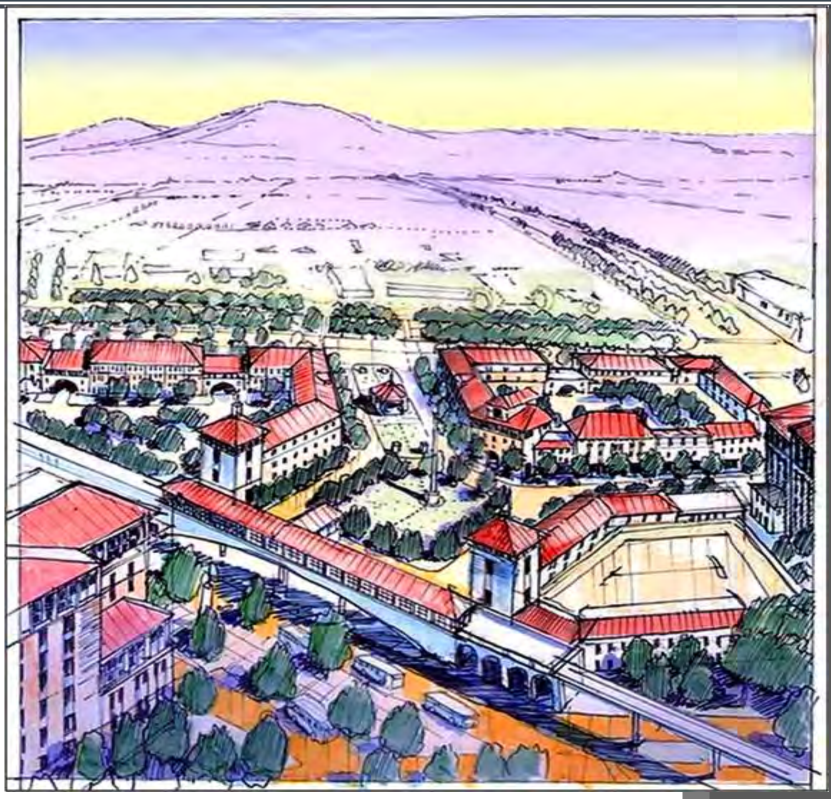
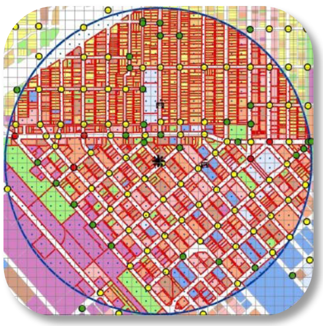
FINAL OVERVIEW REPORT

September 24, 2012

Improved Data and Tools for Integrated Land Use-Transportation Planning in California





- Caltrans
- Fehr & Peers
- SACOG
- UC Davis ULTRANS

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ABSTRACT

This project was initiated in 2009 to address a long-standing need for information and tools on land use-transportation relationships in California. Effective planning requires the ability to estimate potential benefits and impacts of land use-transportation choices, including those regarding “smart growth” and “sustainable communities” strategies (such as urban infill, mixed-use, transit-oriented development, complete streets, etc.). Providing up-to-date, California-specific data allows decision-makers to more effectively consider the potential benefits and impacts of choices regarding transportation infrastructure and land use planning in a consistent and supportable way. This enhances the ability of local, regional, and State agencies, community groups, and others to identify optimal and effective solutions. It also assists them in complying with various requirements, including California’s climate change laws – especially SB 375.

Over the past 20+ years, numerous studies have been conducted in various places in the U.S. regarding land use and travel. Although these studies provide ranges of estimated effects, most are not specific to conditions found in many California communities. Therefore, the first necessary step of this project was to obtain detailed built environment and travel data in California - which was a greater challenge than initially anticipated. The team was able to identify and obtain GIS-based land use data in many (but not all) parts of the state. However, household travel survey data was also needed which was collected during a time period that matched the timeframe of available land use data. Fortunately, Caltrans’ funding of the 2009 National Household Travel Survey (NHTS) enabled this study to address a number of areas that otherwise could not have been included in the San Joaquin Valley, Central Coast, and Northern Sacramento Valley.

In total, the project team obtained and reported detailed built environment and travel survey data for *over 200,000 specific locations* – which is significantly more data than has previously been available. Built environment data was collected for the ½-mile areas surrounding each reported household travel survey “trip end.” Statistical analysis of this data produced sets of “Ds Analysis Modules” (which consist of sets of equations) regarding built environment-travel relationships for four regions: Sacramento (SACOG); San Diego (SANDAG); rail corridors in the S.F. Bay Area; and “small and medium-size” areas: the San Joaquin Valley, Central Coast, Northern Sacramento Valley, “Inland Empire” (Riverside and San Bernardino Counties), and Imperial County.

Another important goal of this project was to incorporate results into planning tools and models and make them available for use in California. These products include two main types of tools:

1) Scenario/”sketch”-planning tools (in both GIS and spreadsheet formats), which are often used as educational tools during public meetings as a “first level” of scenario development and evaluation; and

2) With travel demand forecasting models, which are typically used to analyze and compare the effects of land use and transportation “scenarios” *after* they are developed.

This project has advanced the state-of-practice for planning in California by providing locally-derived quantitative data on land use-travel relationships for most of California’s urban and urbanizing areas, as well as a selection of exurban and rural locations. It has also provided these results for practical use in ”sketch”-planning tools that assist in developing scenarios, as well as with travel demand forecasting models that are used to analyze resulting scenarios. This project is an important step toward an ongoing process of systematized analysis of transportation and land use interactions as updated data becomes available in the future.

These results and tools are described in this Final Report and Technical Appendices, which are posted along with related software tools for free downloading, at:
http://ultrans.its.ucdavis.edu/projects/improved-data-and-tools-integrated-land-use-transportation-planning-california

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1. Executive Summary

The primary goal of the "Improved Data and Tools for Integrated Land Use-Transportation Planning in California" project was to obtain and analyze available data on quantitative relationships between the built environment and travel in various parts of California, and to incorporate the results into tools that are freely available for use in local and regional integrated land use-transportation scenario planning processes. The processes and results of this three-year effort are summarized in this Overview Report, with detailed provided in seven technical Appendices.

Potential uses of the results of this project are:

- Conducting regional integrated Blueprint planning processes.
- Complying with California's Sustainable Communities and Climate Protection Act of 2008 (SB 375), required for all California metropolitan planning organizations.
- Preparing local General and Specific Community Plans and other transportation system plans that incorporate smart growth/sustainable communities strategies.

Background:

Effective integrated land use/transportation planning requires the ability to quantitatively estimate interrelationships between built environments in various locations and the way that people tend to travel in those places.

This project's goal is to develop and provide information and tools on quantitative relationships between built environment factors and travel in various locations throughout California. Regional and local agencies need these tools in order to effectively comply with SB 375 requirements, and for a variety of other planning and analysis requirements.

In 2009, the "Sustainable Communities and Climate Protection Act of 2008" - SB 375 - became effective.[1] In early 2009, Caltrans' Division of Transportation Planning and its partners – the Sacramento Area Council of Governments (SACOG) and two subcontractors, UC Davis ULTRANS and Fehr & Peers Consultants - initiated this study.

In 2010, the California Transportation Commission (CTC) updated the State's Regional Transportation Planning (RTP) Guidelines to address SB 375 implementation.[2] Importantly, these Guidelines - as well as other policy and technical documents - recommended the use of data and tools that are capable of estimating quantitative interactive effects of smart growth/sustainable communities strategies (SCS) and travel.[3]

1 CA Govt. Code Section 65080
2 CTC's 2010 RTP Guidelines. Especially see Chapter 3 – Modeling.
3 "*Assessment of Local Models & Tools for Analyzing Smart-Growth Strategies*" 2009. DKS Assoc. et.al. for Caltrans.

During the early 2000s, the Sacramento Area Council of Governments (SACOG) pioneered the development of regionally-specific land use/transportation data and tools for its successful Blueprint plan which was unanimously adopted in 2004. However, in 2009, nearly all other metropolitan planning organizations (MPOs) in California self-reported that they do *not* have such capabilities.[4]

This project has developed and provided important data, analysis, and practical tools that help fill these gaps for most areas of California that can be used in a variety of ways.

The project included the following major tasks:

1) Review and summarize **available research and practices** in the U.S.

2) Establish **Experts and Practitioners Panels** to provide input.

3) Collect and summarize detailed local **built environment and travel survey data** in areas where it is available.

4) Conduct **statistical analyses of the data** to derive important relationships.

5) **Provide the results for scenario planning and travel model post-processing:**
   a) Offer special technical assistance to eight “demonstration” MPOs to develop and use post-processors with their travel demand forecasting (TDF) models.
   b) Incorporate new “Ds Analysis Modules” into UCD’s “UPlan” and SACOG’s “iPLACE3S” GIS sketch-scenario planning tools.
   c) Convert Ds modules into “python” code to enable providers of other GIS sketch/scenario planning tools to also use the project’s results.
   d) Develop a VMT estimation spreadsheet sketch tool for large land use projects.
   e) Provide documentation for all tools directly produced via this project.

6) **Conduct testing, calibration, and validation of tools produced in this project.**
   a) Provide guidance regarding “Ds” post-processors used with travel demand forecasting (TDF) models to enhance their sensitivity to various “scenarios.”
   b) Evaluate the operation and accuracy of Ds modules incorporated into sketch-planning tools: “UPlan” GIS tool; and the VMT estimation spreadsheet tool.

7) **Provide Users Guides and a Final Project Report.**
   a) Provide user guides for all tools produced by this project.
   b) Produce a final study report and technical appendices. Distribute the report and tools produced by this project free of charge via a public Internet site.

The following sections provide a brief overview of activities conducted for each major task of this study, and resulting products – followed by the Final Overview Report describing this project. *Additional detail is provided in the technical appendices, as referenced.*

[4] “Recommendations of the Regional Targets Advisory Committee (RTAC) Pursuant to Senate Bill 375: Report to the California Air Resources Board,” 2009 http://www.arb.ca.gov/cc/sb375/rtac/report/092909/finalreport.pdf

Task 1) Conduct Literature Review.
The project team first conducted a thorough review of recent U.S. research on land use-travel demand relationships and also identified tools used in integrated planning processes. *(Note: Appendix A provides detailed results of this review.)*

Overall, the reviewers found that opportunities to lower rates of per-capita or per-household of vehicle trips (VT) and vehicle miles of travel (VMT) are greatest in places where urban areas and transit systems offer accessibility options that provide truly attractive alternatives to automobile travel.

The review also found that certain land use factors can significantly influence modes of travel, numbers of vehicle trips (VT), and rates of vehicle miles of travel (VMT). Most important are: location within or near an urban area, development density, land use mixture, and design for non-motorized and transit travel.

Reviewers also found that most research and tools available in the U.S. on land use–travel relationships were derived from data that is at least a decade old. And, only a few are based primarily on California data. *Importantly, these findings pointed to a significant need for locally-derived, up-to-date data and tools for use in integrated land use-transportation planning processes in California – which this project has provided.*

Task 2) Establish Advisory Panels. The project team established two technical advisory panels that have provided important input during project implementation:

- An "Expert Panel" of nationally recognized land use, travel, and modeling researchers has advised the project's data collection and analysis processes.[5]
- A "Practitioners Panel" of planning and modeling staff of California MPOs and local governments within the areas included in this study, as well as interested staff of three State agencies: Caltrans, the CA Air Resources Board (CARB), and the Governor's Office of Planning & Research (OPR). *(See Appendix B for details.)*

Task 3) Compile built environment and travel survey data.
The project team coordinated with numerous regional and local agencies staff to identify areas that could provide detailed GIS built environment data which was collected during roughly the same time period(s) as available travel behavior surveys.[6] Based primarily on the availability of adequate data, the project team selected the areas listed below, which include nearly all regions to which SB 375 applies.[7]

These regions include a variety of urban, suburban, exurban and rural areas that have a full range of transportation, development, and demographic conditions found in California.

[5] The Expert Panel included: Drs. Marlon Boarnet, University of Southern California (USC); Susan Handy, UC Davis; Robert Cervero and Dan Chatman, UC Berkeley; and John Thomas, US EPA's HQ Office of Smart Growth.
[6] Results of the 2009 National Household Travel Survey (NHTS) were used for most areas, *except*: the S.F. Bay Area Metropolitan Transportation Commission's (MTC) 2000 travel survey (BATS); and SACOG's 2000 regional travel survey.
[7] In 2011, the Southern CA Association of Governments (SCAG) conducted a separate similar effort, and used the results as a "post-processor" with its regional travel forecasting model to analyze SCS scenarios for its RTP.

The selected areas include 13 smaller and medium-size MPOs, two major metropolitan areas, and several sub-regions within the state's two largest MPOs: *(see map below)*

Small & Medium-size MPOs:

- **Northern Sacramento Valley:** Two MPO areas: Shasta and Butte, and the RTPAs of Glenn and Tehama Counties**.**
- **San Joaquin Valley**: Eight MPOs representing Kern, Kings, Tulare, Fresno, Madera, Merced, Stanislaus, and San Joaquin Counties.
- **Central Coast**: Three MPOs, covering Santa Barbara and San Louis Obispo Counties; and the Association of Monterey Bay Area Governments (AMBAG) which includes Monterey, San Benito, Santa Cruz counties.

Major Metropolitan MPOs:

- **Sacramento region**: Sacramento Area Council of Governments (SACOG).
- **San Diego region**: San Diego Association of Governments (SANDAG).

Subregions within largest MPOs:

- **High growth sub-regions of the Los Angeles region**: the "Inland Empire" (Riverside and San Bernardino Counties) and Imperial County – all within the Southern California Association of Governments (SCAG) MPO.
- **Urban rail corridors in the San Francisco Bay region**: areas within ¼ to ½ mile radii of these passenger rail corridors: ACE commuter train, Amtrak interregional rail, BART rail rapid transit, Caltrain commuter rail, SF MUNI light rail, and Silicon Valley Transportation Agency light rail systems.

(note: grey areas were not included in study)

In coordination with technical modeling and planning staff of various local and regional planning agencies, the project team identified, collected, and compiled available GIS data for: land uses, transportation facilities and services, and related information for each of these regions. The team also obtained household travel survey results for each region that are consistent with the timeframe in which the built environment data was collected. Travel surveys data provided each respondent's: vehicle ownership (VO), number of trips, travel modes, trip lengths, and estimated VMT.

Notably, the team compiled built environment data within the ½-mile area surrounding 108,000 trips ends reported in the 2009 National Household Travel Survey (NHTS) and regional travel surveys, plus more than 100,000 trip ends near passenger rail corridors in the S.F. Bay Area. This is significantly more data than has ever been compiled and analyzed on the built environment and travel in the U.S. *(note: see Appendix C.)*

Task 4) Analyze built environment and travel data (collected in Task 3).
Considering input from the Experts Panel on appropriate statistical methods, the Fehr & Peers team conducted in-depth statistical analyses of the travel survey, built environment, and socio-demographic data collected for this study to derive significant interrelationships. This process resulted in a set of "Ds Analysis Modules" for each type of area: smaller and medium-size MPOs; large MPOs; and the SF Bay Area rail corridors. These new Ds Analysis Modules can be used by themselves; within available scenario sketch planning tools; and/or as post-processors to (or incorporated within) agencies' available travel demand models. *(Appendix D describes the analyses conducted and significant results.)*

Task 5) Provide tools and technical assistance implementing the results.
The next major task was to develop planning analysis tools that incorporate the results of previous tasks, and to provide documentation for each of those tools. The project team also provided special technical assistance to two groups of potential end-users: staff of eight interested MPOs, and several providers of GIS "sketch" scenario planning tools.

Travel Model Post-processors: Technical assistance (T.A.) was offered to participating MPOs to develop "Ds" post-processing spreadsheets for use with available travel demand models. Eight MPOs were selected to receive this T.A. based on their: 1) expression of interest and willingness to participate; 2) availability of a completed and calibrated travel demand forecasting model; and 3) need for technical assistance in meeting near-term SB 375 requirements.[8] During May and June 2012, special T.A. was provided to: a) assess the MPOs' available travel models to determine their existing level of sensitivity to smart growth/sustainable communities strategies; b) develop customized "post-processors" derived from Ds Analysis Modules for each area; and c) provide training to MPO and Caltrans modeling staff regarding the new tools. For details, please see *Appendix E.*

[8] These MPOs were: Six San Joaquin Valley MPOs: San Joaquin, Merced and Stanislaus COGs (Northern San Joaquin Valley); Fresno COG (Central San Joaquin Valley); Tulare CAG and Kern COG (Southern San Joaquin Valley); San Luis Obispo COG (Central Coast); and Butte CAG (Northern Sacramento Valley).

In addition, the Fehr & Peers team provided a travel model post-processor calibration template tool to assist other agencies to: 1) evaluate their travel demand models' sensitivities to built environment-travel "D" variables, and 2) develop "Ds" calibration adjustments to the degree that their models do not already fully capture these effects.

Sketch/Scenario Planning Tools: UCD incorporated the new Ds Analysis Modules produced by this project into its "UPlan" sketch/scenario planning GIS tool. And, to assist providers of other GIS sketch/scenario planning tools used in California to incorporate the new Ds Analysis Modules into their tools, UCD developed a set of special "python" modules. In June 2012, UCD provided a webinar to interested GIS tool providers that described these modules and how to incorporate them into GIS tools. *(note: see Appendix F for details).*

In addition, SACOG staff developed a spreadsheet sketch tool for estimating VMT and GHG effects of large proposed land use projects within the context of their regional location and surrounding conditions. *(note: see Appendix G and for details).*

Task 6) Test and validate the operation and accuracy of tools.

The project team tested each new tool produced to evaluate whether it operates correctly and its results are within acceptable ranges. One "reasonableness check" compared the "elasticities" of the regionally-specific "Ds modules" to those reported in national research; results indicate that this study's results compare well with other available data. *(Note: Please see the **Final Overview Report** and Appendix D for details.) In addition, Appendix E* provides recommendations for testing and "validating" Ds analysis modules that are used with available travel demand models.

Results of evaluations of GIS and spreadsheet sketch/scenario planning tools that were produced by this project are described in:

- *Appendix F (Section 6)* describes UCD's evaluation of: 1) "Python" modules developed to facilitate incorporating Ds Modules into GIS planning tools; and 2) the operation of Ds modules within UCD's "UPlan" GIS planning tool. To summarize, tests found that "these tools work successfully and produce reasonable results."
- *Appendix G (Section 4)* describes the results of tests that SACOG staff conducted of a VMT Estimator spreadsheet that can be used to assess large land use projects in relation to their location and context. To summarize, results "were reasonable regarding sketch-level planning and trend in the expected direction."

Task 7) Provide User Guides and a Final Report.

The project team also developed a "User Guide" for each tool produced by this project, *which are provided in Appendices E, F, & G for each of the tools.*

With the Caltrans project manager's input, the team produced this Executive Summary the following Final Overview Report and seven detailed Technical Appendices.

2. Background and Overview

A. Overview of Land Use-Transportation Scenario Planning in California

According to the Federal Highway Administration (FHWA), numerous transportation agencies - including State Departments of Transportation (DOTs), metropolitan planning organizations (MPOs), and rural transportation planning agencies (RTPAs) throughout the U.S. - use scenario planning techniques. Scenario planning involves anticipating and assessing the potential effects of various potential alternatives regarding selected indicators, which can be either qualitative or statistical values that are used to compare two or more scenarios based on agreed-upon goals, values, and/or objectives.[9]

The current use of scenario analysis techniques in land use-transportation planning is derived, in part, from military and business strategic planning. During the 1960s and 1970s, large companies started using scenario planning to anticipate future market conditions and reduce risk. Current land use-transportation scenario planning processes have their roots in federally-funded activities starting with the Federal-Aid Highway Act of 1962, which required “continuing, comprehensive, and cooperative” planning.

However, in traditional transportation planning processes, the allocation of future land uses typically does not vary across scenario alternatives. These processes typically don’t consider the effects that variations in land use patterns may have on the future use and operation of transportation systems, nor do they estimate the effects of transportation system changes on future land use patterns. In short, these processes have largely overlooked the interactive nature of land uses and transportation systems.[10]

Since the early 1990s, scenario planning - that takes changes to land use patterns into consideration regarding future potential alternatives - became more widespread in the U.S. It was accompanied by terms such as: “vision,” “blueprint,” “livable,” “sustainable,” “smart growth,” etc. During the early 2000s, numerous planning efforts were conducted in various regions which considered the effects that various future land use patterns and transportation systems may have on each other and on human and natural environments.

One of these efforts was the “Preferred Blueprint Scenario” that the Sacramento Area Council of Governments (SACOG) Board of Directors adopted in December 2004. It was the product of an extensive three-year, award-winning public involvement effort intended to guide land use and transportation choices over the following 50 years, as the region's population grows from 2 million to nearly 4 million people.[11]

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[9] FHWA Scenario Planning Guidebook: “Phase 5. What Impacts Will Scenarios Have?”
[10] “Integrating Land Use Issues into Transportation Planning: Scenario Planning - Summary Report” 2005. Keith Bartholomew, University of Utah, for FHWA.
[11] See: http://www.sacregionblueprint.org/adopted/ and http://www.sacregionblueprint.org/

Following SACOG's adoption of the 2004 Blueprint Plan, the then-Director of the California Business, Transportation & Housing Agency, Ms. Sunne Wright McPeak, encouraged Caltrans' HQ Transportation Planning Division (DOTP) to provide funding for similar integrated scenario planning efforts in other regions. Between 2005 and 2011, Caltrans' Blueprint Planning Grant Program granted nearly $22 million in federal funding to a variety of large, medium, and small regional agencies throughout California.[12]

The stated objective of these grants was to: *"help the regions develop better land use and transportation patterns and help State agencies make better infrastructure investment decisions that support the Blueprint Plans and lead to a better quality of life in California based on the 3Es (environment, economy, and equity)."*[13] The Caltrans-funded Blueprint program has resulted in improved integrated land use-transportation planning, better data and analysis tools, and increased coordination among various groups who have worked to achieve consensus on integrated land use-transportation plans throughout California.

In 2009, California's "Sustainable Communities and Climate Protection Act of 2008" (SB 375) became law. Its primary objective is to reduce per-capita rates of vehicle travel and resulting greenhouse gas (GHG) emissions via integrated land use and transportation planning, consistent with California's landmark climate change legislation, AB 32.[14] SB 375 requires all California MPOs, in coordination with local agencies and groups, to develop and adopt a Sustainable Communities Strategies (SCS) scenario projected to meet per-capita GHG reduction targets set by the California Air Resources Board for each MPO region. If an SCS is unable to achieve the region's GHG reduction target, the MPO may instead adopt an "Alternative Planning Strategy" (APS).

SB 375 also provides options for streamlining environmental review under the California Environmental Quality Act (CEQA) for certain "residential/mixed use" projects and "transit priority projects." Local governments may voluntarily revise their General Plans and/or develop Specific Community Plans to more closely align their land uses and transportation systems with adopted regional sustainable communities strategies.

In spring of 2009, Caltrans' Division of Transportation Planning initiated this study to develop and provide "Improved Data and Tools for Integrated Land Use-Transportation Planning in California." **The rationale and goals of this project are described below.**

3. Project Goals

The primary goals of this project are to: 1) obtain and analyze available data on quantitative relationships between the built environment and travel in various parts of California, and 2) incorporate the results into tools that are freely available for use in local and regional integrated land use-transportation scenario planning processes.

[12] For more information, see: http://calblueprint.dot.ca.gov/
[13] Blueprint Learning Network overview: http://www.dot.ca.gov/hq/tpp/offices/orip/bln.html
[14] CA Govt. Code Section 65080.

Potential applications of the results of this project are:

- Conducting regional integrated Blueprint planning.
- Complying with California's Sustainable Communities and Climate Protection Act of 2008 (SB 375), required for all California metropolitan planning organizations.
- Preparing local General and Specific Community Plans and transportation system plans that incorporate smart growth or sustainable communities strategies.

In 2010, the California Transportation Commission (CTC) updated the State's Regional Transportation Planning (RTP) Guidelines to address SB 375 implementation.[15] Importantly, these Guidelines - as well as previous policy and technical documents - recommend the use of tools and models that are capable of estimating quantitative interactive effects of smart growth/sustainable communities strategies and travel.[16]

Although the Sacramento Area Council of Governments (SACOG) pioneered the creation of regionally specific land use-transportation data and tools for its successful "Blueprint" plan during the early 2000s, most other metropolitan planning organizations (MPOs) do not have similar capabilities. During 2009 and 2010, California's MPOs performed self-evaluations of their travel forecasting models for the California Air Resources Board's (ARB) SB 375 Regional Targets Advisory Committee (RTAC).[17] With respect to model micro-scale sensitivity to built environment and travel relationships:

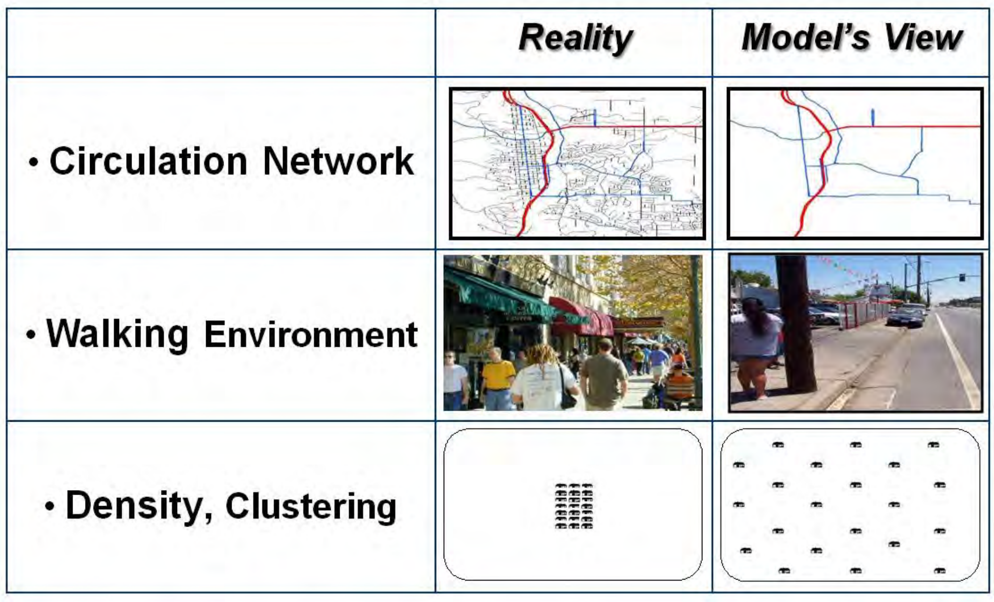
- All 13 mid-size and smaller MPOs reported that they had only limited sensitivity or no capacity at all with respect to at least one of the factors, and 11 reported little or no capability with respect to two or more factors.
- Three of the State's four large MPOs reported their models' sensitivities regarding sustainable communities strategies were either limited or unknown at that time.

As illustrated in Figure 1 (below), most travel demand forecasting (TDF) models have significant "blind spots"[18] regarding connectivity offered by local circulation networks, walking environments, and land uses.

Two recent reports (cited on the previous page) recommend that travel models therefore should be tested regarding their existing sensitivity to such factors, and that modeling processes use empirically-derived built environment-travel relationships to compensate for significant lack of sensitivity. This project has provided quantitative relationships that can be used to test travel demand models and adjust them regarding such factors.

[15] CTC's 2010 RTP Guidelines Chapter 3 – Modeling.
[16] *Assessment of Local Models & Tools for Analyzing Smart-Growth Strategies* 2009. DKS Assoc. et.al. for Caltrans.
[17] "Recommendations of the Regional Targets Advisory Committee (RTAC) Pursuant to Senate Bill 375: Report to the California Air Resources Board," 2009 http://www.arb.ca.gov/cc/sb375/rtac/report/092909/finalreport.pdf
[18] "Blind spot" refers to the fact that most travel models capture only a portion of the effects of land use characteristics, or those of a transportation system, or both; this constrains the accurate use of the model.

Figure 1. Typical Transportation Model "Blind Spots"



4. Land Use-Transportation Relationships

Over the past 20+ years, researchers in the U.S. have conducted numerous studies on relationships between travel and the built environment. Research indicates that, although various approaches are used, there is some general agreement among studies regarding interrelated effects of the built environment and travel at local and regional levels. Overall, opportunities to lower rates of per-capita or per-household vehicle trips (VT) and miles of travel (VMT) are greatest in places where urban areas and transit systems offer accessibility options that provide attractive alternatives to auto travel. The literature also indicates that certain built environment variables - especially location within or near an urban area ("destinations)", density, land use mixture (diversity), and design for walkability and transit access - can influence travel behavior in terms of rates of travel mode, vehicle trips (VT), and vehicle miles of travel (VMT).

A. Nature of Relationships

Some researchers have simplified the description of key relationships between travel and built environments to a series of "D" factors:

Density:	of dwellings, jobs, etc.
Diversity:	mix of housing, jobs, retail
Design:	connectivity, walkability
Destinations:	regional accessibility
Distance to Transit:	proximity to rail stations
Development Scale:	overall # of residents, jobs
Demographics:	household size, income, auto ownership, etc.

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

- **Density**
  - Shortens trip lengths
  - More walking/biking
  - Supports quality transit

- **Diversity**
  - Links trips, shortens distances
  - More walking/ biking
  - Allows shared parking

- **Design**
  - Improves connectivity
  - Encourages walking, cycling
  - Reduces travel distance

- **Destination Accessibility**
  - Links travel purposes
  - Shortens trips
  - Offers transportation options

- **Distance from Transit**
  - Facilitates transit use
  - Enlivens streetscapes
  - Encourages trip-linking, walking

- **Development Scale**
  - Provides critical mass
  - Increases local opportunities
  - Integrates transportation modes

- **Demographics**
  - Suits households to preferred settings and travel modes
  - Allows businesses to locate convenient to clients
  - Allows socio-economic "fit" among residents, businesses, activities

Interactions among these factors require attention when estimating the quantitative effects of various combinations of land uses and transportation. Recent research - including the results of this study - provides important insights regarding these interactions. *(Please note: A number of recent studies are summarized in Appendix A.*

B. Research Evidence

Of the seven "D" factors listed above, five have been studied broadly in the U.S. A major "meta-analysis" of research on relationships between travel and built environments examined over 70 prominent studies conducted in the U.S. and synthesized results.[19] This analysis revealed the following "elasticities" for VMT rates regarding these five significant "D" characteristics, listed in Table 1 (below):

[19] "Travel and the Built Environment," Journal of the American Planning Association, Summer 2010. Reid Ewing and Robert Cervero.

Table 1. Average VMT Elasticities*
with respect to Built-Environment Factors

Density	
Household/population density	- 0.04
Diversity	
Land use mix (entropy index)	- 0.09
Jobs-housing balance	−0.02
Design	
Intersection/street density	- 0.12
% 4-way intersections	- 0.12
Destination Accessibility	
Job accessibility by auto	- 0.20
Job accessibility by transit	- 0.05
Distance to downtown	- 0.22
Distance to Transit	
Nearest transit stop	-0.05

** Note: "Elasticity" is the percentage change in VMT per one percent change in a built environment variable (such as density).*

Among the five main "D" factors covered in this synthesis, "Destination accessibility" generally exhibits the greatest influence on rates and modes of travel: development in highly accessible areas of cities is related to lower per capita rates of VMT as compared to even dense mixed-use development located on the edges of urban areas. "Diversity" (mixture of land uses) is also influential, as is density, urban design or connectivity, and proximity to transit. However, neither the Ewing/Cervero synthesis nor individual studies fully address the transferability of relationships across various metropolitan areas.

Research has also shown that demographic variables – especially income, household size and composition, and automobile ownership/availability – often do have a significant influence on travel. And, the scale or size of development can be an important variable at a project or community level, as indicated in one national study.[20] Importantly - reviewers also found that most research and tools available in the U.S. on built environment–travel relationships were derived from data that is at least a decade old. And, only a few use primarily California data.

These findings point to a significant need for locally-derived, up-to-date data and tools for integrated land use-transportation planning processes in California, which this project has provided.

[20] "Traffic Generated by Mixed-Use Developments—Six-Region Study Using Consistent Built Environmental Measures" Ewing et.al, Journal of Urban Planning and Development. American Society of Civil Engineers, September 2011.

5. California Built Environment & Travel Data

A. Selection of Study Areas

The project team coordinated with numerous regional and local agencies staff to identify areas that had adequate GIS built environment data that was collected during roughly the same time period(s) as available travel behavior surveys.[21] Based primarily on the availability of adequate data, the project team selected the areas listed below.

These areas, which include nearly all regional MPOs to which SB 375 applies,[22] represent a variety of urban and suburban areas - as well as a selection of exurban and rural areas – that have a full range of transportation, development, and demographic conditions found in California. These study areas include 13 smaller and medium-size MPOs, two major metropolitan areas, and several sub-regions within the state's two largest MPOs: *(Please see map on the following page)*

Small & Medium-size MPOs:

- **Northern Sacramento Valley:** Two MPO areas: Shasta and Butte, and including the RTPA areas of Glenn and Tehama counties.
- **San Joaquin Valley**: Eight MPOs representing Kern, Kings, Tulare, Fresno, Madera, Merced, Stanislaus, and San Joaquin Counties.
- **Central Coast**: Three MPOs, covering Santa Barbara and San Louis Obispo Counties; and the Association of Monterey Bay Area Governments (AMBAG) which includes Monterey, San Benito, Santa Cruz counties.

Major Metropolitan MPOs:

- **Sacramento region**: Sacramento Area Council of Governments (SACOG).
- **San Diego region**: San Diego Association of Governments (SANDAG).

Subregions within the Largest MPOs:

- **High growth sub-regions of the Los Angeles region**: the "Inland Empire" (Riverside and San Bernardino Counties) and Imperial County – all within the Southern California Association of Governments (SCAG) MPO.
- **Urban rail corridors in the Francisco Bay region**: areas within ¼ and ½-mile walking distances of major passenger rail corridors: ACE commuter train, Amtrak interregional rail, BART rail rapid transit, Caltrain commuter rail, SF MUNI light rail, and Silicon Valley Transportation Agency light rail.[23]

[21] Results of the 2009 National Household Travel Survey (NHTS) were used for most areas included in the study, *except*: MTC's S.F. Bay Area 2000 travel survey (BATS); and SACOG's 2000 regional travel survey.
[22] In 2001, the Southern CA Association of Governments (SCAG) conducted a separate similar effort, and used the results as a "post-processor" with its regional travel forecasting model to analyze SCS scenarios.
[23] The MPO for the S.F. Bay Area region is the Metropolitan Transportation Commission, MTC, in coordination with the Association of Bay Area Governments, ABAG.

Figure 2. Map of Areas Included in Study

*note: grey areas were not included in this study.

B. Data Collection

The processes used to obtain and summarize detailed local built environment and available travel survey data are summarized below. *(Please note: Appendix C provides additional detail about these processes and their results.)*

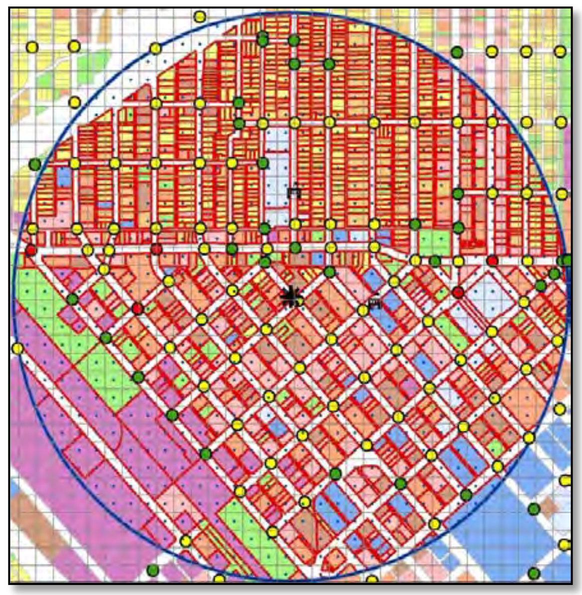
For most of the study regions, UC Davis extracted household demographic and travel data from the 2009 National Household Travel Survey (NHTS), provided by the Caltrans Transportation & Systems Information Division. The team used regional household travel survey results from 2000 for the SACOG area and for the Rail Corridors Analysis, which were temporally consistent with built environment data available for those two regions.

Data obtained from these travel surveys includes: household vehicle ownership (VO), person trips and travel mode shares, and the number of vehicle trips (VT) generated, as well as trip length and vehicle miles travelled (VMT). To understand the built environment factors important in influencing travel, the team obtained GIS data for the ½-mile areas surrounding each household's address as well as for all reported travel destination "trip ends." **This produced detailed data for nearly 210,000 locations.**

Figure 3 (below) illustrates the GIS "buffering" process that UC Davis used to obtain and report data within the half-mile radius surrounding each NHTS travel survey trip-end. The image on the right illustrates the buffering inventory of land use and intersection types within a half-mile radius of a typical household.

The image on the left illustrates the overlapping nature of individualized buffer areas surrounding the households surveyed. This data included: types of land uses (residential, commercial, industrial, office, schools and other institutions), density, land use mix, street network, and available transit service. In addition, the team examined available travel demand models to obtain information about regional accessibility for each household and its reported trip destinations.

Figure 3. Capturing Data within 1/2-Mile of NHTS Travel Survey Trip Ends



For the Sacramento analysis, SACOG provided a version of the 2000 SACOG Household Travel Survey for which a land use buffering process had been previously conducted that was similar to the process used in this study for the NHTS dataset.

For the S.F. Bay Area Rail Corridors analysis, MTC's Bay Area Travel Survey 2000 (BATS2000) was the principal source of data. BATS2000 is an activity-based travel survey that collected data on in-home and out-of-home activities over a two-day period, including weekdays and weekends. Over 15,000 Bay Area households participated, and information was collected on more than 34,000 residents. Household, work, and trip end locations were used for ¼ and ½-mile buffer data surrounding reported trip ends.

The detailed "buffered" built environment data surrounding each household's home and reported non-residential destination allowed for extensive analysis of resulting data.

The analysis processes and their results are summarized in the following section.

6. Assessing Built Environment & Travel Relationships

This section provides an overview of the statistical analyses that the project team performed to assess the detailed built environment and travel data for each study region, including the most successful outcomes of the analyses and principle results. *(Please note: Appendix D provides detailed information about these processes and results.)*

This process involved the following main steps:

A) Pilot studies

i. The project team developed statistical models in three types of regions, which also represent each of three major types of models that resulted from this process:

- **Small/Medium MPOs** – to establish a modeling approach in the San Joaquin Valley, Northern Sacramento Valley, Central Coast, and Inland Empire. *Pilot study region: Fresno COG.*
- **Larger MPOs** – as a prototype of the modeling approach for major metropolitan areas, such as Sacramento and San Diego. *Pilot study region: SACOG.*
- **Major Rail Corridors** – as a pilot study for modeling travel in rail corridors throughout transit-rich regions. *Pilot study region: S.F. Bay Area rail corridors.*

ii. For each pilot region, the team performed statistical analyses of relationships between household travel and built environment "D" variables, including: demographics, solving for vehicle ownership (VO), vehicle trip generation (VT), and vehicle miles travelled (VMT).

- As described in the previous section, each household included in the applicable travel survey was "buffered" regarding built environment variables potentially affecting travel at production locations. The team also "buffered" the geo-location of each reported non-home trip-end regarding built environment characteristics at the attraction end of each trip.
- Built environment variables captured various measures of density, diversity, design, destination accessibility, distance to transit, demographics, and development scale. Parking price was also considered if data was available.
- The Fehr & Peers team tested individual VO, VT and VMT models.[24] They then summarized the best results and alternative models for review.

iii. The pilot-test models were reviewed by the "Expert Panel" of nationally recognized land use, travel, and modeling researchers who voluntarily advised the project's data collection and analysis processes.[25]

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[24] Using various regression formulations, hierarchical linear modeling, log likelihood, binary hierarchical, binary logit, negative binomial and tobit modeling. *(Please see Appendix D for details.)*

[25] The Expert Panel included: Drs. Marlon Boarnet, University of Southern California (USC); Susan Handy, UC Davis; Robert Cervero and Dan Chatman, UC Berkeley; and John Thomas, US EPA's HQ Office of Smart Growth. For more information, please refer to *Appendix B*.

The “Expert Panel” recommendations included:

- Begin evolving the models as much as possible toward a common sequential form incorporating, for example, the lessons learned from estimates of person travel using the Fresno data, which could be incorporated into the approach to modeling person travel for the small and medium MPOs, Sacramento, and the San Francisco Bay Area.
- Check elasticities captured in the models with published national elasticities.
- Consider accessibility in terms of: a) local accessibility (diversity), and b) regional accessibility (destination accessibility).
- Recognize that transit accessibility is not a linear function. At the extreme low sensitivity end of transit availability, consider dropping “outliers.” At the extreme high end of the spectrum, parse the dataset into ranges to capture differences in the effect that the variable might have in different portions of the range.
- While trip chaining may reduce the number of vehicle trips generated in single-use sprawled settings, chaining also occurs in mixed urban settings due to the convenience afforded by concentrated attractions.
- Combine the data in order to increase sample size for the small and medium-size MPOs, as there may be greater variation between small, medium-size, and large MPOs than within each of these groups.

B. “Post-Pilot” Models

The study team incorporated all of the Expert Panel’s recommendations in finalizing the Fresno, Sacramento, and SF Bay Area rail “pilot” models. They then applied the same methods to the other study regions. For the post-pilot model development, UC Davis and Fehr & Peers assembled household travel survey data and buffered built-environment data for all surveyed households and trip-end coordinates in the 2009 NHTS for these additional regions: the entire San Joaquin Valley; Northern Sacramento Valley; Central Coast; San Diego; and the Inland Empire and Imperial County in Southern California. This process produced a set of “Ds Analysis Modules” specific to each type of area in California: small-medium areas; two major metropolitan areas; and a region with high-quality transit - the San Francisco Bay Area.

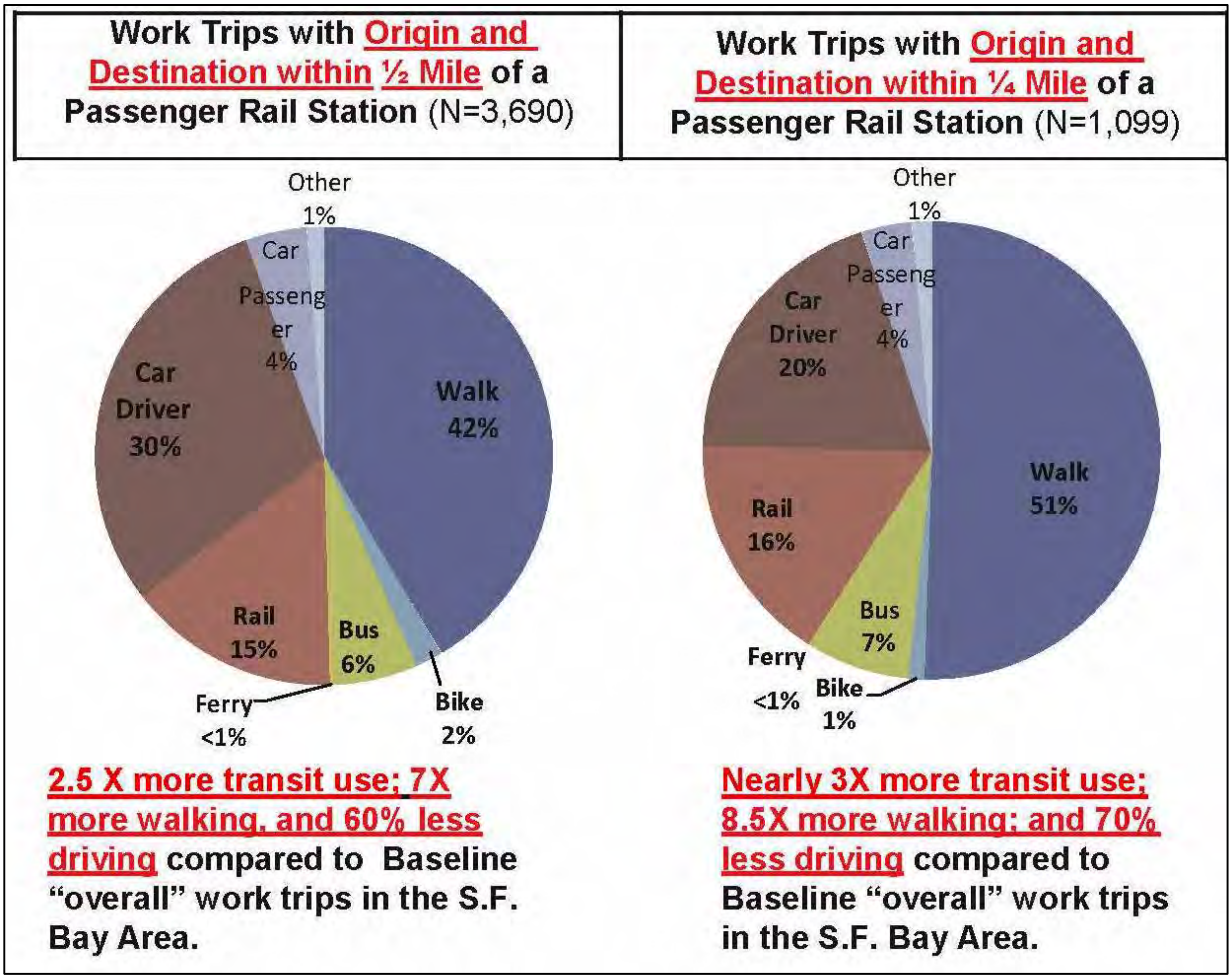
C. Example of Findings

The following example illustrates quantitative relationships between aspects of the built environment and travel that this study found during data compilation and analysis.

- **San Francisco Bay Area Rail Corridors –**

Detailed analysis of the Metropolitan Transportation Commission’s (MTC) 2000 Bay Area Household Travel Survey was conducted in areas located within ¼ and ½ miles of rail stations. It revealed significant differences in how people travel for work compared to baseline overall commute trips in this region. These are illustrated in Figure 4 (below).

Figure 4. Work Travel Modes near S.F. Bay Area Rail Stations



- The "baseline" mode split for work trips overall in the nine-county S.F. Bay Area (based on 67,881 reported trips in 2000) was: 9% Transit use (bus, ferry, train); 6% Walking; and 84% Driving.[26]

- Work trips in which both the origin and destination were located within ¼ to ½ mile of a passenger rail station had: 2.5 to 3 times more transit use (bus, ferry, rail); 7 to nearly 9 times more walking; and 60% to 70% less auto travel compared to commute trips in the S.F. Bay Area overall.

- Work travel in which only the home portion of a trip was ¼ to ½ mile from a rail transit station had: 3 times more transit trips; 2.5 to 3 times more walking trips; and 60% fewer automobile trips as compared to overall commute trips in the region as a whole.

(For additional details about this example, please see Attachment 4 to Appendix D.)

[26] Rail transit stations included the: ACE commuter train, Amtrak interregional rail, Bay Area Rapid Transit (BART), Caltrain commuter rail, SF MUNI light rail, and Silicon Valley Transportation Agency light rail.

7. Implementation of Project Results

A. Scenario/"Sketch" Planning Tools

The software technology used to support scenario planning has evolved radically within the last several years. Since 2000, a number of sophisticated geographic information system (GIS) analysis tools have emerged that allow users to more easily undertake scenario planning exercises and produce feedback on estimated results of decisions.

These tools enable users to input land use-transportation scenarios, either graphically or numerically, and receive projected estimates regarding the effects of choices.[27]

For this project, UC Davis coded the results of the statistical analyses of built environment and travel demand data (described above) into a set of modules designed to operate within sketch-scenario planning models commonly used in California. These modules have been incorporated into UCD's "UPlan" and SACOG's "iPLACE3S" GIS planning tools. In addition, SACOG staff used elasticities derived from the Ds modules to develop a spreadsheet "buffering" analysis tool that can be used to estimate VMT rates of large land use projects. *(Appendix F and Appendix G provide detailed information about each tool.)*

Depending on their interest, developers of other sketch-scenario planning tools (e.g., Envision Tomorrow, Vision California Urban Footprint, CommunityViz, INDEX) may also decide to incorporate the modules produced by this project into their tools. If they do so, it will enable the sketch-scenario planning tool that a California MPO uses in developing various scenarios to contain "Ds" relationships that match sensitivities in the regional travel demand model "post-processor" that is then used to analyze and compare proposed scenarios regarding selected performance metrics.

B. Travel Demand Forecast Model "Post-Processors"

Quantitative relationships between "D" built environment factors and travel behavior can be used to modify travel models used by MPOs in analyzing SCS scenarios for RTPs, as well as by local governments for General and Specific Planning. This applies to traditional "four-step" trip-based travel demand forecasting (TDF) models as well as emerging activity-based TDF models.

In order to demonstrate the application of the new Ds analysis modules produced by this project with travel demand models, eight MPOs were selected to receive special technical assistance, based solely on their: 1) expressed willingness, 2) availability of a completed and calibrated travel demand forecasting model (TDF) by June 2012, and 3) need for assistance in meeting near-term SB 375 requirements.[28]

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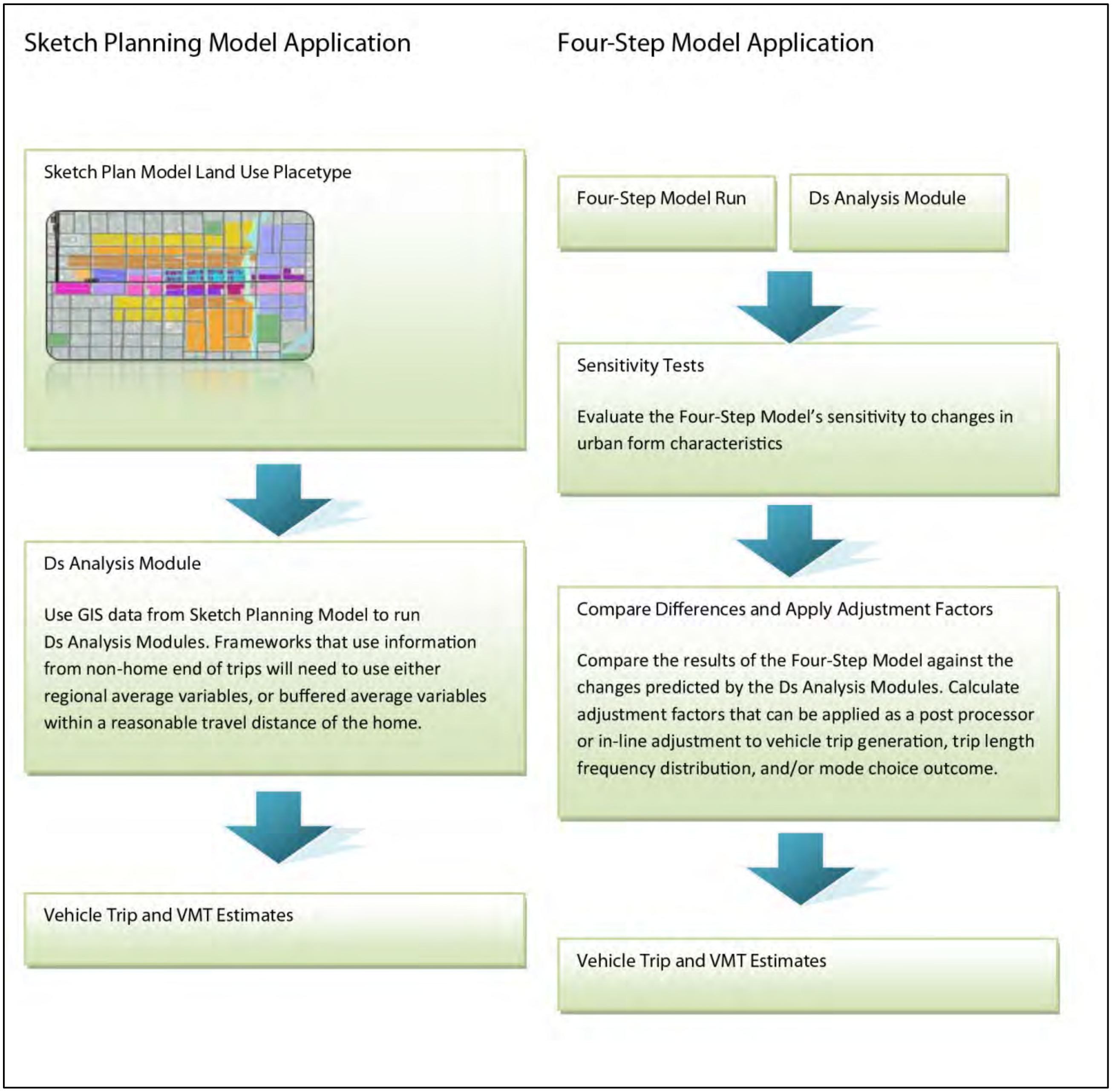
[27] Scenario sketch tools used in California include: "CommunityViz," "Envision Tomorrow," "iPLACE3S," Criterion's "INDEX"®, UCD's "UPlan," and Calthorpe Associates' "Rapid Fire" and "Vision California Urban Footprint".

[28] These included: **San Luis Obispo COG** (Central Coast); **San Joaquin, Merced and Stanislaus COGs** (Northern San Joaquin Valley); **Fresno COG** (Central San Joaquin Valley); **Tulare CAG and Kern COG** (Southern San Joaquin Valley); and **Butte CAG** (Northern Sacramento Valley).

During May and June 2012, staff of the eight MPOs received special technical assistance via this project from the Fehr & Peers team to: a) assess their TDF model to determine its existing level of sensitivity to smart growth/sustainable communities strategies; b) develop a customized travel model post-processor derived from the new Ds Analysis Modules for each area; and c) provide training on using the new post-processor with their TDF model. *(Please note: results of this process are provided in Appendix E.)*

Figure 5 (below) illustrates uses of the Ds Analysis Modules produced by this project in two ways: 1) within "sketch"-scenario planning tools; and 2) with travel demand models.

Figure 5. "Sketch Planning" and Travel Demand Model Applications



Source: Fehr & Peers (for this study).

8. Evaluation of Project Results

A. Comparison of "Ds analysis modules" elasticities to national research

One type of "reasonableness check" conducted for this study compared the elasticities represented in each of the regionally-specific "Ds analysis modules" to those reported in national research. The results of these comparisons indicate that the relationships between built environments and travel found in this study compare well with national research. *(Please refer to Appendix D for detailed information.)*

Comparisons for the Sacramento, San Diego, and smaller MPO regions indicate that - in each case - the regional elasticities are within national ranges. These California results also provide two additional factors not typically available in national research:

1) Travel choice differences associated with built environments at workplace and shopping destinations in addition to home locations; and

2) Variations regarding uniqueness of the study regions relative to national norms.

In the S.F. Bay Area rail corridors, the combined effects of density and diversity are well within the range of national research. However, the small and medium-size California regions included in this study exhibit lower sensitivities to transit proximity than national averages. That may be primarily due to the relatively limited extent of transit service within those regions and the fact that, compared with more highly urbanized areas, it is far less convenient to travel by transit than by auto. However, these areas also exhibit higher sensitivities to "density" and "diversity" factors than national averages, perhaps due to the relative uniqueness of opportunities to live and work in such settings.

B. Testing, calibration, and validation of planning tools

1. <u>Travel demand model post-processors</u>

a. Calibration to determine travel models' needs for post-processing

Appendix E *(Sections 1-3)* describes the processes used in this study to evaluate existing travel demand forecasting (TDF) models for eight selected "demonstration" MPOs to determine the extent of each model's need for adjustment regarding sensitivity of travel to built environment variables. In such cases, the Ds module is not used in a manner that would bias the model's base validation.[29] Instead, the module enhances the degree of precision with which the future forecast scenario is presented to the validated TDF model, better equipping it to recognize detailed attributes of land use and local access.[30] As a result, further validation or calibration of the Ds analysis module itself is not necessary.

[29] in which Ds Analysis Modules were used to "pivot" from a future baseline forecast produced by a TDF model to estimate incremental change in VMT between the future baseline and an alternative future land use scenario.
[30] in much the same manner that TDF models themselves are customarily refined by disaggregating large rural traffic zones in cases where future urbanization increases land use allocations.

b. Testing and validating the post-processor with travel demand models

An important step in applying the results of this study with a travel demand forecasting (TDF) model is checking that the application does not adversely affect the validation of the TDF model. Travel models used to analyze Regional Transportation Plans and for air quality conformity are tested and validated to demonstrate that they replicate traffic count data from Caltrans' Highway Performance Monitoring System (HPMS, or PEMS). Travel models typically must demonstrate that they produce VMT estimates that match HPMS data for the same year within 3% when applied to information regarding a base year land use and transportation system. *Section 4 of Appendix E* to this report recommends a five-step validation process to help ensure that the application of D Analysis Modules as post-processors do not result in a travel model falling outside of this acceptable range.

2. Scenario "Sketch-Planning" Tools

a. GIS Tools: Python modules and Uplan tool
Appendix F (Section 6) describes the processes that UCD used to test and validate:

- "Python" GIS modules, which UCD developed to facilitate the incorporation of Ds Analysis Modules produced by this project into GIS scenario planning tools; and
- the operation of Ds modules within UCD's "UPlan" GIS scenario planning tool.

The python modules were compared to their "reference model" to ensure that the same inputs produce effectively identical results.[31] Overall, python module results for projected household VMT were within an acceptable range re: the reference model (0.00003%).

In evaluating UPlan's use of these modules, the results of a "base case" scenario for a selected area (Tulare County) were compared to expected values in published literature. This evaluation found that "the percent changes in per household VMT produced by the UPlan implementation fall within a reasonable range compared to the available literature." It also concluded that "these tools work successfully and produce reasonable results given the inputs in the test area." *(Please see Appendix F, Section 6 C for details.)*

b. VMT Estimator Spreadsheet tool. The following evaluations were conducted:[32]

- Testing the accuracy of the calculations
- Testing the reasonableness of the results

The test of calculations used in this spreadsheet tool indicated that they function correctly. To test the reasonableness of results, three sample areas in Sacramento were analyzed; the results were reasonable and trended in the expected direction. *(note: Please refer to Appendix G, Section 4, for detailed results regarding these evaluations and their results.)*

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[31] The "reference model" is a spreadsheet version of the Ds analysis modules developed by Fehr & Peers for this study.
[32] These tests are appropriate for sketch tools, which are not intended to provide specific numbers to be used in more rigorous evaluations, but rather to give users a sense of magnitude and direction among various planning scenarios.

9. Summary & Conclusions

This study has met its goal of producing regionally-specific quantitative data and analyses regarding land use-transportation relationships in a large portion of California. This information can improve existing analysis tools used in local and regional integrated land use-transportation scenario planning. California's regional and local agencies need such tools for their integrated land use-transportation planning efforts, including developing and analyzing SB375-required SCS/APS scenarios for MPOs' regional transportation plans. The data and tools provided by this project will be especially helpful to California's mid-size and smaller regional agencies, as well as many local governments, which may lack sufficient resources to develop land use-transportation planning tools using local data.

Specifically, this project developed a set of "Ds Analysis Modules" that the project team derived via statistical analysis of travel survey and detailed built environment data collected at more than 200,000 locations in various parts of California.

It also provided improvements to selected analysis tools used in land use-transportation planning. The project team incorporated the Ds analysis modules into two GIS "sketch"-scenario planning tools used in California: UC Davis' UPLAN, and SACOG's iPLACE3S. In addition, UCD developed GIS modules to enable the new Ds analysis modules to be applied within other tools that are often used in California planning processes (potentially: Envision Tomorrow, Urban Footprint, INDEX, CommunityViz, etc.).

The team also provided specialized technical assistance to eight MPOs to develop and implement "Ds" post-processors for their travel demand forecasting (TDF) models. These regions were: Butte CAG (northern Sacramento Valley); San Luis Obispo COG (Central Coast); and San Joaquin COG, Merced and Stanislaus COGs, Fresno COG, Tulare CAG, and Kern COG (San Joaquin Valley). These MPOs will be able to use the new customized tools in their upcoming SCS/APS and RTP processes.

To summarize, this project has advanced the state-of-practice for integrated land use-transportation planning in California by providing locally derived quantitative data on land use-travel relationships for most of California's urban and urbanizing areas, as well as a selection of exurban and rural locations. It has made these results available in forms that can be incorporated into available sketch-scenario planning tools used in public participation processes, as well as via travel demand forecasting model post-processors.

The analyses performed for this project sought - and achieved - the translation of available data from household surveys and built environment factors in California into a common, consistent set of definitions, equations, and tools. It serves as a template and important initial step toward an ongoing process of systematized analysis of transportation and land use interactions as updated data becomes available in the future.

FINAL REPORT – Improved Data & Tools for Integrated Land Use-Transportation Planning in California

APPENDIX “A”

Annotated Literature Review on Land Use-Transportation Relationships

<u>TOPICS</u>:

1. Overview and Synopsis of Available Literature

2. List and summaries of relevant and important studies

- UC Davis ITS: Susan Handy, Richard Lee & Rachel Maiss
- Fehr & Peers: Jerry Walters
- Caltrans: Terry Parker

JANUARY 2012

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This document builds on an annotated literature review initially prepared in 2010 by Susan Handy, Richard Lee and Rachel Maiss (UC Davis ITS) for the Caltrans-funded project-scale "Trip-Generation Rates Method for Smart Growth Land Uses in California."

During 2011, Jerry Walters and Richard Lee (Fehr & Peers) augmented this review with additional literature relevant to the integrated local and regional land use/transportation planning project.

Terry Parker, Caltrans' HQ project manager for both studies, provided input and review during both phases.

*** Study is relevant to travel related to site-specific "smart growth" land use projects.**
**** Study is relevant to integrated land use and transportation analysis and scenario planning.**

1. Synopsis of Available Literature in the U.S.

A. Overview

This literature review provides an annotated synopsis of studies produced by the transportation research and practitioner communities on relationships between the characteristics of the built environment and the generation of travel demand. It also identifies prominent tools used by planners and engineers to integrate these relationships into planning and project evaluation processes employed by local and regional governments and state agencies. The review was conducted to support two Caltrans-sponsored projects underway to create improved planning tools for evaluating: transportation impacts of smart growth land uses; and integrated local and regional land use/transportation planning. This document represents the combined work of the study teams working on the two projects.

The review includes literature found in online research resources such as TRIS/TRID, Google Scholar and the archives of *Transportation Research Record*. Bibliographies of key documents were reviewed for additional resources. Additionally, pertinent literature with which the researchers are familiar was included. The literature acquired was assessed regarding the development of analysis tools for assessing relationships between the built environment and travel demand, including vehicle trips and vehicle miles of travel (VMT).

B. Organization

This review divides available literature identified into two types: (1) "empirical research," and (2) "applied methods." The first category contains studies that focus on quantitatively analyzing the relationship between urban form and travel behavior, as well as meta-analyses and large-scale reviews of such literature. The second category contains literature that describes methods, models, and tools used by practitioners for improved understanding of the built environment and travel behavior, or specific elements thereof. Though the literature was divided as logically as possible, some overlap may exist between these categories. Where available, links to documents are provided. Studies especially relevant to the site-specific smart growth trip-generation rates methodology effort are preceded by a single asterisk (*). Those especially relevant to integrated land use/transportation analysis tools and scenario planning processes are preceded by a double-asterisk (**).

C. Overview and Conclusions

The literature reviewed shows great diversity in the approaches taken by theorists and practitioners in studying relationships between the built environment and travel behavior in the U.S. Even so, there appears to be some consensus regarding key relationships useful for performing analysis of potential

*** Study is relevant to travel related to site-specific "smart growth" land use projects.**
**** Study is relevant to integrated land use and transportation analysis and scenario planning.**

effects of alternative land use and transportation strategies on travel at the local and regional levels. This type of analysis is needed to develop and assess land use and transportation planning scenarios and implementation programs for integrated "Blueprint" planning and Sustainable Communities Strategies (SCSs), which are required as part of Regional Transportation Plans (RTPs) for California's MPOs under SB 375[1]. There is also interest by cities, counties, special interest and community groups, developers, etc. in such strategies.

The body of available literature indicates that certain built environment variables, such as development density, land use mixture (diversity), and design for walkability and transit access, can have an important influence on travel behavior expressed in travel mode, vehicle trips (VT) and vehicle miles traveled (VMT). However, the built environment does not represent the only, nor even the most important, determinant of household travel. Demographic variables, especially income, household size and composition, and automobile ownership/availability, have a larger influence on travel behavior. Even so, local land use and transportation variables are important because they are more susceptible to policy influence in the US political context compared to variables such as income, auto ownership and household size and composition. It should also be noted that certain of these variables, such as auto availability, can be estimated as a function of urban form and demographic variables (e.g., Holtzclaw et al, 2007).

A variety of studies indicate that if local variables - such as density, diversity, design, and accessibility to significant destinations via transit and non-motorized modes - are all enhanced simultaneously in urban areas, reductions in vehicle trips and vehicle miles traveled on the order of 25 percent or greater per household are possible in those areas.

The literature suggests that some of the explanations for lower VT and VMT rates in such "smart growth" areas are due to "self selection" – people wishing to reduce their need to drive seek out urban areas where this desire can be realized. The self-selection process occurs both in residential choice and well as the choice of workplace and shopping destinations. The self-selection process implies that, to the extent that there may be underserved demand for less auto-centric urban environments in a given region, estimates of the elasticity of VT and VMT with respect to the built environment provide better predictions of the changes that could occur if additional "less auto-centric urban environments" are built.

A parallel study (Vision California) suggests that "smart growth" development of all types may be significantly under-provided in local plans, indicating that there will be substantial unmet demand for "smart growth" in California in the decades ahead. This implies that if more "smart growth" development is built, there will be a sufficient supply of "self-selectors" to live, work, and shop in them. This attenuates

[1] See the California Transportation Commission *2010 Regional Transportation Guidelines*, Chapter 3, available at: http://www.catc.ca.gov/programs/rtp.htm

the need to adjust for self-selection, at least in California. Self-selection is still important from a policy standpoint, in that the under-supply of smart growth development needs to be addressed if we want to take full advantage of the connection between the built environment and travel behavior.

Among local land use factors affecting travel demand, the literature indicates that access to regional destinations via non-automobile modes is the single most important built environment factor. Development in areas of high accessibility— e.g., in or near central cities—tends to produce lower VMT per capita compared to even dense mixed-use development located on the "fringe." Diversity – land use mixture -- is also influential, though identifying appropriate land use mixtures can be challenging. (For example, a restaurant located near an office or home may attract walking trips, while a furniture store might not - even though both may be classified as "retail" in land use databases and local zoning codes.) **Density (of population and employment), and design or connectivity (especially when measured as the density of intersections and/or streets, bicycle facilities, and sidewalks), are often highly correlated variables** (which often results in only one variable appearing significant in regression analyses). An optimal method of sorting out these intertwined variables has not yet emerged in the literature reviewed, though methods have been developed by researchers.

Another set of issues the literature does not fully address include the transferability of relationships between built environment and travel behavior: there is variation across metropolitan areas regarding alternatives to automobile travel. **Opportunities to lower levels of VT and VMT are greatest where urban areas and transit systems offer accessibility that provides truly attractive alternatives to automobile travel.**

The land use–travel literature, though vast, is lacking in longitudinal and retrospective studies. Very few "before and after" studies exist, and the literature remains dominated by cross-sectional studies and forecasting model analyses. Another limitation is that the current body of literature is almost entirely comprised of studies based on data that is at least a decade old. And, only a few are based primarily on California data.

Thus, the data collection and analyses being conducted for the two Caltrans-funded data and tools development projects are important to advancing the state-of-practice in California. These projects are providing locally-derived and up-to-date quantitative data regarding land use/travel relationships. And, the "Improved Data and Tools for Integrated Land Use-Transportation Planning in California" project (by SACOG, Fehr & Peers consultants, UC Davis' ULTRANS, and Caltrans) will make these relationships available for use in "sketch-planning" analysis tools, GIS-based "visioning" software, as well as travel demand modeling. The "Smart Growth Trip-Generation Methodology" effort that researchers at the Institute of Transportation Studies at UC Davis are developing will provide a methodology for use in preparing

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transportation impact analyses of proposed “smart growth” land use development projects (for which ITE’s suburban-based vehicle trips estimation data are not applicable).

Such data and tools will be useful for integrated regional Blueprint scenario planning, preparing and analyzing Sustainable Communities Strategies and Regional Transportation Plans, as well as for local land use General and Specific Community planning and smart growth project implementation.

A. Empirical Research

- *Arrington, G. B. and Cervero R. (2008). **Effects of TOD on Housing, Parking, and Travel**, Transit Cooperative Research Program (TCRP) Report 128 http://144.171.11.107/Main/Public/Blurbs/160307.aspx

The objectives of this research were to learn more about the behavior and motivation of TOD residents, employees, and employers in their mode choice, as well as identify and recommend use of best practices to promote transit ridership in TODs. An extensive literature review was conducted regarding the TOD travel behavior and motivation. Unveiled in this review were the findings that transit system extensiveness, parking prices, and traffic congestion are all positively correlated with transit ridership. Relative transit travel time to auto travel time is more important to ridership than any land use factor. Aside from this, the most effective way to increase TOD transit ridership is to increase development densities in close proximity to transit. Also discovered was a lack of information regarding TOD trip generation characteristics, as the grid patterns typically associated with the dense development within TODs make it more difficult to conduct trip counts. Overall, it was found that policy factors that most strongly influence transit ridership in TODs include transit service levels, prices, and parking supply and costs.

Beyond the literature review, the study aimed to provide more information regarding vehicle trips generated by TODs, by collecting empirical trip generation data at a representative sample of TODs. Seventeen residential case studies were conducted in four metropolitan areas of the U.S.: (1) Philadelphia/Northeast New Jersey, (2) Portland, OR, (3) Washington D.C., and (4) the East Bay of the San Francisco Bay Area. Six of the surveyed projects included ground-floor commercial, but were primarily residential, and none of the projects were immediately accessible to a freeway interchange. Based on these counts, over a weekday period residential TODs averaged 44% fewer vehicle trips than estimated by ITE (based on a weighted average). The data collected by these counts are made available in the report. Additionally, the researchers ran a multivariate regression analysis to predict trip generation rates of residential TODs based on (1) distance of the project to the central business district, (2) distance of the project to a transit station, (3) residential densities around the station, and (4) parking provision. The bivariate relationships between residential TOD trip generation and other variables were weak and statistically insignificant.

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Residential density within ½ mile from the transit station proved to be the most explanatory of the variables included in the regression. Thus, the effect of increased parking provision due to overestimating trip generation is discussed. As increased parking typically leads to decreased density (as previously mentioned, the most explanatory predictor of trip generation for TODs), the implications of overestimating trip generation rates for TODs are significant. Essentially, a feedback cycle is created in which developers decide to decrease density and increase parking provision at their TODs in order to get their development approved, which in turn leads to less transit use than originally anticipated by the TOD, and reaffirms initial concerns regarding the traffic impacts of the development. Thus, more accurate predictions of traffic generated by TODs are necessary in order for TODs to reach their full potential. This report provides valuable data that can serve as a starting point in putting together a tool that more accurately estimates trip generation for smart growth type developments.

- ******Boarnet, Marlon G. (2011). **A Broader Context for Land Use and Travel Behavior, and a Research Agenda.** *Journal of the American Planning Association*, 77:3, 197-213

Planning studies of land use and travel behavior focus on regression analysis of travel as a function of traveler demographics and land use near study subjects' residences. Methodological debates have tended to focus almost exclusively on the possibility that persons choose their residence based on how they wish to travel. This longer view steps back from the confines of the regression-based literature to explain the historical roots, methods, and results of the literature, and to assess how the land use–travel literature must be transformed to be more relevant to planning.

The article acknowledges the many prior summaries and meta-analyses of the impact of land use on travel. Its primary intent is not to summarize the results of past studies, but rather to explain how a literature that has become fundamental to planning scholarship is failing to be sufficiently planning-focused. It then describes how the literature can be transformed to address the planning challenges of today and tomorrow.

Over 100 articles are summarized, covering transportation methods from the dawn of the interstate highway era to topics that include program evaluation, land development, and cognitive aspects of travel behavior. The primary focus is on the land use and travel literature, but the review and analysis is broad ranging and places the literature and its challenges within the broader context of recent developments in the social sciences, planning, policy, and electronic data collection.

Progress on three research frontiers is needed to move the land use–travel literature forward: First, behavioral models of land use and travel must expand to consider how land is developed, how places are planned, and how cities are built. Second, the land use–travel literature should build a robust retrospective program evaluation tradition, which is currently almost completely absent in a scholarly field dominated by

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cross-sectional hypothesis tests and forecasting models. Third, economic social welfare analysis must be carefully researched, including questions of preferences for neighborhood types and whether such preferences are fixed or malleable.

The article concludes by noting that planning is fundamentally about city building, and the literature and practice on land use and travel behavior should adapt to better support city building. This requires both a serious commitment to social science research and planning's characteristically broad view of context, problem, and place. In an era of climate change, and amidst debates about sustainability, the land use–travel literature must more aggressively examine the process of plans and place-making, evaluate the increasingly innovative transportation policies being implemented at the local level, and develop methods that allow more informed discussion about the costs and benefits of transportation policies.

- **Boarnet, M., Nesamani, K.S., & Smith, C. (2003). **Comparing the Influence of Land Use on Nonwork Trip Generation and Vehicle Distance Traveled: An Analysis Using Travel Diary Data.** Transportation Research Board, 83rd Annual Meeting. http://www.its.uci.edu/its/publications/papers/CASA/UCI-ITS-AS-WP-03-1.pdf

This article examines the relationship between land use and non-work trip generation and vehicle miles traveled (VMT). The authors hypothesize that land use impacts VMT more than it impacts trip generation. They use travel survey data to test this hypothesis. Portland Travel Diary data are used, which include information regarding ethnicity, income, employment, and a "pedestrian environment factor" based on the area's level of pedestrian infrastructure and design. Further, census data for the Portland region were examined, in addition to transportation network data from Portland's Regional Land Information System. The authors used regression techniques to model non-work vehicle trip frequency and VMT separately, both as functions of socio-demographic variables, and land use variables. Three of the "D-factors" were taken into account. First, density was measured by population density within the respondent's census tract. Second, employment density, and retail employment density within the respondent's census tract served as indicators of land use diversity. Finally, design was measured by the percent of the street grid comprised of four-way intersections within a ¼ mile of the respondent's home. Based on their models, the authors conclude that income plays the largest role in determining both trip generation and VMT. However, after income is taken into account, the effect of land use variables is comparable to that of other socio-demographic variables. Ultimately, the authors' initial hypothesis was rejected in favor of the conclusion that land use variables have a similar effect on both VMT and trip generation.

- **Cambridge Systematics, Inc. (2009). **Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions**. Washington D.C.: Urban Land Institute.

Moving Cooler is a study designed to analyze the potential for different strategies to reduce transportation related greenhouse gas (GHG) emissions in the United States. Various greenhouse gas (GHG) reducing

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strategy bundles are explored and analyzed. GHG reductions are estimated from reductions in vehicle miles traveled (VMT) and improvements in system efficiency. The bundles are analyzed at two levels of deployment: (1) aggressive, and (2) maximum. The bundle that is most reflective of the VMT reduction strategies examined by projects attempting to explore the relationship between land use and transportation is the "Land-Use/Transit/Non-Motorized Bundle." This bundle could potentially achieve significant GHG reductions through reduced automobile dependence by 2050. Specifically, GHG emissions could be reduced by up to 9% under aggressive deployment (assuming 54% of new development by 2050 is dense development of 5 or more units per acre), and up to 15% under maximum deployment (assuming 90% of new development by 2050 is dense development as defined above). Specific explorations of VMT reductions achieved through each bundle are not provided.

- **Cervero, R. (2007). **Transit-Oriented Corridors**. *The Transportation/Land Use Connection,* T. Moore, P. Thornes, B. Appleyard, Planning Advisory Service Report Number 546/547, pp. 136-137.

The author notes that "atomized" transit-oriented development (TOD) – i.e., development around a single transit station – has not produced significant regional benefits – reduced congestion, improved air quality, and land conservation. In fact, isolated TODs in a sea of auto-oriented development may be counter-productive, creating pockets of congestion as residents beyond the TOD drive to and through it. What is needed is a sufficient number of TODs aligned in a corridor, six to eight miles in length that will enable many trips to and from a TOD to also be made by transit. The author suggests that Transit Oriented Corridors (TOCs) on this scale are the important planning construct for analyzing the effectiveness of the TOD concept. Stockholm, Sweden is cited as an example of successful implementation of TOC; over decades planners there worked to coordinate development along linear axes, forming a "necklace of pearls."

TODs within the corridor can be specialized toward employment or housing, or mixed, but ideally the resulting corridor land use pattern will result in high transit use in both directions, facilitating both regional goals and efficient transit operations.

- **Cervero, R; Duncan, M (2006). **Which Reduces Vehicle Travel More: Jobs-Housing Balance or Retail-Housing Mixing?** *Journal of the American Planning Association,* Autumn 2006, 72; 4; 475-490

Which land-use strategy yields greater reductions in vehicular travel: improving the proximity of jobs to housing or bringing retail and consumer services closer to residential areas? The authors' probe this question by examining the degree to which job accessibility is associated with reduced work travel and how closely retail and service accessibility is correlated with miles and hours logged getting to shopping destinations. Based on data from the San Francisco Bay Area, they find that jobs-housing balance reduces travel more, by a substantial margin. The article concludes by discussing policy measures that have been

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introduced in California to bring housing, workplaces, and retail centers closer together. The authors document an inverse relationship between jobs housing balance and VMT of 0.05.

- Chatman, Daniel G. (2003). **How Density and Mixed Uses at the Workplace Affect Personal Commercial Travel and Commute Mode Choice.** *Transportation Research Record, 1831,* 193-201.

This paper describes a model that examines the relationship between land use characteristics at the workplace and commute and commercial travel choices. The built environment at the workplace is of particular interest as changes in land use patterns may be more politically feasible in these areas than in residential locations, and the self-selection problem is less of a concern when examining workplace locations. Data for the model is drawn from the 1995 Nationwide Personal Transportation Survey (NPTS). The test independent variables to estimate VMT are employment density and share of retail employment. A variety of demographic variables are included as controls. The model determined that high workplace density demonstrates a slight correlation with reduced VMT (with an increase of 10,000 employees per square mile yielding a 0.5 mile reduction in per capita personal commercial VMT), and retail at the workplace did not demonstrate a statistically significant correlation with VMT. However, a potential explanation for the latter finding could be that retail employment density is not a good indicator of activity accessibility as it does not include non-retail services such as banks or restaurants.

- **Chatman, D. (2009). **Residential choice, the built environment, and nonwork travel: evidence using new data and methods.** Environment and Planning A, Vol. 41, No. 5, pp.1072 – 1089.

This study confirms that residents of dense, mixed-use, transit-accessible neighborhoods use autos less. Recent studies have suggested that this relationship is partly because of the phenomenon of self-selection, i.e., households that prefer to use transit and walk or bike seek and find such neighborhoods. If this is the case, and if the number of such households is small, policies to alter the built environment may not influence auto use very much. The author argues that many of these studies are inconclusive on methodological grounds, and that more research is needed. A purpose-designed survey of households in two urban regions in California (the San Francisco Bay Area and San Diego region) is investigated, with the aid of a new methodological approach. The study finds that most surveyed households explicitly consider travel access of some kind when choosing a neighborhood, but that this process of residential self-selection does not bias estimates of the effects of the built environment very much. To the extent that it does exert an influence, the bias results both in underestimates and overestimates of the effects of the built environment, contrary to previous research. The analysis not only implies a need for deregulatory approaches to land-use and transportation planning, but also suggests that there may be value in market interventions such as subsidies and new prescriptive regulations.

- **Chatman, Daniel G. (August 2006). **Transit-Oriented Development and Household Travel: A Study of California Cities.** Institute of Transportation Studies, School of Public Affairs, University of California, Los Angeles. For the California Department of Transportation (Caltrans).
  http://www.policy.rutgers.edu/faculty/chatman/documents/TODs_and_travel_in_CA.pdf

This paper outlines a model of travel patterns of those living in transit-oriented developments (TODs) in California. The model is based on data from a survey of randomly selected households and workers within a 0.4 mile radius of selected rail stops in San Diego and the San Francisco Bay Area. The survey consisted of a telephone questionnaire and 24-hour activity and travel diaries. It included not only those living in TODs, but also those living in the greater metropolitan area in which the TODs were located, providing for better "control" than census data. The built environment characteristics included in the model were as follows: (1) built form density (structural density of developed land), (2) activity density (mix of uses), and (3) network load density (number of local users per unit of network capacity).

Combined home and work transit proximity demonstrated the strongest correlation with transit commuting; however, the built environment variables most strongly correlated with travel decisions were those that reduce the convenience of auto use. The important consideration is not so much that these variables increase the convenience of non-motorized travel, but that they typically decrease the convenience of motorized travel. Thus, TODs that accommodate the automobile through increased capacity do not tend to produce the desired effect of TODs on travel.

The residential self-selection problem is explored as well. In order to incorporate the potential for residential self-selection into the model, respondents were asked to describe what factors were considered when choosing their current neighborhood, instead of describing their travel preferences (which could be influenced by current travel patterns). Based on statistical tests conducted on survey data, the residential self-selection problem exists, but is not necessarily a strong indicator of travel behavior.

One important policy implication of this study, as discussed previously, is the fact that changes made to the built environment in order to make alternative travel modes more convenient must also make auto use less convenient (i.e. avoid improving road capacity and parking provisions). The second critical policy implication is that TODs should be conceived within the context of a regional scale rather than a local scale, as the large-scale built environment has a substantial impact on travel behavior.

- **Ewing, R., Bartholomew, K., Winkelman, S., Walters, J., & Chen, D. (2007). **Growing Cooler: Evidence on Urban Development and Climate Change.** Washington D.C.: Urban Land Institute.

Growing Cooler examines the relationship between the built environment, transportation, and greenhouse gas (GHG) emissions. The relationship between smart growth type land use patterns and travel is discussed, as well as the potential for the general public to embrace smart growth strategies. A

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comprehensive review and analysis of the literature regarding the relationship between land use and travel patterns is conducted. The EPA's Smart Growth Index is presented, which defined sprawl as being composed of four factors (density, mix, centeredness, and street accessibility), and demonstrated that as sprawl decreases, average vehicle ownership and daily VMT per capita decrease, though the density factor has the strongest and most significant relationship to travel. In order to quantify the effects of density on congestion, data from a study examining the relationship between density and congestion were used by the authors to develop an elasticity of congestion with respect to density of 0.14, indicating that density only exacerbates congestion mildly. Elasticities comparing the initial three "Ds" (density, diversity, and design) to VMT and vehicle trips are provided (taken from Ewing and Cervero 2001). The effects of site location on the VMT of project-scale development are examined, and it is found that VMT reductions between 30 and 60 percent are typical of infill locations, when compared to Greenfield development. Overall, the evidence on the built environment and driving indicates compact development can reduce the need to drive by 20 to 40 percent relative to sprawl.

- ******Ewing R, & Cervero R, (2010). **"Travel and the Built Environment: A Meta-Analysis"** *Journal of the American Planning Association,* Vol. 76, No. 3, pp. 265 – 294.

The study begins by noting that both local governments and states are turning to land planning and urban design for help in reducing automobile use and related social and environmental costs. The effects of such strategies on travel demand have not been generalized in recent years from the multitude of available studies. To address this, the authors conducted a meta-analysis of the built environment-travel literature existing at the end of 2009 in order to draw generalizable conclusions for practice. The authors aimed to quantify effect sizes, update earlier work, include additional outcome measures, and address the methodological issue of self-selection. Elasticities were collected and in some cases computed for individual studies and pooled them to produce weighted averages.

<u>Key results:</u> Travel variables are generally inelastic with respect to change in measures of the built environment. Of the environmental variables considered here, none has a weighted average travel elasticity of absolute magnitude greater than 0.39, and most are much less. Still, the combined effect of several such variables on travel could be quite large. Consistent with prior work, the authors find that vehicle miles traveled (VMT) is most strongly related to measures of accessibility to destinations and secondarily to street network design variables. Walking is most strongly related to measures of land use diversity, intersection density, and the number of destinations within walking distance. Bus and train use are equally related to proximity to transit and street network design variables, with land use diversity a secondary factor. Surprisingly, the authors find population and job densities to be only weakly associated with travel behavior once these other variables are controlled.

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The elasticities derived in this meta-analysis may be used to adjust outputs of travel or activity models that are otherwise insensitive to variation in the built environment, or be used in sketch planning applications ranging from climate action plans to health impact assessments. However, because sample sizes are small, and very few studies control for residential preferences and attitudes, it cannot be said that planners should generalize broadly from our results. While these elasticities are as accurate as currently possible, they should be understood to contain unknown error and have unknown confidence intervals. They provide a base, and as more built-environment/travel studies appear in the planning literature, these elasticities should be updated and refined.

- **Ewing, R., & Cervero, R. (2001). **Travel and the Built Environment: A Synthesis.** *Transportation Research Record, 1780,* 87-114.

This paper summarizes the majority of recent (as of 2001) studies examining the potential to influence travel behavior through land use changes. Elasticities of VMT and vehicle trips with respect to the three Ds (density, diversity, and design) as well as regional accessibility are provided. General findings regarding household VMT include the fact that trip frequency (regardless of mode) is more dependent on sociodemographic characteristics than on land use variables, whereas trip length is more dependent on land use variables, and mode choice is dependent on both land use and sociodemographic variables. The direct relationship between density and travel is uncertain (i.e. other variables associated with density could be the true cause of observed changes in travel patterns). The evidence regarding the relationship between vehicular travel and transportation networks (e.g. grid patterns versus arterials) is considered inconclusive. The elasticities provided by this study are small, but significant, and could have considerable impacts if additive effects are taken into account.

- Ewing, R., Dumbaugh, E., & Brown, M. (2001). **Internalizing Travel by Mixing Land Uses: Study of Master-Planned Communities in South Florida.** *Transportation Research Record, 1780,* 115-120.

This study seeks to model the effects of land use mix on internal trip rates using 20 mixed use master-planned communities in south Florida. Prior to this, no study had modeled the interaction of such variables. The authors discuss the problems posed by lack of research on internal capture rates of mixed use developments, and state that "...traffic impact studies for mixed use developments are little more than exercise in speculation." Internal capture rates (i.e. trips with both trip ends within the community) were found to range from 0 to 57 percent. Land use measures examined were community size (population + jobs), density (size / area), entropy (level of land use mix within the development), balance (the development's jobs-housing ratio as compared to that of the county as a whole), and accessibility. After controlling for size and regional accessibility in the model, land use mix and density were not found to be

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significant determinants of internal capture rates. This could be due to a variety of sampling errors, or issues of construct validity in the density and land use variables. For example, the density variable included all land area in its denominator, including land unable to be developed. Further, construct validity problems in the land use mix and balance measures may arise due to the fact that many of the businesses included in the commercial category meant to serve larger regional markets (e.g. furniture stores, automobile dealers, etc.). The variable found to be most strongly correlated to internal trip rates in this model was development size, with regional accessibility following as the second most strongly correlated variable (a negative correlation). The authors conclude with a discussion of the need for further empirical research on internal capture rates for such developments.

- **Ewing, R., et al. (2009). **Traffic Generated by Mixed-Use Developments – A Six Region Study Using Consistent Built Environmental Measures.** Transportation Research Board, 88th Annual Meeting. http://www.reconnectingamerica.org/public/show/trafficmixedusedevelopments2009

This study aims to measure the traffic impacts of multi-use developments using a variety of innovative methods. Six regional household travel databases of multi-use developments were chosen for analysis. All trips were able to be classified by purpose and mode, socioeconomic characteristics were controlled for, and data were linked to built environment databases. A total of 35,877 trip ends were generated by the multi-use developments, 29% of which were either internal trips, or non-motorized or transit trips, detracting from the total amount of external vehicle trips generated by these developments. Elasticities are developed to quantify the relationships between a variety of land use and sociodemographic variables and internal trip capture rates, the likelihood of walking or taking transit on external trips, and trip distances for external automobile trips. Overall, variables found to contribute to a reduction in automobile travel include: (1) total and relative amounts of on-site population and employment, (2) site density, (3) size of households and auto ownership characteristics, (4) level of employment within walking distance of the site, (5) pedestrian-“friendliness” of the site, and (6) level of transit provision and access to employment via transit.

- Handy, S. (2004). **Critical Assessment of the Literature on the Relationships among Transportation, Land Use, and Physical Activity.** Department of Environmental Science and Policy, University of California, Davis. Prepared for the Committee on Physical Activity, Health, Transportation, and Land Use, July. http://onlinepubs.trb.org/onlinepubs/archive/downloads/sr282papers/sr282Handy.pdf

This report provides a discussion and review of the empirical evidence regarding the interaction of the built environment and physical activity (often times associated with non-motorized travel). A variety of travel behavior and built environment theories are discussed, most of which shed light on the fact that the relationship between the built environment and travel behavior is complex. Studies examining the

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relationship between the built environment and active travel are explored. Dependent variables examined in these studies included walk trips, non-motorized trips (i.e. walk and bike trips), and non-automobile trips (including transit). Built environment characteristics (i.e. independent variables) included in the studies are population and employment density, land use mix, transportation system measures, measures of accessibility, design measures, and neighborhood type. Control variables consisted of sociodemographic characteristics typically included in regional travel surveys.

Many studies found that population and density measures are significantly positively correlated with non-motorized travel modes. The findings across studies of effects of transportation system measures on active travel were somewhat inconsistent. The variable capturing the distance to destinations generally demonstrated a negative correlation with walking trips, as expected, while other measures of accessibility tended to demonstrate positive correlation with non-motorized trips. Design variables were shown to be statistically insignificant, which could simply serve as an indicator that the variables typically used to measure design are insufficient. The studies that focused on neighborhood type as opposed to various built environment variables tended to demonstrate higher levels of non-motorized trips in traditional or walkable neighborhoods, than in suburban or auto-oriented neighborhoods.

Next, physical activity studies are explored, falling into two categories: (1) correlative studies, and (2) intervention studies. The former identifies relationships between a dependent variable and a variety of independent variables at one point in time, while the latter surveys participants before and after an intervention, and results are compared to a control group in order to determine the effect of the intervention. Many of the correlative studies relied on subjective reported measures of the built environment and mode choice, while a few used more objective measures of the built environment to supplement or replace the reported measures. Measures of physical activity in these studies fell into the categories of walking, other physical activity, and total physical activity. Neighborhood characteristics used to measure the built environment for these studies were different from those in the travel behavior literature. Transportation, design, and safety characteristics were the most used measures of the built environment in the physical activity literature. Overall, it was found that measures of accessibility demonstrate a positive impact on total physical activity, while perceived neighborhood aesthetics, and objective neighborhood characteristics demonstrated strong positive associations with walking.

Although various methodologies were used in these studies, the travel behavior and physical activity studies produced consistent results, indicating that a strong association exists between the built environment and physical activity. However, some ambiguity is present regarding which specific features of the built environment influence physical activity. Though density and neighborhood type were found in some studies to have a strong impact on active travel, more exploration is needed to determine the specific qualities of these variables that impact travel behavior as measures of these variables were inconsistent across studies. On the other hand, accessibility is one variable that, regardless of how it is measured, seems to have a strong influence on physical activity.

Finally, the question of causality versus correlation is raised, and the self-selection problem is discussed. The built environment's interaction with residential self-selection can be conceptualized in a variety ways. One with a propensity toward active travel modes can either be encouraged or inhibited depending on neighborhood characteristics, or the neighborhood characteristics of one with a low preference for active travel modes can reinforce this low preference, or encourage one to change preferences. Various cross-sectional (correlative) studies have indicated that residential self-selection does play a role in travel behavior, though the author discusses the potential of intervention studies to improve understanding of residential self-selection.

Overall, the author finds that further research is needed in order to sort out the degree to which different aspects of the built environments can have a causal effect on physical activity. However, the author concludes that the lack of definitive evidence should not serve as a deterrent to changing the way our communities are designed. Based on existing research, a causal link between the built environment and physical activity is certainly a possibility. Further, other positive outcomes are associated with making neighborhoods less auto-oriented, and minimal risk and cost is associated with doing so.

- **Handy, S., Cao, X, & Mokhtarian, P. (2005). **Correlation or Causality between the Built Environment and Travel Behavior? Evidence from Northern California.** Transportation Research Part D 10, 427-444. http://www.dot.ca.gov/researchconn/past_speakers/DrHandy/trd_paper.pdf

This study seeks to move beyond establishing a correlation between built environment characteristics (e.g. density, land use mix, transit accessibility, pedestrian friendliness, etc.) and travel choices by exploring a causal relationship between the two. In other words, this study aims to explore whether neighborhood design affects travel behavior, or if instead travel preferences play a role in determining neighborhood choice. In order to do this, a survey was conducted comparing those who had recently switched neighborhood types (the "treatment" group) to those who had not recently moved (the "control" group). Reported vehicle miles driven were used as the dependent variable. Independent, or explanatory, variables included: reported neighborhood characteristics and neighborhood preferences, objective measures of accessibility, travel attitudes, and sociodemographics. Based on a cross-sectional analysis of reported vehicle miles driven, it was found that residential self-selection plays a significant role in the observed correlations between the built environment and travel behavior. Based on the quasi-longitudinal analysis of the change in travel behavior after a move, or after one year of staying in the same neighborhood (controlling for attitudes toward different modes of travel), it was found that changes in the built environment do have an impact on vehicle miles driven. Increased accessibility was the variable that had the greatest negative impact on driving. These findings serve to substantiate the conclusions of

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previous cross-sectional studies that found a direct relationship between the built environment and travel behavior.

- **Holtzclaw, J., Clear, R., Dittmar, H., Goldstein, D., and Hass, P. (2002). **Location Efficiency: Neighborhood and Socio-Economic Characteristics Determine Auto Ownership and Use – Studies in San Francisco, Los Angeles and Chicago.** *Transportation Planning and Technology*, Vol. 25, pp. 1-27.

This study, sponsored by the Natural Resources Defense Council (NRDC), the Center for Neighborhood Technology (CNT) in Chicago, and the Surface Transportation Policy Project in Washington, DC, includes every neighborhood in the San Francisco, LA and Chicago areas. The zones analyzed are the Chicago Area Transportation Study's 316 Dram-Empal model zones covering the Chicago metropolitan area, the Southern California Association of Governments' 1700 Travel Analysis Zones covering the Los Angeles metropolitan area and the Metropolitan Transportation Commission's 1099 Travel Analysis Zones in the San Francisco metropolitan area.

The dependent variables estimated are vehicles available per household and vehicle miles traveled (VMT). Average vehicle availability for each zone is from the 1990 U.S. Census. VMT per vehicle is derived from odometer readings recorded when owners take their vehicles in for emission systems inspections (smog checks) in California and Illinois. Average VMT per household is calculated as the VMT per vehicle times the number of vehicles per household for each zone. The dependent variables were tested against a wide range of potential explanatory variables, including the most important socio-economic factors of household income and household size. Locational variables tested were: density, transit service and access to jobs by transit, availability of local shopping, pedestrian and bicycle friendliness, and proximity to jobs.

The authors predict a household's VMT as a function of home-zone density, transit service and access to jobs by transit, availability of local shopping pedestrian and bicycle "friendliness"; that is, the "attractiveness" of these options as compared to driving, and proximity to jobs. The elasticities for vehicle ownership with respect to density for Chicago, Los Angeles, and San Francisco were -0.33, -0.32, and -0.35. Elasticities for VMT with respect to density were -0.350, -0.4, and -0.43.

- *Kimley Horn & Associates, with EPS and the Association of Bay Area Governments, for Caltrans (2008). **Trip-Generation Rates for Urban Infill Land Uses in California (Phase 1).** http://www.dot.ca.gov/newtech/researchreports/reports/2008/ca_infill_trip_rates-phase_1_final_report_appendices_4-24-08.pdf

The purpose of this study was to provide information regarding the travel characteristics of urban infill development in California. Specifically, the study aimed to: develop a methodology for infill trip generation data collection and analysis; develop trip generation rates for urban infill developments in California; and

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make these rates available for use in a database that can serve to supplement ITE *Trip Generation* for estimating trip generation rates for infill developments in California. Ultimately, the research team's goal was to incorporate data collected into future relevant ITE publications. Land uses examined by this study include commercial and office developments, high density housing and mixed-use and transit-oriented developments. Sites were selected in metropolitan areas based on multi-modal travel options, with the goal of providing a representative sample of different urban areas around the state of California. Methods for collecting data included counts as well as intercept surveys. Representative site selection was relatively easy compared to obtaining permission to survey the sites, which was the most challenging aspect of the study as of the completion of phase 1. The most effective approach to gaining permission to survey was found to be soliciting permission from those developers or organizations that had prior relationships with members of the research team, or soliciting permission/recognition from larger groups or organizations that represent or are affiliated with multiple developers (e.g. American Planning Association, local Chambers of Commerce, etc.). In addition to counts and intercept surveys, data were collected regarding independent site variables (e.g. building size, number of employees, etc.), and population size (i.e. the number of people accessing a site during the study period).

Various methodologies were explored for empirically measuring as well as estimating daily trip generation rates on site. The most viable methodology was determined to be peak-period counts and intercept surveys to estimate daily trip generation rates. Three pilot studies were conducted at infill sites in Oakland and San Francisco to test this methodology. Following these three pilot studies, ten other sites were identified as appropriate for an expanded pilot study. These sites, in the cities of Berkeley, San Diego, and Los Angeles, were mostly residential, though a few commercial/business land uses were included. Based on this small sample, on average residential sites had lower trip rates than ITE estimates. All non-residential sites surveyed, aside from a supermarket in San Diego, demonstrated lower trip rates than the ITE estimates as well. Overall, this report was very informative regarding optimal data collection techniques and methodologies in order to calculate trip generation rates for urban sites.

- *Kimley Horn & Associates, with Economic & Planning Systems and Gene Bregman & Associates, for Caltrans (2009). **Trip-Generation Rates for Urban Infill Land Uses in California (Phase 2).** http://www.dot.ca.gov/research/researchreports/reports/2009/final_summary_report-calif._infill_trip-generation_rates_study_july_2009.pdf

This is second phase of this project, and provides an overview of the method used for site selection and data collection described in the Phase 1 report. Ten land use types were chosen for data collection to estimate trip generation rates for urban infill developments: high-rise apartment, mid-rise apartment, mid-rise residential condominium/townhouse, high-rise residential condominium/townhouse, hotel, general office building, shopping center/specialty retail, and pharmacy/drug store without drive-through window,

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quality (sit-down) restaurant, and fast-food restaurant without drive-through window. Based on the sample consisting of 25 sites surveyed during both phase 1 and phase 2, observed trips were lower (by 26% to 40%) during peak periods than the ITE trip rates would indicate for all land uses, except: a mid-rise apartment complex in Pasadena, a mid-rise condominium/townhouse site in San Diego, a chain clothing store in San Francisco, and a supermarket in San Diego.

Ultimately, the report concluded that a larger database is needed in order to adequately compare trip generation rates in urban infill developments to those provided by ITE *Trip Generation.* Recommendations for future research include: trip rate validations, development of correlations between specific site characteristics and trip generation rates, and exploring incentives for developers to allow site surveys.

- **Kockelman, Kara, Matt Bomberg, Melissa Thompson, and Charlotte Whitehead (2008) **GHG Emissions Control Options: Opportunities for Conservation.** Report Commissioned by the National Academy of Sciences for the Committee for the Study on the Relationships among Development Patterns, VMT, and Energy Conservation.

This paper summarizes the magnitude of greenhouse gas (GHG) emissions reductions one can expect from a variety of widely discussed (and often debated) policies and design strategies. These include vehicle technologies, transport modes, fuel types, appliances, home and building design, and land use patterns. Through a detailed review of existing literature, the work strives to identify the greatest opportunities for carbon savings, reflecting, to some extent, cost implications and behavioral shifts needed. Greatest near-term gains mostly emerge in relatively conventional vehicle design shifts, dietary changes, and home weathering. In the medium term, significant energy and emissions savings are likely to come from fuel economy regulations approximating those abroad, appliance upgrades, plug-in hybrid purchases, home heating and cooling practices, and power generation processes. In the longer term, building design practices, carbon capture and sequestration, and a shift towards cellulosic and other fuels appear promising. Ultimately, however, to achieve 50- to 80-percent reductions in GHG emissions, relative to current or past levels, major behavioral shifts are probably needed, motivated by significant fuel economy legislation, energy taxes, household-level carbon budgets, and cooperative behavior in the interest of the global community.

With respect to urban form factors the authors note that these do not appear to be as influential as demographic and economic variables, but are more subject to public policy and regulation. The authors cite Bento et al. (2005) who found that road network and distribution of population throughout the city were the greatest urban form determinants of VMT, while VMT and commute mode were most dependent upon the pattern of residential land use and distribution of employment. The authors note that the 2001 National Household Travel Survey results suggest that VMT per vehicle is rather stable across households owning one to three vehicles. Thus, reducing vehicle ownership may be an important means to reducing

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VMT. Tables 22, 23, and 24 summarize elasticities of demand for vehicle with respect to parking, density and urban design variables.

- Lin, J.J. & Yang, A.T. (2009). **Structural Analysis of How Urban Form Impacts Travel Demand: Evidence from Taipei.** *Urban Studies, 46(9),* 1951-1967.

This study analyzes the relationship between the built environment and travel demand in Tapei, Taiwan. The complex relationship between land use variables and travel is discussed, and structural equation modeling is used to clarify this complex relationship. Urban form variables used in the model include density (residential density, building density, and employment density), diversity (land use type mix, housing-job mix, housing-retail mix, retail-job mix, and land use entropy), and design (road density, grid network, and sidewalk density). Travel demand variables included in the model were trip generation and private mode split. Finally, control factors in the model include transit service, private mode facility (e.g. access to automobiles, and parking space density), and socioeconomic variables. Data were obtained at the traffic analysis zone level for the model from the Tapei City Bureau of Transport, and other Tapei City Government Agencies. Based on the model, it was found that density is positively related to trip generation and negatively related to private mode split. Land use mix is negatively associated with trip generation, and indirectly positively related to private mode split. Pedestrian friendly design was found to reduce private mode split. Though most of these findings support findings from studies conducted in the United States, national differences in previous land use patterns may serve to explain any differences.

- Lund, H., Willson, R., and Cervero, R. (2006). **A Re-evaluation of Travel Behavior in California TODs.** *Journal of Architectural and Planning Research*, Vol. 23, No. 3, pp. 247-263.

Building on the authors' prior work (Lund, Cervero & Wilson, 2004) , this reevaluation of survey data from residents living near rail station notes that transit-oriented development (TOD) clearly, but unevenly, encourages walking to transit as well as transit use California region's with rail transit. Survey sites were all located in non-Central Business District (CBD) locations, within walking distance of a transit station with rail service headways of 15 minutes or less, and were intentionally developed as TODs. Surveys were conducted along each of California's major urban rail systems, including: the San Diego Trolley, San Diego Coaster, Los Angeles Blue and Red Lines, Los Angeles Metrolink commuter rail, San Jose VTA light rail, Caltrain commuter rail, the Bay Area Rapid Transit District (BART), and Sacramento Light Rail.

The 2004 study found that residents living near transit stations were around five times more likely to commute by transit as the average resident worker in the same city, while office workers at work sites near transit were three and a half times as likely to use transit as average workers in the same cities. The reevaluation suggests that TOD can reduce per capita automobile travel, but this is only likely to be realized when transit systems reach sufficient coverage and efficiency to provide an attractive alternative to automobile travel.

- Saelens, B., & Handy, S. (2008). **Built Environment Correlates of Walking: A Review.** *Medicine and Science in Sports and Exercise, Vol 40, No 7S,* S550-S566.

This paper reviews the literature between 2002 and 2006 on the relationship between specific characteristics of the built environment and walking for transportation and recreation. Specifically, this report synthesizes reviews of research, and original research conducted in both the transportation and public health fields regarding the interaction between the built environments and walking. Many reviews found that accessibility, measured as distance to destinations, is associated with walking. Aesthetics were found to be another important indicator of walking in multiple reviews, though factors used to measure aesthetics varied widely across studies. Street connectivity also played an important role as it is closely related to accessibility. Safety attributes were also positively correlated with walking. Most reviews discussed a need for more objective measures of environmental variables, and improved measures of walking, though the authors do mention that recent studies have incorporated more objective measures of the built environment than their predecessors.

The more recent studies found consistent positive relationships between walking for transportation and density, distance to nonresidential destinations, and land use mix. However, the question of causality still poses a problem for those wishing to understand more about the relationship between the built environment and active travel (in this case, walking). The following policies are specifically recommended to shape the built environment, influence aesthetic qualities, and encourage walking: designation of mixed use zoning districts, infill development and redevelopment programs, designation of historic districts, greyfield redevelopment, traffic calming programs, street connectivity ordinances, and requiring developers to provide amenities that make communities more livable.

- ******San Francisco Bay Area Metropolitan Transportation Commission (2006). **Characteristics of Rail and Ferry Station Area Residents in the San Francisco Bay Area.** Oakland, CA. http://www.mtc.ca.gov/planning/smart_growth/stars/

This study was undertaken to characterize the demographic and travel characteristics of station area residents — individuals living within close proximity to stops and/or ferry terminals in the region — compared to residents living elsewhere in the region. Transit Oriented Development (TOD) was defined as development within a one-half-mile *walking* distance (taking account of barriers and walkway circuity) of a rail or ferry terminal. Demographic and travel data were from MTC's 2000 Bay Area Travel Survey. This survey compiled travel and demographic data for some 35,000 individuals aged 16 years and above residing in nearly 15,000 Bay Area households.

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Analysis of Bay Area survey results revealed that people living within a half-mile walking distance of a rail transit or ferry station are four times more likely to use transit than those living farther away than a half-mile. The data show that people who live and/or work within a half-mile of major transit or ferry stations averaged 42% of their daily trips by transit, walking or biking. Nearly a third of these do not own a vehicle. By comparison, people who live and/or work within a half-mile walking distance of ferry or major transit stations generate about one-half the VMT of suburban and rural residents in the SF Bay Area.

The study also found that the vehicle mode share of residents within a half mile of a rail station or ferry terminal is 28 percent lower than for the region as a whole. The same data also indicate that the transit mode share of residents increased by 14 percent in such areas. This suggests that about half of the reduction in vehicle trips observed for station/terminal area residents may be attributed to the substitution of transit for private vehicle trips.

- **Shay, E. & Khattak, A. (2007). **Autos, Trips, and Neighborhood Type: Comparing Environmental Measures.** Transportation Research Board, 86th Annual Meeting. http://www.eng.odu.edu/transportation/khattak/New_Clusters_TRB_2007.pdf

This paper examines the relationship between neighborhood design, socio-demographic characteristics, auto ownership, and trip generation. The authors discuss "neo-traditional" development as typically associated with lower auto ownership rates, higher pedestrian/transit trips, and lower VMT, while offering the caveat that this may be due to self-selection. The paper describes a model developed by the authors using survey data from the Charlotte, NC region. In the process of developing this model, the authors used 34 direct measures of the built environment, then derived factors out of these direct measures using factor analysis, and finally performed cluster analysis to group together similar neighborhoods in terms of factors. These factors and clusters were then compared with auto ownership and trip generation. According to the authors, examination of the factors yielded more interesting results than that of the clusters. Factors derived from factor analysis were walkability, accessibility, agglomeration, property value, and level of industrial land use. Based on regression analysis, accessibility was the one land-use factor that was highly correlated with auto ownership (indicating a negative correlation between the two), while both accessibility and walkability were positively correlated with overall trips. The coefficients derived from regression analysis may be of interest in the development of a new trip generation model. However, because this analysis is based on data from North Carolina, it is less applicable in California.

- **Transportation Research Board Special Report 298. (2009). **Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO_2 Emissions.** Washington, D.C.: Transportation Research Board.

This study aimed to establish a scientific basis for analysis of the relationships between development patterns, vehicle miles traveled (VMT), energy consumption, and greenhouse gas (GHG) emissions for the

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purpose of informing policymakers as they adapt to California's Senate Bill 375. This bill requires the state's metropolitan planning organizations to provide incentives for local jurisdictions to incorporate more compact development and transportation alternatives into their future plans for the purpose of reducing GHG emissions by assigned target amounts. A decline in metropolitan density due to suburbanization and its implications for transit use are discussed. The generally accepted density threshold for a successful transit system is noted to be 7 to 15 dwelling units per residential acre, and the typical ½ mile catchment area for transit stations is mentioned. The importance of accounting for the many variables often associated with both density and VMT is discussed. These variables include accessibility, land use mix, development design, connectivity of street network, and demand management policies. Explanations for variability in the findings across studies are explored, including the use of disaggregate versus aggregate data, cross-sectional versus longitudinal studies, the self-selection problem and the uncertainties associated with causality, the measurement and scale of the different variables, and the generalizability of results.

The researchers found that developing at higher population and employment density is likely to reduce VMT rates. Further, evidence from the literature suggests that a doubling of residential density across a metropolitan area may reduce household VMT by 5 percent to 12 percent, and up to 25 percent if combined with other land use practices and policies thought to reduce VMT (e.g. higher employment density, mixed land uses, transit improvements, etc.). Particularly, the effects of land use strategies and transit availability together were found to be considerably greater than those of either one individually.

Chapter four introduces strategies to overcome impediments to compact development. These strategies include a focus on building compact new housing developments, relaxing zoning restrictions to enable more compact and mixed use developments, creating incentives for developers and lenders to invest in compact and mixed use development, and implementing integrated street design and reduced parking requirements in such developments.

Finally, previous national estimates are examined to determine the potential impact of compact development patterns on VMT, and the results of the authors' own development scenarios are presented. One study estimated that shifting growth by 2025 from sprawl to a controlled growth scenario (which moves 11 percent of new housing, and 6 percent of jobs to more urbanized areas) would reduce person miles traveled by 4 percent overall. Another study estimated VMT per capita to be 30 percent less in compact developments than in their conventional counterparts. Results of a scenario study conducted by the authors indicate that a doubling of density in 25 percent of new residential development could reduce VMT by 12 percent in both 2030 and 2050, while a doubling of density in 75 percent of new residential development could reduce VMT by 25 percent in the same time frame. Further benefits and costs of compact development are explored. Noted benefits include improved energy efficiency of buildings, land conservation, and increased physical activity. One potential cost is that of increased necessity for transit investment. Overall, the authors recommend to policymakers that policies in support of more compact, mixed use development should be encouraged.

- **Wallace, B., Mannering, F., & Rutherford, G.S. (1999). **Evaluating Effects of Transportation Demand Management Strategies on Trip Generation by Using Poisson and Negative Binomial Regression.** *Transportation Research Record, 1682,* 70-77.

This paper examines how various travel demand management (TDM) strategies can be incorporated into trip generation models for planning purposes. Using multi-modal travel survey data from the Puget Sound Transportation Panel (PSTP), the authors use Poisson regression techniques to analyze the effects of five TDM strategies on home-based work trip generation. The five strategies examined are as follows: (1) telecommunications strategies (i.e. telecommuting), (2) alternative work schedules (i.e. compressed work weeks), (3) on-site amenities at work, (4) pricing strategies (i.e. parking charges), and (5) land use strategies (i.e. urban center vs. non-urban, and distance from home to work). The results from the regression analysis are provided in the paper, including correlation coefficients for each of the variables examined. Variables of interest to the Smart Growth Trip Generation Rates spreadsheet effort include the two land-use variables of urban center vs. non-urban, and distance from home to work. Distance from home to work is negatively correlated with home-based work trips, while living in an urban center is much more highly (and positively) correlated with home-based work trips. The authors speculate that this may be due to trip-chaining: those living in urban centers (which tend to incorporate a mix of land uses, higher density, etc.) are less likely to feel the need to trip-chain between work and home, as making personal trips independent from their commute is presumably not as difficult for these people as it is for those living outside urban areas. This could also provide an explanation for the negative correlation between distance from home to work and home-based work trips: if trip-chaining occurs on the way to or from work, this trip is no longer counted as a home-based work trip. Finally, the authors discuss the differences between land-use strategies and other TDM strategies, and it is determined that perhaps instead of treating land-use strategies as variables within a trip generation model, separate trip generation models should be created for distinct land-use types.

- ****Zhang, M. (2005). **Intercity Variations in the Relationship Between Urban Form and Automobile Dependence: Disaggregate Analyses of Boston, Massachusetts; Portland, Oregon; and Houston, Texas.** *Transportation Research Record, 1902,* 55-62.

This study focuses on improving understanding of the relationship between urban form, access to a variety of travel mode choices, and the shift in mode choice from automobile travel to non-automobile travel. This is done through a modeling of mode availability and mode choice in three distinct cities: Portland, Oregon; Boston, Massachusetts; and Houston, Texas. Trip diary surveys were used as the primary source of data for

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all three cities. Based on the model, it was found that vehicle ownership and home distance to transit tend to influence whether people consider non-automobile modes feasible, with increased automobile ownership and poor transit service both correlated with high automobile dependence. When socioeconomic and transit supply variables are controlled for, population density was associated with a lower probability of automobile dependence in both Portland and Boston. However, no such association was found in Houston. After completion of the modeling phase, the authors estimated disaggregate elasticities of automobile dependence and driving choice with respect to density, transit access, and vehicle ownership. Houston, which is quite automobile dependent, demonstrated the smallest elasticities. The authors speculate that this may indicate that places with established high levels of automobile dependence will have a harder time overcoming this automobile dependence through improvements in density and transit access and decreased vehicle ownership. Overall, the authors found that land use densification and improved access to transit can help to increase travel options and encourage modal shifts from driving to non-driving.

B. Applied Methods

- **California Department of Transportation (Caltrans). (2010). **Smart Mobility 2010: A Call to Action for the New Decade.** February 2010. http://www.dot.ca.gov/hq/tpp/offices/ocp/smf.html

In this guidebook, "Smart Mobility" is defined as the provision of a safe, efficient, and equitable transportation system that facilitates reductions in auto use and greenhouse gas emissions. Keys to Smart Mobility are the principles of location efficiency, reliable mobility, health and safety, environmental stewardship, social equity, and robust economy. The concept of location efficiency includes coordinating land use and transportation decisions to facilitate multi-modal travel while improving accessibility. Many features that can be categorized under the concept of the "Ds": mixed land uses, high quality urban design, increased density, distribution of public facilities, and quality transit service. Next, reliable mobility emphasizes efficient congestion response, provision of multi-modal options, and avoidance of capacity increases that may induce vehicle travel. Important to the concept of health and safety is the promotion of "active" travel modes (e.g. walking, biking), system optimization to reduce injuries and fatalities, and reduction of public exposure to transportation related pollutants.

Environmental stewardship, from a Smart Mobility perspective, consists of preserving current infrastructure and development, enhancing the natural and built environment through transportation programs that encourage their preservation, and contribution to climate and energy sustainability through improved land use and transportation planning. The concept of social equity is discussed as focusing on efficient access to non-vehicular travel modes, and developing performance measures that evaluate the impacts of land use and transportation decisions on diverse population groups. Finally, a robust economy

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can be cultivated through Smart Mobility through improved freight operations, minimized transportation costs, and maximized public return on transportation investments through improved project foresight.

Seven “Place Types” are introduced, which are distinguished based on community design and regional accessibility, both of which have been shown to affect travel behavior. Priorities in each of these place types are defined for the advancement of Smart Mobility. Priorities in Urban Centers include: provision of efficient multi-modal travel, re-investment in existing roadways, and pricing strategies to optimize roadway and parking capacity.

Priorities in compact communities and compact communities in close proximity to urban centers include: improved transit and enhanced connectivity to foster non-motorized travel modes. Priorities in suburban areas include: increased connectivity to reduce average trip length, improved bicycle and pedestrian infrastructure, and investments to increase the efficiency of existing roadways. Included in the many performance measures proposed to determine the success of Smart Mobility implementation are transit mode share, and pedestrian and bicycle mode share.

- **Cervero, R. (2006). **Alternative Approaches to Modeling the Travel-Demand Impacts of Smart Growth.** *Journal of the American Planning Association*, Vol. 72, No. 3, pp. 285-295.

This study begins by noting that four-step trip-based travel demand forecasting models were not developed to estimate the travel impacts of neighborhood-level smart growth initiatives like transit villages, but rather to guide regional highway and major transit investments. It notes that while progress has been made in enhancing large-scale models to make them more sensitive to local, small-scale elements of smart growth, some analysts have turned to post-processing and direct models to reduce modeling time and cost, and to better capture the travel impacts of neighborhood-scale land use strategies.

This article presents examples of direct or off-line modeling of rail and transit-oriented land uses for greater Charlotte, the San Francisco Bay Area exurbs, and south St. Louis County. These alternative approaches provided a useful platform for scenario testing, and their results revealed that concentrating development near rail stations produced an appreciable ridership bonus. The study deems these alternative models are appropriate as sketch-planning supplements to, but not substitutes for, traditional travel models.

- Chang, T. (2005). **Memorandum re: INFORMATION – Level of Service Technical Working Group Update.** San Francisco County Transportation Authority.

This memorandum discusses the Transportation Authority Board's adoption of the Transportation Level of Service (LOS) Methodologies Strategic Analysis Report (SAR), which recommends adjustments to the measurement of transportation impacts as well as the review of transportation impacts under CEQA. Specifically, the SAR recommends that LOS be replaced with vehicle trips generated as an indicator of

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traffic impact. This ensures that improvements to transit, pedestrian, and bicycle infrastructure are not adversely impacted by unnecessary mitigation fees. In order to determine vehicle trips generated, the methodology outlined in the San Francisco Planning Department's Guidelines for Environmental Review is suggested. Additionally, the SAR recommends that mitigation fees for various projects should be combined in order to fund multi-modal transportation projects to mitigate growth at the system-wide level. The methodology mentioned for estimating vehicle trip generation will be examined in more detail as a part of our project's tools search.

- **DKS Associates, the University of California, Irvine & Santa Barbara, and Utah State University (2007) **Assessment of Local Models and Tools for Analyzing Smart-Growth Strategies – Final Report** (for Caltrans) http://www.dot.ca.gov/newtech/researchreports/reports/2007/local_models_tools.pdf

Objectives of this project were to: review existing local travel models in California, assess their ability to analyze the effects of smart growth strategies on travel behavior, and examine the availability of techniques and tools that can contribute to the overall sensitivity of travel models. More specifically, this paper discusses the extent to which the "4D" elasticities (density, diversity, design, and destinations) contribute to the sensitivity of travel models to smart growth strategies. The many limitations of the Urban Transportation Modeling System (UTMS), or the "traditional four-step travel demand model" as it is commonly known, are discussed regarding sensitivity to smart growth. Methods to overcome these limitations are introduced, which can be divided into four categories: (1) post-processor to UTMS for application of smart growth trip and VMT elasticities, (2) stand-alone tools for aggregate application of smart growth trip and VMT elasticities, (3) enhancement of UTMS models, and (4) integrated land-use, economic, and transportation models.

Next, the 4D elasticities are introduced, which measure the interactions between the characteristics of built environments, vehicle trips, and VMT. Included in the discussion of these elasticities is an overview of "Do's and Don'ts" provided by Fehr and Peers Consultants, which outline conditions for optimal use of 4D elasticities. Among other restrictions, they "indicate that the 4D elasticities were not appropriate for use in analysis of small-scale developments (below 200 acres) and/or in CEQA analyses. An overview of a few existing tools that utilize these elasticities includes: PLACE3S/I-PLACE3S, INDEX (both of which are "stand-alone tools for aggregate application of smart growth trip and VMT elasticities"), and URBEMIS. PLACE3S is a software tool for assessing and comparing planning scenarios. I-PLACE3S is an internet-based version of PLACE3S that the Sacramento Area Council of Governments (SACOG) developed and used in its regional Blueprint planning program. INDEX is a GIS-based sketch-planning tool developed by Criterion Engineering in Portland, Oregon that incorporates a 5th D (distance to heavy rail transit stations). Also discussed is URBEMIS, a primarily air-quality impact assessment tool that estimates multi-modal trip generation, VMT, and related air quality impacts of land uses up to 50 acres in size.

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Next, the state of the practice of travel modeling in California is discussed. Though many smaller metropolitan planning organizations (MPOs) and regional transportation planning agencies (RTPAs) rely on travel demand models that lack sensitivity to smart growth, some of the larger MPOs and local jurisdictions have improved their models including: the San Francisco Transportation Authority, SACOG, MTC, SLOCOG, Contra Costa County, Humboldt County, Fresno and Madera Councils of Government, the City and the County of Sacramento, among others. To expand upon this analysis, case studies were presented of six cities in California regarding their plans to improve the sensitivity of their travel models, including four cities that use multi-modal travel models: (1) San Diego, whose model tests smart growth developments and transit focused areas, (2) San Jose, whose model incorporates certain socio-demographic variables (auto ownership and income), (3) Fresno, and (4) West Sacramento, both of latter two cities' models use a 4D post-processor. Other jurisdictions identified in the case studies were: the City of Irvine, which plans to incorporate the 4Ds in its travel model; and the City of San Luis Obispo, which has tested the potential use of 4Ds elasticities for planning.

- Ercolano, J.M., Olson, J.S., & Spring, D.M. (1997). **Sketch-Plan Method for Estimating Pedestrian Traffic for Central Business Districts and Suburban Growth Corridors.** *Transportation Research Record, 1578,* 38-47.

This paper analyzes a method to determine future peak-hour pedestrian-trip volumes in central business districts and suburban growth corridors. The method consists of three steps: 1) Estimating sources of pedestrian trips (i.e. determining potential sources of pedestrian trips from motor vehicle, transit, and walk and bike-only trips), 2) Estimating average peak pedestrian-per-hour (pph) trip rates per person (i.e. estimating peak pph using vehicles-per-hour (vph) and other mode data), and 3) Determining pph trip distribution and assignment. The second step is of particular interest for this analysis. These steps were tested using two different methodologies for the estimation of peak pph trip rates in the town of Plattsburgh, NY. The first of these methodologies is a mode-based estimation for pedestrian trip generation rates. In this methodology, pedestrian trips are divided into three types: 1) Car-walk linked person-trips (CWL trips – estimated at 90% of total mode share), 2) Walk-only and bike-only person-trips (WBO trips – estimated from census data for the state of NY to be 7%), and 3) Transit-walk linked person-trips (TWL trips – estimated from census data to be 3%). The peak pph for the first type of pedestrian trips (WBO trips) is calculated using the following methodology, taking into account through-trips and vehicle occupancy:

Peak pph = (Peak vph - through-movement trips) = [(vph turning movements) x

(1.5 default average vehicle occupancy) x (5 trips per person) x (20 percent drive-through, etc.)]

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**** Study is relevant to integrated land use and transportation analysis and scenario planning.**

The second methodology used to estimate peak pph trip rates is based on land-use. The first step in this methodology was to estimate the on-site trip rate average, which is assumed to equal the local trip rate times 93 m^2. This will be of greater significance in the final step of the methodology. The second step is to adjust this data for various land uses. The adjustment factors are as follows: 0.67 for urban areas with populations up to 50,000, 2) 1.0 for urban areas with populations from 50,000 to 500,000, and 3) 1.33 for urban areas with populations from 500,000 to +1,000,000. Third, a peak-hour adjustment factor was determined based on historical pedestrian-peaking characteristics and variations in peak demand by land use types. This factor was determined to be 1.5 times the average hourly volume for peak hours (to be applied to the average trip rate during peak hours). Finally, in order to calculate the total peak pedestrians per hour walk trips as generated by land use, the following formula was used:

Total peak pph (for each TAZ by land-use type) = (total m^2 per TAZ/93 m^2) x (av. trip rate as calculated above)

When these two methods were compared, the mode-based pedestrian trip generation model was found to be 9% less on average than the land-use pedestrian trip generation model. Although this methodology is simple and straightforward, the methodology for deriving the adjustment factors and numbers is not provided.

- Fulton, W. & Aubry, R. (2005) **Utilizing GIS to Help Both Cities and Developers Analyze Infill Development Potential.** Solimar Research Group, Inc. http://www.esri.com/industries/planning/docs/solimar_gis.pdf

This paper outlines the creation of and potential uses for the Infill Analysis Tool created by Solimar Research Group. This tool uses GIS software and Microsoft Excel to analyze which areas within a city would be appropriate for infill development. Since its creation, the tool has been used by housing developers in New York, New Jersey, and California. The tool relies on a combination of parcel-level data (e.g. parcel vector data, assessor attribute data, and zoning data) and block- or district-level data (e.g. census data, employment data, environmental constraints, transportation data, infrastructure capacity and scheduled capital improvements, etc.). In the transportation sector, the tool can be used to identify where infill sites would best be located in order to take advantage of existing transportation infrastructure, as well as to better forecast the environmental impacts of infill policy proposals under CEQA. This is the case as the tool allows policymakers to focus specifically on the parcels eligible for redevelopment under a given policy, instead of assuming all parcels would be eligible. Though no direct examples were provided regarding the ability of the tool to estimate the environmental (or traffic) impacts of infill development, this paper provides an interesting overview of the process used to develop a user-friendly tool using software that is readily available for most practitioners.

- **Johnston, R. (2008) **Review of U.S. and European Regional Modeling Studies of Policies Intended to Reduce Transportation Greenhouse Gas Emissions.** *Institute of Transportation Studies,* University of California, Davis, Research Report UCD-ITS-RR-08-12. http://pubs.its.ucdavis.edu/publication_detail.php?id=1166.

With the enactment of new federal transportation legislation in 2005, State and regional transportation plans and programs are for the first time required to achieve the objectives of the SAFETEA-LU planning process, which focus on enhancing mobility and supporting economic development, while minimizing conventional emissions and greenhouse gas emissions. In 2007, the U.S. Supreme Court held that greenhouse gases are a pollutant and so are covered by the Clean Air Act and, consequently, the USEPA can regulate them. California and 13 other states are now attempting to regulate the emissions of greenhouse gases from vehicles.

The results from over 40 long-range regional scenario exercises performed in the U.S. and Europe demonstrate that substantial reductions in vehicle-miles of travel (VMT), fuel use, and emissions of both criteria pollutants and greenhouse gases are possible using transportation pricing policies and investment priorities that have been demonstrated as acceptable and effective in a modest but growing number of metropolitan areas and regions around the world. These studies show that substantial reductions in travel and emissions of pollutants and greenhouse gases are possible (10%-30%, compared to the future base case), but only with combined transportation investment, land use, and travel pricing policies.

- **Matley, T., Goldman, L., & Fineman, B. (2000). **Pedestrian Travel Potential in Northern New Jersey: A Metropolitan Planning Organization's Approach to Identifying Investment Priorities.** *Transportation Research Record, 1705,* 1-8.

This paper outlines the development of a "pedestrian potential index" (PPI) by the New Jersey Transportation Planning Authority (NJTPA). The NJTPA developed this tool in order to determine where increased pedestrian trips may take place if the proper infrastructure were developed. The PPI is based on the relationship between land use mix, density, and urban design, with a strong emphasis on the importance of proximity and connectivity. Census tract level data were used to measure gross employment density, gross population density, and land use mix as indicators of proximity, in addition to street network density as an indicator of connectivity. Employment density and population density were calculated per square mile, using only census information. In order to measure land use mix, an entropy formula was used to determine how evenly land areas in each tract were distributed among different land use types. Finally, street network density was measured in street miles per square mile using GIS and census tract land areas. All of these indicators were verified through a comparison with cities of three distinct land use types (urban, suburban, and rural). A low and high threshold was set for each indicator, and a census tract had to pass three of the four thresholds in order to be considered a "high potential" pedestrian area. Those tracts passing the higher threshold were considered high priority areas for improved pedestrian infrastructure.

*** Study is relevant to travel related to site-specific "smart growth" land use projects.**
**** Study is relevant to integrated land use and transportation analysis and scenario planning.**

Though this process does not directly estimate pedestrian trips generated, it is an effective method of using readily available data to produce indicators of walkability at the census tract level.

- *Muldoon, D., & Bloomberg, L. (2008). **Development of Best Practices for Traffic Impact Studies.** Transportation Research Record, 2077, 32-38.

The Oregon Department of Transportation (ODOT) completed a Best Practices for Traffic Impact Studies (TISs) in response to concerns that TISs are typically not as accurate as they could be. As a part of the research for this project, case studies for actual developments were conducted to verify estimated traffic impacts, in addition to a literature review regarding the state of the practice. Based on verification of case studies, trip generation estimates tended to overestimate peak-hour trip generation. It was determined that this overestimation is in part due to confusion regarding the proper use of ITE's *Trip Generation.* Cited sources for such errors include improper land use code selection, inadequate assessment of pass-by trip reductions, failure to consider seasonal variations in traffic counts, and lack of multi-modal evaluation. Although this project seems to do little more than advise practitioners to exercise caution when using ITE's *Trip Generation* estimates, it certainly supports arguments in favor of a more flexible, context-sensitive trip generation tool to for Traffic Impact Studies.

- **Replogle, M. (1993). **Land Use/Transportation Scenario Testing: A Tool for the 1990s.** Transportation Research Board 72nd Annual Meeting. http://tmip.fhwa.dot.gov/resources/clearinghouse/docs/landuse/luts/luts.pdf

This paper begins by discussing the need for alternative analysis methods for land use and transportation scenarios. In particular, scenarios that do not favor automobile oriented development are emphasized. The author discusses the inadequacies of standard methods used to determine transportation impact fees for new developments (particularly their insensitivity to urban design factors). Next, advancements in modeling efforts which include more long-range planning scenarios are discussed. Of particular focus are planning efforts that were underway in Montgomery County, Maryland at the time. Montgomery County crafted various planning scenarios incorporating different growth levels and jobs/housing mixes, in addition to different types of growth in transportation infrastructure. These scenarios were tested in particular for their effects on VMT. Ultimately, based on the Montgomery County scenarios, the author concludes that VMT and mode share can be influenced by transportation incentives and enhancements, urban design, and changes in land use patterns that complement transportation investments. Though this paper is somewhat outdated, it serves as an interesting indicator that the issues inherent in current transportation impact analysis methods have been recognized as significant impediments for decades.

- **Rodier, C.J. (2009). **An International Review of the Modeling Evidence on the Effectiveness of Transit, Land Use, and Auto Pricing Strategies.** *Transportation Research Record*, 2132, 1-12.

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With an eye toward recent greenhouse gas (GHG) reduction legislation in California, this paper reviews the international modeling literature on land use, transit, and auto pricing policies. Modeling-based studies in California, elsewhere in the US, and in Europe are analyzed to suggest a range of VKT and GHG reduction that regions might achieve if such policies were implemented separately or in combination. To account for the fact the three types of policies examined have different time frames for full implementation and effectiveness (e.g., land use changes take longer to be effective than pricing changes), the author develops order of magnitude estimates for 10-, 20-, 30-,and 40-year time horizons.

The review concludes that land-use-only policy packages can potentially reduce VKT by up to 2% in the 10-year time horizon. The effectiveness of land use strategies may increase by approximately 2 to 3 percentage points to a higher reduction level at 10-year increments. Land use plus transit scenarios may reduce VKT by 2% to 6% during a 10-year time horizon, and these figures may increase by approximately 2 to 5 percentage points for each future 10-year increment. Combined land use, transit, and pricing policy measures would bring significantly greater reductions in both the shorter- and the longer-term time horizons. The review also concludes that even improved calibrated travel models are likely to underestimate VKT reductions from land use, transit, and pricing policies. Most California models are not yet suited for the policy analysis demands in the era of global climate change.

- Samdahl, D.R. (2009). **Multi-Modal Impact Fees.** *Washington State ITE Newsletter* Vol. 19, No. 8, 9-13. http://www.westernite.org/Sections/washington/newsletters/Samdahl%20multimodal%20impact%20fees.pdf

This article outlines the process used by the cities of Seattle and Portland, OR to assess appropriate multi-modal allocation of revenue generated by traffic impact fees. In order to do this, the cities had to develop methods of determining multi-modal trip generation rates. Seattle's method utilized data from the regional household activity survey in order to determine the typical person trips to vehicle trips ratio. This allowed them to convert ITE's vehicle trip generation rates to person trip generation rates. Then modal split factors from the same survey were used to determine the total person trips per mode. Portland took a similar approach to determine multi-modal trip generation rates. Again, ITE vehicle trip generations rates were converted to person trip generation rates. In this case, two factors were combined to determine person trips from vehicle trips. These factors were (1) average vehicle occupancy for Portland, based on a region-wide traffic count, and (2) a motorized mode share determined for geographic conditions such as those on which the ITE trip generation rates are based (90%). Once person trips were determined from vehicle trips, they were split into modes using 2017 travel forecasting data for Portland.

Additionally, the number of vehicle trips was multiplied by an unspecified trip length adjustment factor. The assumption behind this effort is that a method for assessing multi-modal impact fees will be necessary as urban areas will no longer be able to accommodate further road development and growth of vehicle infrastructure. Thus, the enhancement of multi-modal infrastructure to accommodate increased trip rates associated with new development projects will be a better investment of revenue collected from traffic impact fees. Overall, this paper provides a fairly simple method for deriving multi-modal trip generation estimates from ITE estimates. However, this methodology may not be ideal to incorporate into a tool for widespread use as it relies heavily on local travel data.

- *San Francisco Planning Department. (2002). **Transportation Impact Analysis Guidelines for Environmental Review.** http://www.sf-planning.org/Modules/ShowDocument.aspx?documented=6753

This document introduces guidelines for conducting traffic impact analyses (TIAs) in the City and County of San Francisco. Included in these guidelines are estimates of person-trip generation rates for different land use types. The land uses included in these estimates are representative of most of the current developments in San Francisco. If a particular land use is not listed in the document, the planning department encourages the use of the SANDAG tool or ITE's *Trip Generation,* using average auto occupancy to convert vehicle trips to person-trips. The trip generation table provided in this document provides estimates of person-trips generated per square feet, in addition to percentage splits between work and non-work trips for a 24-hour period, as well as the PM peak period. Sources of these estimates include data from the Citywide Travel Behavior Survey, various environmental impact reports (EIRs) including Mission Bay 1990 FEIR, 525 Golden Gate FEIR, and 1000 Van Ness FEIR, as well as ITE *Trip Generation*, 6th edition. Although this trip generation table is simple and user-friendly, the methodology used to estimate the numbers provided in the table is not well documented in this paper.

- **Turner, S., Hottenstein, A., & Shunk, G. (1997). **Bicycle and Pedestrian Travel Demand Forecasting: Literature Review.** Texas Transportation Institute. http://tti.tamu.edu/documents/1723-1.pdf

Researchers from the State of Texas Department of Transportation (DOT) performed a review of the literature regarding current practices in bicycle and pedestrian travel demand forecasting techniques, as a preliminary step in the development of a methodology of forecasting bicycle and pedestrian travel demand in Texas. This review identifies four basic categories of bicycle and pedestrian demand forecasting models: (1) aggregate or simplified trip generation models (using survey data at the zonal level to predict the extent of bicycle and pedestrian travel demand at this level); (2) facility locator or "market travelshed" models, which treat bicycle and pedestrian facilities as trip destinations; (3) sequential stand-alone bicycle and pedestrian demand models similar to current four-step traffic models; and (4) four-step traffic models modified to account for bicycle and pedestrian environments.

Many of the models discussed are not entirely relevant to site-specific trip generation, as they are estimated at the zonal-level (e.g. TAZ, census tract, etc.). One model used bicycle trip generation rates per capita in order to estimate new bicycle trips generated by a bike path in Rhode Island. This model used

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rates developed previously by planners in the state of Pennsylvania for a similar project, which were later compared to actual trip counts and were found to overestimate bicycle trips by about 10 to 15 percent. These rates are provided in Table 1 of the paper; however, they are based on relatively old data from the 1980s. Of further interest are the models that provide correlations for variables thought to affect bicycle and pedestrian trips (i.e. Dade County Demand Models, North Central Texas Council of Governments' (NCTCG) Bicycle Needs Index, and NCTCG's Pedestrian Needs Index). Though these correlations are based on somewhat newer survey data (1990s) they are still outdated.

- University of North Carolina, Highway Safety Research Center. (1994). **A Compendium of Available Bicycle and Pedestrian Trip Generation Data in the United States.** http://drusilla.hsrc.unc.edu/cms/downloads/BikePedTripGenerationData1994.pdf

This report summarizes the findings of bicycle and pedestrian counts, surveys, and studies conducted in various cities to estimate the effects of bicycle and pedestrian facilities. The document includes many charts and tables displaying various bicycle and pedestrian counts conducted in cities throughout the United States. Overall, this document is a rich source of data (albeit quite old) and methodologies for bicycle and pedestrian trip data collection. As this research was focused on trip generation counts and estimates for bicycle and pedestrian facilities (e.g. bike lanes, sidewalks, recreational paths, etc.), it is not directly applicable to trip generation estimates for developments, but it provides an interesting assessment of what environmental factors influence biking and walking trips.

Of particular interest is a methodology for assessing pedestrian level of service (A through F) based on square feet per pedestrian, average speed, and flow rate taken from the Transportation Research Board's *Highway Capacity Manual.* However, other researchers (Seneviratne and Morrall, 1985) have argued that this is not an appropriate method of analyzing pedestrian level of service as it does not take into account enough environmental captures to account for an area's “walkability.” Also of interest is Table 7-1 in this document, which presents rates of bicycle and walking for major trip purposes in large urban areas (>1 million) with rail transit, large urban areas without rail transit, and small urban areas (<1 million).

One interesting finding demonstrated in this table is that levels of biking and walking are usually similar between small urban areas and large urban areas without rail transit. Ultimately, this study found that data for bicycle trips were more readily available than data for pedestrian trips, potentially due to the relative ease of collecting bicycle data as opposed to collecting pedestrian data. Unfortunately no studies were found that assigned bicycle and pedestrian trip generation rates to a wide range of land uses. Thus, the authors recommend using local modal split data to convert ITE *Trip Generation* estimates into multi-modal trip generation rates.

- Vernez Moudon, A., Kavage, S.E., Mabry, J.E., & Sohn, D.W. (2005). **A Transportation-Efficient Land Use Mapping Index.** *Transportation Research Record, 1902,* 134-144.

This paper explores a Transportation-Efficient Land Use Mapping Index (TELUMI) that was developed by the Washington State Department of Transportation (WSDOT) in order to better-evaluate the effects of land use patterns on Level of Service (LOS). The idea of Land Use Level of Service (LULOS) is introduced as a more comprehensive, less mode-specific alternative to traditional LOS. In a LULOS the capacity and characteristics of the entire transportation network for a given area would be examined relative to the total number network users, regardless of mode-choice. The result would be a multi-modal travel behavior model as opposed to models looking at LOS for single modes.

WSDOT's TELUMI is an instrument which incorporates the concept of LULOS. TELUMI takes into account multi-modal networks, in addition to context-sensitive trip generation. Land use variables that relate to travel behavior are established, and then Cartographic Modeling (CM) techniques are used to explore the relationship between these variables and different levels of transportation-efficient land use. Then, different levels of transportation efficiency are identified, which correspond to standard LOS levels. The result is a tool which can receive a variety of different types and quantities of input and in turn produce a visual and quantitative output that is a better indicator of an area's true LOS for all network users. This tool also incorporates context-sensitive trip generation rates derived from ITE rates, but the methodology for doing so is not provided.

- Walters, G., Ewing, R., & Schroeer, W. (2000). **Adjusting Computer Modeling Tools to Capture Effects of Smart Growth: Or "Poking at the Project Like a Lab Rat."** *Transportation Research Record,* 1722, 17-26.

This paper describes the application of travel forecasting methods to determine the air quality impacts of a mixed-use, infill development centrally located in Atlanta that required construction of a bridge in order to make it a viable project. Many design and travel demand management variables known to affect travel demand (i.e. the "Ds") were taken into account in the analysis of this project, in order to determine whether such a project would have less of an environmental impact than a similar project in a less central, undeveloped area.

The literature on the Ds was used to develop adjustment factors, and analysis of the site was facilitated by INDEX. Ultimately it was determined that regional location and site design can be used to foster multi-modalism, which in turn can lead to reduced emissions and environmental impacts. Specifically, travel reductions for the mixed use, infill site were found to be 14 to 52 percent compared to development at greenfield locations. Such findings indicate a need for tools that analysts can use in order to determine reductions in trip generation from site location and design.

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APPENDIX "B"

Project Technical Advisory Panels: Experts and Practitioners

TOPICS Include:

1. Experts Advisory Panel

2. Practitioners Panel

Compiled - July 18, 2012

Terry Parker, Caltrans

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B. Meeting Dates

C. Summary of Input Provided

2. PARTICIPANTS PANEL……………………….5

A. Participants

B. Areas Included in Study

C. Meeting Dates and Topics

1. EXPERT PANEL

A. Participants:

- **Marlon Boarnet - UC Irvine,** Department of Planning, Policy, and Design
- **Robert Cervero - UC Berkeley,** Department of City and Regional Planning
- **Dan Chatman - UC Berkeley,** Department of City & Regional Planning
- **Susan Handy - UC Davis,** Director, Center for Sustainable Transportation
- **Rich Kuzmyak -** Transportation Consultant
- **John Thomas – U.S. Environmental Protection Agency**, Development Community and Environment Division, Smart Growth program

B. Meeting Dates (all via teleconference):

- April 9, 2010
- May 28, 2010
- November 2, 2011

C. Summary of Input Provided re: Analysis of Detailed Land Use and Transportation Data

1. Begin evolving the models as much as possible toward a common form incorporating, for example, the lessons learned from attempts to estimate person travel with the (pilot) Fresno data could be incorporated into the approach to modeling person travel in the models for Sacramento, Bay Area, and the other small and medium MPOs
2. If using a sequence of models such as those illustrated, check for propagation of error from one step to the next.
3. Check elasticities captured in the models with published national elasticities.
4. Consider destination accessibility in terms of two phenomena, using at least two variables to address: local accessibility (diversity) and regional accessibility. Recognize the difference between high accessibility caused by being relatively close to medium sized destinations versus being a greater distance from very large destinations.

5. Recognize that accessibility is not a linear function, particularly transit accessibility or relationships that compare transit accessibility to roadway accessibility. At the extreme low sensitivity end of the spectrum, consider dropping outliers. At the extreme high-sensitivity end of the spectrum, “spline” the independent variable in a manner that captures different dependent variable relationships for different ranges of independent variable.

6. Stratifying households to model different ranges is based on the assumption that there's substantially more between-group than within-group variation of the key dependent variables of interest, but one always has to be on guard that adding so many statistical refinements makes the modeling tool unwieldy to the user and requires so much fine-grained disaggregation that it becomes difficult to use for small to medium size places with limited modeling capacities.

7. Test discrete statistical relationships for predicting integer outcomes such as number of trips. For example, check whether the S.F. Bay Area trip generation model would perform better using negative binomial or logistic analysis rather than regression.

8. Try using “seemingly unrelated regression (SUR)” or simultaneous equations in place of simple regression

9. While trip-chaining may reduce the number of vehicle trips generated in single-use sprawled settings, chaining also occurs in mixed urban settings because of the convenience afforded by concentrated attractions

10. In addition to refined accessibility metrics, it might be worthwhile to add a mode split component. That is, after vehicle trip generation, one could then measure the accessibility of a resident to activities for a specific trip purpose -- e.g., job accessibility for work trips.

11. If considering simultaneous equations modeling (SEM), accessibility brings the time/distance element into the SEM which feeds directly into VMT -- if one has high access to jobs, the generated trips will generally involve relatively low VMT.

12. It makes sense to increase sample size and in light of the fact that attributes such as commute times and mode splits do not vary a lot among smaller MPOs -- i.e., there's greater variation in such factors between small, medium-size, and large MPOs than there is variation within each of these groups.

13. Hierarchical Linear Modeling (HLM) works well if there are variables that work at different scales -- e.g., walking access influences travel at the neighborhood scale; transit accessibility works at the regional scale, thus these variables should be modeled at different levels. To capture regional differences, as an alternative to HLM, more typically fixed-effects variables are added to models (e.g., 0-1 dummies and possible interactive terms).

2. PRACTITIONERS PANEL

A. <u>Participants</u>: *(note: Agencies located in study areas are highlighted)**

Planning & Modeling Staff:	REGIONAL AGENCIES:
Charles Field	Amador County Transportation Commission (CTC)
Bhupendra Patel, Anais Schenk	**Association of Monterey Bay Area Governments AMBAG**
Brian Lasagna	**Butte County Association of Govts. (CAG)**
Mike Bitner, Kristine Cai	**Fresno Council of Governments (COG)**
Rob Ball, Troy Hightower	**Kern COG**
Terri King	**Kings Co. COG**
Dylan Stone, Derek Winning	**Madera Co. CTC**
Matt Fell, Rich Green	**Merced CAG**
Doug Johnson, David Ory	**Metropolitan Transportation Commission - MTC** (S.F. Bay Area)
Farah Korishodi, Kevin Vierra	**Riverside COG**
Bruce Grisenbeck, Kacey Lizon	**Sacramento Area Council of Governments - SACOG**
Steve Smith	**San Bernadino CAG**
Rick Curry, Clint Daniels	**San Diego Association of Governments - SANDAG**
Kim Anderson	**San Joaquin COG**
Brian Bresolin	**Santa Barbara CAG**
Kim Shultz	**Santa Cruz Regional Transportation Commission (RTC)**
Mark Butala, Sungbin Cho, Hsi-hwa Hu, Junga Uhm, Frank Wen	**Southern California Association of Governments SCAG**
Sean Tiedgen, Dan Wayne	**Shasta Regional Transportation Planning Agency (RTPA)**
Geoffrey Chiapella, Steve Devencenzi, James Worthley	**San Luis Obispo (SLO) COG**
Jim Schoeffling, Carlos Yamzon	**Stanislaus (Stan) COG**
Roberto Brady, Mark Hays	**Tulare CAG**

	STATE DEPARTMENTS:
Jennifer Gray, Doug Ito, Leslie Kimura Szeto	**California Air Resources Board** (ARB) Air Quality/Transportation Planning
Chris Ganson	**Governor's Office of Planning & Research** (OPR)
Chad Baker	**Caltrans HQ Transportation Systems Information** (TSI) Division
Scott White (D2), **Nicholas Deal** (D3), **Phillip Cox** (D4), **Claudia Espino** (D5), **David Berggren** (D6), **Chao Wei** (D7), **Dan Kopulsky** & **Gary Green** (D8), **Homer Zarzuela, Pat Robledo, Sarah Lesnikowski** (D10) **Maurice Eaton** (D11)	**Caltrans District Modeling Staff** in areas included in study*

* B. <u>Areas included in study:</u>	Caltrans Districts	<u>Area Represents</u>:
1. **Sacramento Region**	3	**Major Metro MPO, inland - *North***
2. **San Diego Region**	11	**Major Metro MPO, coastal - *South***
3. **SF Bay Area – *Passenger Rail corridors (only)***	4	**CA's most transit-rich corridors**
4. **Central & North San Joaquin Valley:** *San Joaquin, Stanislaus, Merced, Madera, & Fresno Counties*	6, 10	**Small & medium cities; rural areas**
5. **So. San Joaquin Valley -** *Tulare, Kings & Kern Counties*	6	**Small & medium cities; rural areas**
6. **Inland Empire –** *Riverside and San Bernardino Counties; and Imperial County*	8, 11	**Urban Growth Areas** (Inland Empire). **Small cities & rural– *Southern*** (Imperial Co.)
7. **Central Coast -** *Monterey & Santa Cruz Counties (AMBAG), San Luis Obispo (SLOCOG), Santa Barbara (SBCAG)*	5	**Small cities & rural –coastal *(Central)***
8. **No. Sac Valley -** Shasta Co.(RTPA), Butte(CAG) + nearby rural counties	2, 3	**Small cities & rural –inland *(North)***

C. <u>Meeting Dates and Primary Topics</u> (all via webinar):

- Meeting #1: **May 18, 2010** – iPLACE3S Improvements
- Meeting #2:* **July 27, 2011** – Overview of Project
- Meeting #3: **January 27, 2012** – Data and Analysis Tools
- Meeting #4: **March 29, 2012** – Results of Analysis of Built Environment and Travel data; overview of new "Ds Analysis Modules" produced for various regions
- Meeting #5:** **June 26, 2012** – T.A. to MPOs re: the development of travel demand model post-processors for eight "demonstration" areas

* Recording of this meeting is available at: Webinar: Project Overview (July 27, 2011)

** Recording of this meeting is available at: Webinar: Project Update (June 26, 2012)

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APPENDIX "C"

Data Assembly and Summarization for Model Estimation and Validation

TOPICS Include:

1. Overview and Definitions
2. Methods Used
3. Processes
4. Outputs
5. Buffering for Validation and Testing

Attachments:

C.1. Land Use/Land Cover Buffering SQL/Code

C.2. References

University of California, Davis

July 6, 2012

Authors:

- **Nathaniel Roth**, GIS Programmer & Project Manager*,**
- **Laurel Torney & Kyle Shipley**, Junior Specialists*,**
- **Michael McCoy**, Principal Investigator*

* The Urban Land Use and Transportation Center (ULTRANS), Institute of Transportation Studies (TS), University of California at Davis (UCD)

** The Information Center for the Environment (ICE), Department of Environmental Science & Policy, University of California at Davis (UCD)

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Abstract

Summarizing the land uses and demographics surrounding trip endpoints in travel surveys is a necessary process for evaluating local effects on travel. This is particularly true in the case where one wishes to develop a statistical representation of relationships between the built environment and travel behavior. These summaries must be created through the integration of multiple data sources and their summary for use in model estimation. The method described here used a hybrid approach to data preparation with some data being summarized at a parcel scale, and some being at a 50m square grid cell. Parcels are the legal frame work for land ownership and have useful attributes attached to them. The grid framework provides a useful structure for calculating the values as a single process for each grid cell and then allowing the user to summarize the contents of the grid cells that are within specified radii of the trip end points. Both approaches allow for great flexibility in re-aggregating data for different radii or additional endpoints.

These methods were used to produce summaries of land use, classification by industry, employees by industry, residential form, local demographics, transit stops, and urban form within a half mile radius of each trip endpoint reported in the available travel survey. They were applied to the following regions in California: The Northern Sacramento Valley (Shasta, Butte, Tehama and Glenn Counties); the San Joaquin Valley (San Joaquin, Stanislaus, Merced, Madera, Fresno, Tulare, Kings, and Kern Counties); the Central Coast (Santa Cruz, Monterey, San Benito, San Luis Obispo, and Santa Barbara Counties); the Inland Empire (San Bernardino, Riverside, and Imperial Counties); and San Diego County.

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1. Introduction

A. Overview and Definitions

This document describes the methods used in preparing land use and land cover data surrounding known locations reported in the 2009 National Household Travel Survey (NHTS) in California. It is a hybrid system using both parcels and rasters, and in some cases using densities of housing or employment per parcel to represent partial inclusion of parcels. While the focus of this report is on integration with travel surveys, the methods are flexible and could be used in many ways.

These techniques were used to develop datasets for the following regions of California included in this study:

- The Northern Sacramento Valley (Shasta, Butte, Tehama, and Glenn Counties)
- The San Joaquin Valley (San Joaquin, Stanislaus, Merced, Madera, Fresno, Tulare, Kings, and Kern Counties)
- The Central Coast (Santa Cruz, Monterey, San Benito, San Luis Obispo, and Santa Barbara Counties)
- The Inland Empire (San Bernardino and Riverside Counties), and Imperial County
- San Diego County

These areas were selected primarily due to the availability of GIS-based built environment data as well as travel survey data – both of which were collected during roughly the same time period.

Most of the data collection processes involved the use of a “buffer” surrounding particular locations used to summarize land use data. The buffer may be based on a Euclidean distance, as was done for this effort, or on network distances. In almost all cases, the focus has been on the built environment surrounding each travel survey respondent’s home location, with a somewhat lesser emphasis on urban environments surrounding respondents’ reported non-home trip endpoints.

For the purpose of clarity, a differentiation is between “land use” and “land cover”, though the generic ‘land use’ will also be used to indicate the combination of both:

- “Land Use” identifies the presence of activities that use land, such as housing, employment, recreation, agriculture, etc. This is communicated as the number of housing units, employment locations, etc. on any particular piece of land. i.e. 100 single family dwelling units.
- “Land Cover” is used to identify areas of land that are host to some land use. This will be expressed as a measurement of area. i.e. 25 acres of single family dwelling units.

A “geodatabase” is a relational database with a spatial component. A common characteristic of a geodatabase is the ability to interactively query within the geodatabase, much as one would in a common relational database. These can take several forms; the most common commercial geodatabases are: [1]

- Personal geodatabases stored in a Microsoft Access database, an ESRI specific format, which has a maximum size of 2GB.

[1] There are also several open source geodatabase applications, spatialite built on the sqlite3 platform, and PostGIS (Refractions Research Inc. 2010) build on PostGRES (PostgreSQL Global Development Group 2010). PostGIS in particular provides a useful environment because it has a robust set of tools for summarizing and aggregating data. The methods were applied in PostGIS, though an early prototype was built using ESRI ArcGIS and Microsoft Access.

- File geodatabase (a proprietary ESRI format capable of storing much larger data sets than a personal geodatabase)
- An enterprise database used in conjunction with ESRI ArcSDE or ArcGIS Server.

A majority of the work conducted for this project was completed using the PostGIS geodatabase which is an extension of the PostGRES database (an enterprise level Open Source relational database) that enables the use of spatial processing and summarization.

In consultation with team members, the following metrics were arrived at based on land use and other spatial data in 804 meters (one-half mile). Each of these metrics was joined to detailed demographic, household, trip purpose, and mode information for the persons that reported traveling to each of the locations identified in the NHTS. *They were:*

- Area of each land use type
- Number of units of each residential or employment type (housing units, or employees)
- Population
- Average street block size
- Number of road intersections
- Number of four-way road intersections
- Total distance of roads
- Distance to local transit
- Distance to long distance rail
- School enrollment by type

B. Land Uses

Land uses are defined as follows:

- **Single-family detached dwelling units (SFD):** Single households on parcel, multiple households on one plot of land but detached living spaces per family home.
- **Multi-family or attached dwelling units (MFD):** Apartment or condo living areas, multiple family attached living quarters, Rest and Retirement facilities, group quarters
- **Retail (R):** Grocery stores, material stores such as hardware or equipment, general merchandise or department store, automotive dealers, home furnishing, gas stations, Other, parking lots associated with retail use
- **Regional Retail (RR):** Grocery stores, material stores such as hardware or equipment, general merchandise or department store, automotive dealers, home furnishing, gas stations, other, parking lots associated with retail use, with greater than 50 acres of contiguous retail space.
- **Service (S):** Banking, personal, day care, automotive service, hotels, resorts, bed and breakfasts, private medical related facilities, restaurants, doctors' offices, other recreational service facilities, parking lots associated with service use
- **Office (O):** Multiple large office complexes, insurance, law offices, architectural, engineering offices, accounting, other professional offices
- **Mixed-use (M):** Single or multiple residential home(s) with one or multiple uses from these other categories on one parcel of land. (not including agricultural fields with a couple houses which is labeled as agriculture)
- **Industrial (ID):** Primary metal and wood production, queries and other hard rock associated productions, cottage/home industry, other production facilities, storage facilities, Construction.
- **Utility (U):** Electrical, gas, water, or other utilities facilities.
- **Airport (AP):** Airports facilities, hangers, runways
- **Institutional (I):** Police, fire, health, military, religious, post offices, government offices, other government owned facilities, hospitals and associated medical and health clinics facilities, nursing, social organizations/associations, and government land parcels that are not open space.
- **Schools (SC):** Schools, elementary schools through university
- **Military (MIL):** Military bases and facilities

- **Prison (P):** Detention facilities
- **Agriculture (A):** Row-crops, orchards, vineyards areas with developed crops; this may include single family dwellings on a primarily agricultural lot.
- **Open Space (OS):** Parks, large parcels of land with small employment and no residential, canals, lakes, reservoirs, timber, vacant parcel space without structures, pastures and grazing fields, golf courses, fair grounds, duck clubs, parcels in uncompleted construction phases, forested or undeveloped parcels
- Vacant (V): A sub-category of Open Space adopted partway through the process. This takes over the Vacant and undeveloped space portion of OS.
- **Road (RD), RailRoad (RL), Bikeway(B);** Identifier for polygons that are not actually parcels, but are included in the dataset serving a transportation related function. These are very inconsistently coded.

2. Methods

A. NHTS Data Preparation

A first step in doing the spatial data preparation includes developing a list of all unique trip end locations, including household and work locations as well as intermediate stops such as shopping and personal business. This was accomplished through unioning a SELECT DISTINCT query on trip ends, with a similar query on household locations and work locations. The latitude and longitude for each trip end, or household or work location was cast as a text field prior to this process and saved to a new field in the dataset for later rejoining. This unioned dataset created a list of all unique latitude and longitude pairs referenced in the NHTS. Each of these pairs was assigned a unique id (locno) that could be used to reference the location unambiguously. The locno was joined back to the original trip, and household tables for later use in relating the land use metrics to the NHTS.

B. Built Environment Data Preparation

Land use planners and transportation modelers both refer to land use frequently, but they also frequently mean different things by it. To the land use planner, land use is more closely related to the concept of land cover. More generally, the land use planner is laying out or analyzing the land based on what the purpose put to the land is. For example, a land use planner will talk about an area being commercial. This commercial development could take many forms of employment with a mix of both retail and service. A travel modeler will think of the land use probably in terms of how many employees or how many square feet of space are there for retail, and the same for service. This is a simple but fundamental difference in meaning and level of detail.

Land use data, in the transportation modeler's lexicon, was prepared from multiple sources. Parcel data with land use codes from county assessors, the American Community Survey (ACS), and On the Map 4, both products of the US Census Bureau were combined to produce a land use dataset that had parcel specific land use codes, and housing, population and employment totals distributed to potentially appropriate parcels based on the parcel's land use code.

i. Parcel Data

Parcel data was collected from the county assessors, and crosswalked to the more aggregate land use classification described above. Every one of the parcel datasets had some significant omissions from its classification system. Almost every parcel system also has a unique land use classification system. The most common omission was the omission of government or otherwise untaxed properties from the classification. This is almost certainly the result of the assessors being concerned primarily with land uses that are taxable and not investing effort in creating or maintaining these data. Maintaining a specific of separation of commercial types into retail, service, office is another weakness in many of the classification systems.

Following conversion of the land use classification, blank land use codes were filled in through manual verification against aerial and street view data. Where ever possible, 2008-9 imagery was used for verification. In most cases the land use was apparent from planimetric imagery, but in cases where further identification street level imagery such as that provided by Google Maps/Earth was used. When multiple uses were present on the parcel, the predominant land use (by area) was assigned. The entire dataset was reviewed for accuracy against 2008-9 imagery and an accuracy assessment comprised of one hundred randomly selected parcels of each land use code being verified against the 2008 imagery was completed. In cases where there were less than 100 parcels of the type, all were verified. The results showed better than 85% accuracy across all parcels with variations within classes, and patterns of confusion between similar land uses.

Table 1: LU Accuracy Assessment for San Bernardino County

Total Sampled	LU Code	A	I	OS	RS	RM	O	S	R	M	ID	RD	AP	V
100	A	98			2									
100	I		95			2		3						
100	OS		1	94	2					1	2			
100	RS		2	1	97									
100	RM					100								
100	O				1	4	95							
100	S						2	98						
100	R					1		10	89					
100	M		1		3			3		91	1			1
100	ID			1	2	1					96			
100	RD											100		
100	AP												100	
100	V													100

For this process, the reviewer went through the land use table in ArcMap and selected only a certain Ds Code and randomly picked 100 of that assigned code. The reviewer would then find that parcel and compare the assigned Ds code to aerial imagery to confirm the accuracy of that code. If the reviewer deemed the code to be correct, he or she would move to the next. If it is incorrect, the reviewer would change the code in ArcMap and note what the code was changed to in the LU_assess_table. In the table, the yellow cells indicate the number of correct parcel picks for that code.

ii. Housing Units and Population

Housing units and population were prepared from the 2005-2009 five year American Community Survey dataset. These data are available by 2000 Census block group geographies. The ACS is a dataset sampled from the population not a true census like previous US Census datasets for the same information. This has significant implications for its use. First, the sampling period is multiple years. Among other things, this means that the five year datasets available by block group, span 5 years. Notably in the 2005-2009 time period, a significant economic bubble burst with direct impacts on housing markets. Second, it is a sampled, dataset meaning that a margin of error exists, and in some cases where there are small sample sizes, it can be large. Regardless, for block group level data, the ACS is our primary source for the immediate future. Table B01001 is the source population data, and table B25024 the source of housing type data. The housing type data is aggregated from the ACS data. Field B25024001 alone provides the total single family detached unit count. The sum of fields B25024002 through B25024009 creates the total multiple unit count. Mobile homes are B25024010 and other structures, such as house boats and recreational vehicles are counted in B25024011. For simplicity, mobile homes were also added to the multi-family unit count.

iii. Employment

The On The Map 4 (OTM) data is available through the Longitudinal Employer-Household Dynamics program in the U.S. Census Bureau. OTM is a synthetic employment dataset built on a data sharing agreement between state labor market agencies, the California Employment Development Department (EDD), and the Census Bureau. The dataset protects personal and employer confidentiality through the use of statistical processes to generate a count of employees in the twenty top level (two digit) NAICS (North American Industry Classification System) sectors, as well as three age and three earnings classes. These data are available in three formulations. Residence area characteristics (RAC) show types of employment by residential location. Workplace area characteristics (WAC) contain the type of employment by employment location, and origin-destination data shows the routes from home to work for the employees.

Data submitted to the U.S. Census Bureau mirrors the ES202 submissions from states to the Federal Bureau of Labor Statistics. As such it suffers from several common issues in employment data. First, it does not include informal employment. Second, because the majority of the data is based on State unemployment insurance records, it does not include Federal employees (military or civilian). And, it suffers from many of the same workplace location errors that other datasets have. Many dispersed employment types all appear as if they were located at the central office. In addition, because this is a synthetic dataset, and the data has been modified to protect personal and corporate privacy, it is not unusual to see that employment has been displaced to another nearby block, rather than the one that independent verification might place it in.

Regardless, it is a useful dataset for dealing with large areas, and a relatively fine geographic scale (U.S. Census Block).

iv. Zonal land use disaggregation to parcels

The zonal land use data, population, housing and employment, were disaggregated using a simple but flexible disaggregation tool built by UC Davis for this purpose. This tool disaggregates zonal totals to parcels based on a list of allowable land use codes for each of the zonal types, and a method for allocation. In the simplest case, a zonal total, SFD for example, is allocated to land use codes that permit single family dwellings. In this case, SFD were allowed into the SFD land use type, mixed-use, and agriculture. Each of the zonal totals was also assigned a method of allocation. The three allocation methods are: by area, by parcel, by other. By area assigns the total assuming equal density across all allowed space. By parcel allocates the total assuming an equal portion of the total is allocated to each parcel. By other accepts a query to provide the allocation method. By other was used in this case to allocate population based on a query that generated the total number of housing units on each parcel and assigned an equal population to each housing unit.

There are several fall back positions should allocation not be possible to the preferred list of land use types. The first falls back to allowing a wider list of land use codes, restricted by a “prohibited” list. The second fall back, distributes equally to all parcels in the area regardless of restriction.

Operationally, the tool works by first building a list of all parcels that intersect each zone in the input zonal totals dataset. For example, an index is built with a list of all parcels that intersect each block group. In the case of blocks, this index was built with all parcels within 50 meters of the block to avoid blocks that had no parcels intersecting them. This was also justified because of the frequency with which the synthesis process moved employment from one Census block to a neighboring one. This index is then iterated through by zone allocating the total to the parcels using the specified allocation method.

This tool is written in python and uses Postgresql/PostGIS as the database. Many of the spatial operations are removed from the actual execution of the model, and are front loaded in the index process mentioned above to reduce the run time. The index can be built once and reused indefinitely. Because allocation within each zonal dataset is controlled by a dictionary, the order of allocation for individual types is not controlled, requiring that the population allocation running based on a prior allocation of housing units must be executed in its own step.

Each of the zonal total types is iterated through completely assigning the totals to parcels before moving onto the next zonal type in the specified order. As used in this project the order of allocation was: Block group (SFD, MFD), Block group (Population), Block (Employment by type).

The final output is the result of a query against the allocated data. In this case, the employment sectors are aggregated to produce totals for the aggregate employment types (retail, service, office, industrial, institutional, school). The result can then be viewed as a PostGIS dataset using any of several tools, with Quantum GIS being one of the more user friendly options. Please see the section “County Parcel Data Notes” at the conclusion of this section for details on individual counties.

iv. Road Data and Derivative Products

Roads data was assembled from several sources. The Tiger Linefile Data (US Census 2008), served as the primary resource, but was updated based on a visual comparison with the currently available Open Streetmap (Add link) data, and aerial imagery for approximately 2008.

Using these road data, the road and road intersection characteristics were prepared. First the road data was planarized so that there was exactly one feature on each road connecting intersections.

This dataset saved for later querying, was also built, using the county boundary as an outer limit into polygons to serve blocks (i.e. city blocks).

Intersection of each of these links was queried and the number of features that intersected each intersection was counted to create the input data for the two road intersection datasets (greater than 3 roads, and 4 way intersections).

v. Other Data

Most of the other datasets were straight forward. School enrollment was prepared using data directly from the California Department of Education, geocoded using ESRI ArcGIS. Transit stop locations are based on point data obtained from each county’s MPO, RTPA, or manually prepared through digitizing paper or pdf maps.

3. Processes

First, here are a few conventions for the following description: all datasets are assumed to be in a projection with distances measured in meters and all datasets are assumed for simplicity to be in a PostGRES database called “postgis” and within a schema of either “ds_smpo” for the small MPO region, or “ds_sand” for San Diego. The dataset “locno” is the point location of the distinct set of trip endpoints, house locations and work locations. “lu” is the parcel land use dataset with a field containing the land cover type assigned to each parcel and the disaggregated totals of sfd, mfd, population, retail, service, office, industrial, institutional, and school employees.

In many cases, we’ve chosen to create new tables as the result of queries when views might also be appropriate. In this case we must ensure that we drop tables and rerun queries as appropriate. Creating a view might avoid the necessity of this book keeping, but also requires that the query be rerun each time you wish to view the data, or use it in another query.

At various points during the project counties were dealt with either individually or in small regions. By the time of the final data assembly, all of the counties that fell into the “small MPO” category were being processed as a single entity, and San Diego remained independent. Because of the code is effectively identical for both the small MPO and San Diego region, only the small MPO code will be presented in the summary.

A. Initialize the schema with the parcel land use data and raster grids

The prepared parcel data, having been processed as described above, the 50m grid cells (polygons), and the centroids of those 50m grid cells are imported into the schema “ds_smpo” as datasets that cover the entire area of analysis.

Datasets for the entire region were assembled from the each of the individual regional datasets (North Sac. Valley, San Joaquin Valley, Central Coast, and Inland Empire). This process was applied to the roads, road intersections, road blocks, and transit stops. The SQL is almost identical between among these datasets. Again, a spatial index is created.

```
CREATE TABLE ds_smpo.roads_all WITH OIDS AS
SELECT a.the_geom
FROM ds_ie.roads_all a
UNION
SELECT b.the_geom
FROM ds_cc.roads_all b
UNION
SELECT c.the_geom
FROM ds_nsac.roads_all c
UNION
SELECT d.the_geom
FROM ds_sjv2.roads_all d;

CREATE INDEX roads_all_the_geom_gist
ON ds_smpo.roads_all
USING gist
(the_geom );
```

School locations and enrollment (elementary, middle, and high schools) were selected out of a statewide dataset and indexed spatially

```
CREATE TABLE ds_smpo.v_sd_elemschools WITH OIDS AS
```

```
SELECT a.gid, a.cdscode, a.school, a.eilcode, a.sumofenr_t, a.sumofgr_1, a.sumofgr_2,
a.sumofgr_3, a.sumofgr_4, a.sumofgr_5, a.sumofgr_6, a.sumofgr_7, a.sumofgr_8, a.sofug_elm,
a.sumofgr_9, a.sumofgr_10, a.sumofgr_11, a.sumofgr_12, a.sofug_sec, a.sumofadult, a.the_geom
FROM pubschools_2008enr a
WHERE (a.eilcode in ('ELEM', 'ELEMHIGH']) AND a.county in ('Riverside', 'Imperial', 'San
Bernardino','Santa Cruz', 'San Benito', 'Monterey', 'San Luis Obispo', 'Santa Barbara','Shasta',
'Tehama', 'Butte', 'Glenn','San Joaquin', 'Stanislaus', 'Merced', 'Madera','Fresno','Tulare', 'Kings',
'Kern') AND a.sumofenr_t > 0;

CREATE INDEX v_sd_elemschools_the_geom_gist
ON ds_smpo.v_sd_elemschools
USING gist
(the_geom);
```

B. Establish trip endpoint datasets and their buffers

The next step is to isolate the trip ends that are within the region based on the US Census FIPS codes attached to the trip end location data and export them first to a dataset with just the point locations.

```
DROP TABLE IF EXISTS ds_smpo.locno_all;
CREATE TABLE ds_smpo.locno_all WITH OIDS AS
SELECT a.gid, a.mainid, a.purp, a.locid, a.geocoded, a.locno, a.fips, a.the_geom
FROM public.locno_all as a
WHERE a.fips in
('06007','06021','06089','06103','06019','06029','06031','06039','06047','06077','06099','06107','0605
3','06069','06079','06083','06087','06071','06065','06025');

CREATE INDEX locno_all_the_geom_gist
  ON ds_smpo.locno_all
  USING gist
  (the_geom);
```

And second, export a version of the same dataset buffered by 804.67 meters (one half mile):

```
DROP TABLE IF EXISTS ds_smpo.locno_all_buf;
CREATE TABLE ds_smpo.locno_all_buf WITH OIDS AS
SELECT a.gid, a.mainid, a.purp, a.locid, a.geocoded, a.locno, a.fips,
ST_BUFFER(a.the_geom,804.67) as the_geom
FROM public.locno_all as a
WHERE a.fips in
('06007','06021','06089','06103','06019','06029','06031','06039','06047','06077','06099','06107','0605
3','06069','06079','06083','06087','06071','06065','06025');

CREATE INDEX locno_all_buf_the_geom_gist
  ON ds_smpo.locno_all_buf
  USING gist
  (the_geom);
```

In each case the resulting table has a spatial index built on it to enable faster processing of the relationships between the point or buffer and other spatial data.

The parcel based analysis proceeds in a straight-forward manner. A buffer radius of 804m (one half mile) is drawn around each of the distinct locations in the travel survey, as shown in Figure 1 (below).

This buffer can be created in PostGIS using the following query (assuming that the dataset “locno” is a PostGIS spatial layer with the unique points).

```
CREATE TABLE ds_smpo.locno_all_buf WITH OIDS AS
SELECT a.gid, a.mainid, a.purp, a.locid, a.geocoded, a.locno, a.fips,
ST_BUFFER(a.the_geom,804.67) as the_geom
FROM public.locno_all as a
WHERE a.fips in
('06007','06021','06089','06103','06019','06029','06031','06039','06047','06077','06099','06107','06053','06069','06079','06083','06087','06071','06065','06025');

CREATE INDEX locno_all_buf_the_geom_gist
  ON ds_smpo.locno_all_buf
  USING gist
  (the_geom);
```

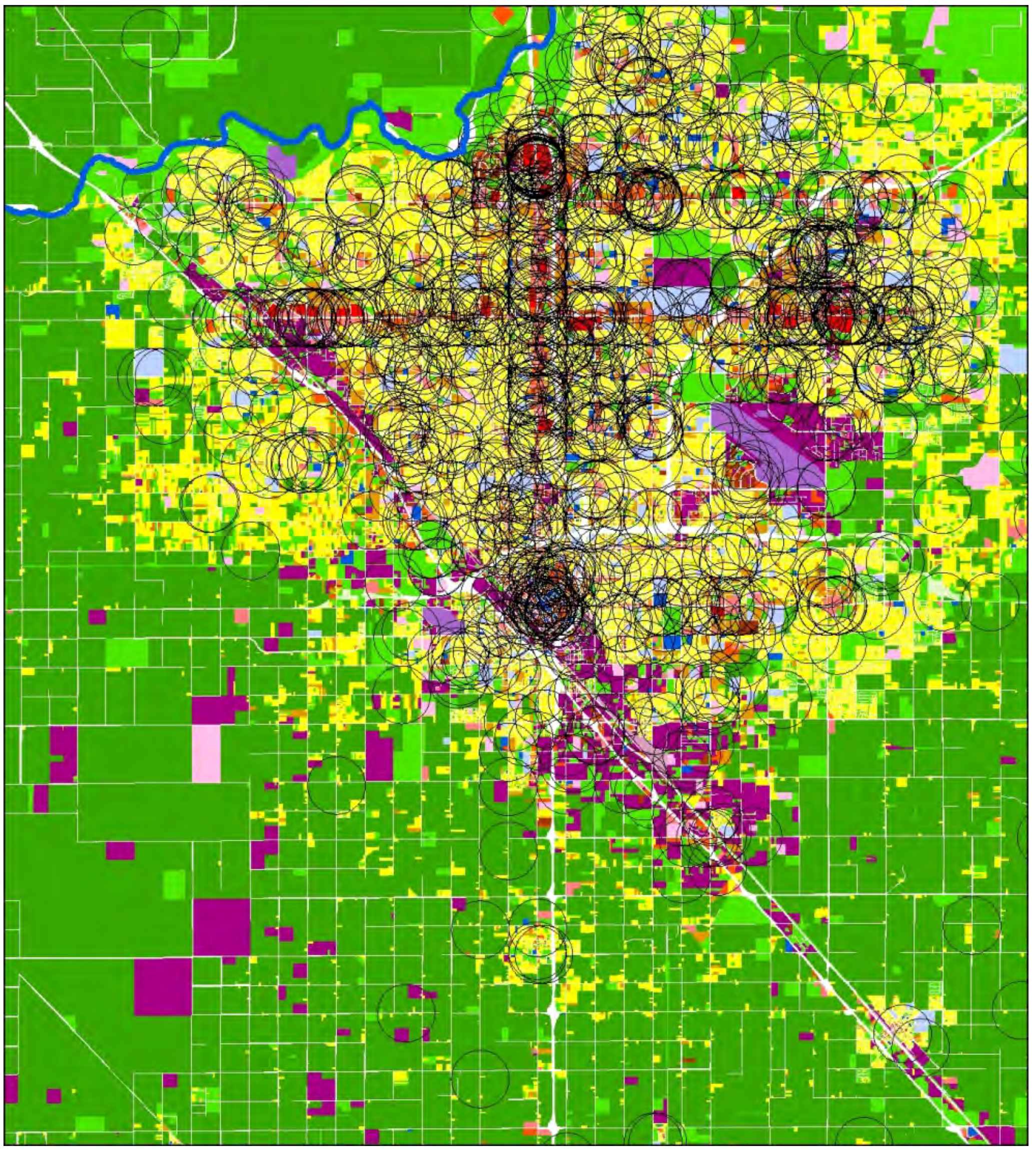

Figure 1. Fresno land cover (parcel based) with 804m buffer radii around trip end locations

These buffers can then be used to summarize land uses around each location. For example: the total number of acres of each land cover within the buffer is:

```
CREATE TABLE ds_smpo.acres_by_locno_luf WITH OIDS AS
SELECT a.locno, a.lu_f, (sum(ST_AREA(a.the_geom))/ 4046.82) as acres
FROM ds_smpo.lu_inttot as a
GROUP BY a.locno, a.lu_f;
```

The total acreage of each land cover type and totals of land use were calculated by calculating the density of each land use on each parcel, then selecting only the portions of each parcel that overlap the buffer radius, and multiplying the density times the resulting included area of each parcel, before summing all of those sections for each buffered location.

Calculate the densities of each land use on each parcel:

```
CREATE TABLE ds_smpo.lu_dens WITH OIDS AS
SELECT a.the_geom, a.lu_f, (a.sfd/a.sqm) as dsfd, (a.mfd/a.sqm) as dmfd, (a.pop/a.sqm) as dpop,
(a.ret/a.sqm) as dret, (a.ser/a.sqm) as dser, (a.office/a.sqm) as doff, (a.ind/a.sqm) as dind,
(a.inst/a.sqm) as dinst, (a.school/a.sqm) as dschool
FROM ds_smpo.lu_all_output AS a;
```

Calculate the intersection of the land use dataset with the buffers:

```
CREATE TABLE ds_smpo.lu_int WITH OIDS AS
SELECT ST_INTERSECTION(a.the_geom, b.the_geom) as the_geom,
ST_AREA(ST_INTERSECTION(a.the_geom, b.the_geom)) as sqm2, b.locno, a.lu_f, a.dsfd, a.dmfd,
a.dpop, a.dret, a.dser, a.doff, a.dind, a.dinst, a.dschool
FROM ds_smpo.lu_dens AS a, ds_smpo.locno_all_buf AS b
WHERE ST_INTERSECTS(a.the_geom, b.the_geom);
```

Multiply the area of each piece of parcel in the buffer by its densities to get the total hh, pop, and emp (by type) in each parcel section:

```
CREATE TABLE ds_smpo.lu_inttot WITH OIDS AS
SELECT a.the_geom, a.locno, a.lu_f, (a.dsfd * a.sqm2) as sfd, (a.dmfd* a.sqm2) as mfd,
(a.dpop*a.sqm2) as pop, (a.dret*a.sqm2) as ret, (a.dser*a.sqm2) as ser, (a.doff * a.sqm2) as office,
(a.dind*a.sqm2) as ind, (a.dinst * a.sqm2) as inst, (a.dschool*a.sqm2) as school
FROM ds_smpo.lu_int AS a;
```

Calculate the acrage of each land cover type within the buffer. This will emerge as a long form table with each row there being as many rows for each buffer as there are distinct land cover types.


```
CREATE TABLE ds_smpo.acres_by_locno_luf WITH OIDS AS
SELECT a.locno, a.lu_f, (sum(ST_AREA(a.the_geom))/ 4046.82) as acres
FROM ds_smpo.lu_inttot as a
GROUP BY a.locno, a.lu_f;
```


Reformat the data table so that there is one row for each buffered location with independent columns for each land cover type.

```
CREATE TABLE ds_smpo.acres_by_locno_crosstab WITH OIDS AS
SELECT main.locno, a.acres AS a_acres, ap.acres AS ap_acres, i.acres AS i_acres, id.acres AS
id_acres, mi.acres AS mi_acres, o.acres AS o_acres, os.acres AS os_acres, p.acres AS p_acres,
r.acres AS r_acres, rr.acres as rr_acres,
```

```
rm.acres AS rm_acres, rs.acres AS rs_acres, s.acres AS s_acres, sc.acres AS sc_acres, u.acres
AS u_acres, ml.acres as ml_acres, v.acres as v_acres
FROM ds_smpo.locno_all as main
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'A') AS a ON
main.locno = a.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'AP') AS ap
ON main.locno = ap.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'I') AS i ON
main.locno = i.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'ID') AS id
ON main.locno = id.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'MI') AS mi
ON main.locno = mi.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'O') AS o ON
main.locno = o.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'OS') AS os
ON main.locno = os.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'P') AS p ON
main.locno = p.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'R') AS r ON
main.locno = r.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'RM') AS rm
ON main.locno = rm.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'RS') AS rs
ON main.locno = rs.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'S') AS s ON
main.locno = s.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'SC') AS sc
ON main.locno = sc.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'U') AS u ON
main.locno = u.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'ML') AS ml
ON main.locno = ml.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'RR') AS rr
ON main.locno = rr.locno
LEFT JOIN (SELECT locno, acres FROM ds_smpo.acres_by_locno_luf WHERE lu_f = 'V') AS v ON
main.locno = v.locno;
```

Summarize the land uses for each buffered location.

```
CREATE TABLE ds_smpo.emphhpop_tot_by_locno WITH OIDS AS
SELECT a.locno, sum(a.sfd) as sfd, sum(a.mfd) as mfd, sum(a.pop) as pop, sum(a.ret) as ret,
sum(a.ser) as ser, sum(a.office) as office, sum(a.ind) as ind, sum(a.inst) as inst, sum(a.school) as
school
FROM ds_smpo.lu_inttot AS a
GROUP BY a.locno;
```

Similar query structures are used for school enrollment, intersections, road lengths, number of transit stops, and schools.

Calculating the distance to the closest transit stop, railroad station, or school from the location is more involved with a nested query because the PostGIS database does not have a built in “Nearest Neighbor” function. The process involves calculating the distance to each transit stop from each location, and then selecting the one with the minimum distance. In the example below, only railroad stations within 100km (straight line distance) were considered.

```
DROP TABLE IF EXISTS ds_smpo.rrstop_min_by_locno;
```

```
CREATE TABLE ds_smpo.rrstop_min_by_locno WITH OIDS AS
SELECT d.locno, min(d.dist) as mindist
FROM (SELECT a.locno,
        CASE ST_DWITHIN(a.the_geom, b.the_geom, 100000)
        WHEN true THEN ST_DISTANCE(a.the_geom, b.the_geom)
        WHEN false THEN -1
        END as dist
        FROM ds_smpo.locno_all as a, public.rr_stops as b WHERE ST_DWITHIN(a.the_geom,
b.the_geom, 100000))  as d
GROUP BY d.locno;
```

Developing an average block size, when road blocks overlap the edges of the buffered area, proved somewhat intellectually challenging. Because a very large block may touch only a small portion of a buffer, simply taking the average of block sizes that are within, or touch the buffer may easily produce an average block size that far exceeds the total area of the block, even when most of the blocks within the buffer are substantially smaller. Similarly, taking an average of only blocks that are contained by the buffer may produce areas that are far less than that of the buffer, effectively leaving a sizable portion of the buffer unaccounted for.

To answer these challenges, road block sizes were calculated in two manners. The first used a vector method reminiscent of a raster process. The steps outlined below are as follows. First a dataset that has built the road network into blocks by assembling the roads into closed loops that define the blocks is intersected with a what is known as a poly-grid or fishnet. That is, a polygon dataset where each polygon is an identically shaped, spaced, and sized square that covers the entire region. Then the acreage from the block is transferred without change to the grids based on the location of the center of each grid cell. Finally, the average of the acreages for the grids within each buffer is taken. This provides an area weighted average block size for each buffered location.

```
CREATE TABLE ds_smpo.grid_loc_lut WITH OIDS AS
SELECT a.locno, b.code50
FROM ds_smpo.locno_all_buf as a, ds_smpo.ptgrid as b
WHERE ST_INTERSECTS(a.the_geom, b.the_geom);

CREATE TABLE ds_smpo.blk_pt WITH OIDS AS
SELECT a.code50, b.acres
FROM ds_smpo.ptgrid AS a, ds_smpo.road_blocks AS b
WHERE ST_INTERSECTS(a.the_geom, b.the_geom);

CREATE TABLE ds_smpo.ave_blk WITH OIDS AS
SELECT a.locno, AVG(b.acres), COUNT(b.code50)
FROM ds_smpo.grid_loc_lut AS a, ds_smpo.blk_pt AS b
WHERE a.code50 = b.code50 GROUP BY a.locno;
```

A vector based process was also used as an alternate formulation. This method extracted only the area of each road block that was within the buffered area, recalculated the acreage, and took the average of the areas of all road blocks that intersected the buffer. Instead of an area weighted average, this produced an average block size for only the area within the buffer.

```
CREATE TABLE ds_smpo.stblock_int_locno WITH OIDS AS
SELECT ST_INTERSECTION(a.the_geom, b.the_geom), a.locno,
(ST_AREA(ST_INTERSECTION(a.the_geom, b.the_geom))/4046.85642) as acres
FROM ds_smpo.locno_all_buf AS a, ds_smpo.road_blocks AS b
WHERE ST_INTERSECTS(a.the_geom, b.the_geom);

CREATE TABLE ds_smpo.stblock_avg WITH OIDS AS
```

```
SELECT a.locno, AVG(a.acres) as blkavg, MIN(a.acres) as blkmin, MAX(a.acres) as blkmax,
STDDEV(a.acres) as blkstdev, COUNT(a.acres) as numblks
FROM ds_smpo.stblock_int_locno AS a
GROUP BY a.locno;
```

4. Outputs

The resulting data tables were then exported and delivered to Fehr & Peers Consultants for analysis in conjunction with the 2009 NHTS household and person tables. The necessary additional fields were added to the household, person, and trip tables to identify which “locnos” were identified with the origin and destination of each trip, and the household and work locations for each person or household. Additionally, identifiers for the MPO, and census block were added to each location number for use in identifying the geographic context of each trip.

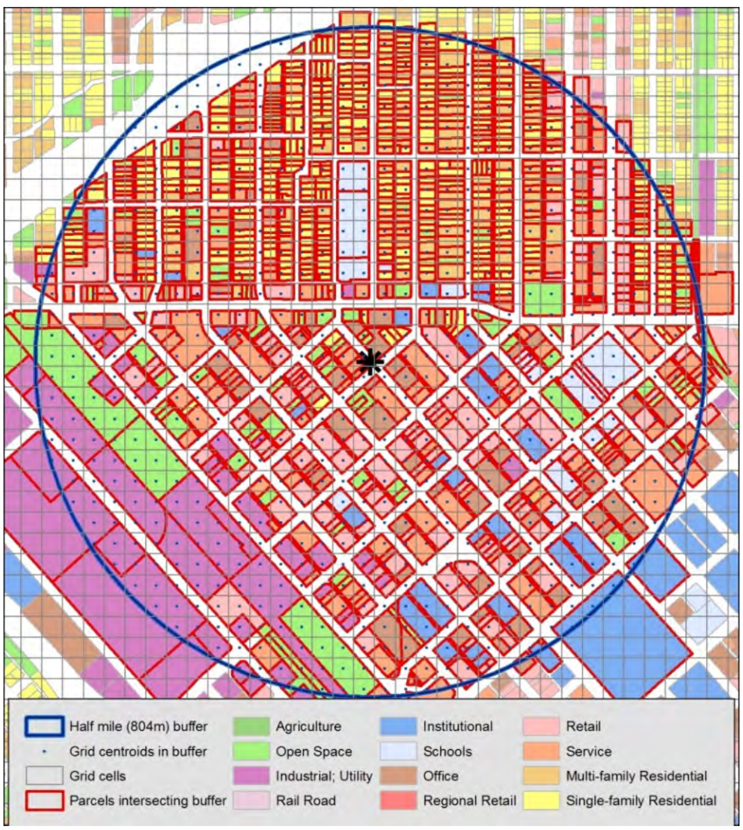

Figure 2: Illustration of Parcel and Grid Intersection with Buffered Regions

The primary visible result is that in every case, the grid based system has a lower total of acreages, population, housing units and population. For demonstration purposes, four trip end locations were chosen: 346074: a small town; 109712: Downtown; 231443: Large lot suburban; 97041: high intensity suburban with a shopping mall (Figure 3):

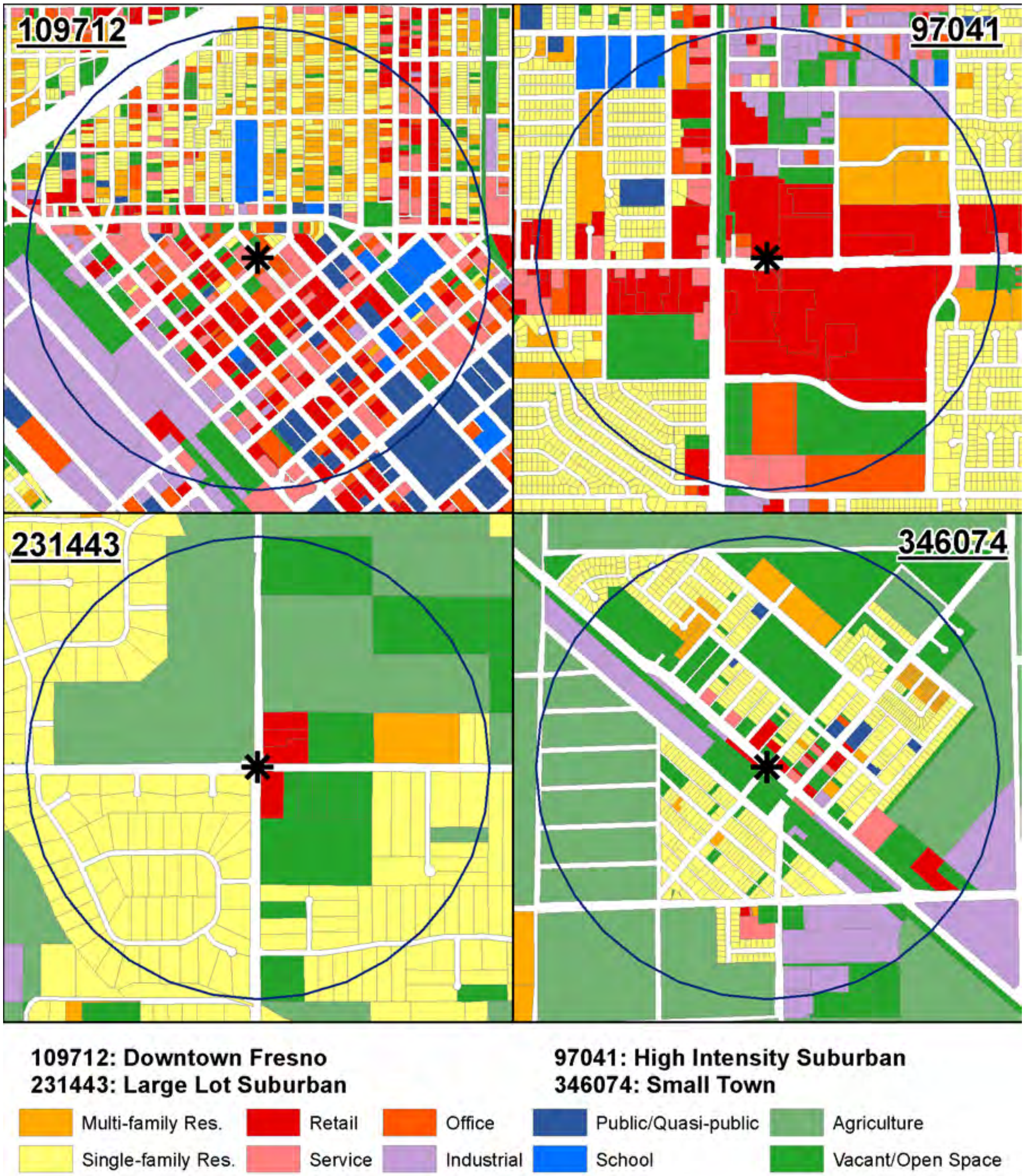

Figure 3: Diagram of Four Sample "Demonstration" Locations

Average block size varies probably most dramatically due to the area weighted average being calculated in the grid method. With those exceptions, the results are similar for the land use and employment totals. The other metrics are calculated identically, and as a result show no difference:

Table 2: Land Use Summary Results for 4 Trip End Locations by Parcel and Grid Methods

Variable	Locno 346074 Parcel	Locno 109712 Parcel	Locno 231443 Parcel	Locno 97041 Parcel
Population (People)	3,234	8,100	364	2,371
Single Family Dwellings (Acres)	87.5	59.8	264.4	69.6
Multi-Family Dwellings (Acres)	16.3	32.1	13	45.5
Retail (Acres)	7.1	49.2	10.2	48.5
Regional Retail (Acres)	0	0	0	114
Service (Acres)	7.9	52.7	0	30
Office (Acres)	0.2	32.8	0	30.1
Industrial (Acres)	73	76.2	0	27.8
Institutional (Acres)	3	34.1	0	3.6
School (Acres)	0	14.8	0	7.8
Agriculture (Acres)	474	0	190.7	0
Open Space (Acres)	114.2	0	93.1	70.3
Single Family Dwellings (Housing Units)	582	542	121	370
Multi-Family Dwellings (Housing Units)	222	1,525	12	751
Retail (Employees)	11	374	8	1,334
Service (Employees)	17	5,712	22	1,130
Office (Employees)	29	751	8	281
Industrial (Employees)	228	704	19	1,059
Institutional (Employees)	4	31	0	5
School (Employees)	0	755	0	50
Average Block Size (Acres)	26.7	6.1	2871.9	15.9

Table 3: Other Land Use Summary Data

Variable	Locno 346074	109712	231443	97041
Nearest elementary school (m)	402	300	3,138	881
Nearest middle school (m)	17,300	897	11,388	1,695
Nearest high school (m)	212	244*	9,885	1,803
Nearest post-secondary school (m)	38,978	2,701	12,837	1,678
Elementary school enrollment (within 804m)	808	436	-	-
Middle school enrollment (within 804m)	-	-	-	-

High school enrollment (within 804m)	13	268*	-	-
Post-secondary school enrollment (within 804m)	-	-	-	-
Number of 4 way intersections	18	74	2	10
Number of intersections	63	108	16	64
Nearest transit stop (m)	18,282	87	7,367	99
Number of transit stops (within 804m)	-	26	-	27
Nearest railroad station (m)	38,984	1,212	21,713	10,891
Number of railroad stations (within 804m)	-	-	-	-

* This total represents home study students registered through a school district office.

A. County Parcel Data Notes

All counties required significant review and validation against aerial imagery. In particular, public or otherwise untaxed space is frequently not maintained in County assessor's parcel data. As a result, schools, public buildings, parks, and tax exempt organizations were frequently not well coded and needed manual review.

- **Central Coast**
  - Monterey: Very detailed Land Use coding system with very few parcels requiring aerial assignment. Assessment had very high percentages of correct initial coding (average of all types 97.42%)
  - San Benito: Very detailed Land Use coding system with very few parcels requiring aerial assignment. Assessment had very high percentages of correct initial coding (average of all types 98.08%)
  - Santa Barbara: Very detailed Land Use coding system with very few parcels requiring aerial assignment. Many parcels that represented condominiums or overlapping ownerships were represented with overlapping polygons. Topology fixes were applied. Assessment had very high percentages of correct initial coding (average of all types 97.92%)
  - Santa Cruz: Very detailed Land Use coding system with very few parcels requiring aerial assignment. Majority of parcels requiring aerial checking were parking lots, and other common areas. Assessment had very high percentages of correct initial coding (average of all types 98.92%)
  - San Luis Obispo: Received data from SLO COG so obtaining the data took longer than expected, but the cross-walk was straight forward and the data quality relatively high. The presence of additional data not available in many other counties allowed overriding of some portions of the data disaggregation through using data from SLOCOG for the number of dwelling and type of dwelling units on each parcel.
- **Northern Sacramento Valley**
  - Butte: Butte County had high quality parcel data available to this project. Initial accuracy assessment yielded a average 98.08% accuracy rate.
  - Glenn: the coding system was very complicated and Glenn did not provide a description for their codes. Reviewers were forced to discern land use by previous knowledge and aerial imagery. Assessment had very high percentages of correct initial coding (average of all types 98%)

  - Shasta: the coding system was very detailed, but so much so that cross-walking was difficult. Assessment had very high percentages of correct initial coding (average of all types 98.95%)
  - Tehama: The coding system was very detailed and a majority of parcels were able to crosswalk easily. However, code descriptions such as “Vac Lot w/Prob, Precludes Bldg a Res (Possibly Curable)” were harder to cross-walk and therefore reviewer had to code based on aerial imagery. Assessment had very high percentages of correct initial coding (average of all types 97.38%)
- **Inland Empire.** The parcel data for San Bernardino, Riverside, and Imperial Counties were obtained from Sungbin Cho at SCAG (the Southern California Area Governments). All of the SCAG area used one land use coding system, so a majority could be “cross-walked” easily. However, the counties themselves had hundreds of thousands of parcels, so the codes that could not be cross-walked easily still took a significant amount of time to determine.
  - Riverside: Assessment had high percentages of correct initial coding (average of all types 96.08%)
  - San Bernardino: Original data sent by county was incorrectly coded, so a review with SCAG required a revision of the dataset on their end to remedy the data errors. Lots of initial problems with coding so more time was spent on aerial assignment. Assessment percent was lower mostly due incorrect cross-walking for some service codes and retail codes (average of all types 89.5%)
  - Imperial had a high number of parcels requiring verification against aerial imagery.
- **The San Joaquin Valley**
  - Fresno: Land use codes were very detailed so a lot more time was spent on the crosswalk itself over aerial imagery assignment.
  - Kern: Assessment percent was lower mostly due to roads being miscoded during cross-walk (average of all types 92.9%)
  - Kings: 88.82% initial accuracy assessment. The parcel land use code was of reasonable detail, though several categories required substantial manual review including some systematic issues with duplex coding, and commercial properties.
  - Merced: Assessment percent was lower mostly due to the county labeling commercial categories as “major” and “minor” commercial. These effectively mixed use categories did not crosswalk well and required extensive manual review. Initial accuracy was 85.92% which improved to 89.25% with manual recoding of commercial properties.
  - Madera: Very detailed, but also confusing Land Use coding system with many parcels requiring aerial assignment. Initial accuracy assessment yielded an 81.32% accuracy rate.
  - San Joaquin: Very detailed land use codes, but still required a lot of aerial imagery assignment. Assessment had very high percentages of correct initial coding (average of all types 98%)
  - Stanislaus: Very detailed Land Use coding system with yet a large amount of parcels required aerial assignment.
  - Tulare: Assessment percent was lower mostly due to the county miscoding Single Family Residential, and due to vacant lots and open space being mislabelled by the county as well (average of all types 88.3%)
- **San Diego County**
  - Data for San Diego County was obtained from SANDAG. The data was both highly detailed, and accurate based on comparison to aerial imagery. The land use coding was easily crosswalkable, and while no formal accuracy assessment was conducted, initial results were very good. Populuation totals were available from SANDAG at a more disaggregate level than the ACS block groups and was used in

place of the ACS. Employment totals were also available at a disaggregate resolution, but they lacked the categorical depth necessary so LEHD/OTM data was used for civilian employees, and supplemented with a military total from SANDAG for military employees.

5. Buffering for Validation and Testing

In support of the efforts to validate and test the travel demand model postprocessors, a very similar set of processes was run that integrated TAZ level socio-economic data(SE) with the land cover data produced for the initial model development. This data extraction occurred in three forms. All of the test locations were in the Small MPO Region.

1. **Base Case datasets:** Made use of the existing (current conditions) land cover data and socio-economic data at a TAZ level to produce buffered summaries surrounding the activity centroids of each TAZ.

2. **Swaps:** TAZ SE data were selectively swapped between geographic locations to establish the marginal effects of geography on VMT. Additionally, the land cover mixes were adjusted in some TAZs as a form of Place Type change, and densities were incrementally increased or decreased.

3. **Future Years:** Future year SE data for each TAZ was integrated with the existing land cover data, reflecting an increase in total dwelling units and employment. Because the land cover data was not changed, this creates a de facto increase in density as well as net growth.

These processes are illustrated in Figure 4 (below).

The base case scenario ran through the full set of steps for data preparation. Again, all of this was done using PostGIS as the analytical platform. Several steps run by the base case, notably some of the time consuming ones, did not need to be repeated for the future and swap scenarios.

All of these commands are controlled by a set of python programs that prepare and execute the queries in the PostGIS database.

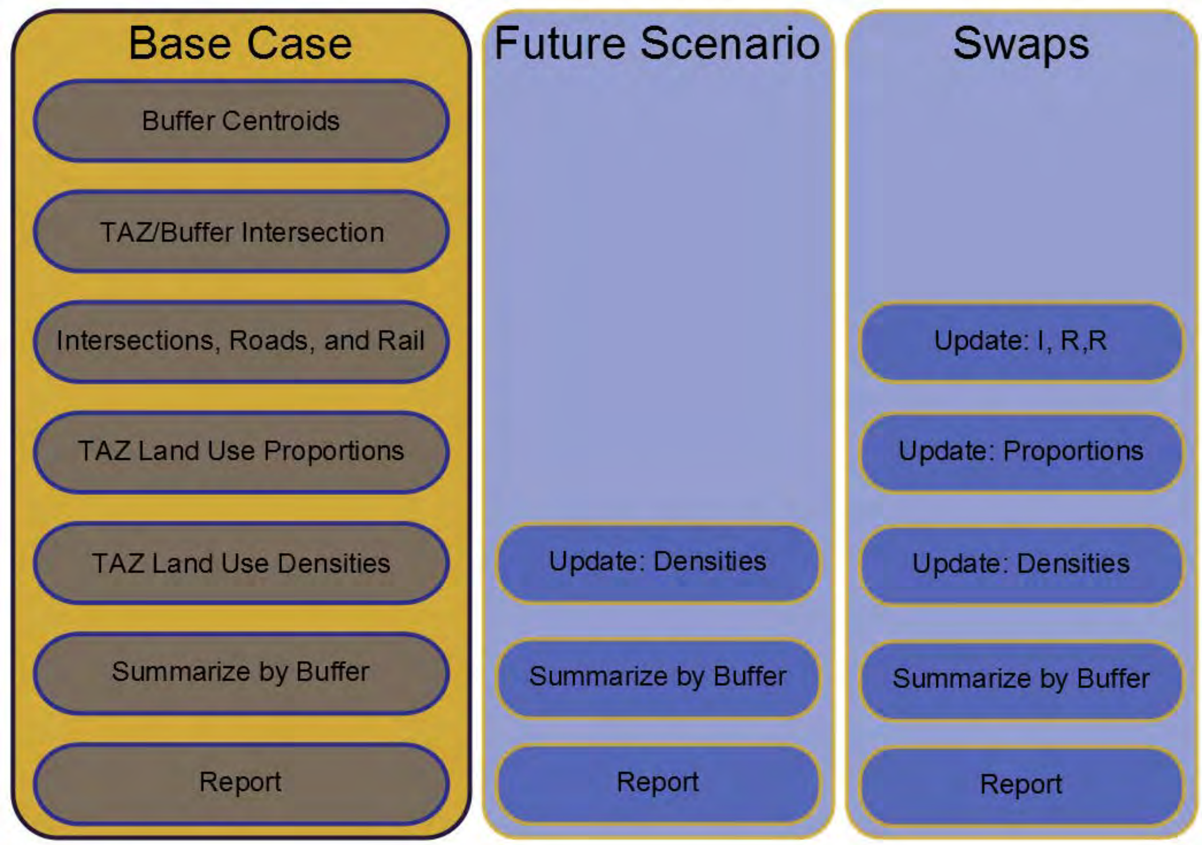

Figure 4. Process diagram for buffering. Showing the steps for the base case, and the additional steps needed to generate the future and swap scenarios.

A. "Base Case"

The base case calculation steps are as follows for a hypothetical county in the San Joaquin Valley: (An example set of SQL code is available in the following code section)

1. Import base data into postgis, this includes the import of the land cover, TAZ boundary, road intersection, road way, rail stops, and TAZ activity centroids to PostGIS.
2. Buffer the TAZ activity centroids by 804m (one half mile)
3. Intersect the TAZ boundary with the land cover dataset to build a list of parcels with their centroids in each TAZ.
4. Calculate the proportion of the total area of a TAZ made up by each parcel (with land cover)
5. Calculate the acres, and the proportion of each TAZ made up of each land cover type
6. Intersect the buffered activity centroid with the TAZ data set so that the amount of each buffer that overlaps adjoining TAZs is known.
7. Preparation of the TAZ SE table for use. This step is customized to the table structure of the MPO's model..
8. The results of steps 6 and 8 can be combined to get the land use and land cover for each buffer. This includes some handling for error cases that would produce zero totals.
9. Computing the entropy indicies is divided into three separate sub-steps for manageability. The first identifies how many of the land cover types are present in the

buffer. The second does some precalculation of values to be used by the final entropy index calculation section. Again this includes handling to avoid division by zero errors
10. Identify whether the activity centroid is in an “urban area” as defined by the 2010 US Census.
11. Calculate road length and road intersections for each buffered area
12. Calculate the distance to the nearest railroad station
13. Final assembly of all needed inputs into a single table with one row per TAZ.

B. “Swap” Scenarios

Fehr & Peers provided alternate Socio-economic data for each TAZ and a spreadsheet containing the intended translations of TAZ properties under the splits. These inputs became the core of the changes under the “swap” scenario.

Several of the initial steps for the base case scenario did not need to be repeated. These included many of the “setup” steps that create tables describing the land cover mixture found within each TAZ, and what proportion of the buffer overlaps other TAZs. Conveniently, these are also the most time consuming steps of the calculation.

Under the swap scenario, the new SE data is imported directly for use in exactly the same role it played in the base case, merely presenting an alternate set of land use inputs representing the changed land use values.

The spreadsheet containing the translation became what was called the “rubric” within the code. This identified each of the TAZs that was changed, and how it was changed so that other items could be updated appropriately. Specifically, with a change in place type, the land cover and land use mixtures present in the tables copied from the base case could be updated to reflect the change in place type before summing the land cover and land use totals for the buffer. Similarly, the density of road ways and road intersections were factored based on the destination place type.

An initial exploration was done to determine if the original place types assigned to each TAZ could be used to inform the land cover changes for swaps. Unfortunately, the place type assignment to original TAZs had a very wide range of values associated with it, rendering the results unsatisfactory for further analysis. To answer this challenge, and look up table with a set of informed estimates of the mixtures that might be found in each type in the San Joaquin Valley was created (Table 4, below).

Place Type	SFD	MFD	Ret. (all)	Loc Ret.	Reg Ret.	Servce	Offce	Edu	Publc	Ind.	Res (tot)	Emp (tot)	Dev-eloped	Road Fctor
City Mixed Use	0.00	0.15	0.10	0.10	0.00	0.15	0.15	0.02	0.02	0.00	0.15	0.48	0.70	1.20
High Intensity Activity Center	0.00	0.20	0.30	0.25	0.00	0.15	0.10	0.02	0.02	0.00	0.20	0.65	0.93	1.00
Industrial Focus	0.00	0.00	0.05	0.02	0.03	0.05	0.02	0.00	0.00	0.30	0.00	0.46	0.51	1.00
Large Lot Residential Area	0.40	0.00	0.01	0.01	0.00	0.01	0.00	0.05	0.02	0.00	0.40	0.10	0.55	0.90
Mixed Office and R&D	0.00	0.00	0.01	0.01	0.00	0.20	0.20	0.00	0.05	0.05	0.00	0.56	0.62	1.10
Office Focus	0.00	0.00	0.05	0.03	0.02	0.20	0.20	0.02	0.02	0.00	0.00	0.54	0.59	1.00
Office/ Industrial	0.00	0.00	0.02	0.01	0.01	0.10	0.10	0.00	0.02	0.20	0.00	0.48	0.53	1.00
Residential Subdivision	0.50	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.55	0.06	0.67	1.00
Retail: Strip Mall/ Big Box	0.00	0.00	0.30	0.10	0.20	0.10	0.05	0.00	0.00	0.00	0.00	0.50	0.54	1.00
Rural Residential	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.30	0.04	0.38	0.90
Town Mixed Use	0.00	0.15	0.05	0.05	0.00	0.05	0.02	0.02	0.02	0.00	0.15	0.18	0.36	1.00
Urban Mixed Use	0.00	0.20	0.02	0.02	0.00	0.20	0.20	0.02	0.02	0.00	0.20	0.51	0.78	1.20
Vacant	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Village Mixed Use	0.02	0.10	0.05	0.05	0.00	0.05	0.05	0.02	0.02	0.00	0.12	0.21	0.36	1.10
Village Commercial	0.01	0.05	0.20	0.20	0.00	0.10	0.05	0.02	0.02	0.00	0.06	0.43	0.54	1.10
Neighborhood Low	0.40	0.02	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.00	0.42	0.08	0.55	0.90
Neighborhood Residential	0.40	0.02	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.00	0.42	0.08	0.55	1.00
Retail: Strip Mall/Big Box	0.00	0.00	0.60	0.20	0.40	0.10	0.00	0.00	0.00	0.00	0.00	0.70	0.80	1.00

Table 4: Estimates of land cover and road factors by place type.

Following the update of the necessary tables, the processing finishes out along an identical track to the base case and is compiled into the final summary for analysis.

C. Future scenarios

Future year scenarios required very little modification from the base case. The base case datasets were copied over with the exception of the SE dataset, which was replaced with an updated version representing a future condition. The remainder of the analysis continues unchanged.

Attachment C.1.
Land Use/Land Cover Buffering SQL/Code

The following SQL examples are the code that would be executed for a hypothetical county in the San Joaquin Valley (using the SJV MIP TAZ data structure). Notes are included on locations where the “swap” (steps 5, 7,12) or “future” (step 7) scenarios intervene in this code to create the scenario.

1. Import base data into postgis, this includes the import of the land cover, TAZ boundary, road intersection, road way, rail stops, and TAZ activity centroids to PostGIS.
2. Buffer the TAZ activity centroids by 804m (one half mile)

```
CREATE TABLE ds_county.buff WITH OIDS AS
SELECT a.n, ST_BUFFER(a.the_geom, 804) as the_geom
FROM ds_county.centroids a;
```

3. Intersect the TAZ boundary with the land cover dataset to build a list of parcels with their centroids in each TAZ.

```
CREATE TABLE ds_county.taz_pcl WITH OIDS AS
SELECT b.gid, ST_INTERSECTION(b.the_geom, c.the_geom) as the_geom, ST_AREA(ST_INTERSECTION(b.the_geom,
c.the_geom)) as int_sqm, b.taz, c.lu_f
FROM ds_county.taz b, ds_county.lu c
WHERE ST_INTERSECTS(b.the_geom, c.the_geom);
```

4. Calculate the proportion of the total area of a TAZ made up by each parcel (with land cover)

```
CREATE TABLE ds_county.area_totals AS
SELECT taz.taz, d.sum_sqm as taz_sqm, c.lu_f, c.sum_sqm as pt_sqm, (c.sum_sqm/d.sum_sqm) as portion
FROM ds_county.taz taz
JOIN
(SELECT a.taz, a.lu_f, COUNT(a.int_sqm) as cnt_polys, SUM(a.int_sqm) as sum_sqm
FROM ds_county.taz_pcl a
GROUP BY a.taz, a.lu_f) c
ON c.taz = taz.taz
JOIN
(SELECT b.taz, COUNT(b.gid) as cnt_polys, SUM(ST_AREA(b.the_geom)) as sum_sqm
FROM ds_county.taz b
GROUP BY b.taz) d
ON d.taz = taz.taz
ORDER BY taz.taz ASC;
```

5. Calculate the acres, and the proportion of each TAZ made up of each land cover type. The totals represented here are updated on a TAZ by TAZ basis in the swap scenario based in the rubric provided by Fehr & Peers.

```
CREATE TABLE ds_county.taz_by_lu WITH OIDS AS
SELECT taz.taz,
(ST_AREA(taz.the_geom)/4046.85642) taz_ac,
CASE WHEN sfd.pt_sqm > 0 THEN (sfd.pt_sqm/4046.85642) ELSE 0 END as sfd_ac,
CASE WHEN sfd.pt_sqm > 0 THEN (sfd.pt_sqm/ST_AREA(taz.the_geom)) ELSE 0 END as sfd_por,
CASE WHEN mfd.pt_sqm > 0 THEN (mfd.pt_sqm/4046.85642) ELSE 0 END as mfd_ac,
CASE WHEN mfd.pt_sqm > 0 THEN (mfd.pt_sqm/ST_AREA(taz.the_geom)) ELSE 0 END as mfd_por,
CASE WHEN ret.pt_sqm > 0 THEN (ret.pt_sqm/4046.85642) ELSE 0 END as ret_ac,
CASE WHEN ret.pt_sqm > 0 THEN (ret.pt_sqm/ST_AREA(taz.the_geom)) ELSE 0 END as ret_por,
CASE WHEN loc_ret.pt_sqm > 0 THEN (loc_ret.pt_sqm/4046.85642) ELSE 0 END as loc_ret_ac,
CASE WHEN loc_ret.pt_sqm > 0 THEN (loc_ret.pt_sqm/ST_AREA(taz.the_geom)) ELSE 0 END as loc_ret_por,
CASE WHEN reg_ret.pt_sqm > 0 THEN (reg_ret.pt_sqm/4046.85642) ELSE 0 END as reg_ret_ac,
CASE WHEN reg_ret.pt_sqm > 0 THEN (reg_ret.pt_sqm/ST_AREA(taz.the_geom)) ELSE 0 END as reg_ret_por,
CASE WHEN ser.pt_sqm > 0 THEN (ser.pt_sqm/4046.85642) ELSE 0 END as ser_ac,
CASE WHEN ser.pt_sqm > 0 THEN (ser.pt_sqm/ST_AREA(taz.the_geom)) ELSE 0 END as ser_por,
CASE WHEN office.pt_sqm > 0 THEN (office.pt_sqm/4046.85642) ELSE 0 END as off_ac,
```

```
CASE WHEN office.pt_sqm > 0 THEN (office.pt_sqm/ST_AREA(taz.the_geom)) ELSE 0 END as off_por,
CASE WHEN edu.pt_sqm > 0 THEN (edu.pt_sqm/4046.85642) ELSE 0 END as edu_ac,
CASE WHEN edu.pt_sqm > 0 THEN (edu.pt_sqm/ST_AREA(taz.the_geom)) ELSE 0 END as edu_por,
CASE WHEN inst.pt_sqm > 0 THEN (inst.pt_sqm/4046.85642) ELSE 0 END as inst_ac,
CASE WHEN inst.pt_sqm > 0 THEN (inst.pt_sqm/ST_AREA(taz.the_geom)) ELSE 0 END as inst_por,
CASE WHEN ind.pt_sqm > 0 THEN (ind.pt_sqm/4046.85642) ELSE 0 END as ind_ac,
CASE WHEN ind.pt_sqm > 0 THEN (ind.pt_sqm/ST_AREA(taz.the_geom)) ELSE 0 END as ind_por,
CASE WHEN res.pt_sqm > 0 THEN (res.pt_sqm/4046.85642) ELSE 0 END as res_ac,
CASE WHEN res.pt_sqm > 0 THEN (res.pt_sqm/ST_AREA(taz.the_geom)) ELSE 0 END as res_por,
CASE WHEN emp.pt_sqm > 0 THEN (emp.pt_sqm/4046.85642) ELSE 0 END as emp_ac,
CASE WHEN emp.pt_sqm > 0 THEN (emp.pt_sqm/ST_AREA(taz.the_geom)) ELSE 0 END as emp_por,
CASE WHEN dev.pt_sqm > 0 THEN (dev.pt_sqm/4046.85642) ELSE 0 END as dev_ac,
CASE WHEN dev.pt_sqm > 0 THEN (dev.pt_sqm/ST_AREA(taz.the_geom)) ELSE 0 END as dev_por
FROM ds_county.taz taz
-- all res
LEFT JOIN (SELECT at.taz, sum(at.pt_sqm) as pt_sqm FROM ds_county.area_totals at WHERE at.lu_f in ('RS','RM')
GROUP by at.taz )res
ON taz.taz = res.taz
-- sfd
LEFT JOIN (SELECT at.taz, sum(at.pt_sqm) as pt_sqm FROM ds_county.area_totals at WHERE at.lu_f in ('RS') GROUP by
at.taz )sfd
ON taz.taz = sfd.taz
-- mfd
LEFT JOIN (SELECT at.taz, sum(at.pt_sqm) as pt_sqm FROM ds_county.area_totals at WHERE at.lu_f in ('RM') GROUP by
at.taz )mfd
ON taz.taz = mfd.taz
-- retail
LEFT JOIN (SELECT at.taz, sum(at.pt_sqm) as pt_sqm FROM ds_county.area_totals at WHERE at.lu_f in ('R','RR','MI')
GROUP by at.taz )ret
ON taz.taz = ret.taz

-- local retail
LEFT JOIN (SELECT at.taz, sum(at.pt_sqm) as pt_sqm FROM ds_county.area_totals at WHERE at.lu_f in ('R','MI') GROUP
by at.taz )loc_ret
ON taz.taz = loc_ret.taz

-- regional retail
LEFT JOIN (SELECT at.taz, sum(at.pt_sqm) as pt_sqm FROM ds_county.area_totals at WHERE at.lu_f in ('RR') GROUP by
at.taz )reg_ret
ON taz.taz = reg_ret.taz

-- office
LEFT JOIN (SELECT at.taz, sum(at.pt_sqm) as pt_sqm FROM ds_county.area_totals at WHERE at.lu_f in ('O') GROUP by
at.taz )office
ON taz.taz = office.taz
-- education
LEFT JOIN (SELECT at.taz, sum(at.pt_sqm) as pt_sqm FROM ds_county.area_totals at WHERE at.lu_f in ('SC') GROUP by
at.taz )edu
ON taz.taz = edu.taz
-- institutional
LEFT JOIN (SELECT at.taz, sum(at.pt_sqm) as pt_sqm FROM ds_county.area_totals at WHERE at.lu_f in ('I') GROUP by
at.taz )inst
ON taz.taz = inst.taz
-- service
LEFT JOIN (SELECT at.taz, sum(at.pt_sqm) as pt_sqm FROM ds_county.area_totals at WHERE at.lu_f in ('S') GROUP by
at.taz )ser
ON taz.taz = ser.taz
-- industrial
LEFT JOIN (SELECT at.taz, sum(at.pt_sqm) as pt_sqm FROM ds_county.area_totals at WHERE at.lu_f in ('ID','U','AP')
GROUP by at.taz )ind
ON taz.taz = ind.taz
-- employment
LEFT JOIN (SELECT at.taz, sum(at.pt_sqm) as pt_sqm FROM ds_county.area_totals at WHERE at.lu_f in
('I','O','R','M','ID','AP','RR','SC','ML','P','U','AP') GROUP by at.taz )emp
ON taz.taz = emp.taz
-- developed
LEFT JOIN (SELECT at.taz, sum(at.pt_sqm) as pt_sqm FROM ds_county.area_totals at WHERE at.lu_f NOT in ('V','OS','A',
'RD', 'RL') GROUP by at.taz )dev
ON taz.taz = dev.taz
ORDER by taz.taz ASC;
```

6. Intersect the buffered activity centroid with the TAZ data set so that the amount of each buffer that overlaps adjoining TAZs is known.

```
CREATE TABLE ds_county.taz_buff WITH OIDS AS
SELECT ST_INTERSECTION (a.the_geom, b.the_geom) as the_geom, a.n as otaz, b.taz as ptaz,
ST_AREA(ST_INTERSECTION(a.the_geom, b.the_geom)) as sqm, (ST_AREA(ST_INTERSECTION(a.the_geom,
b.the_geom))/ 2030775.757) as portion
FROM ds_county.buff a, ds_county.taz b
WHERE a.n >= 100 AND ST_INTERSECTS(a.the_geom, b.the_geom)
ORDER BY a.n ASC, b.taz ASC;
```

7. Preparation of the TAZ SE table for use. This step is customized to the table structure of the MPO's model. The example here is for the SJV MIP model structure. This step is obviously scenario specific.

```
CREATE TABLE ds_county.taz_comp WITH OIDS AS
SELECT taz, hhpop, tothh,totemp, (ru1+ru2) as sfd, (ru3+ru4+ru5+ru6+ru7+ru8+ru9+ru10) as mfd,
retail as ret, -- retail 1
(informatn + finan_insr + realestate + svc_prof + svc_mngmnt) as office, -- office 5
education,--education 1
public,--institutional 1
(health + ent_rec + accomodtns + food + svc_admin + svc_other) as service,--service 6
(agricultur + mining + utilities + constructn + manufactur + wholesale + warehouse) as ind --industrial 7
FROM ds_county.taz_se;
```

8. Calculate the densities of each of the land uses within potentially appropriate land cover, with handling of error conditions.

```
CREATE TABLE ds_county.densities WITH OIDS AS
SELECT a.taz,
CASE WHEN a.taz_ac > 0 THEN (b.hhpop/a.taz_ac) ELSE (b.hhpop/a.taz_ac) END AS dhhpop_gr,
CASE WHEN a.taz_ac > 0 THEN (b.tothh/a.taz_ac) ELSE (b.tothh/a.taz_ac) END AS dtothh_gr,
CASE WHEN a.taz_ac > 0 THEN (b.totemp/a.taz_ac) ELSE (b.totemp/a.taz_ac) END AS dtotemp_gr,
CASE WHEN a.res_ac > 0 THEN (b.hhpop/a.res_ac) ELSE (b.hhpop/a.taz_ac) END AS dpop_net,
CASE WHEN a.res_ac > 0 THEN (b.tothh/a.res_ac) ELSE (b.tothh/a.taz_ac) END AS dtothh_net,
CASE WHEN a.emp_ac > 0 THEN (b.totemp/a.emp_ac) ELSE (b.totemp/a.taz_ac) END AS dtotemp_net,
CASE WHEN a.sfd_ac > 0 THEN (b.sfd/a.sfd_ac) WHEN a.res_ac > 0 THEN (b.sfd/a.res_ac) ELSE (b.sfd/a.taz_ac) END AS
dsfd,
CASE WHEN a.mfd_ac > 0 THEN (b.mfd/a.mfd_ac) WHEN a.res_ac > 0 THEN (b.mfd/a.res_ac) ELSE (b.mfd/a.taz_ac) END
AS dmfd,
CASE WHEN a.ret_ac > 0 THEN (b.ret/a.ret_ac) WHEN a.emp_ac > 0 THEN (b.ret/a.emp_ac) ELSE (b.ret/a.taz_ac) END AS
dret,
CASE WHEN a.off_ac > 0 THEN (b.office/a.off_ac) WHEN a.emp_ac > 0 THEN (b.office/a.emp_ac) ELSE (b.office/a.taz_ac)
END AS doffice,
CASE WHEN a.edu_ac > 0 THEN (b.education/a.edu_ac) WHEN a.emp_ac > 0 THEN (b.education/a.emp_ac) ELSE
(b.education/a.taz_ac) END AS deducation,
CASE WHEN a.inst_ac > 0 THEN (b.public/a.inst_ac) WHEN a.emp_ac > 0 THEN (b.public/a.emp_ac) ELSE
(b.public/a.taz_ac) END AS dpublic,
CASE WHEN a.ser_ac > 0 THEN (b.service/a.ser_ac) WHEN a.emp_ac > 0 THEN (b.service/a.emp_ac) ELSE
(b.service/a.taz_ac) END AS dservice,
CASE WHEN a.ind_ac > 0 THEN (b.ind/a.ind_ac) WHEN a.emp_ac > 0 THEN (b.ind/a.emp_ac) ELSE (b.ind/a.taz_ac) END
AS dind
FROM ds_county.taz_by_lu a
LEFT JOIN ds_county.taz_comp b ON a.taz = b.taz
LEFT JOIN ds_county.taz c ON a.taz = c.taz
ORDER BY a.taz ASC;
```

9. The results of steps 6 and 8 can be combined to get the land use and land cover for each buffer. This includes some handling for error cases that would produce zero totals.

```
CREATE TABLE ds_county.buff_comp WITH OIDS AS
SELECT e.otaz as taz,
sum(e.sfd) as sum_sfd, sum(e.sfd_ac) as sum_sfd_ac,
sum(e.mfd) as sum_mfd, sum(e.mfd_ac) as sum_mfd_ac,
sum(e.ret) as sum_ret, sum(e.ret_ac) as sum_ret_ac,
sum(e.loc_ret_ac) as sum_locret_ac,
sum(e.ser) as sum_ser, sum(e.ser_ac) as sum_ser_ac,
sum(e.office) as sum_office, sum(e.off_ac) as sum_off_ac,
```

```
sum(e.education) as sum_edu, sum(e.edu_ac) as sum_edu_ac,
sum(e.public) as sum_public, sum(e.inst_ac) as sum_inst_ac,
sum(e.ind) as sum_ind, sum(e.ind_ac) as sum_ind_ac,
sum(e.tothh) as sum_tothh, sum(e.res_ac) as sum_res_ac,
sum(e.totpop) as sum_totpop,
sum(e.totemp) as sum_totemp, sum(e.emp_ac) as sum_emp_ac,
sum(e.dev_ac) as sum_dev_ac
--sum(e.ints) as sum_ints,
--sum(e.roads) as sum_roads
FROM (
SELECT a.otaz, a.ptaz, a.portion,
CASE
   WHEN c.sfd_por > 0 THEN (502.6548246 * a.portion * c.sfd_por * d.dsfd)
   WHEN c.res_por > 0 THEN (502.6548246 * a.portion * c.res_por * d.dsfd)
   ELSE (502.6548246 * a.portion * d.dsfd)
END as sfd,
CASE
   WHEN c.sfd_por > 0 THEN (502.6548246 * a.portion * c.sfd_por)
   ELSE 0
END as sfd_ac,
CASE
   WHEN c.mfd_por > 0 THEN (502.6548246 * a.portion * c.mfd_por * d.dmfd)
   WHEN c.res_por > 0 THEN (502.6548246 * a.portion * c.res_por * d.dmfd)
   ELSE (502.6548246 * a.portion * d.dmfd)
END as mfd,
CASE
   WHEN c.mfd_por > 0 THEN (502.6548246 * a.portion * c.mfd_por)
   ELSE 0
END as mfd_ac,
CASE
   WHEN c.ret_por > 0 THEN (502.6548246 * a.portion * c.ret_por * d.dret)
   ELSE (502.6548246 * a.portion * d.dret)
END as ret,
CASE
   WHEN c.ret_por > 0 THEN (502.6548246 * a.portion * c.ret_por)
   ELSE 0
END as ret_ac,
CASE
   WHEN c.loc_ret_por > 0 THEN (502.6548246 * a.portion * c.loc_ret_por)
   ELSE 0
END as loc_ret_ac,
CASE
   WHEN c.reg_ret_por > 0 THEN (502.6548246 * a.portion * c.reg_ret_por)
   ELSE 0
END as reg_ret_ac,
CASE
   WHEN c.ser_por > 0 THEN (502.6548246 * a.portion * c.ser_por * d.dservice)
   ELSE (502.6548246 * a.portion * d.dservice)
END as ser,
CASE
   WHEN c.ser_por > 0 THEN (502.6548246 * a.portion * c.ser_por)
   ELSE 0
END as ser_ac,
CASE
   WHEN c.off_por > 0 THEN (502.6548246 * a.portion * c.off_por * d.doffice)
   ELSE (502.6548246 * a.portion * d.doffice)
END as office,
CASE
   WHEN c.off_por > 0 THEN (502.6548246 * a.portion * c.off_por)
   ELSE 0
END as off_ac,
CASE
   WHEN c.edu_por > 0 THEN (502.6548246 * a.portion * c.edu_por * d.deducation)
   ELSE (502.6548246 * a.portion * d.deducation)
END as education,
CASE
   WHEN c.edu_por > 0 THEN (502.6548246 * a.portion * c.edu_por)
   ELSE 0
END as edu_ac,
CASE
   WHEN c.inst_por > 0 THEN (502.6548246 * a.portion * c.inst_por * d.dpublic)
   ELSE (502.6548246 * a.portion * d.dpublic)
```

```
END as public,
CASE
   WHEN c.inst_por > 0 THEN (502.6548246 * a.portion * c.inst_por)
   ELSE 0
END as inst_ac,
CASE
   WHEN c.ind_por > 0 THEN (502.6548246 * a.portion * c.ind_por * d.dind)
   ELSE (502.6548246 * a.portion * d.dind)
END as ind,
CASE
   WHEN c.ind_por > 0 THEN (502.6548246 * a.portion * c.ind_por)
   ELSE 0
END as ind_ac,
CASE
   WHEN c.res_por > 0 THEN (502.6548246 * a.portion * c.res_por * d.dtothh_net)
   ELSE (502.6548246 * a.portion * d.dtothh_net)
END as tothh,
CASE
   WHEN c.res_por > 0 THEN (502.6548246 * a.portion * c.res_por)
   ELSE 0
END as res_ac,
CASE
   WHEN c.res_por > 0 THEN (502.6548246 * a.portion * c.res_por * d.dpop_net)
   ELSE (502.6548246 * a.portion * d.dpop_net)
END as totpop,
CASE
   WHEN c.emp_por > 0 THEN (502.6548246 * a.portion * c.emp_por * d.dtotemp_net)
   ELSE (502.6548246 * a.portion * d.dtotemp_net)
END as totemp,
CASE
   WHEN c.emp_por > 0 THEN (502.6548246 * a.portion * c.emp_por)
   ELSE 0
END as emp_ac,
CASE
   WHEN c.dev_por > 0 THEN (502.6548246 * a.portion * c.dev_por)
   ELSE 0
END as dev_ac
FROM ds_county.taz_buff a
LEFT JOIN ds_county.taz_comp b ON b.taz = a.otaz
LEFT JOIN ds_county.taz_by_lu c  ON c.taz = a.ptaz
LEFT JOIN ds_county.densities d ON d.taz = a.ptaz
) e
GROUP BY e.otaz
ORDER BY e.otaz;
```

10. Computing the entropy indicies is divided into separate steps for manageability. Again this includes handling to avoid division by zero errors.

```
CREATE TABLE ds_county.nonzero_lu_ac WITH OIDS AS
SELECT b.taz, (b.sfd_ac + b.mfd_ac + b.ret_ac + b.office_ac + b.edu_ac + b.inst_ac + b.ser_ac) as nonzero_lu,
(b.ret + b.ser + b.office + b.inst + b.edu) as nonzero_emp
FROM (
   SELECT a.taz,
   CASE WHEN a.sum_sfd > 0 THEN 1 ELSE 0 END as sfd,
   CASE WHEN a.sum_mfd > 0 THEN 1 ELSE 0 END as mfd,
   CASE WHEN a.sum_ret > 0 THEN 1 ELSE 0 END as ret,
   CASE WHEN a.sum_ser > 0 THEN 1 ELSE 0 END as ser,
   CASE WHEN a.sum_office > 0 THEN 1 ELSE 0 END as office,
   CASE WHEN a.sum_edu > 0 THEN 1 ELSE 0 END as edu,
   CASE WHEN a.sum_public > 0 THEN 1 ELSE 0 END as inst,
   CASE WHEN a.sum_ind > 0 THEN 1 ELSE 0 END as ind,
   CASE WHEN a.sum_tothh > 0 THEN 1 ELSE 0 END as res,
   CASE WHEN a.sum_totpop > 0 THEN 1 ELSE 0 END as pop,
   CASE WHEN a.sum_totemp > 0 THEN 1 ELSE 0 END as emp,
   CASE WHEN a.sum_sfd_ac > 0 THEN 1 ELSE 0 END as sfd_ac,
   CASE WHEN a.sum_mfd_ac > 0 THEN 1 ELSE 0 END as mfd_ac,
   CASE WHEN a.sum_ret_ac > 0 THEN 1 ELSE 0 END as ret_ac,
   CASE WHEN a.sum_ser_ac > 0 THEN 1 ELSE 0 END as ser_ac,
   CASE WHEN a.sum_off_ac > 0 THEN 1 ELSE 0 END as office_ac,
   CASE WHEN a.sum_edu_ac > 0 THEN 1 ELSE 0 END as edu_ac,
   CASE WHEN a.sum_inst_ac > 0 THEN 1 ELSE 0 END as inst_ac,
```

```
    CASE WHEN a.sum_ind_ac > 0 THEN 1 ELSE 0 END as ind_ac,
    CASE WHEN a.sum_res_ac > 0 THEN 1 ELSE 0 END as res_ac,
    CASE WHEN a.sum_emp_ac > 0 THEN 1 ELSE 0 END as emp_ac,
    CASE WHEN a.sum_dev_ac > 0 THEN 1 ELSE 0 END as dev_ac
    FROM ds_county.buff_comp a
    ORDER BY a.taz) b;

CREATE TABLE ds_county.ent_prep WITH OIDS AS
SELECT
a.taz,
--ent_emp
CASE WHEN a.sum_ret > 0 THEN (a.sum_ret/d.memp)*ln((a.sum_ret/d.memp)) ELSE 0 END AS ent_emp_ret,
CASE WHEN a.sum_ser > 0 THEN (a.sum_ser/d.memp)*ln((a.sum_ser/d.memp)) ELSE 0 END AS ent_emp_ser,
CASE WHEN a.sum_office > 0 THEN (a.sum_office/d.memp)*ln((a.sum_office/d.memp)) ELSE 0 END AS ent_emp_off,
CASE WHEN a.sum_public > 0 THEN (a.sum_public/d.memp)*ln((a.sum_public/d.memp)) ELSE 0 END AS ent_emp_pub,
CASE WHEN a.sum_edu > 0 THEN (a.sum_edu/d.memp)*ln((a.sum_edu/d.memp)) ELSE 0 END AS ent_emp_edu,

--ent_lu
CASE WHEN a.sum_sfd_ac > 0 THEN (a.sum_sfd_ac/d.mlu)*ln(a.sum_sfd_ac/d.mlu) ELSE 0 END AS ent_lu_sfd,
CASE WHEN a.sum_mfd_ac > 0 THEN (a.sum_mfd_ac/d.mlu)*ln(a.sum_mfd_ac/d.mlu) ELSE 0 END AS ent_lu_mfd,
CASE WHEN a.sum_ret_ac > 0 THEN (a.sum_ret_ac/d.mlu)*ln(a.sum_ret_ac/d.mlu) ELSE 0 END AS ent_lu_ret,
CASE WHEN a.sum_ser_ac > 0 THEN (a.sum_ser_ac/d.mlu)*ln(a.sum_ser_ac/d.mlu) ELSE 0 END AS ent_lu_ser,
CASE WHEN a.sum_off_ac > 0 THEN (a.sum_off_ac/d.mlu)*ln(a.sum_off_ac/d.mlu) ELSE 0 END AS ent_lu_off,
CASE WHEN a.sum_inst_ac > 0 THEN (a.sum_inst_ac/d.mlu)*ln(a.sum_inst_ac/d.mlu) ELSE 0 END AS ent_lu_inst,
CASE WHEN a.sum_edu_ac > 0 THEN (a.sum_edu_ac/d.mlu)*ln(a.sum_edu_ac/d.mlu) ELSE 0 END AS ent_lu_edu
FROM ds_county.buff_comp a
LEFT JOIN (SELECT c.taz, (c.sum_ret + c.sum_ser + c.sum_office + c.sum_edu + c.sum_public) as memp,
    (c.sum_sfd_ac + c.sum_mfd_ac + c.sum_ret_ac + c.sum_off_ac + c.sum_edu_ac + c.sum_inst_ac + c.sum_ser_ac) as
mlu,
    (c.sum_ret/(c.sum_ser + c.sum_office + c.sum_edu + c.sum_public + c.sum_ind)) as ma
    FROM ds_county.buff_comp c) d ON a.taz = d.taz
;

CREATE TABLE ds_county.indices WITH OIDS AS
SELECT a.taz, b.nonzero_emp, b.nonzero_lu,
(
e.ent_emp_ret +
e.ent_emp_ser +
e.ent_emp_off +
e.ent_emp_pub +
e.ent_emp_edu
) as ent_e,
CASE WHEN b.nonzero_emp > 1 THEN
(-1*
(
e.ent_emp_ret +
e.ent_emp_ser +
e.ent_emp_off +
e.ent_emp_pub +
e.ent_emp_edu
)
/ln(b.nonzero_emp)
)
WHEN b.nonzero_emp = 1 THEN
(-1*
(
e.ent_emp_ret +
e.ent_emp_ser +
e.ent_emp_off +
e.ent_emp_pub +
e.ent_emp_edu
)
/ln(1.01)
)
WHEN b.nonzero_emp = 0 THEN
(-1*
(
e.ent_emp_ret +
e.ent_emp_ser +
e.ent_emp_off +
e.ent_emp_pub +
e.ent_emp_edu
```

```
)
/ln(0.01)
)
END as ent_emp,
(
e.ent_lu_sfd +
e.ent_lu_mfd +
e.ent_lu_ret +
e.ent_lu_ser +
e.ent_lu_off +
e.ent_lu_inst +
e.ent_lu_edu
) as ent_a,
CASE WHEN b.nonzero_lu > 1 THEN
(-1*
(
e.ent_lu_sfd +
e.ent_lu_mfd +
e.ent_lu_ret +
e.ent_lu_ser +
e.ent_lu_off +
e.ent_lu_inst +
e.ent_lu_edu
)
/ln(b.nonzero_lu)
)
WHEN b.nonzero_lu = 1 THEN
(-1*
(
e.ent_lu_sfd +
e.ent_lu_mfd +
e.ent_lu_ret +
e.ent_lu_ser +
e.ent_lu_off +
e.ent_lu_inst +
e.ent_lu_edu
)
/ln(1.01)
)
WHEN b.nonzero_lu = 0 THEN
(-1*
(
e.ent_lu_sfd +
e.ent_lu_mfd +
e.ent_lu_ret +
e.ent_lu_ser +
e.ent_lu_off +
e.ent_lu_inst +
e.ent_lu_edu
)
/ln(0.01)
)
END as ent_lu,
CASE WHEN (d.ma*a.sum_ret + (a.sum_ser + a.sum_office + a.sum_ind + a.sum_public + a.sum_edu)) > 0 THEN
(1-abs
(
(d.ma*a.sum_ret - (a.sum_ser + a.sum_office + a.sum_ind + a.sum_public + a.sum_edu))
/
(d.ma*a.sum_ret + (a.sum_ser + a.sum_office + a.sum_ind + a.sum_public + a.sum_edu))
)
)
ELSE
(1-abs
(
(d.ma*a.sum_ret - (a.sum_ser + a.sum_office + a.sum_ind + a.sum_public + a.sum_edu))
/
(0.01)
)
)
END as jobsmix
FROM ds_county.buff_comp a
LEFT JOIN ds_county.nonzero_lu_ac b ON a.taz = b.taz
```

```
LEFT JOIN (SELECT c.taz, (c.sum_ret + c.sum_ser + c.sum_office + c.sum_edu + c.sum_public) as memp,
   (c.sum_sfd_ac + c.sum_mfd_ac + c.sum_ret_ac + c.sum_off_ac + c.sum_edu_ac + c.sum_inst_ac + c.sum_ser_ac) as
mlu,
   CASE WHEN (c.sum_ser + c.sum_office + c.sum_edu + c.sum_public + c.sum_ind) > 0 THEN (c.sum_ret/(c.sum_ser +
c.sum_office + c.sum_edu + c.sum_public + c.sum_ind)) ELSE (c.sum_ret/0.01) END as ma
   FROM ds_county.buff_comp c) d ON a.taz = d.taz
LEFT JOIN ds_county.ent_prep e ON a.taz = e.taz;
```

11. Identify whether centroid is in an “urban area” as defined by the 2010 US Census.

```
CREATE TABLE ds_county.uac10 WITH OIDS AS
SELECT a.n as taz, 1 as uac
FROM ds_county.centroids a, ds_basedata.uac10 b
WHERE ST_INTERSECTS(a.the_geom, b.the_geom);
```

12. Calculate road length and road intersections for each buffered area. In the swap scenario the road density and intersection density are adjusted by the road factor in the place type look up table (Table 4 above).

```
CREATE TABLE ds_county.roadinfo WITH OIDS AS
SELECT a.taz, b.count_int, (c.sum_len/1609.344) as road_len --miles
FROM ds_county.taz a
LEFT JOIN (
SELECT f.n as taz,
count(g.gid) as count_int
FROM ds_county.buff f, ds_county.roads_int g
WHERE ST_INTERSECTS(f.the_geom, g.the_geom) AND g.intcnt > 2
GROUP BY f.n
) b ON a.taz = b.taz
LEFT JOIN (
SELECT i.n as taz, sum(ST_LENGTH(ST_INTERSECTION(i.the_geom, j.the_geom))) as sum_len
FROM ds_county.buff i, ds_county.roads j
WHERE ST_INTERSECTS(i.the_geom, j.the_geom)
GROUP BY i.n
) c ON a.taz = c.taz
ORDER BY a.taz ASC;
```

13. Calculate nearest railroad station

```
CREATE TABLE ds_county.rr_dist WITH OIDS AS
SELECT c.taz, min(c.dist/1609.344) as mdist
FROM (
SELECT a.n as taz, b.gid, ST_DISTANCE(a.the_geom, b.the_geom) as dist
FROM ds_county.centroids a, ds_basedata.rr_stops b)c
GROUP BY c.taz
ORDER BY c.taz;
```

14. Final assembly

```
CREATE TABLE ds_county.final WITH OIDS AS
SELECT a.taz,
b.sum_totpop as tot_pop, b.sum_tothh as tot_hh, (b.sum_tothh*0.27) as hh_0015, (b.sum_tothh*0.6) as hh_1621,
b.sum_totemp as tot_emp, b.sum_res_ac as res_acres, b.sum_emp_ac as emp_acres, b.sum_locret_ac as loc_retail_acres,
CASE WHEN b.sum_res_ac > 0 THEN
(b.sum_totpop/b.sum_res_ac)
ELSE -1
END as pop_per_res_ac,
CASE WHEN b.sum_tothh > 0 THEN
(b.sum_totemp/b.sum_tothh)
ELSE
-1
END as jobs_per_hh,
g.w_p_hh as workers_per_hh, b.sum_dev_ac as developed_acres,
CASE WHEN c.uac = 1 THEN 1 ELSE 0 END as urban,
d.count_int as intersection_count, d.road_len as road_length, e.mdist dist_to_rr_station,
f.ent_emp as emp_entropy, f.ent_lu as lu_entropy, f.jobsmix as jobs_diversity
from ds_county.taz a
LEFT JOIN ds_county.buff_comp b ON a.taz = b.taz
LEFT JOIN ds_county.uac10 c ON a.taz = c.taz
```

```
LEFT JOIN ds_county.roadinfo d  ON a.taz = d.taz
LEFT JOIN ds_county.rr_dist e  ON a.taz = e.taz
LEFT JOIN ds_county.indices f  ON a.taz = f.taz
LEFT JOIN ds_county.taz_buff_w_p_hh g ON a.taz = g.taz
ORDER BY a.taz ASC;
```

Attachment C.2. References

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FINAL REPORT – Improved Data & Tools for Integrated Land Use-Transportation Planning in California

APPENDIX “D”

Results of Analyses of Detailed Built Environment and Travel Data

TOPICS:

1. **Travel and Built Environment Relationships in California Regions**
2. **Findings on Regionally-Relevant Quantitative Relationships**
3. **Applying Ds Relationships in Planning and Forecasting**

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July 17, 2012

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TECHNICAL ATTACHMENTS:

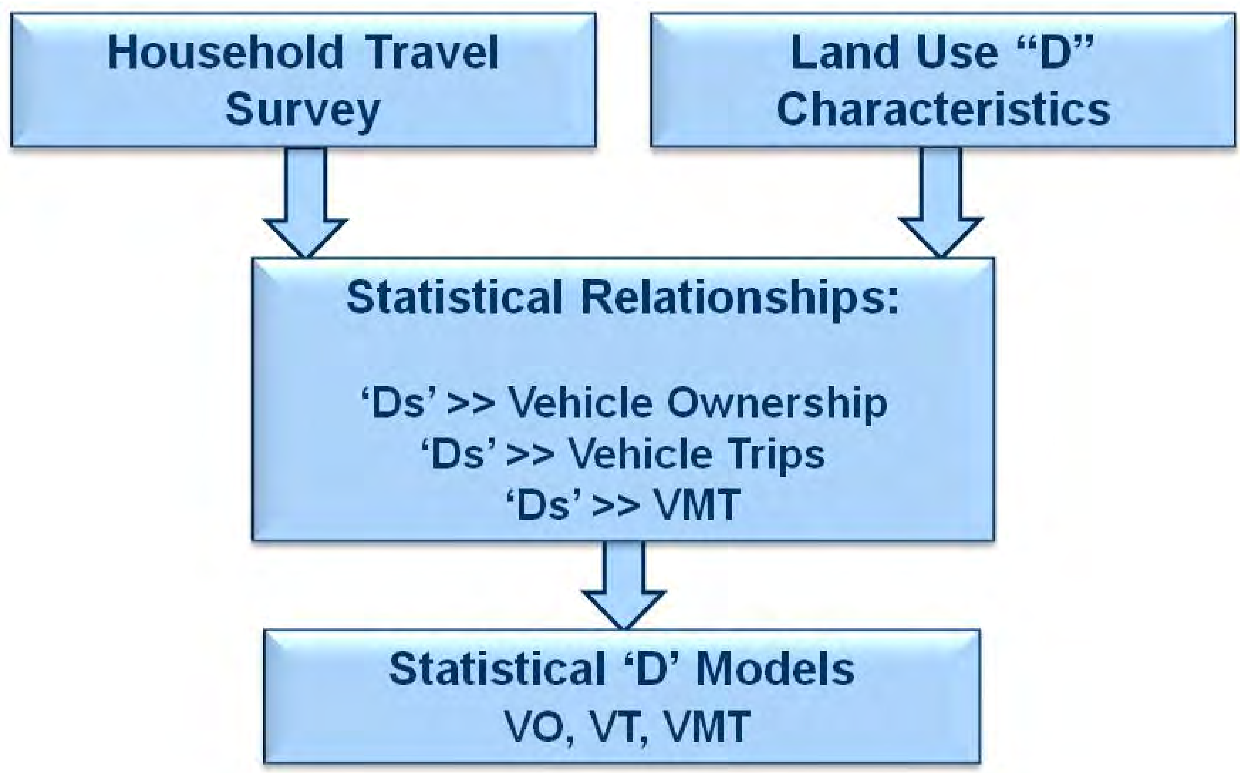
Statistical Analyses Results of Land Use/Transportation Data for:

- **Attachment D1. The Sacramento Metropolitan Region**
- **Attachment D2. The San Diego Metropolitan Region**
- **Attachment D3. Small and Medium-size Metro Regions**
- **Attachment D4. Urban Rail Corridors in the S.F. Bay Area**

1. Travel & Built Environment Relationships in California Regions

The study team employed the approach illustrated in Figure 1 to find the underlying quantitative relationships between travel and the built environment for California's regions. For each study region, the team collected 2009 National Household Travel Survey (NHTS) and local household travel survey data which indicates travelers' vehicle ownership (VO), number of vehicle trips generated (VT), trip length, and vehicle miles travelled (VMT). Then the team statistically correlated these travel behaviors with socio-demographic and available land use and transportation system characteristics. The statistical analysis process was advised by an Expert Panel consisting of national experts in travel research.[1] Results were shared with a Practitioners Panel consisting of modeling and planning staff of California regional and local planning agencies in the areas included in this study.

Figure 1. Research Approach on Statistical "D" Relationships



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[1] The Expert Panel included Drs.: Marlon Boarnet - University of Southern California (USC); Susan Handy - UC Davis; Robert Cervero & Dan Chatman - UC Berkeley; John Thomas - US EPA's Smart Growth Program.

STUDY REGIONS

The study focuses on a cross-section of rural, urbanized, and urbanizing regions throughout the state. This includes areas representing: 13 of California's small and medium MPOs, the entirety of two major regional MPOs, and several sub-regions within the state's largest MPOs:

- **San Joaquin Valley**: Comprised of eight MPOs: Kern, Kings, Tulare, Fresno, Madera, Merced, Stanislaus and San Joaquin Counties.
- **Northern Sacramento Valley**: Two MPO/RTP areas, Shasta and Butte, and nearby counties.
- **Central Coast**: Three MPOs: The Santa Barbara County Association of Governments (CAG); San Louis Obispo Council of Governments (COG); and the Association of Monterey Bay Area Governments (AMBAG) which includes Monterey, San Benito, and Santa Cruz Counties.
- **Sacramento region**: One MPO: The Sacramento Area Council of Governments (SACOG), with four counties (Sacramento, Sutter, Yolo, and Yuba) and the non-Tahoe Basin portions of two counties (El Dorado and Placer).
- **San Diego region**: One MPO: The San Diego Association of Governments (SANDAG).
- **Sub-region of the Los Angeles region**: The Inland Empire sub-region consisting of Riverside and San Bernardino Counties, as well as Imperial County within the Southern California Association of Governments (SCAG) MPO.
- **Transit supportive corridors within the San Francisco Bay region**: Rail corridor areas containing many of this region's MTC/ABAG Priority Development Areas (PDA)

These areas represent most of the demographic, transportation, and land use conditions found within most regions of California – especially those areas covered by SB 375's requirements. They are indicated on the Figure 2 map (below).

Figure 2. California Analysis Regions

(Note: Grey areas were not included in this study. See Appendix C for details.)

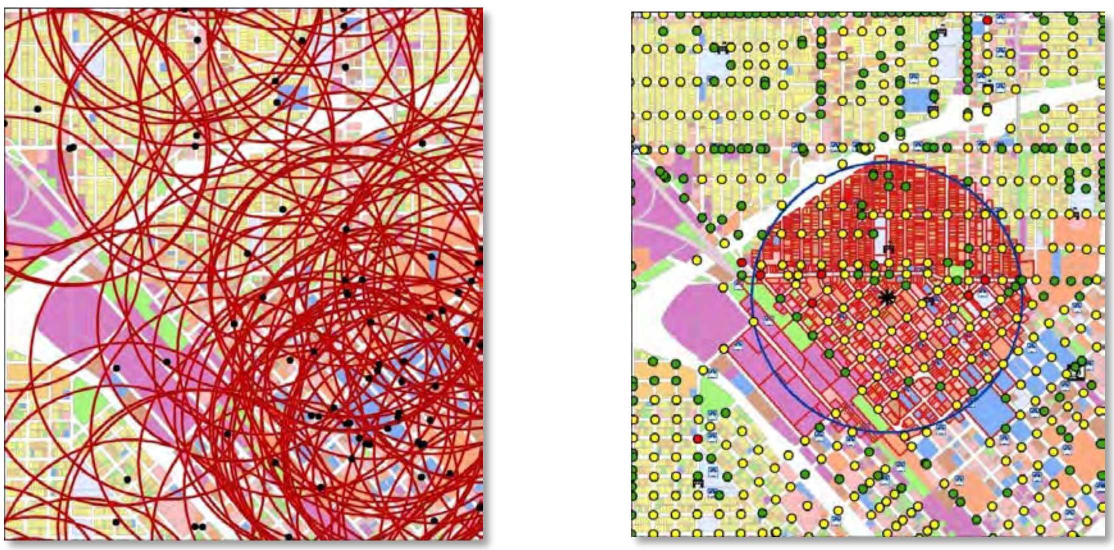
LAND USE AND TRAVEL DATA

Within most of the study regions, the team extracted household demographic and travel data from results of the 2009 National Household Travel Survey (NHTS) within the California study areas. Local household travel surveys were used for the Sacramento area (2000 SAGOG Household Travel Survey) and the Rail Corridors Analysis (2000 Bay Area Travel Survey – BATS), because both SACOG and MTC had already added key variables to their datasets related to "D" factors.

UC Davis developed a methodology to process the NHTS data to include the variables necessary for this study. The NHTS data was provided by Caltrans Transportation & Systems Information (TSI) Division. Among the data obtained from the statewide NHTS were household vehicle ownership (VO), person trips and travel mode shares, and the number of vehicle trips (VT) generated, as well as trip length and vehicle miles travelled (VMT). To ascertain the built environment factors influencing trips, the team also obtained land use data for the areas surrounding each household and each reported travel destination "trip end."

Figure 3 illustrates the GIS "buffering" process used to obtain and report data within a half-mile radius of each travel survey trip-end, including surrounding density, land use mix, street network connectivity, and available transit service. The image on the right illustrates the buffering inventory of land use and intersection types within a half-mile radius of a typical household. The image on the left illustrates the overlapping nature of the individualized buffer areas around the households surveyed, indicating that even though many nearby households share similar built environments, the statistical modeling buffers included in this study are highly customized from the precise perspective of the household generating the travel. (Note: This process is described in greater detail in Appendix C.) Available regional travel models were also examined to obtain data on regional accessibility for each household and trip destination.

Figure 3. Capturing "D" Data within a Half-Mile of NHTS Trip Ends



For the Sacramento analysis, SACOG provided a version of the SACOG Household Travel Survey that had gone through a land use buffering process similar to that described for the NHTS dataset. In the case of the SACOG dataset, buffers were developed at 0.25-, 0.5-, 1- and 2-mile radii from the household locations, although to remain consistent with the other analyses, only the 0.5 mile buffers were used. (note: Attachment D1 to this Appendix details the variables included in the SACOG dataset.)

For the Rail Corridors analysis, the S.F. Bay Area Travel Survey 2000, or BATS2000, was the principal source of data. BATS2000 is an activity-based travel survey conducted by the Metropolitan Transportation Commission (MTC) that collected information on all in-home and out-of-home activities over a two-day period, including weekday and weekend pursuits. Over 15,000 Bay Area households participated, and information was collected on more than 34,000 residents. The data were weighted and expanded based on Census 2000 data to reflect the nearly 2.4 million households and 6.5 million residents of the Bay Area. The final weighting and expansion process was based on Public Use Microdata Area (PUMA) of residence, household size, vehicles available, tenure, and race/ethnicity. The survey collected precise activity locations, including home and work locations that were used to categorize residents based on their home and work place's proximity to rail stations, and was the basis for the half-mile buffer data around trip ends.

The Ds Analysis Modules produced by this study, which are described below, address travel generation at a household level as a function of each household's demographic characteristics and regional accessibility, as well as the built environment within the buffer area surrounding the household. These modules also take into account the built environment and accessibility of each destination to which members of the household reported traveling. They do this by "buffering" the built environment characteristics within various radii around each household and non-residential location visited. The method of applying the Ds Analysis Modules developed from this statistical analysis is described in Section III of this Appendix.

OVERVIEW OF STATISTICAL TESTS

The following section provides a review of the statistical analyses performed for each study region, including the most successful outcomes and principle statistical findings. Appendices to this report contain more complete information on the full range of statistical methods and models deemed less significant. As an overview, the process and statistical methods encompass the following steps:

1) **Pilot studies** – the Fehr & Peers team developed Ds Analysis Modules in three MPO regions representing each of three major types of models:
   - **Large MPOs** – as a prototype example of modeling approach to be applied in SACOG and SANDAG travel modeling. *Pilot study region: Sacramento*
   - **Major Rail Corridors** – as a pilot study for modeling travel generated in rail corridors in transit-rich regions. *Pilot study region: SF Bay Area*
   - **Small/Medium MPOs** – to establish a modeling approach to be applied to small and medium MPO areas throughout the San Joaquin Valley, Northern Sacramento Valley, Central Coast and Inland Empire. *Pilot study region: Fresno*
2) For each pilot region, the team performed statistical analyses of relationships between household travel and built environment "D" variables, including demographics, "solving" for vehicle ownership (VO), vehicle trip generation (VT) and vehicle miles travelled (VMT).
   - Each household in the most recent available regional travel survey and/or 2009 NHTS was "buffered" individually to ascertain built environment variables affecting travel at trip production locations. "Buffering" is a process of delineating the area within a specified radius of the point of interest (in this case a household) and quantifying the amount of activity within that radius. In this case, for example, the team measured the amount of employment and counted the number of bus stops within a half-mile radius of each household. The team also buffered the geo-location

of each non-home trip-end contained in the travel survey to determine built environment characteristics at the attraction end of each trip.

- Built environment variables captured various measures of density, diversity, design, destination accessibility, distance to transit, demographics, development scale, and key aspects of demand management such as parking price.
- Individual VO, VT and VMT models were tested using various regression formulations, hierarchical linear modeling, log likelihood, binary hierarchical, binary logit, negative binomial and Tobit modeling. (Note: These terms are explained in Appendices A, B and C.)
- Best results and alternative models were summarized for review by the study's Expert Panel.

3) The pilot-test models were reviewed with the Expert Panel. Their recommendations included:

   - Evolve the models as much as possible toward a common sequential form incorporating, for example, the lessons learned from attempts to estimate person travel with the Fresno data which could be incorporated into the approach to modeling person travel in the models for Sacramento, Bay Area, and the other small and medium MPOs.
   - Check elasticities captured in the models with published national elasticities.
   - Consider accessibility in terms of two phenomena, using two variables to address: local accessibility (diversity) and regional accessibility (destination accessibility).
   - Recognize that transit accessibility is not a linear function. At the extreme low sensitivity end of transit availability, consider dropping "outliers." And at the extreme high end of the spectrum, "parse" the dataset into ranges to capture differences in the effects that the variable might have in different portions of the range.
   - While trip chaining may reduce the number of vehicle trips generated in single-use sprawled settings, trip chaining also occurs in mixed urban settings because of the convenience afforded by concentrated attractions.
   - Combine the data in order to increase sample size for the small MPOs, as there may be greater variation between small-, medium-, and large-size MPOs than variation within each of these groups.

The study team incorporated the Expert Panel's recommendations in finalization of Sacramento, Bay Area rail, and Fresno models; and then applied the same methods to the other study regions.

4) For the post-pilot model development, these additional regions were included: the entire San Joaquin Valley, Northern Sacramento Valley, Central Coast, San Diego, and the Inland Empire of the Southern California SCAG region. For each of these areas, UC Davis and Fehr & Peers assembled household travel survey data and buffered built-environment ("D") data for all surveyed households and trip-end coordinates in the 2009 NHTS. The results of the statistical analyses and resulting "D" factor models for each study area are presented in the following section (with details in Attachments).

2. Findings on Regionally-Relevant Relationships

SACRAMENTO AND SAN DIEGO REGIONS

This section summarizes the analysis of statistical relationships between travel and urban form for the Sacramento (SACOG) and San Diego (SANDAG) regions. The Sacramento analysis used the 2000 SACOG household travel survey dataset, and the SANDAG analysis relied upon on the 2009 National Household Travel Survey (NHTS) results for San Diego County.

DATASETS

The Sacramento dataset provides information for 3,941 households and 28,630 trips. The San Diego NHTS dataset provides information for 6,002 households and 43,527 trips.[2] Table 1 summarizes both datasets.

TABLE 1
DATASET STATISTICS

	Sacramento	San Diego
Households	3,941	6,002
Average Persons per Household	2.32	2.45
Average Workers per Household	1.14	0.96
Average Vehicles per Household	1.96	2.10
Trips	28,630	43,527
Average Household VMT	30.08	33.2
Average Household Trips	7.26	7.4
Average Household Vehicle Trips	4.99	4.76
Percentage of Households Making At Least One Vehicle Trip	80.0%	79.7%

Source: NHTS, 2009 and SACOG, 2000.

APPROACH

For each region, we took two approaches to estimating VMT at the household level, as shown in the following figure. The first step to both approaches includes estimating the probability a household will make a vehicle trip using a binary logistic model. Framework 1 (also called the Two-Step Ds Analysis

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[2] Some trips were removed from the dataset due to unidentifiable trip ends or very long trip lengths. Please refer to Attachment D1 of this Appendix for additional information.

Module) then uses a linear regression model to estimate the household VMT. Framework 2 (also called the Three-Step Ds Analysis Module) involves a more complex approach, one that allows for more relationships to be evaluated. After calculating household vehicle trip making probability, two regression models3 are used to estimate the number of vehicle trips and the average vehicle trip length. Household VMT is then calculated as the product of the number of trips and average trip length for each household predicted to make vehicle trips.

Both model frameworks assess travel generation at a household level as a function of each household's demographic characteristics and regional accessibility, as well as the built environment within the buffer area surrounding the household. The Framework 2 models also take into account the built environment and accessibility of each destination to which members of the household travel by buffering the built environment characteristics within half-mile radii around each non-residential location visited. Both model frameworks rely on input of exogenous estimates of household vehicle availability from regional travel models that predict changes in future auto ownership as a function of demographic and income changes, and changes in regional auto and transit accessibility.

Figure 4 (below) illustrates the two-step and three-step sequential modeling approaches under Framework 1 and 2, respectively.

[3] Several model forms were evaluated, including negative binomial and hierarchical linear modeling. However, the linear regression models presented in this chapter had the best results. Please see the SACOG Analysis (Attachment D1) for additional details on the other model forms.

Figure 4. Two-Step and Three-Step Ds Analysis Modules for VMT

Framework 1: **Two-Step Ds Analysis Module**

Household Vehicle Trip Generation Probability
Form: Binary Logistic

D Variables:

- Density (Sacramento and San Diego)
- Diversity (San Diego)

Household VMT Generation
Form: Linear Regression

D Variables:

- Density
- Diversity (Sacramento only)
- Design
- Destinations
- Distance to Transit (San Diego only)

Framework 2: **Three-Step Ds Analysis Module**

Household Vehicle Trip Generation Probability
Form: Binary Logistic

D Variables:

- Density (Sacramento and San Diego)
- Diversity (San Diego)

Household Vehicle Trip Generation
Form: Linear Regression

D Variables:

- Density
- Diversity (San Diego only)
- Distance to Transit (Sacramento only)

Vehicle Trip Length
Form: Linear Regression

D Variables:

- Density
- Diversity
- Design
- Destinations
- Distance to Transit (San Diego only)
- Parking Charges (San Diego only)

VMT

Framework 1: Two-Step Ds Analysis Module

The Two-Step Ds Analysis Module begins with a vehicle trip making probability model that is applied to estimate whether or not a household will make any vehicle trips. The second step then provides a direct estimate of a trip-making household's VMT using a linear regression model. To develop these models, we started with the full list of "D" variables (nearly 40 for each region) in both the SACOG and SANDAG datasets, and performed some initial correlation tests and regression analyses to eliminate some of the variables from the final models. The list was reduced to the most influential variables based upon two criteria: the statistical significance of the variable in predicting the outcome, and the logical intuitiveness of the relationship with the outcome (i.e., does the relationship between the independent and dependent variable make sense)[4]. With the variables reduced to the most relevant factors, the models were refined by making minor adjustments to the list of independent variables and the form of those variables (e.g., log transformed versus untransformed). Ultimately both the vehicle trip probability and household VMT models performed well. In total, the sub-models that comprise the Two-Step Ds Analysis Module include up to six demographic and six household-end built-environment variables that were found to be statistically significant.

- The trip making probability sub-models perform similarly, with nearly 81 percent of cases predicted correctly for Sacramento and more than 82 percent of the cases predicted correctly for San Diego. The Sacramento household VMT model has an R^2 of 0.25 and the San Diego model has an R^2 of 0.22, which is typical for a model of this type.

Tables 2 and 3 (below) present a more detailed look at each step of the model, with symbology to indicate the relative strength and relationship to the outcome (i.e., a positive or negative correlation) of each step. Coefficients and statistical significance of each variable may be found in the Attachments.

Vehicle Trip Making Probability

The first sub-model predicts a binary outcome: whether or not a household will make a vehicle trip. This step is almost entirely dominated by demographic variables for both regions.

- **Sacramento**: The variable that most strongly influences the outcome is the presence of children in the household. Other demographic variables with strong positive correlations to making a vehicle trip include the number of workers, income, and number of vehicles available to the household. Only one "D" variable was found to be statistically significant in this sub-model: residential density, although it has very minor effects on the overall trip-making probability.
- **San Diego**: The most influential demographic variables for San Diego are similar to those for Sacramento. While the actual number of vehicles available to the household (i.e., 1, 2, 3 or more) has a substantial effect, the single most important determinant of the outcome is whether the household has at least one vehicle available. The other variable with a strong positive correlation to making a vehicle trip is the number of workers living in the household. Income also appears to

[4] In some rare cases, we would find variables with marginal statistical significance (e.g., significant at the 85th percentile level) that had counter intuitive relationships with the dependent variable. For example, retail density within a half-mile of the home occasionally had a positive correlation with more VMT. In these cases, the variable was removed and a test was run to see the impact on the model R^2. In no cases did the removal of these counterintuitive variables have a meaningful impact on overall model performance.

have a strong effect, with lower income households being less likely to make a vehicle trip. Again, the influence of the "D" variables is very weak compared to the demographic variables in this model. However, both residential density and the ratio of households to school employment are statistically significant and are negatively correlated with trip making probability.

If the first sub-model indicates a household will not make any vehicle trips, the household VMT will be zero and the household VMT regression model will not be run.

Household VMT

For both regions, demographic variables are influential predictors of household VMT, with the number of workers living in the household having the strongest effect. These relationships are shown in Tables 2 and 3 below.

- **Sacramento**: In addition to number of workers, there are two demographic variables and two urban form variables that have relationships of similar strength to the household VMT, although the direction of the relationships is opposite. An increase in the demographic variables leads to higher VMT and an increase in the urban form variables leads to lower VMT. Those variables are household size, the number of available vehicles, residential density, and destinations accessibility. Intersection density, households/employment diversity, and household income are statistically significant, but appear to have more minor effects on the VMT. These individual effect sizes may, however, be misleading. Other research indicates, for example, that intersection density (design) sensitivity is included in the sensitivities associated with closely correlated "D" variables, such as population and employment density, diversity, destination accessibility and distance from transit. In general, the magnitude of influence of individual variables may be affected by the degree to which they are correlated with and share effects with other "D" variables.
- **San Diego**: In addition to number of workers, significant demographic variables in the San Diego model include household size and number of vehicles, both with strong positive correlations with household VMT. The effect of the "D" variables is weaker, but there are four statistically significant variables in the model. Intersection density is the strongest of the "D" variables, with employment density, destinations accessibility, and distance to transit also having an effect on the household's VMT. Note that all the "D" variables in the Two-Step model framework are measured at the home-end since non-home-end VMT modeling cannot be conducted with the NHTS dataset.

TABLE 2
TWO-STEP Ds ANALYSIS MODULE – SACRAMENTO

Variables		Household Vehicle Trip Generation Probability		Household VMT
Demo-graphics	Household Size			+ +
	Number of Workers	+ +		+ + +
	Income	+ +		
	Low-Income Household Flag			-
	Children in Household Flag	+ + +		
	Number of Vehicles	+ +		+ +
Density	Residential Density at Home End	-		
	Log of Residential Density at Home End			- -
Diversity	Households/Employment Ratio at Home End			-
Design	Intersection Density at Home End			- -
Destinations	Destinations Accessibility at Home End			- - -

TABLE 3
TWO-STEP DS ANALYSIS MODULE – SAN DIEGO

Variables		Household Vehicle Trip Generation Probability		Household VMT
Demographics	Household Size			+ +
	Number of Workers	+ +		+ + +
	Low-Income Household Flag	- -		- -
	Number of Vehicles	+ + +		+ +
Density	Residential Density at Home End	-		
	Employment Density at Home End			-

Diversity	Households/School Employment Ratio at Home End	-		
Variables		**Household Vehicle Trip Generation Probability**		**Household VMT**
Design	Intersection Density at Home End[1]			- - -
Destinations	Destinations Accessibility at Home End			- -
Distance to Transit	Distance to Transit at Home End			+

Fehr & Peers, 2012. 1. This variable is calculated as the natural log of the product of the number of blocks and the number of intersections within a half mile.

Framework 2: Three-Step Ds Analysis Module

Similar to the Two-Step Ds Analysis Module for predicting VMT, when developing the Three-Step Ds Analysis Module for predicting VMT, we considered a total of 33 variables for each region. For the vehicle trip length sub-model, the urban form variables were tested at both ends of the trip. We trimmed this list down to the most influential variables based upon two criteria: the statistical significance of the variable in predicting the outcome, and the logical intuitiveness of the relationship with the outcome (i.e., does the relationship between the independent and dependent variable make sense). For each region, all three of the sub-models performed well. The trip making probability sub-models perform similarly with nearly 81 percent of cases predicted correctly for Sacramento and more than 82 percent of the cases predicted correctly for San Diego. The vehicle trip generation linear regression sub-models have R^2 statistics of 0.23 and 0.20, for Sacramento and San Diego, respectively. For both regions, the R^2 statistics for the vehicle trip length linear regression models were slightly lower (0.19 for Sacramento and 0.12 for San Diego). These results are typical for models of this type.

Tables 4 and 5 (below) for the Sacramento and San Diego regions, respectively present a more detailed look at each sub-model, with symbology to indicate the relative strength and relationship to the outcome (i.e., a positive or negative correlation) of each step. Full details including the coefficients and statistical significance of each variable may be found in the Attachments. Discussion of each model follows.

Vehicle Trip Making Probability

The first sub-model predicts a binary outcome: whether or not a household will make a vehicle trip. This step is almost entirely dominated by demographic variables for both regions.

- **Sacramento**: The variable that most strongly influences the outcome is the presence of children in the household. Other demographic variables with strong positive correlations to making a vehicle trip include the number of workers, income, and number of vehicles available to the household. Only one "D" variable was found to be statistically significant in this sub-model: residential density, although it has very minor effects on the overall trip-making probability.

- **San Diego**: The most influential demographic variables for San Diego are similar to those for Sacramento. While the actual number of vehicles available to the household (i.e., 1, 2, 3 or more) has a substantial effect, the single most important determinant of the outcome is whether the household has at least one vehicle available. The other variable with a strong positive correlation to making a vehicle trip is the number of workers living in the household. Income also appears to have a strong effect, with lower income households being less likely to make a vehicle trip. Again, the influence of the "D" variables is very weak compared to the demographic variables in this model. However, both residential density and the ratio of households to school employment are statistically significant and are negatively correlated with trip making probability.

If the first sub-model indicates a household will not make any vehicle trips the household VMT will be zero. However, if this sub-model predicts the household will make at least one vehicle trip, then the second and third sub-models must be completed to estimate the total household VMT.

Vehicle Trip Generation

The second sub-model estimates the number of vehicle trips made. For both regions, demographic variables again proved to be the most influential in determining how many vehicle trips are generated by each household.

- **Sacramento**: Household size has the strongest effect on vehicle trip generation. Other key demographic variables affecting the number of vehicle trips include the number of workers, the number of available vehicles, the age of the head of household, and income. However, two "D" variables were significant in the model and exhibited the expected correlations with total number of vehicle trips generated. Increased residential density results in lower vehicle trip generation and increased distance to the nearest bus stop results in higher vehicle trip generation. The relative strength of these two variables is small compared with the demographic variables.
- **San Diego**: As is the case with Sacramento, the two strongest demographic variables are household size and number of workers living in the household. Other key demographic variables affecting the number of vehicle trips also largely mirror those found for Sacramento: the age of the head of household, income, the presence of children, and the number of available vehicles. Two "D" variables were also significant in the model. As the residential density and the ratio of households to school employment in the area within a half-mile of the household increase, the household's vehicle trip generation decreases.

Vehicle Trip Length

The third sub-model estimates the average vehicle trip length for each household. This result is then multiplied by the number of vehicle trips to estimate the VMT for each vehicle trip-making household. Urban form variables become substantially more influential in this step of the model.

- **Sacramento**: Although urban form variables become more influential, demographic variables still play a key role in estimating vehicle trip length. The presence of children in the household, gender of the traveler, and age of the traveler are significant. In particular, whether or not a trip's purpose is home-based work plays a very strong role in the estimated vehicle trip length. For all of the "D" variables included in the model, an increase would result in a shorter vehicle trip length, which is consistent with expectations. At the home-end of the trip, the "D" variables with the strongest impact on the estimated trip length include residential density, household/employment diversity score, and destinations accessibility. At the non-home-end of the trip, several variables were found to be significant, as described below.

  One of the new features introduced in the Three-Step analysis framework is the ability to evaluate how the built environment characteristics of the non-home-end of the trip influence travel. Typically, travel and the built environment studies have focused only at the home-end of the trip, since the surveys are collected at the household-level and built environment data is easy to collect for households. However, it has long been suspected the non-home-end of the trip could be as or even more influential when it comes to trip making. The data displayed in Table 4 (below) shows that several non-home-end built environment variables are important in terms of trip length. Specifically, the models indicate that factors such as household/employment diversity and retail/non-retail employment diversity at the non-home-end were strongly correlated with shorter trips. Higher residential density and intersection density (a design variable) at the non-home-end were also correlated with shorter trips, but were less influential.

  In terms of overall influence, the non-home-end diversity and design variables tended to have a larger impact on reducing trip lengths than similar home-end variables. This result is significant since it suggests that non-home-end urban form characteristics are very influential in determining how people travel. This study spent some time trying to develop additional relationships when looking exclusively at non-home-end variables and trip length; the results, however, were inconclusive. We suggest additional research be conducted on the relationships between workplace and retail area urban form and travel choices.

- **San Diego**: Key demographic variables included in the San Diego model include the number of available vehicles, presence of children in the household, and age of the traveler. As was the case with the Sacramento vehicle trip length model, whether or not a trip's purpose is home-based work is one of the strongest variables. At the home-end of the trip, the "D" variables with the strongest impact on the estimated trip length include destination accessibility (proximity of the home to major employment areas) and intersection density.

At the non-home-end of the trip, variables such as household/employment diversity and roadway network density were very influential with respect to trip length. Other variables such as retail/non-retail diversity and household/school employment ratio at the non-home-end were less influential. One other non-home "D" variable also was related to trip length: parking charges, with a positive correlation (areas with parking charges tend to have longer trips). Although this result may seem counter-intuitive at first, it is reasonable given that parking charges tend to occur in areas such as downtown where shorter trips are more likely to be made by transit, walking, or biking, leaving the vehicle trips skewed toward longer travel. Likewise, the downtown area draws from a more regional population, leading to longer vehicle trips. Overall, the relationships between home-end and non-home-end "D" variables are very similar to what was described in the SACOG analysis, with the non-home-end variables having a slightly larger impact on reducing trip lengths compared to similar home-end variables.

Table 4

Three-Step Ds Analysis Module – Sacramento Region

Variables		Household Vehicle Trip Generation Probability	Household Vehicle Trip Generation	Household Vehicle Trip Length
Demographics	Household Size		+ + +	
	Number of Workers	+ +	+ +	
	Income	+ +		
	Low-Income Household Flag		- -	-
	Number of Vehicles	+ +	+ +	+
	Age of Head of Household		+ +	
	Children in Household Flag	+ + +		- -
	Gender of Traveler			- -
	Senior Traveler Flag			- -
	Home-Based Work Trip Flag			+ + +

Density	Residential Density at Home End	-	-	
	Log of Residential Density at Home End			- -
	Log of Residential Density at Non-Home End			-
Diversity	Households/ Employment Diversity at Home End			-
	Retail/Non-Retail Employment Diversity at Non-Home End			- -
	Households/Employment Diversity at Non-Home End			- - -
Design	Intersection Density at Non-Home End			-
Destinations	Destinations Accessibility at Home End			- - -
Distance to Transit	Distance to Transit at Home End		+	
	Transit Travel Time Competitive Trip Flag			-

Fehr & Peers, 2012.

TABLE 5

Three-Step Ds Analysis Module – San Diego Region

Variables		**Household Vehicle Trip Generation Probability**	**Household Vehicle Trip Generation**	**Household Vehicle Trip Length**
Demographics	Household Size		+ + +	
	Number of Workers	+ +	+ + +	
	Low-Income Household Flag	- -	- -	-
	Number of Vehicles	+ + +	+ +	+ +
	Age of Head of Household		+ +	
	Children in Household Flag		+	- -
	Senior Traveler Flag			- -

TABLE 5

Three-Step Ds Analysis Module – San Diego Region

Variables		Household Vehicle Trip Generation Probability	Household Vehicle Trip Generation	Household Vehicle Trip Length
	Home-Based Work Trip Flag			+ + +
Density	Residential Density at Home End	-	-	
	Employment Density at Home End			-
Diversity	Households/School Employment Ratio at Home End	-	-	
	Retail/Non-Retail Employment Diversity at Non-Home End			-
	Households/ Employment Diversity at Non-Home End			- - -
	Households/School Employment Ratio at Non-Home End			-
Design	Intersection Density at Home End			- -
	Walkability at Home End[1]			+
	Roadway Density at Non-Home End			- - -
	Walkability at Non-Home End[1]			+
Destinations	Destinations Accessibility at Home End			- - -
Distance to Transit	Distance to Transit at Home End			+
Parking Charges	Parking Charges at Non-Home End Flag			+

1. This variable is calculated as the ratio of average block size to number of intersections; so a lower score represents a more walkable area.

Choosing Between the Three-Step and Two-Step Ds Analysis Modules

Choosing between the Two- and Three-Step Ds Analysis Modules depends on data availability and the proposed application. The Two-Step VMT Ds Analysis Module does not incorporate non-home-end variables, so less data is required for application. This can be an advantage when estimating VMT from a data source where only home-end information is known. For example, many GIS-based land use planning tools do not go through the trip distribution step, so no information is known about the non-home-end of trips. In these cases, the Two-Step VMT Ds Analysis Module is more appropriate since it does not require additional information. On the other hand, the Three-Step VMT Ds Analysis Module is generally more sensitive to "D" variables and should be used when the data are available. For example, typical four-step and activity-based travel models have information about the home-end and non-home-end of trips. In these situations, the Three-Step VMT Ds Analysis Module will produce results that are more sensitive to "D" variables. This is important since we demonstrated the non-home-end "D" variables are influential, particularly for diversity and design variables.

Overall Ds Analysis Module Performance

Table 6 (below) summarizes the overall performance of the modules included in each framework. The estimates were calculated by using the dataset's average value for each variable within the module. Of all the module, the household trip probability model is least accurate for both regions. However, all of the other model estimates are very accurate, with the model predicting the actual dataset average within less than half a percent error.

TABLE 6
Ds ANALYSIS MODULE PERFORMANCE

	Sacramento		San Diego	
Model	**Dataset Average**	**Model Prediction**	**Dataset Average**	**Model Prediction**
Household Trip Probability[1]	0.80	0.83	0.80	0.90
Vehicle Trip Generation[2]	6.26	6.27	5.98	5.96
Vehicle Trip Length[2]	4.59	4.58	6.52	6.51
Product of Trip Generation and Trip Length: VMT Estimate (Three-Step Ds Analysis Module)	28.70	28.72	38.96	38.79
Household VMT[3] (Two-Step Ds Analysis Module)	37.69	37.69	41.59	41.60

Notes:
1 Element of Two-Step and Three-Step Ds Analysis Module
2 Element of Three-Step Ds Analysis Module
3 Element of Two-Step VMT Ds Analysis Module
Source: Fehr & Peers, 2012.

At the aggregate level, the Two-Step Ds Analysis Module may be slightly more accurate in predicting the total household VMT compared to the Three-Step Ds Analysis module (however the difference is not particularly large). The difference in predictive ability between the two modules is due to the distribution of trip lengths among households. Specifically, some households make many short trips while others make fewer long trips. This partially explains the difference between the dataset and model prediction of average probability of trip-making. It also means overall household VMT is slightly higher than what is predicted by simply multiplying the average number of vehicle trips by the average vehicle trip length.

As shown in Table 6, the Sacramento dataset shows an average household VMT of 37.7 miles, while the product of the vehicle trips and trip length is 28.7 miles. The difference is less pronounced in the San Diego dataset, which has an average household VMT of 41.6 miles, while the product of the vehicle trips and trip length is 39.0 miles. In both cases, we consider the two-step framework a more accurate predictor of total household VMT when the modules are to be applied at the aggregate level, such as grid cell or traffic analysis zone, while the three-step framework offers certain advantages (such as providing vehicle trip estimates) when the modeling process is applied at the individual household level.

Elasticities

The two VMT calculation approaches were analyzed to determine individual elasticities for each "D" variable. This provides a simple way to compare the relative strength of the "D" variables against each other, as well as previously published results from national analyses of many VMT/built environment studies. The national averages shown below come from Ewing and Cervero's 2010 publication, *Travel and the Built Environment: A Meta-Analysis*. Note that these elasticities only relate to the home-end of a trip and are generic in their classifications. To emulate this approach, we combined multiple variables that relate to the same "D" category as noted in Table 7 (below). For instance, the density elasticity for San Diego was calculated by varying both residential and employment density simultaneously. This approach has an additive effect on elasticity in a linear regression model.

Since the national averages did not control for the non-home-end of each trip it is likely that some of the effects of both trip ends are reflected in the overall national elasticity values. Therefore, evaluating the home-end and non-home-end elasticities separately reveals more polarized values, with the national average falling somewhere in between the values for each trip end.

TABLE 7
ELASTICITIES OF "D" VARIABLES

Variable Name	National Average for Home End of Trip	Sacramento				San Diego			
		Three-Step VMT Ds Analysis Module		Two-Step VMT Ds Analysis Module		Three-Step VMT Ds Analysis Module		Two-Step VMT Ds Analysis Module	
		Home End	Non-Home End	Home End	Non-Home End	Home End	Non-Home End	Home End	Non-Home End
Density[1]	-0.04	-0.14	-0.02	-0.11	N/A	-0.05	N/A	-0.04	N/A
Diversity[2]	-0.09	-0.03	-0.32	-0.02	N/A	-0.02	-0.25	-0.01	N/A
Design[3]	-0.12	--[4]	-0.07	-0.13	N/A	-0.07	-0.20	-0.31	N/A
Destinations	-0.20	-0.33	N/A	-0.26	N/A	-0.31	N/A	-0.08	N/A
Distance to Transit	-0.05	-0.02	N/A	--[5]	N/A	-0.02	N/A	-0.04	N/A
Parking Cost	N/A	N/A	--[6]	N/A	N/A	N/A	0.04[7]	N/A	N/A

Notes:
1. For San Diego, density elasticity was calculated by varying both residential and employment density.
2. For Sacramento at the non-home end, diversity elasticity was calculated by varying the retail/non-retail diversity score and the households/employment diversity score. For San Diego, diversity elasticity was calculated by varying the households/school employment ratio, retail/non-retail diversity score and households/employment diversity score.
3. For San Diego, home end design elasticity was calculated by varying the intersection density and walkability scores. Non-home-end design elasticity was calculated by varying the roadway density and walkability scores.
4. Design elasticity is included in elasticities for closely correlated "D" variables, such as density, diversity, destinations, distance from transit. In general, elasticities of individual variables may be affected by the degree to which they are correlated with and share elasticity with other "D" variables in the same data column (same region, model steps form, home/non-home end).
5. Distance to Transit elasticity is included in elasticities for closely correlated "D" variables, such as density and destinations. In general, elasticities of individual variables may be affected by the degree to which they are correlated with and share elasticity with other "D" variables in the same data column (same region, model steps form, home/non-home end).
6. Demand management (parking cost) elasticity is included in elasticities for closely correlated "D" variables, such as density, diversity and design. In general, elasticities of individual variables may be affected by the degree to which they are correlated with and share elasticity with other "D" variables in the same data column (same region, model steps form, home/non-home end).
7. In the San Diego example, one should be careful when interpreting the demand management impacts on VMT. In this oversimplified elasticity test case presented above, the three-step model did indicate that parking charges are correlated with more VMT; however, parking charges were only a significant variable in the trip length model, Therefore, it may be more appropriate to interpret the result above as: Parking charges are correlated with longer trips. The SANDAG regional travel demand forecasting model and the Rail Corridor models described below generally indicate that auto mode choice is strongly and negatively correlated with parking charges. Therefore, while auto trips to areas with parking charges may be longer, overall VMT is likely to be less when considering mode choice effects.

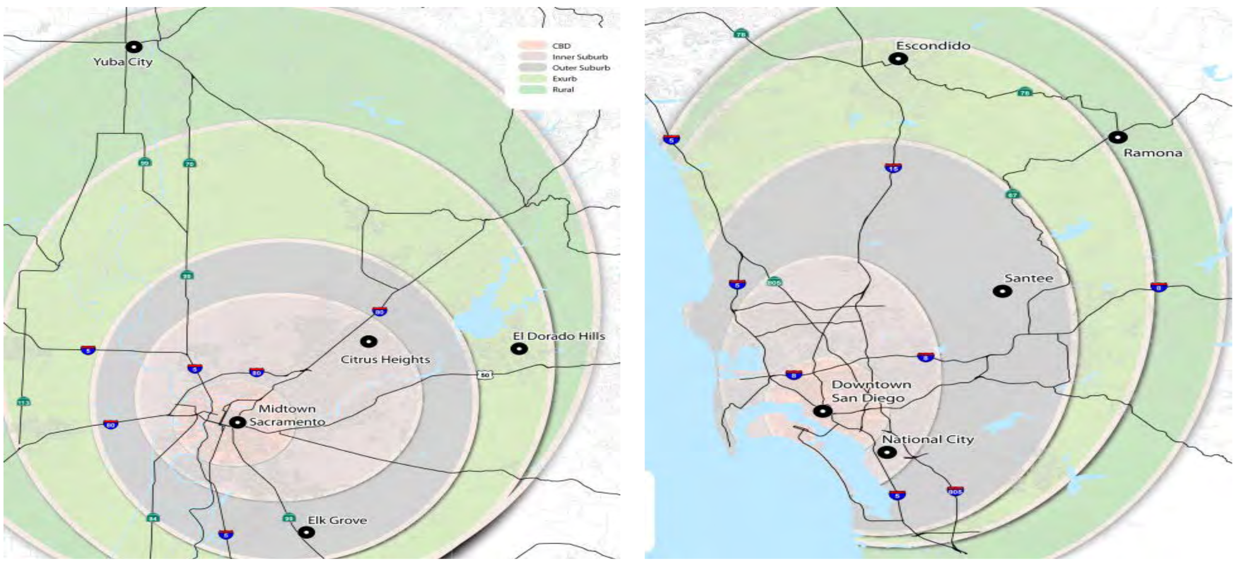
It is important to note that the parking cost elasticity is based solely on the trip length model. While this analysis was not able to definitively determine the impacts of parking cost on mode choice, other research suggests the influence is strong and significant. Therefore, while individual vehicle trips may be longer to areas at which parking fees are charged, other modes are used more frequently in such places, which is likely to reduce overall household VMT generation.

Relative Travel for Different Regional Area-Types

To test the VMT models' ability to represent differences among land use planning concepts generally applied in regional scenario planning, we compared the model estimates to survey data for a sample of households located in various urban settings.

The Area-Types tests consisted of choosing five locations within each region with varying settings and urban form characteristics. The areas include the central business district, an inner suburb, an outer suburb, an exurb, and a rural area.

Figure 5. Regional Test Site Locations



SACOG region SANDAG region

In the SACOG region, we selected sample households located in the following areas: central business district (Midtown), an inner suburb (Citrus Heights), an outer suburb (Elk Grove), an exurb (El Dorado Hills), and a rural area (Yuba City). In the SANDAG region, we selected the San Diego central business district (Midtown), an inner suburb (National City), an outer suburb (Santee), an exurb (Escondido), and a rural area (Ramona). The test site locations for each region are shown in Figure 5 (above).

Within each of those areas, clusters of five households were identified and both the Two-Step and Three-Step Ds Analysis Modules were applied to each. Because only a limited number of survey households were available in each sub-area, the comparisons would be considered anecdotal rather than statistical, and the analysis may be somewhat biased. Table 8 (below) shows the demographic characteristics of the selected households within each area-type, indicating that the small samples may not be fully representative of typical households within their regional area-types.

TABLE 8

COMPARISON OF SELECTED SOCIOECONOMIC CHARACTERISTICS FOR DIFFERENT AREA-TYPES

Area-Type	Sacramento			San Diego		
	Household Size	Average Income	Vehicles Available	Household Size	Average Income	Vehicles Available
Central Business District	1.4	$37k	1.0	2.4	$79k	2.2
Inner Suburb	2.0	$58k	1.6	1.6	$27k	0.6
Outer Suburb	2.8	$74k	2.6	1.8	$63k	2.2
Exurb	3.0	$80k	3.4	2.6	$63k	2.0
Rural	2.6	$39k	1.6	2.0	$29k	1.2

As Table 8 indicates, the small sample sizes result in considerable variability in the selected socioeconomic characteristics. For example, the Sacramento exurban area-type has substantially higher vehicle availability than does the outer suburban area-type, despite similar household sizes and income levels. In San Diego, the inner suburban area-type has very low income and vehicle availability when compared to other area-types. This variability leads to considerable differences in observed and modeled VMT in Table 9 (below). As described earlier, the results in Table 8 are not intended to be representative of all travel within the area-types, but are shown to demonstrate the models' adaptability to different demographic and built environment contexts.

TABLE 9

COMPARISON OF ACTUAL SURVEYS VS. MODEL ESTIMATES OF DAILY VMT PER HOUSEHOLD FOR DIFFERENT AREA-TYPES

Area-Type	Sacramento			San Diego		
	Actual VMT From Survey	Three-Step Ds Analysis Module VMT Estimate	Two-Step Ds Analysis Module VMT Estimate	Actual VMT From NHTS Survey	Three-Step Ds Analysis Module VMT Estimate	Two-Step Ds Analysis Module VMT Estimate
Central Business District	16.6	12.3	4.5	28.1	24.5	41.5
Inner Suburb	26.0	24.4	34.3	1.6	1.9	4.6
Outer Suburb	55.1	37.6	50.6	45.0	41.3	39.9

Exurb	92.6	47.8	57.4	35.6	31.2	38.7
Rural	12.0	28.0	31.1	33.5	23.2	26.6

Fehr & Peers, 2012.

Sacramento

Both the Three-Step and Two-Step Ds Analysis Modules performed fairly well at predicting the relative household VMTs for the area-types. In general, the magnitudes of the predicted daily VMT per household were below the actual data. Therefore, the SACOG model frameworks may be better suited as pivots from a reliable baseline VMT as opposed to directly estimating VMT. In general, the Two-Step VMT Ds Analysis Module did a better job of predicting the high VMT areas while the Three-Step VMT Ds Analysis Module was better at predicting the low VMT areas. Neither model performed particularly well at predicting the VMT of the rural area.

San Diego

In general, we feel the Three-Step VMT Ds Analysis Module performed better in the area-type tests. The model did well in matching the observed data from the NHTS survey for all cases, although the Three-Step Ds Analysis Module did under-predict the VMT of rural households. The Two-Step Ds Analysis Module matched general trends; however the model substantially overestimated the VMT of the more dense and diverse Central Business District (CBD) neighborhood.

One area-type stands out as an outlier – the Inner Suburb. The reason the VMT is so low for the inner suburb is that only two of the five households sampled made any vehicle trips. Moreover, the vehicle trip-making probability model only predicted that one of the households would make a vehicle trip – so VMT was only calculated for a single household, but averaged over all five. This area-type was significant since it demonstrated that the vehicle trip-making probability model can reasonably predict households with no vehicle travel. Another issue worth noting is the observed and estimated VMT in the CBD is higher than was initially expected. A closer look at the demographics of the selected households in the CBD indicates all five sampled households have fairly high incomes, and at least two of the households have three or more cars; plus, one household has four workers. This resulted in relatively high VMT estimates from the Ds Analysis Modules.

Overall Conclusions of Area-Type Analyses

The model area-type tests indicate the following:

- In actuality, there are large variations in vehicle miles of travel even among households with similar socioeconomic characteristics in similar urban form settings. This is illustrated through comparison of the actual average survey VMT of the Sacramento small samples to the San Diego surveys. The regional small samples of VMT differ from one another by at least 22% and by as much as 16-fold, with neither region being consistently higher than the other.

- The Ds Analysis Modules smooth out the individual household variations while capturing the generally expected travel generation trends present as one moves from one regional area-type to another. With one or two exceptions the general area-type trend is that household VMT increases as one moves from the central business district through inner and outer suburbs to exurbs.
- The primary exceptions include situations in which household demographics, such as household size and age of family members, significantly influence travel. This is exhibited in the San Diego inner suburb of National City, where household travel is significantly lower than other areas. Both the two-step and three-step models capture this combination of unique characteristics, closely matching the survey data.
- Where regional accessibility and other "D" factors result in lower trip generation for exurban areas than for outer suburbs, as is the case in the San Diego examples, the models respond accordingly.
- Travel in remote rural areas can be lower than in exurbs and outer suburbs, as isolated areas whose households are less economically tied to the urban core of their region tend to "self-contain" the majority of their travel, particularly related to schools, shopping and social/recreation. The models generally capture this relationship, producing household VMT rates for the rural area -types that are lower than the respective regions' outer suburban and exurban trip rates.

In general, these findings provide confidence that the Ds Analysis Modules track well with both unique and general variations in travel throughout a region as influenced by demographic, locational and urban form characteristics.

SMALLER METRO REGIONS

This section summarizes the travel and the built environment statistical analysis completed for a set of smaller metropolitan regions throughout the State of California. This analysis uses the latest National Household Travel Survey (NHTS) and relatable land use/built-environment data; both the NHTS and land use data represent 2008 to 2009 conditions. Four geographical regions were analyzed: California's Central Coast, Inland Empire, Northern Sacramento Valley, and San Joaquin Valley. There are 20 California counties within these four regions, each of which is represented by a Metropolitan Planning Organization (MPO) or a Regional Transportation Planning Agency (RTPA). Table 11 below provides a comparison of the range of variation in the demographic and land use variables among the smaller areas.

The analysis is presented by first describing the datasets used, and then showing the Ds Analysis Modules built for this effort. The Ds Analysis Modules conceived for the smaller metropolitan regions take inspiration from the four-step transportation model. Two Ds Analysis Modules – a two-step and three-step module – were built to estimate household vehicle miles traveled (VMT). These two sequential modules use binary logit and ordinary least squares (OLS) regression models to capture the built environment's effects on travel.

DATASET

A total of 4,435 households were surveyed in the four geographic regions analyzed, and these households reported a total of 36,049 trips. The household data is distributed across the regions in proportion similar to their population, where 17% (735) of the survey records are found in the Central Coast region, 36% (1,614) are found in the Inland Empire, 10% (439) are found in the Northern Sacramento Valley, and 37% (1,647) are found in the San Joaquin Valley. Figure 6 (below) charts the survey records, and Figure 7 charts the geographical distribution. Table 10 (below) shows the distribution of survey records by county,

Figure 6. Geographic Distribution of NHTS Dataset

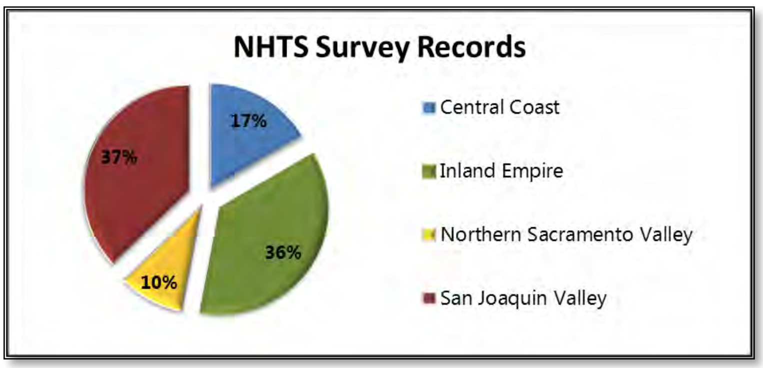
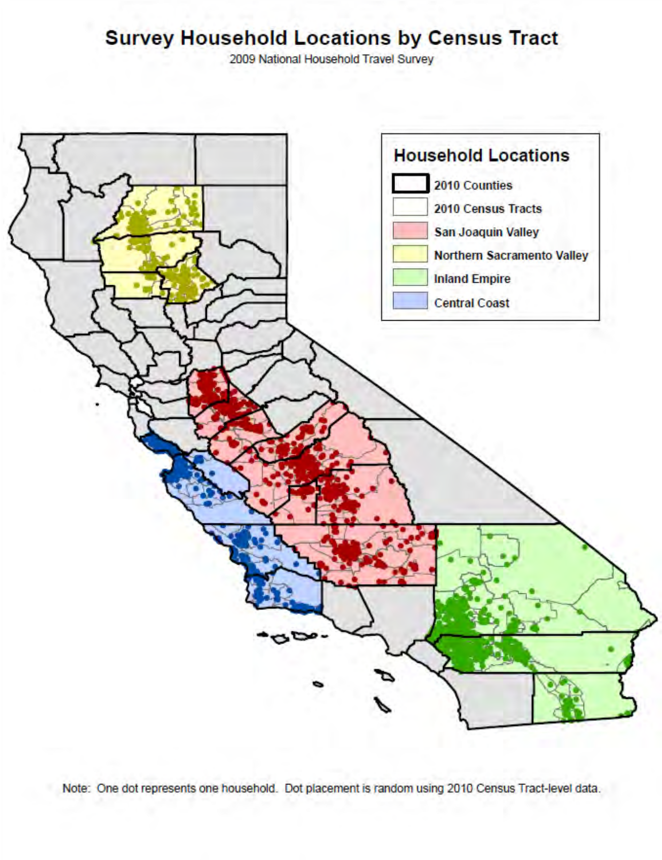


Figure 7. NHTS Travel Survey Record Regional Distribution



The NHTS survey records were joined with half-mile radius land use data to provide two separate travel/built-environment data files. One dataset corresponds to household travel data and its corresponding household land use metrics, and the other file corresponds to all the trips characteristics accounted for by the household and its corresponding trip origin and trip destination land use metrics. These data are related hierarchically, and can be used to develop discrete choice and regression models.

TABLE 10

SMALLER METROPOLITAN REGION DATASET

California Region	County	Total Households	% Urban
Central Coast	Monterey County	167	81%
	San Benito County	16	81%
	San Luis Obispo County	173	77%
	Santa Barbara County	201	96%
	Santa Cruz County	178	76%
	Region Total:	735	83%
Inland Empire	Imperial County	48	79%
	Riverside County	802	83%
	San Bernardino County	764	90%
	Region Total:	1,614	86%
Northern Sacramento Valley	Butte County	185	84%
	Glenn County	17	71%
	Shasta County	176	66%
	Tehama County	61	38%
	Region Total:	439	70%
San Joaquin Valley	Fresno County	381	82%
	Kern County	309	78%
	Kings County	63	84%
	Madera County	64	53%
	Merced County	89	87%
	San Joaquin County	306	82%
	Stanislaus County	262	87%
	Tulare County	173	75%
	Region Total:	1,647	81%
Total Small Regions	20 Counties	4,435	82%

From the start of this study, pooling the smaller regions data set was considered - not only as a way to increase sample size, but also in light of the fact that attributes such as commute times and mode splits do not vary greatly among smaller MPOs. i.e., there is greater variation in such factors between small-, medium-, and large-size MPOs than there is variation within each of these smaller geographical regions. Table 11 (below) summarizes key travel statistics for these four regions.

TABLE 11

TRAVEL STATISTICS ACROSS REGIONS

Parameter	Central Coast	Inland Empire	Northern Sacramento Valley	San Joaquin Valley	Full Dataset [a]
Households	735	1,614	439	1,647	4,435
Average Persons per Household	2.34	2.64	2.28	2.64	2.56
Average Workers per Household	0.91	0.94	0.81	0.92	0.91
Average Vehicles per Household	2.11	2.16	2.21	2.11	2.14
Person Trips	5,807	13,138	3,385	13,719	36,049
Average Household VMT	48.36	51.56	50.95	44.94	48.51
Average Household Trips	7.9	8.1	7.7	8.3	8.1
Average Household Vehicle Trips	4.75	5.04	5.09	5.09	5.02
Percentage of Households Making At Least One Vehicle Trip	80.0%	82.2%	81.5%	80.8%	82.1%
Average Vehicle Trip Length	9.7	9.3	10.4	9.4	9.51 miles
Mode Split					
Private Motorized Vehicles	80.4%	86.7%	88.5%	84.4%	85.0%
Non-Motorized	15.4%	10.2%	9.6%	11.9%	11.5%
Transit/Other	4.2%	3.1%	1.8%	3.7%	3.4%

[a] Source: NHTS, 2009.

After analyzing each regional dataset and having noted that few non-auto trips were reported, and that each region by itself did not possess a large amount of data to conduct a robust analysis for underreported cohorts (such as lower income groups and zero-home households), it was deemed appropriate to pool the smaller metropolitan regions' data. First, however, tests were included to assess any statistically significant variation in relationships among regions. Indicator (or dummy) variables were included in the analysis: these variables aimed at controlling the effect that unique regional factors had on the dependent variables (vehicle trip generation, trip length, or VMT). In most cases, there were enough land use variables to control the differences across each of the regions and their corresponding area-types, so that the region-specific variables did not show statistical significance.

How the Fresno Pilot Study Informed the Smaller Metro Analysis

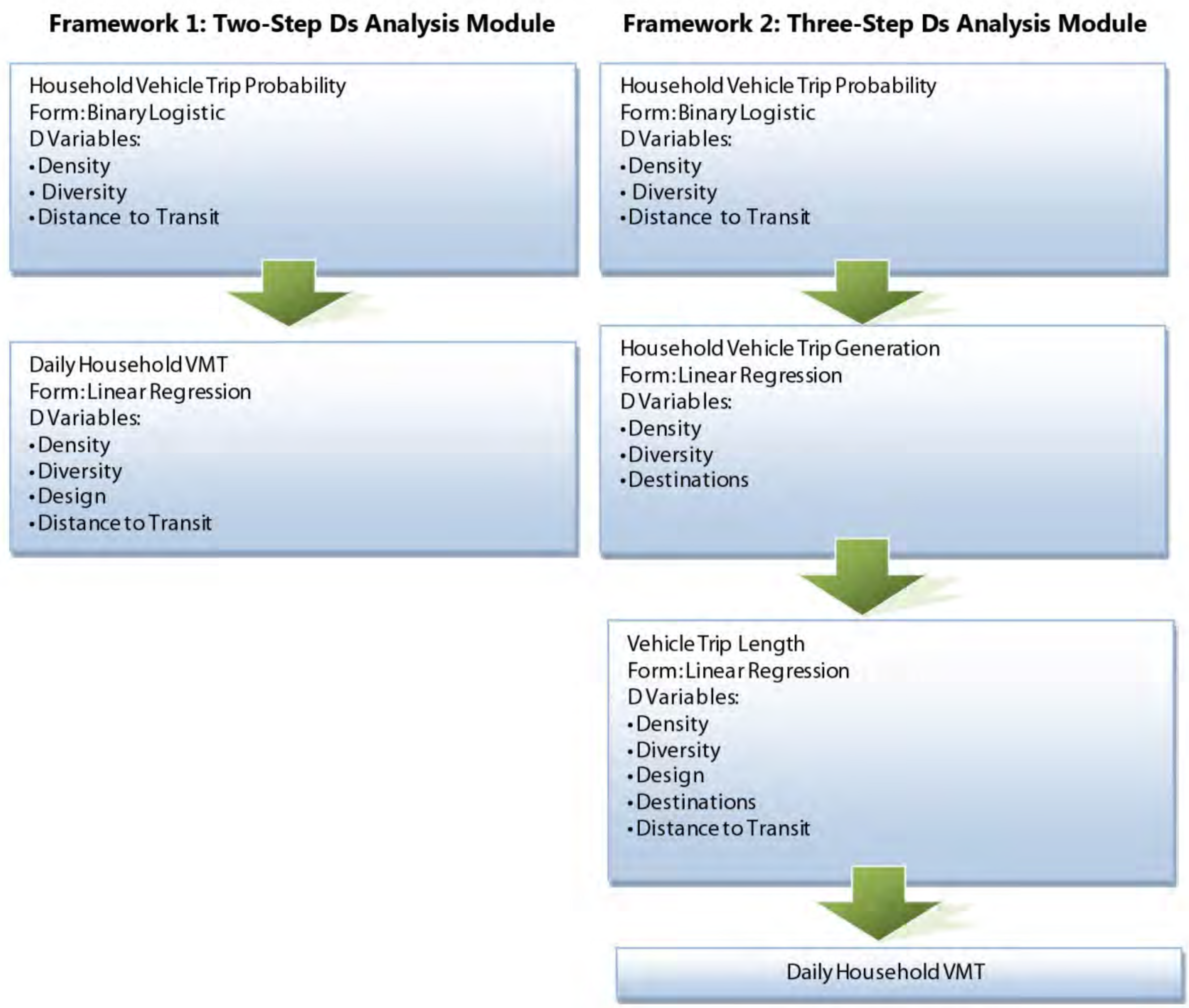
The modeling structure used for the Fresno pilot-study analysis was patterned after the traditional travel decision process captured in four-step transportation models. For this pilot study a three-step sequential model was conceived where person trip generation, mode choice, and trip length were combined to produce VMT estimates. The group analysis of the small metro regions reported in this chapter is more robust than the analysis methods tested in the Fresno pilot study. The smaller region analysis provides more statistical relations with greater statistical significance, not only due to a larger sample size (535 vs. 4,435 survey records), but also because more refined built environment variables were introduced in the smaller regional models. Additional information on the Fresno Pilot study can be found in Appendix C.

An interesting finding of the pilot study which was not explored with the combined smaller region data is the effect of built environment Ds at the person trip-generation level. The pilot study found it is not necessarily reasonable to assume a compatible balance of jobs and housing or a walkable transportation network actually reduces the number of *person* trips generated in a household. Evidence and intuition both suggest such neighborhood characteristics generally reduce motorized vehicle travel, and may actually encourage a greater amount of short distance (often walking and bicycling) travel. Future research could focus on the health impacts associated with the built environment. The Fresno pilot study indicated a sequential modeling structure is an appropriate way to quantify the effects that the built environment Ds have on travel behavior.

Statistical Analysis Approach

As mentioned earlier, two Ds Analysis Modules or Frameworks were developed to estimate household VMT. These two modules are shown in Figure 8 (below). The first step in both modules entails estimating the household vehicle trip making probability using a binary logistic model. Framework 1 (the Two-Step Ds Analysis Module) provides a direct approach, using first the probability model and then the linear regression model to estimate household VMT. Framework 2 (the Three-Step Ds Analysis Module) is composed of the vehicle probability model and two linear regression models, one to estimate household vehicle trip generation and the other to estimate vehicular trip lengths. Daily household VMT is then calculated as the product of the trip generation model and the trip length model.

Figure 8. Ds Analysis Module Frameworks



Framework 1: Two-Step Ds Analysis Module

The Two-Step module produces discrete daily household VMT estimates by first applying the vehicle trip making probability model, and then by the direct estimation of household VMT. The binary logit probability model is applied to estimate whether or not a household makes any vehicle trips. The second step in the sequence provides a direct estimate of a particular household's VMT using a linear regression model. The binary logit model has a Nagelkerke R2 of 0.36, and the VMT linear model has an R2 of 0.19. These statistical performance measures are as expected for these types of models. Table 12 (below) presents a more detailed look at each step of the model, with symbols to indicate the relative strength and relationship to the outcome of each step. The actual coefficients and statistical significance test for each model can be found in the Attachments to this Appendix.

Vehicle Trip Probability

The first step of the module sequence predicts a binary outcome: whether or not a household will make a vehicle trip. Household size (i.e. 1, 2, 3 or more) has a powerful effect; in addition, household income, worker count, driver count, and the presence of children in the households show strong positive correlation to making a vehicle trip. In this model, not having a household vehicle, as expected, shows a strong negative effect on the probability of making a vehicle trip. The influence of the "D" variables is weaker as compared to the demographic variables in this model. However, two density variables, net residential acres and net developed acres, are statistically significant and are negatively correlated with vehicle trip making. In addition, a diversity variable, employment/household balance, shows a statistically significant and negative correlation to vehicular trip making. Lastly, the distance to transit shows weak statistical significance: the closer a household is to rail the lower the probability of making a vehicle trip. The results in this model made sense, and correspond to relationships found in previous research efforts.

VMT Regression Model

The second step in this module predicts daily household VMT. The demographic variables are the most influential predictors of household VMT, with household income, number of workers, number of household vehicles, and number of household drivers showing strong positive correlations with household VMT. The effect of the built-environment variables on VMT was also found to be significant. Six statistically significant "D" variables were found in this regression model. Street density is the strongest of the "D" variables, and affects VMT negatively. Employment density, residential density, and minor commercial density also show statistical significance in the reduction of household VMT. Land use entropy, a variable that aims to capture the diversity of land uses within half-mile from a particular household, shows a statistically significant reducing effect on VMT. Finally, distance to transit also has a reductive effect on household VMT. All the "D" variables included in the Two-Step model are measured at the home-end, since attraction-end (or non-home-end) "D" variables could not be captured within the direct VMT model framework.

TABLE 12

TWO-STEP Ds ANALYSIS MODULE OVERVIEW

Variables	Household Vehicle Trip Probability Effect [a]	Household Daily VMT Effect [a]
Demographics		
HH _VEH_CAT_0 [Zero vehicle household]		
HH_SIZE_CAT_1 [one person household]	+	
HH_SIZE_CAT_2 [two person household]	+	
Workers in Household	+ +	+ +
Drivers in Household	+ + +	+ +
Household with children 0 - 15 yrs old	+	
Household with children 16- 21 yrs old	+	
Income by $10K increments	+	+ + +
Household Vehicle Count		+
Density		
Household population/residential acres in 1/2 mile buffer		
Sum of developed acres in 1/2 mile buffer		
Record in urban area		
Total jobs in 1/2 mile buffer		
Minor commercial acres in 1/2 mile buffer		
Diversity		
Land use mix within 1/2 mile buffer (entropy index)		
Number of jobs per household within 1/2 mile buffer		
Design		
Roadway density		
Distance to Transit		
Nearest railroad station (converted to miles) [b]	+	+

Notes: [a]
The "+" symbol denotes positive effect; "-" symbol denotes negative effect. One symbol denotes <10% of total absolute model effect; two symbols denote between 10% and 20%; three symbols denote >20%.

Framework 2: Three-Step Ds Analysis Module

In the Three-Step VMT Ds Analysis Module, a total of one regional variable, four trip level variables, 12 demographic variables, and 18 built-environment variables were found to be statistically significant. The three models in this sequence performed well, and produced robust estimations. The trip making probability model predicts more than 85 percent of the cases correctly, and the two linear regression models have R^2 ranging from 0.11 to 0.17, which is typical for regression models of this type. Table 13 presents a more detailed look at each step of the model, with symbols to indicate the relative strength and relationship to the outcome (i.e., a positive or negative correlation) of each step. As previously stated, the coefficients and statistical significance of each variable can be found in Appendix C.

Vehicle Trip Probability

The first step of the module sequence predicts the household's vehicle trip probability, just like in the two-step module. The second step in the sequence predicts vehicle trip generation. While the first step predicts whether a household makes any vehicle trips during the day, the second model predicts the number of vehicle trips generated by the household. If the first step of the model indicates a household will not make any vehicle trips the estimated household VMT is zero. However, if the first step predicts the household will make at least one vehicle trip, the second and third steps are used to predict the total household VMT.

Vehicle Trip Generation Regression Model

The second step of the module is the vehicle trip generation model. These models have been widely studied, and it has been concluded that household size, vehicle count, and income are the most powerful predictors for vehicle trip generation at the household level. Cross classification methods that include these three variables have been widely used in transportation planning. In the smaller region analysis, these same demographic variables proved to be most influential. The number of workers in the household also had a powerful effect in the estimation of vehicle generation. In addition, three built-environment "D" variables proved to be statistically significant in the model. As the residential density increases, vehicle trip generation decreases; and as the job/household ratio increases, household vehicle trip generation decreases; lastly, transit accessibility to retail locations proved to be statistically significant in reducing vehicular trip generation.

Vehicular Trip Length Regression Model

The third step of the module estimates the average trip length for each household. This model was specified by regressing all the vehicle trip lengths produced by the surveyed households against trip characteristics (such as home-based-work, non-home-based, age and gender of the trip driver), demographic characteristics (i.e., household size, vehicle count, and presence of children), and the built-environment variables at both the home-end and the non-home-end. This trip length model is unique in many respects. One of the innovative features of this model is its ability to incorporate attraction-end (or non-home-end) built environment variables. The vehicle trip length model can be applied in different ways: for the purpose of this sequential model, trip level characteristics are included as independent variables in order to estimate the trip length of each individual trip made by the household. After each trip length has been estimated, the average trip length for each household is calculated.

The result from the average trip length model is then multiplied by the number of household vehicle trips to estimate the VMT for each trip-making household (i.e., the household-level average trip length from step three is multiplied by the household-level number of trips generated in step two). Built environment variables are more influential in this step of the model. At the home-end of the trip, the "D" variables with significant impact on trip length include density, where household density, employment density, and total developed acres show a reducing effect on trip lengths; diversity, where the job/household balance shows statistical significance in reducing trip lengths; design, where intersection and street density shows a strong effect in the reduction of trip lengths; destination, where accessibility to retail location shows a reductive effect on trip length; and distance to transit, where proximity to a rail line reduces trip lengths.

At the non-home-end of the trip, six built-environment variables were found to be statistically significant. Density, in the form of household and minor commercial density, resulted in a reductive effect on trip lengths. The statistically significant non-home-end Diversity variables that prove to be the most powerful in reducing vehicle trip lengths were job mix, employment entropy, and land use entropy. Design, in the form of intersection and street density, was found to have a trip length reducing effect. In terms of overall influence, the non-home-end diversity and design variables tended to have a larger impact on reducing trip lengths than similar home-end variables. These results are significant since they suggest that non-home-end urban form characteristics are also influential in determining travel behavior.

These relationships are shown in Table 13 (below).

TABLE 13
THREE-STEP Ds ANALYSIS MODULE OVERVIEW

	Variables	Household Vehicle Trip Generation Probability Effect [a]	Household Vehicle Trip Count Effect [a]	Vehicle Trip Length Effect [a]
Regional Indicator	Home in San Joaquin Valley			
Trip Variables	Age of Respondent			
	Respondent is Female			
	Home-Based-Work Trip			+
	Non-Home-Based Trip			+
Demographics	HH _VEH_CAT_0 [Zero vehicle household]			
	HH_SIZE_CAT_1 [one person household]	+		
	HH_SIZE_CAT_2 [two person household]	+		
	HH_SIZE_CAT_3 [3 person household]			
	Workers in Household	+ +	+ + +	
	Drivers in Household	+ + +		
	Household with children 0 - 15 yrs old	+		
	Household with children 16 - 21 yrs old	+		
	Income by $10K increments	+	+ + +	
	Household Size			
	Household Vehicle Count			+
	Number of Drivers in Household			+
Density	Home-End Household Density			
	Home-End Employment acreages			
	Home-End in Urban Core			
	Household population/residential acres			
	Sum of developed acres			
	Non-Home-End Household Density			
	Non-Home-End Minor Commercial emp.			
Diversity	Number of jobs per household			
	Home-End Employment Mix			
	Non-Home-End Job Mix			
	Non-Home-End Employment Mix			
	Non-Home-End Entropy calculation			
Design	Home-End Roadway and Intersection density			
	Non-Home-End Roadway and Intersection density			
Destination	HH Transit Time based Retail Accessibility			
	Home-End Attractions- Distance-based			
Distance to Transit	Home-End Nearest railroad station	+		+

Notes:

The “+" symbol denotes positive effect; the "-" symbol denotes negative effect. One symbol denotes <10% of total absolute model effect; two symbols denote between 10% and 20%; three symbols denote >20%.

Differences between Three-Step and Two-Step Ds Analysis Modules

The two modules developed for California's smaller metropolitan regions provide a way to quantify the effect the built environment has on travel at the local level. Each of these models could be applied to estimate the effects of land use on vehicular travel at the sketch-planning tool level or at the travel demand forecasting level. The Two-Step model is the simpler of the two and requires less data for application. However, it does not incorporate as many built-environment variables as the Three-Step model; the Two-Step contains 10 "D" variables, while the three-step contains 18 "D" variables.

As described earlier, the Two-Step Ds Analysis Module does not incorporate non-home-end variables. This can be an advantage when using this model to estimate VMT from a data source where only home-end information is known. For example, many GIS-based land use planning tools do not go through the trip distribution step, so no information is known about the non-home-end of trips. In these cases, the Two-Step model is more appropriate since it does not require additional information.

On the other hand, the Three-Step VMT Ds Analysis Module is generally more sensitive to "D" variables and should be used when the data are available. For example, typical four-step and activity-based travel models have information about the home and non-home-end of trips. In these situations, the Three-Step model will produce results that are more sensitive to the "D" variables. This is important since this study demonstrates the non-home-end "D" variables are influential, particularly for the density, diversity and design variables. At the aggregate level, the Three-Step model is slightly more accurate in predicting the total household VMT as compared with the Two-Step model (See Appendix C). The difference in predictive ability between the two models is due to the refinements in calculating average trip lengths.

Overall Ds Analysis Module Performance

Table 14 (below) summarizes the overall performance of the two modules. The estimates were calculated by using the dataset's average value for each dependent (or response) variable within the models. Of all the models, the household trip probability model is least accurate, predicting 95 percent of households would make vehicle trips rather than the data average of 81 percent. However, all other model estimates are more accurate; the model predicts the actual dataset average within less than eight percent error.

TABLE 14
AVERAGE Ds ANALYSIS MODULE PERFORMANCE INDICATORS

Model	Dataset Average	Ds Analysis Module Prediction Average
Household Vehicle Trip Probability [a]	0.81	0.95
Vehicle Trip Generation [b]	5.02	5.03
Vehicle Trip Length [b]	9.51	8.76
Household VMT [c] (Two-Step Module)	42.7	39.7
Household VMT [b] Estimate (Three-Step Module)	42.7	43.7

Notes: (Source: Fehr & Peers, 2012)
[a] Element of Two-Step and Three-Step Module
[b] Element of Three-Step VMT Ds Analysis Module
[c] Element of Two-Step VMT Ds Analysis Module

The two Ds Analysis Module developed for this study were validated by comparing the model's built environment elasticities to those previously found in other research efforts. This provides a simple way to compare the relative strength of the "D" variables against each other, as well as vetting results with previously published research. One of the most useful documents, and quoted in Table 6, is "Travel and the Built Environment" by Reid Ewing and Robert Cervero (JAPA, 2010).5 In this paper, a national meta-analysis is presented in which VMT elasticities found in various analyses are synthesized. In addition, Handy and Baronet "Policies and Practices" summaries posted on the California Air Resources Board website have also been taken into consideration.

Note that these elasticities only relate to the home-end of a trip and are generic in their classifications. To emulate this approach, we combined multiple variables that relate to the same "D" category. For instance, the density elasticity was calculated by varying both residential and employment density simultaneously. Note that this approach has an additive effect on elasticity in a linear regression model. More detailed elasticity computations were conducted for both the two-step and the three-step model. These elasticities can be found in Attachment D3 to this Appendix.

5 Travel and the Built Environment," Journal of the American Planning Association, Summer 2010. Reid Ewing and Robert Cervero. http://dx.doi.org/10.1080/01944361003766766

TABLE 15

VMT ELASTICITIES OF BUILT-ENVIRONMENT VARIABLES

Variable Name	National Average for Home End of Trip **	Two-Step Ds Analysis Module		Three-Step Ds Analysis Module	
		Home End	Non-Home End	Home End	Non-Home End
Density [a]	0.00 to -0.04	-0.06	N/A	-0.08	-0.04
Diversity [b]	-0.02 to -0.09	-0.08	N/A	-0.06	-0.14
Design [c]	-0.12	-0.17	N/A	-0.04	-0.21
Destinations	-0.05 to -0.22	N/A	N/A	-0.06	N/A
Distance to Transit	-0.05	-0.04	N/A	-0.04	N/A

Notes:
** Travel and the Built Environment by Reid Ewing and Robert Cervero (JAPA, 2010)
[a] Density elasticity was calculated by varying, residential, employment, and minor commercial densities at the same time. In the Three-Step model, developed acres were also adjusted. More details can be found in Appendix C.
[b] Diversity elasticity was calculated by varying the job/household ratio, land use entropy, and employment entropy at the same time. More details can be found in Appendix C.
[c] Design elasticity was calculated by varying the intersection and street densities. Non-home-end design elasticity was calculated by varying the roadway density. More details can be found in Appendix C.

Area-type Analysis

We developed an "area-types" analysis to help judge how well each Ds Analysis Module operates under demographic and built environment situations that are more representative of real-world conditions. This analysis is designed to complement the elasticity tests shown above. While the elasticity tests confirmed the modules respond well to individual variables, the area-type tests are designed to determine how well the modules respond to many "D" variables changing simultaneously, and to explore the variation in effects among urban, suburban/exurban, and rural locations.

We selected five households from three location types (urban, suburban/exurban, and rural) in five different counties among the smaller regions, for a total of 75 household records. We also selected the 599 corresponding trip records reported by those households. We then applied the models to this subset of data to see how the model performs in a variety of locations. The model appears to more accurately predict travel in suburban and rural locations; however, due to the small sample size, one or two outliers can substantially affect the model outcome.

The area-type analysis conducted for the Two-Step Ds Analysis Module shows this model performs well even in the context of a small sample dataset, providing a 7% overall error in predicting household VMT. Table 15 presents the summary of the area-type analysis results, and more information can be found in

Appendix C, where a complete set of statistics and elasticity calculations are provided. Table 15 below presents the three major area-types used in this analysis: urban, suburban/exurban, and rural. As shown, the Two-Step model performs better for the rural and suburban locations than for the urban locations.

TABLE 15
TWO-STEP Ds ANALYSIS MODULE AREA-TYPE ANALYSIS

Area-type[a]	p(VT)		Household VMT		VMT
	Predicted	From Data	Predicted	From Data	% Error
Urban	1.0	0.8	29.8	38.1	-22%
Suburban/Exurban	1.0	1.0	37.0	40.0	-7%
Rural	1.0	1.0	58.2	57.0	2%

Notes:
[a] For each County, 15 household records were extracted: 5 Urban, 5 Suburban/Exurban, and 5 Rural.

The area-type analysis conducted for the Three-Step Ds Analysis module shows the superiority of this framework compared to the Two-Step Ds Analysis module. The Three-Step Ds Analysis module has only a 2% overall error in predicting household VMT. Additionally, the Three-Step model estimates travel in various area-types with more accuracy.

Table 16 presents a summary of the area-types analysis results, (and more information can be found in Attachment D3 to this Appendix).

TABLE 16
THREE-STEP Ds ANALYSIS MODULE ANALYSIS

Area-type[a]	p(VT)		VT		VTL		VMT		VMT
	Predicted	From Data	Predicted	From Data	Predicted	From Data	Predicted	From Data	% Error
Urban	1.0	0.8	5.6	4.7	5.5	5.5	31.2	31.1	0%
Suburban/Exurban	1.0	1.0	5.9	6.8	7.2	7.3	42.8	40.0	7%
Rural	1.0	1.0	6.2	5.0	9.1	12.4	57.1	57.0	0%

Notes:
[a] For each County, 15 household records were extracted: 5 Urban, 5 Suburban/Exurban, and 5 Rural

Additional Findings: Attraction-End Modeling

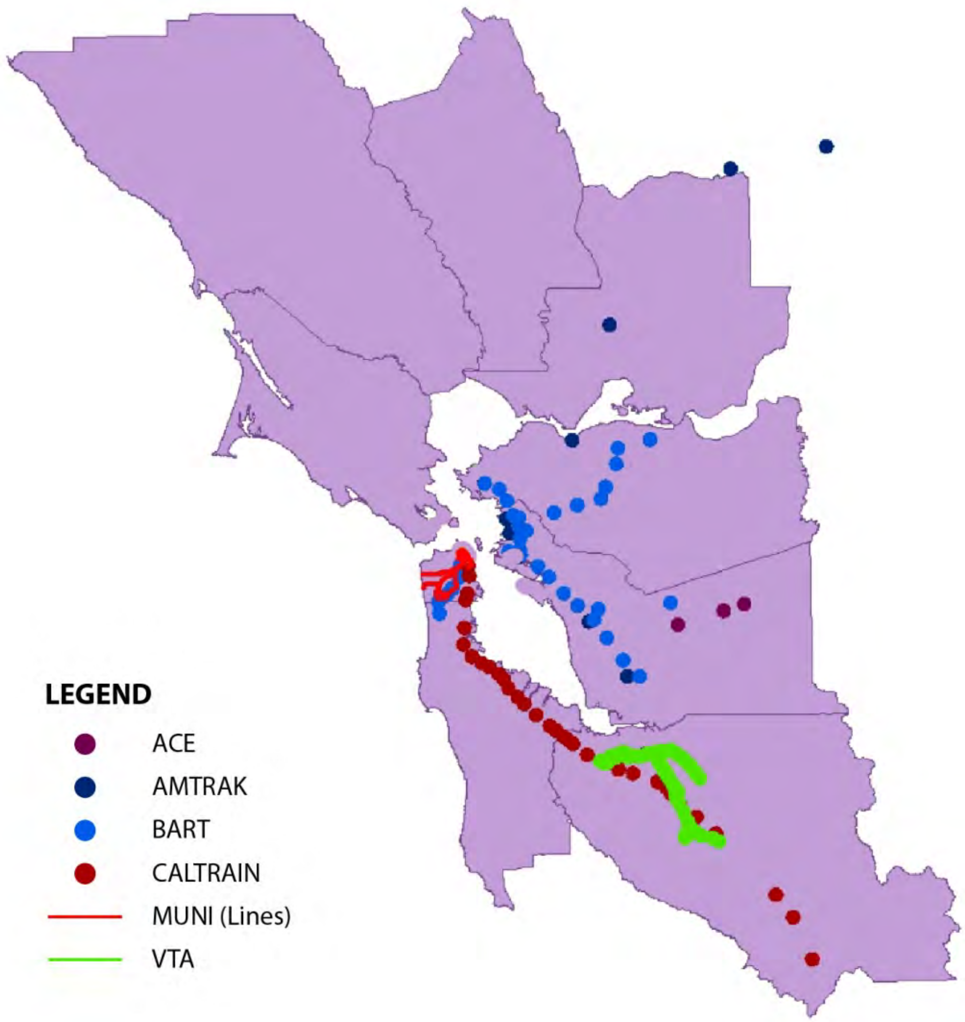
One of the new features introduced as part of Three-Step Ds Analysis Module is the ability to evaluate how the built environment characteristics of the non-home-end of the trip influence travel. Typically, studies have focused on the home-end of the trip, since surveys are collected at the household-level and built environment data is relatively easy to collect near residential locations. However, it has long been suspected the built environment at the non-home-end of trips could be as, or more, influential than at the home-end. The data from this study shows several non-home-end built environment variables are influential in terms of trip length. Specifically, the Three-Step Ds Analysis Module indicates factors such as roadway density and household/employment diversity at the non-home-end are strongly correlated with shorter trips

As part of the smaller region analysis, additional attraction-end relationships were investigated. The analysis focused on the effects of non-home-end built environment characteristics on vehicle trip length. A few regression models were developed, which can be found in Appendix C. These models examine trips classified as non-home-based, for which the attraction/activity type was identified. These activities are divided into work, discretionary, and obligatory trips. The built-environment "D" variables used in the analysis were primarily for the non-home-end side (or attraction-end) of the trip, for which the half-mile land use buffers from the attraction location were used. The important findings in this study indicate the non-home-end Ds also have a reductive effect on vehicle trip lengths and therefore on VMT.

URBAN RAIL CORRIDORS

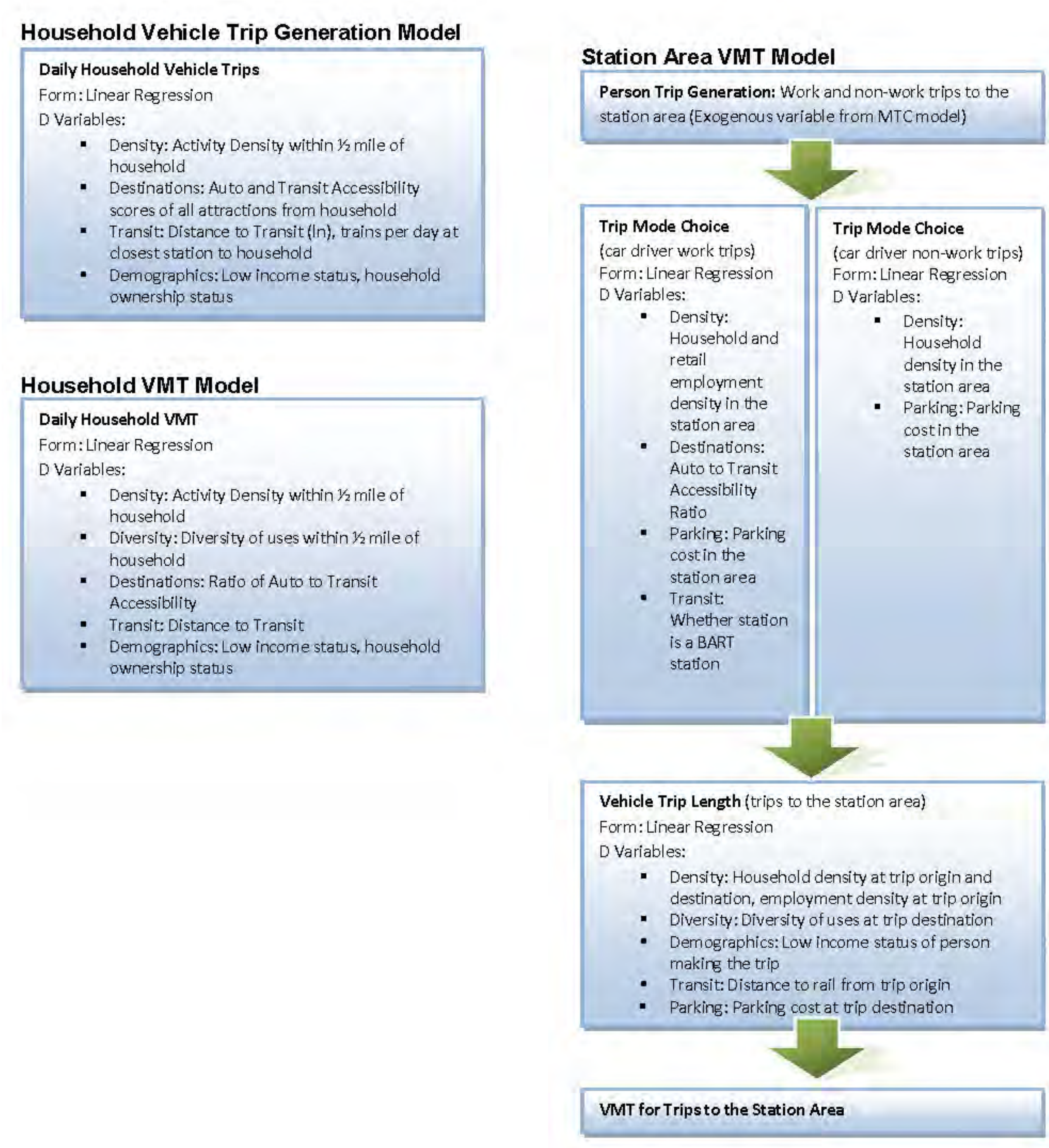
This section describes analysis conducted using 2000 San Francisco Bay Area Travel Survey (BATS) data. This data was used because it represents a sample four times as large as the 2009 NHTS survey subset for the nine-county Bay Area region. Furthermore, the Metropolitan Transportation Commission (MTC) has enhanced the BATS data set with supplemental variables, such as accessibility by auto, transit and non-motorized modes. Numerous regression modules were created to measure the relationships between travel behavior and various demographic, land use, accessibility and pricing characteristics, including variables measuring proximity to rail transit corridors. Travel behavior is measured by vehicle miles traveled, vehicle trip rate, and mode share. Figure 9 (below) shows the major rail stations and corridors in the San Francisco Bay region.

Figure 9. Urban Rail Corridors in the San Francisco Bay Area



Regression models were estimated to predict vehicle trip rates and VMT per household. In addition, mode split of work and non-work trips located near rail transit stations was analyzed and models created to predict mode type and trip distance. These models represent the analytic engines of the Urban Rail Corridor Ds Analysis Modules. The flow chart on the following page, Figure 10 (below) summarizes the three Ds Analysis Modules developed. Attachment D4 to this Appendix provides complete details on the data set used, as well as information on alternative models and modeling approaches that were employed or attempted by the project team, with guidance from the Expert Panel.

Figure 10. VMT "Ds Analysis Modules" for Urban Rail Corridors



Household Vehicle Trip and VMT Modules

Several ordinary least squares (OLS) regression models were run to estimate the dependent variable "average weekday daily household car driver trips" and "average weekday household vehicle miles traveled". Only car driver trips were considered, not car passenger trips, since car driver trips correspond directly to vehicle trips (VT) that contribute to increased VMT and GHG emissions. Key variables found to be statistically significant within both the VT and VMT models include: household size; low-income status; home ownership status; activity density (i.e., population plus employment) within a half-mile of the household; number of trains per day at the closest rail station to the household; the natural log of the distance from the household to the nearest rail station; whether or not the household resides in a multi-family building; and whether the household lacks access to a vehicle.

In addition to these variables, measures of auto accessibility and transit accessibility were also found to be significant in predicting household vehicle trips. Auto and transit accessibility variables created by MTC were used in model development, as were accessibility variables created by Fehr & Peers. These latter accessibility variables are based on over-the-road distance to all productions and attractions in the region; they may prove simpler for other regions to develop compared MTC's more sophisticated accessibility measures, which incorporate other measures of impedance besides distance, and differentiate impedance by mode and time of day. The components of the various accessibility measures are described further in following section and are fully described in Appendix D.

Accessibility Variables Description

MTC Accessibility Variables: The MTC-developed accessibility variables *Auto Accessibility TAZ, Transit Accessibility TAZ*, and *Non-motorized Trip (NMT) Accessibility TAZ* describe the ease of traveling from the traffic analysis zone (TAZ) of origin to all of the other TAZs in the Bay Area using the specified mode. The variables *Auto Access HMi, Transit Access HMi*, and *NMT Access HMi* measure the average accessibility for the area within a half-mile of where the household is located. The variables are unit-less and range in value from 0 to 13.1, where higher values indicate higher accessibility.

Distance-based Accessibility Variables: Three new accessibility variables were calculated by Fehr & Peers for use in the regression analysis: Attractions Accessibility per TAZ (TAZ Accessibility), Attractions Accessibility per Household (HH Accessibility), and High Accessibility. TAZ Accessibility considers the number of attractions per TAZ and the distance between TAZs and assigns the accessibility value for each household based on the TAZ in which the household is located. HH Accessibility proportionally aggregates the TAZ Accessibility value for all of the TAZs within a half-mile of where the household is located and assigns a unique accessibility value to each household. High Accessibility is a binary variable equal to 1 if the household has higher than average distance based accessibility, and 0 otherwise.

A more detailed description of the calculation of all the various variables is included in Attachment D3.

Comparison of Vehicle Trip Rate Models

Trip data were collected through the 2000 Bay Area Travel Survey (BATS). Data were collected on all trips by persons in the household over a period of two days. For our analysis, weekend trips were removed, and weekday trips made by a car driver (either drive alone or carpool) were aggregated to the household level. This two-day sum of household vehicle trips was divided by two to get a daily average.

Table 17 (below) shows the results of OLS regression models with average daily vehicle trips per household as the dependent variable. Model 1 includes the MTC auto and transit accessibility variables as independent variables. Model 2 includes TAZ Accessibility as an independent variable and Model 3 includes HH Accessibility as an independent variable. Model 4 includes a simplified accessibility variable that equals 1 if the household is in an area with high accessibility and 0 otherwise. Model 2 and Model 3 are very similar: between these two, Model 3 is preferred because using the household based accessibility variable may help reduce problems of heteroscedasticity. Model 4 can be used in cases where a more detailed accessibility variable per household cannot be calculated. The coefficients for TAZ Accessibility and HH Accessibility are slightly higher than for Auto Access. The coefficients for other independent variables are similar among the four models.

Overall we recommend **Model 1** as the preferred Ds Analysis Module for estimating Vehicle Trips because it has the highest R^2 value. However, since the Auto Access and Transit Access variables might be difficult to calculate, the HH Accessibility was created as a simpler alternative. In the case that Auto Access and Transit Access cannot be calculated, Model 3 should be used instead. If the household distance based accessibility variable cannot be calculated, Model 4 should be used.

TABLE 17
VEHICLE TRIP RATE MODEL OUTPUTS COMPARISON

	Model 1: (recommended)	Model 2:	Model 3:	Model 4:
Constant	**0.217**	1.909	1.901	2.178
Household Size	**0.930**	0.935	0.935	0.933
Low Income	**-0.652**	-0.670	-0.672	-0.683
Owner	**0.529**	0.551	0.552	0.555
Activity Density (population + jobs/acre)	**-0.004**	-0.007	-0.007	-0.004
Trains per Day	**-0.001**	-0.001	-0.001	-0.001
Ln(Rail Distance)	**0.072**	0.086	0.088	0.064
Zero Car HH	**-2.247**	-2.260	-2.260	-2.249
Multi Family Dwelling	**-0.377**	-0.390	-0.385	-0.377
Auto Access (MTC)	**0.200**	-	-	-
Transit Access (MTC)	**-0.057**	-	-	-
TAZ Accessibility (F&P)	**-**	0.353	-	-
HH Accessibility (F&P)	**-**	-	0.361	-
High Accessibility	**-**	-	-	0.122
R-Square	**0.261**	0.259	0.259	0.259

Table 18 (below) shows the results of OLS regression models similar to Models 1-4 but with most demographic and household vehicle variables removed, i.e., besides household size, there are only physical "D" variables in the equations. This comparative model framework was recommended by one member of the Panel as a means of quantifying the extent to which demographic and socioeconomic factors affect travel behavior. The larger coefficients in Models 5 - 8 suggest the degree of influence that self-selection of residential location in relation to transport opportunities has on travel outcomes.

Model 6 and Model 7 are very similar. Again, the coefficients for TAZ Accessibility and HH Accessibility are slightly higher than for Auto Access. The coefficients for other independent variables are similar among the four models.

TABLE 18
VEHICLE TRIP RATE MODEL OUTPUTS COMPARISON

	Model 5:	Model 6:	Model 7:	Model 8:
Constant	-0.118	2.047	2.067	2.441
Household Size	0.992	1.001	1.001	0.999
Activity Density	-0.010	-0.016	-0.015	-0.011
Trains per Day	-0.001	-0.001	-0.001	-0.001
Ln(Rail Distance)	0.062	0.095	0.094	0.060
Multi Family Dwelling	-0.790	-0.828	-0.822	-0.813
Auto Access (MTC)	0.263	-	-	-
Transit Access (MTC)	-0.084	-	-	-
TAZ Accessibility (F&P)	-	0.501	-	-
HH Accessibility (F&P)	-	-	0.482	-
High Accessibility	-	-	-	0.157
R-Square	0.229	0.226	0.226	0.226

Comparison of VMT Models

Average weekday vehicle miles traveled (VMT) were calculated for each household in the BATS survey to be used as the dependent variable in the regression analysis. BATS survey data includes information about trip origin and destination locations. TAZ to TAZ skim distance estimates provided by MTC across the 2000 road network were used to estimate trip distance for each weekday trip by a car or carpool driver in the BATS survey. These car driver trip distances were then aggregated by household to get average daily weekday VMT per household.

Table 19 (below) shows the results of OLS regression models with average daily VMT per household as the dependent variable. Model 9 does not include the MTC auto or transit accessibility variables as independent variables but does include the ratio of auto to transit accessibility. Model 10 includes TAZ Accessibility as an independent variable. Model 11 includes HH Accessibility as an independent variable, and Model 12 includes a binary variable indicating high accessibility. Model 10 and Model 11 are very similar but the accessibility coefficient in Model 10 is larger. Also, in Models 10 and 11 the variable Distance to Rail is no longer significant and the sign for Activity Density has changed from negative to positive. In Model 12 the sign for Activity Density is negative but the significance of the variable is reduced. These results support the exclusion of the raw accessibility variables from the VMT models. Overall we recommend **Model 9** as the preferred Ds Analysis module for estimating VMT because all of the variables are significant and the coefficients have the expected sign.

TABLE 19

HOUSEHOLD VMT MODEL OUTPUTS COMPARISON

	Model 9: (recommended)	**Model 10:**	**Model 11:**	**Model 12:**
Constant	**4.229**	17.866	15.806	8.048
Household Size	**3.474**	3.391	3.412	3.454
Low Income	**-8.992**	-9.432	-9.316	-9.052
Auto Transit Ratio	**17.639**	11.913	12.790	14.175
Owner	**-1.054**	-1.122	-1.077	-1.107
Diversity	**-5.042**	-3.927	-3.962	-4.875
Distance to Rail	**0.102**	-.001*	0.011*	0.072
Activity Density	**-0.018**	0.097	0.082	-0.015*
HH Vehicles	**8.892**	8.805	8.840	8.908
TAZ Accessibility (F&P)	**-**	-11.298	-	-
HH Accessibility (F&P)	**-**	-	-9.890	-
High Accessibility	**-**	-	-	-3.427
R-Square	**0.208**	0.211	0.210	0.209

Notes: *Significance value > 0.2

Station Area Ds Analysis Module

Local and regional agencies and transit agencies are increasingly interested in planning for the areas surrounding transit stations. Empirical evidence suggests travel behavior is significantly different in the vicinity of transit stations, particular rail stations with frequent service. To assist such station-area planning, a series of models were developed to predict the mode and distance of trips that originate or have a destination within one-half mile of a rail station.

A total of 146 Bay Area station areas were analyzed, including rail stations for the following transit agencies: SF Muni, BART, VTA, Caltrain, Amtrak, and ACE. A station area was defined as the area within a half-mile radius of the station. As expected, car driver mode share for both work and non-work trips to a rail station area were found to be lower than for car driver mode share for all trips, with SF Muni and BART station areas having the lowest car driver mode shares. Similarly, walk and rail mode shares were found to be higher for trips to station areas than for all trips.

Several models were run to analyze the relationship between station area characteristics and trips to those station areas. OLS regressions were run using the following dependent variables: car driver mode share for work trips to a station area, transit mode share for work trips to a station area, car driver mode share for non-work trips to a station area, car (passenger or driver) mode share for non-work trips to a station area, and transit mode share for non-work trips to a station area.

The station area variables found to be statistically significant within the various models include parking cost at the station area, auto to transit accessibility ratio, auto accessibility of the station area, transit accessibility of the station area, household density of the station area, employment density of the station area, retail employment density of the station area, and whether or not the station was a BART station. The model coefficients are summarized in Table 20 (below). The model outputs are values between 0 and 1, which represent the proportion of trips to the station area which are expected to be made by the specified mode (i.e., car driver).

TABLE 20
STATION AREA MODE SHARE MODULE: REGRESSION COEFFICIENTS

	Work Trips		Non-Work Trips		
	Car Driver Mode Share	Transit Mode Share	Car Driver Mode Share	Car (passenger or driver) Mode Share	Transit Mode Share
Parking Cost	-.127		-.163	-.183	.127
Auto to Transit Accessibility Ratio	.408				
Auto Accessibility		-.031			
Transit Accessibility		.028		-.019	.011
Household Density	-.007	.003	-.008	-.011	
Employment Density	-.001	.001			
Retail Employment Density					.004
BART	-.077				
(Constant)	.763	.219	.643	1.040	-.046
Adjusted R^2	.699	.718	.416	.723	.718

The results of the models indicate that increases in parking costs in station areas as well as increases in household and employment density in station areas are associated with reductions in car driver mode share to a station area. However, increases in parking costs and densities in station areas are associated with increased transit mode share. In addition, increases in station area transit accessibility are associated with increases in transit mode share to the station area.

Other Models of Interest and Potential Use

Station Area Trip Models. Trips from the BATS survey were also analyzed to estimate ***mode*** and ***distance of trips*** to a rail station area. The results of the **mode choice** models indicate that as the following variables increase, the trip is more likely to be made by a car driver: distance between the trip origin and the nearest rail station, and trip distance. In addition, as the following variables decrease, the trip is more likely to be made by a car driver: household and employment density at the trip origin, household density at the trip destination, household size, and parking cost at the trip origin or destination. In addition, owner-occupied households are more likely to make a car driver trip than renter-occupied households, and low-income households are less likely to make a car driver trip than non-low-income households.

The **trip distance** models indicate that as the following variables increase, the trip distance is expected to increase: household size, distance between trip origin and nearest rail station, household density at the trip destination, parking cost at the trip destination. As the following variables decrease, the trip distance is expected to increase: household and employment density at the trip origin, parking cost at the trip origin, and land use diversity at the trip destination. Trips by low-income households tend to be shorter than trips made by non-low-income households. Work trips tend to be longer than non-work trips. Car drivers are expected to make longer trips than non-car drivers.

Applicability and Caveats

The aforementioned Ds Analysis Modules were developed using data from the Bay Area. They may be most applicable to the four large regions of California that currently have significant rail transit. They may also be used with caution in other regions where rail is in the planning stages.

COMPARISON OF ELASTICITIES ACROSS REGIONS

The results presented above provide useful comparisons of travel effects among the study regions and to the results of prior research conducted by a variety of means at locations across the U.S. In addition, demographics more strongly influence travel in all regions than do the built environment "D" variables discussed above, as shown in greater detail in Appendices of this report. The tables in the preceding chapters also show that trip generation is less sensitive to "D" variables than trip length. Trip length is affected, to a significant degree, by more of the "D" variables, and the levels of sensitivity are greater than for trip generation.

Table 21 (below) compares the elasticities from the Ds Analysis Modules for all regions to one another and to the synthesis of prior research.

TABLE 21
COMPARISON OF FINDINGS FROM ALL REGIONS: VMT ELASTICITIES

Variable Name	National Average for Home End of Trip	SACOG		SANDAG		Small MPO		Rail Corridors
		Home End	Non-Home End	Home End	Non-Home End	Home End	Non-Home End	Home End
Density	0.00 to -0.04	-0.14	-0.02	-0.05	N/A	-0.08	-0.04	-0.01
Diversity	-0.02 to -0.09	-0.03	-0.32	-0.02	-0.25	-0.06	-0.14	-0.10
Design	-0.12	N/A	-0.07	-0.07	-0.20	-0.04	-0.21	N/A
Destinations	-0.05 to -0.22	-0.33	N/A	-0.31	N/A	-0.06	N/A	N/A
Distance to Transit	-0.05	-0.02	N/A	-0.02	N/A	-0.04	N/A	-0.03*
Demand Management (Parking)	N/A	N/A	N/A	N/A	0.04	N/A	N/A	N/A*

Notes:
SACOG, SANDAG and Small MPO elasticities are based on the Three-Step VMT Model. BATS elasticities are based on the Household VMT Model
* The Rail Corridors analysis has a different methodology which precludes a direct apples-to-apples comparison of "D" elasticities

The results show this new research generally agrees with the prior findings while showing key differences from region to region. Density elasticities for VMT generation in each region, combining the effects of home-end and non-home-end density, are in the upper end of the range found in national studies. In the SACOG case, the high elasticity for home-end density is a consequence of interactions between density and urban design in the Sacramento region's data set. The region's combined density and design effects are in the range found for the two combined effects in the national studies. Similar, but less extreme, overlap of density and design effects are seen in the SANDAG and small MPO regions.

As one of the first studies to explicitly address the effects of the built environment at employment and commercial locations, the strength of these non-home-end variables was even higher than home-end effects, as expected. Influence of non-home-end "D" variables appears to be greater for diversity and design than for density. The non-home diversity effects on VMT are orders-of-magnitude stronger than the home end effects, indicating the importance of providing a diversity of land uses in commercial and employment centers in order to link and reduce auto use for non-home-based trips. The effect of design demonstrates a similarly strong dichotomy for non-home-end and home-end effects as shown in the SANDAG and small MPO results. Providing well-connected, walkable urban design in commercial and employment centers encourages short distance walking trips for non-home-based purposes such as lunchtime and errands by local workers.

The home-end and non-home-end effects for individual "D" variables straddle national averages, which were based on studies of household behavior only or a blend of household and non-household effects. This indicates that the new results are consistent with the prior single-focus or blended studies and give a deeper understanding of the relative effects of residential built environments relative to the built places near jobs and shopping destinations.

Several of the "D" variables are less influential in the small regions, as would be expected given the more dispersed nature and limited travel mode alternatives found in most smaller MPOs than in regions with major urban centers and established fixed transit networks. Non-home diversity and destination accessibility are among the variables with lower elasticities in small urban regions than in the metropolitan regions. Parking charges tend to produce longer average auto trip lengths by incentivizing shorter trips to use options such as walking, cycling or transit. The number trip generated in urban rail corridors is especially sensitive to parking charges.

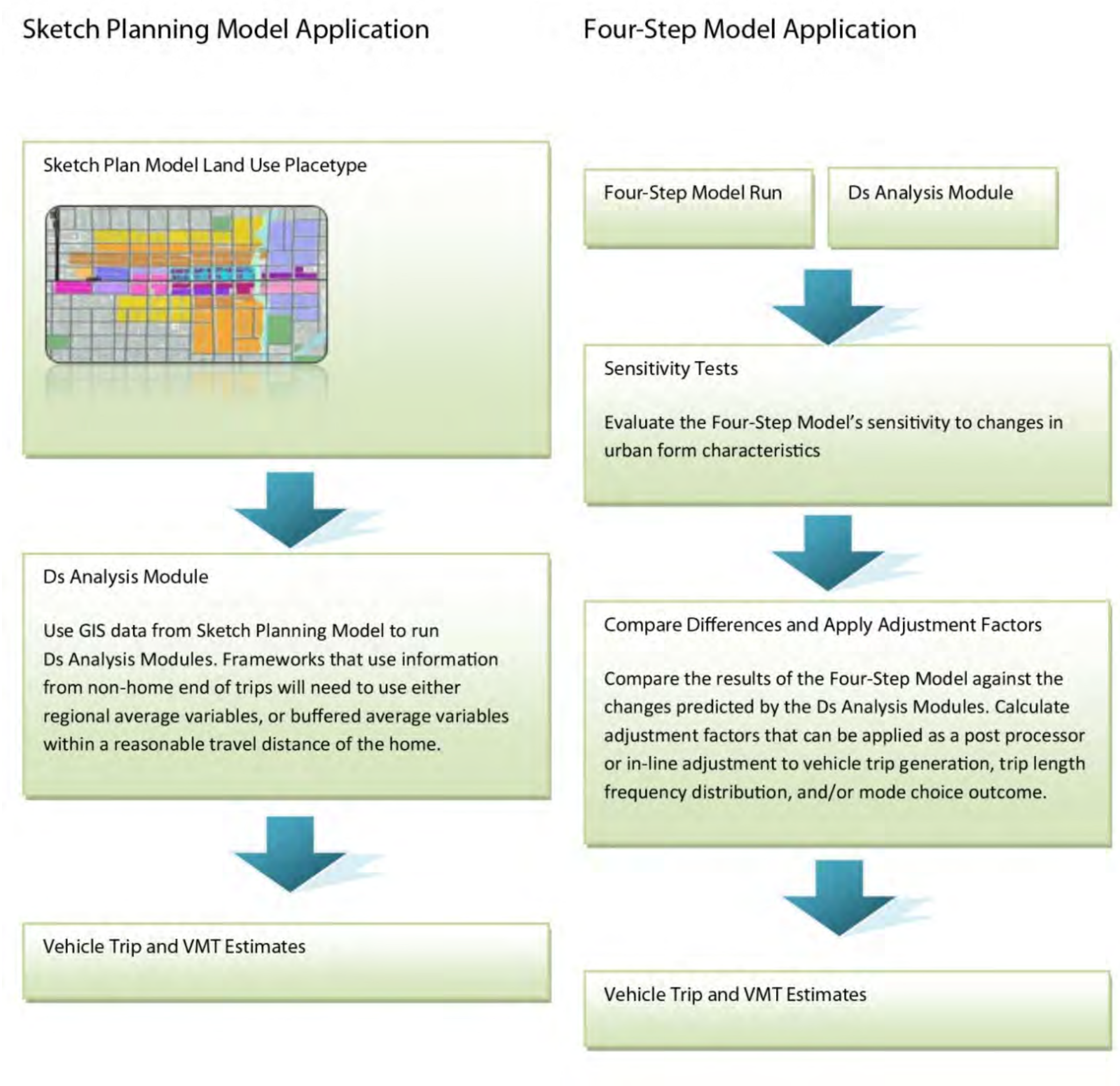
Transit elasticities were somewhat lower in all of the regional studies than in the national summary. This is likely to be a result of the fact that our study accounted explicitly for the effects of demographic and socioeconomic variables, while many of the national studies did not. In our results, socioeconomic and demographic factors inducing transit use are accounted for separately from the effects of built-environment factors, allowing us to address both types of factors individually.

3. Applying Ds Relationships in Planning and Forecasting

OVERVIEW

The Ds Analysis Modules described earlier in this document have the flexibility to be applied under several circumstances. The flowcharts in Figure 11 below highlight two possibilities – for "sketch" and scenario planning and with four-step travel demand forecasting (TDF) models, respectively.

Figure 11. Sketch Planning & Regional Four-Step Travel Demand Model Application



The recommended application of the two- and three-step Ds Analysis Module frameworks is:

- **For "sketch" scenario planning tools**: apply the two-step Ds Analysis Module framework as pivot calculation of VMT change from the region's official VMT travel forecast at as fine-grained a level of detail as available.

- **For regional travel model post processing**: Apply the three-step elasticity check on regional model sensitivity based on elasticities presented in Table 21. If needed based on elasticity test results, follow with a three-step regression-based model calibration tool.

SCENARIO PLANNING TOOLS

UC Davis coded the Ds Analysis Modules described in the preceding chapter into sub-modules that can run in conjunction with scenario planning and visualization tools most commonly used in California. This may include GIS and sketch or spreadsheet tools such as: iPLACE3S, UPlan, Envision Tomorrow, Vision California Urban Footprint, Community Viz, or others. If incorporated into a region's scenario planning tool, that tool would contain relationships that match sensitivities built into the regional travel model provided by the use of a post-processor (as described in the next section).

Scenario tools most often visualize land use in terms of place-types, community-types, or area-types. The area-type examination of the Ds Analysis Modules in the preceding section provides a degree of confidence that the new Ds Analysis Modules will support such scenario planning processes in California.

The methodologies developed to implement such analyses are affected by whether the two-step or three-step Ds Analysis module (described in the previous section) is used, as well as the geographic units of analysis addressed by the scenario planning tool. With respect to geographic units of analysis, the Ds Analysis Modules can be implemented according to the following guidelines, which provide for geographic consistency between a region's scenario planning tool and its travel forecasting model that has been calibrated through a post-processor tool to the findings of this study:

- For regions with land use expressed at a disaggregate level (parcel or grid cell), the modules need to be applied at that level, operating on the total number of households and average household characteristics within the parcel or cell and the quantities of and built environment variables (density, diversity, intersections, transit stations) within a half-mile buffer around it.
- For regions with land use data only at the aggregate level (TAZ), the Ds Analysis Modules can be applied to the distribution of data within each TAZ, including a cross-classification of household demographics by, for example, size and income or vehicle ownership. The module will operate on the total number of households and distribution of household characteristics within each TAZ and the quantities of and built environment variables (density, diversity, intersections, transit stations) within a half-mile buffer of the center of gravity of the TAZ households. The method of measurement of the center of gravity will depend on TAZ size. For TAZs of approximately 500 acres (equivalent to an area of a half-mile radius), the measurement will be the entire content of the TAZ. For smaller TAZs, the center of gravity will include the entire TAZ and any neighboring TAZs whose centroids are within a half-mile of the home TAZ centroid. For larger TAZs, it is recommended that either the TAZ be split to maximum 500-acre or sub zones, or that the content of the TAZ be assumed uniformly distributed throughout the TAZ.
- This same buffering method will be used for computing the travel-reduction effects of built environments in non-residential settings. For parcels, grid cells, or small TAZs containing only

non-residential uses, the modeling process will compute the effects of built environment variables on trip length and VMT reduction for non-home-based purposes through variables such as employment density within the ½-mile buffer area.

The sketch scenario tools can also operate in conjunction with regional travel models for measures of accessibility, TAZ data on demographic variables and auto ownership, and baseline TAZ VMT. The implementation of Ds Analysis Modules also use regional travel model TAZ forecasts as baseline vehicle ownership and trip generation pivot values for sketch tool grid cells or parcels within each TAZ.

TRAVEL FORECASTING MODELS

The statistical relationships between the "D" variables and travel behavior can be used to modify both traditional trip-based model and newer activity-based travel demand forecasting (TDF) models. *Additional detailed information about this process is provided in Appendix E of the Final Project Report*.

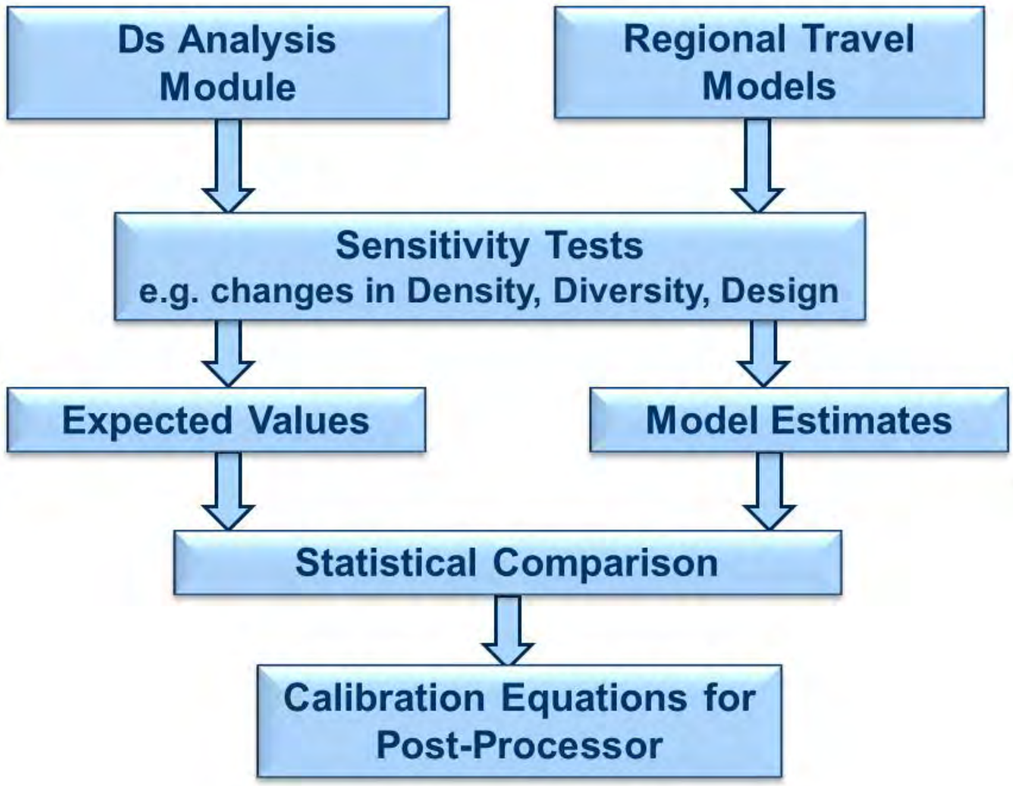
For each type of model, adjustments typically occur toward the end of the modeling stream. To apply the Ds Analysis Modules with regional travel demand forecasting (TDF) models, a tiered model sensitivity analysis was conducted for eight selected MPO demonstration regions.[6]

An initial test was conducted to determine how well each agency's travel model (whether trip-based or activity-based) accounts for various built environment factors. This verified the level of sensitivity already present in the model, and identified missing or potential double-counting of effects. Elasticities were calculated for all key variables discovered in the regional TDF models and the Ds Analysis Module.

For travel demand models needing calibration, the general model testing and post-process calibration approach used is illustrated in Figure 12 (below).

6 These were: six San Joaquin Valley MPOs - Fresno COG; Tulare CAG; Kern COG; San Joaquin COG, Merced and Stanislaus COGs (which share a three-county model); plus Butte CAG; and San Luis Obispo COG.

Figure 12. **Post-Process Calibration of MPO Travel Modes**



Appropriate Ds Analysis Modules were applied to two of each region's land use scenarios using the same transportation network and pricing assumptions in each case. The net change in VMT was determined by comparing the two sets of scenario results produced by the appropriate Ds Analysis Module. The regional travel demand model was also applied to the same two scenarios, and the travel model-estimated net VMT change determined, thereby measuring the differences at a geographically detailed level (traffic analysis zone or parcel). For the net change in VMT, the travel model estimates were compared to the expected values from the appropriate Ds Analysis Module. The statistical differences between the two types of model results became the factors used in developing a tool to calibrate the regional model.

Most of the Ds Analysis Modules produce modifications of the final VMT estimates by TAZ. It is also possible to use Ds Analysis Modules that modify Vehicle Trips regarding auto trip tables, and to allow the model's traffic assignment procedure to be used in calculating VMT. It is important to note that the adjustment should be applied at only at one of the two potential points of intervention.

Figure 13 illustrates the two potential points for Ds adjustment in a trip-based TDF model. Figure 14 (below) shows the points of adjustment in an activity-based TDF model.

Figure 13. Trips-Based TDF Model Flowchart

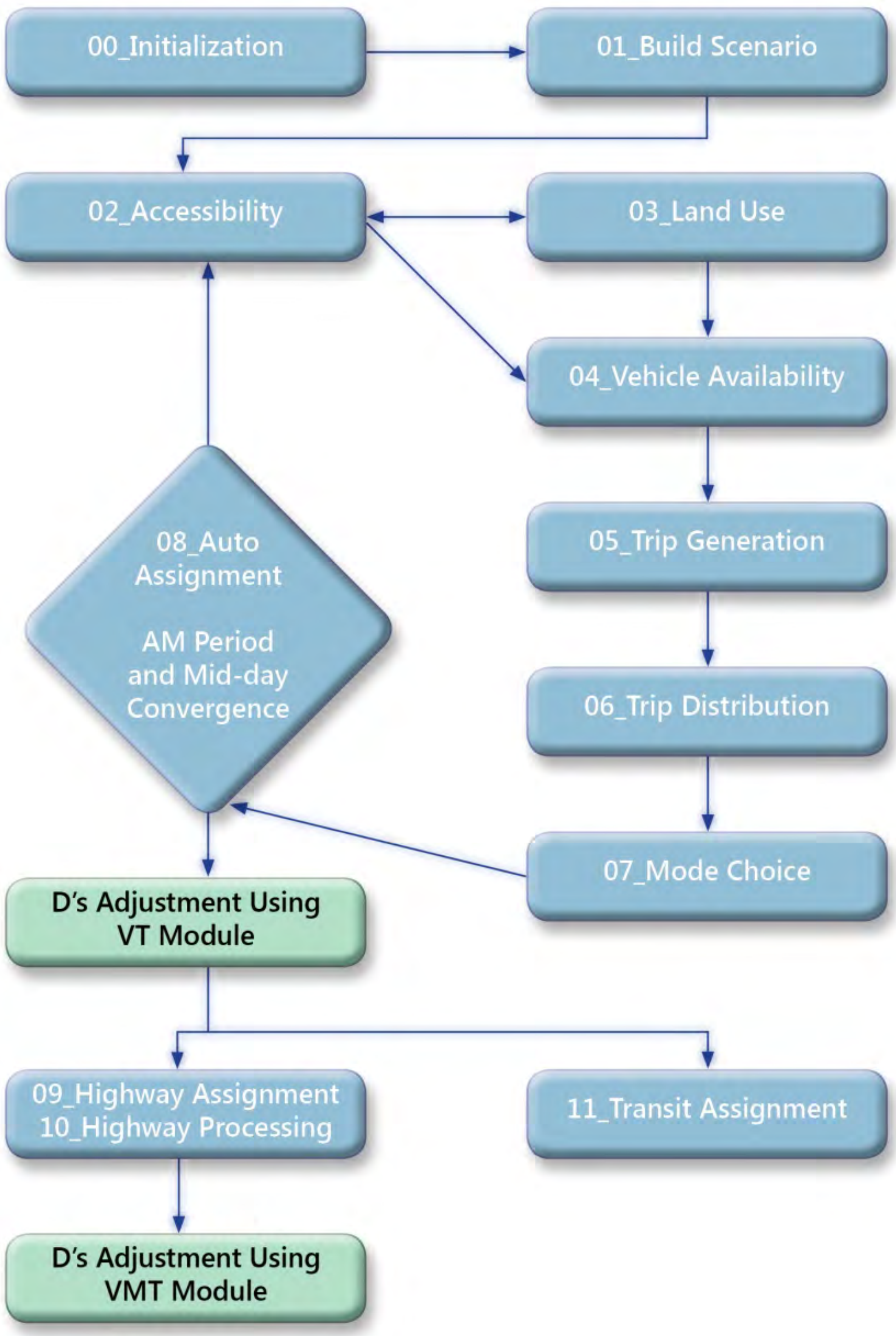
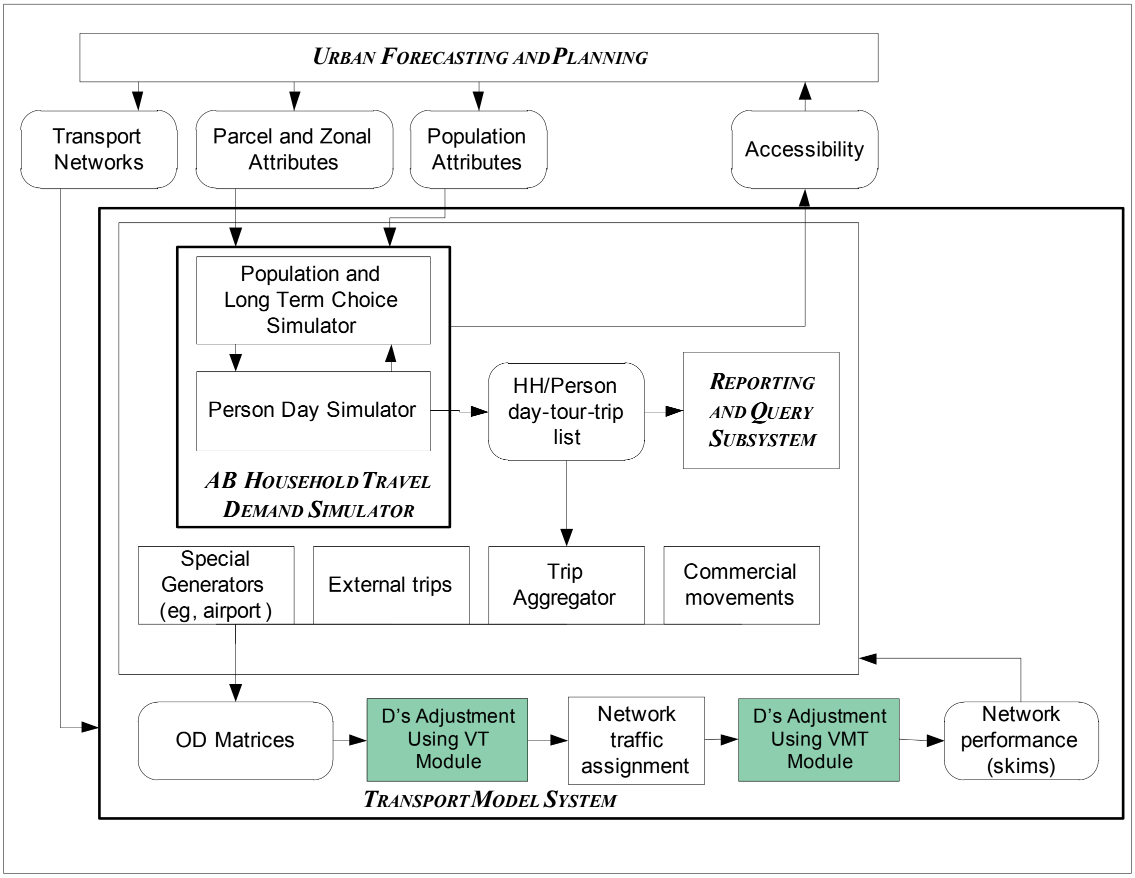


Figure 14. Activity-Based TDF Model Flowchart



GUIDELINES FOR USING NEW ANALYSIS MODULES

SELECTING THE MODULE APPROPRIATE TO A REGION

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

- 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.

- Areas near 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 avoid overstating the potential smart growth benefits. This is accomplished using the model diagnostic testing and calibration process described in Appendix E of this report.

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 agency should continue to use the Ds Analysis Module developed specifically for its region based on its 2000 regional or 2009 NHTS travel survey.

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 local 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, 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.
- 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.
- 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.
- 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.
- 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.
- Accounts 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.
- 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.

- 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.

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 to operationalize 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.

FINAL REPORT:

Improved Data and Tools for Integrated Land Use-Transportation Planning in California

APPENDIX "E"

Implementation of Ds Analysis Modules with Regional Travel Demand Models

TOPICS:

1. Technical Assistance Provided to Selected MPOs in California
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
6. Conclusions and Further Research

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July 18, 2012

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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 adjustments to compensate for any model insensitivity, and comment.

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 spilt 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-models 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:

Original (“Base”) Land-Uses	Changed (“Swap”) Land-Uses
Retail: Strip Mall/ Big Box	Office Focus
Town Mixed Use	Retail: Strip Mall/ Big Box
Rural Residential	City Mixed Use
Large Lot Residential Area	Town Mixed Use
Town Mixed Use	Office Focus
Office Focus	City Mixed Use
Office/Industrial	City Mixed Use
Office/Industrial	City Mixed Use
Office/Industrial	Village Mixed Use
Large Lot Residential Area	City Mixed Use
Town Mixed Use	Large Lot Residential Area
High Intensity Activity Center	Mixed Office and R&D
Urban Mixed Use	City Mixed Use

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[1].

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

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 acreages, 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:

Model	**Base LU**	**Sustainable LU Swap**	**Percent Difference**	**Ds Adjust. Regression Equation**
Ds Analysis Module (1/2 - mile buffer)	VMT/HH $_{Base}$ LU Buffer Ds $_{Base}$	VMT/HH $_{Smart}$ LU Buffer Ds $_{Smart}$	$\mathbf{Y}_{\mathbf{DsM}}$= VMT/HH $_{(Smart-Base)}$% $\mathbf{X}_{\mathbf{d\mathit{i}\ DsM}}$ = LU Buffer $_{(Smart-Base)}$ %	Dependent (**Y**) = % (Y $_{DsM}$ - Y $_{TDF}$) Independent (β) = % (X***di*** $_{DsM}$) Where d***i*** = Each D-variables
MPO TDF Model (TAZ level)	VMT/HH $_{Base}$ LU Ds by TAZ $_{Base}$	VMT/HH $_{Smart}$ LU Ds by TAZ $_{Smart}$	$\mathbf{Y}_{\mathbf{TDF}}$= VMT/HH $_{(Smart-Base)}$% $\mathbf{X}_{\mathbf{d\mathit{i}\ TDF}}$= LU by TAZ $_{(Smart-Base)}$%	

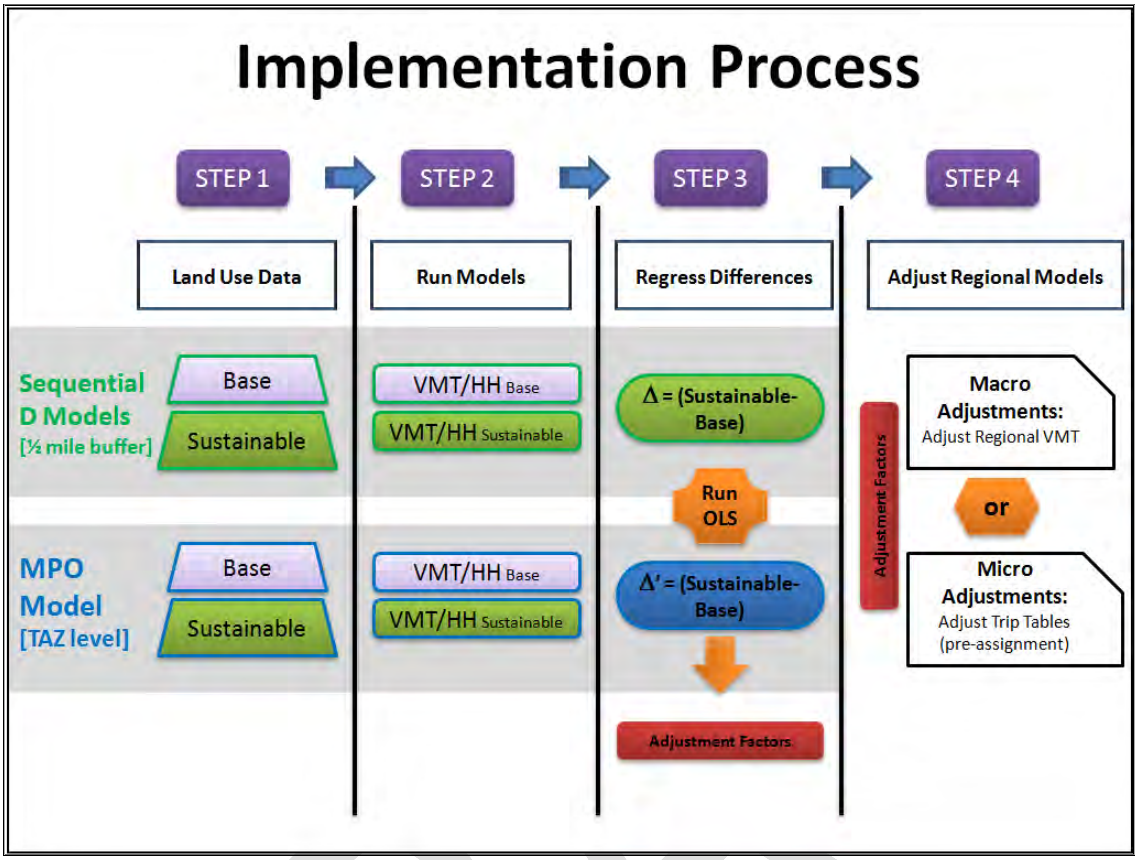
Ds Adjustment Equation: { $\mathbf{Y}_{\mathbf{VMT\ Change}} = \alpha + \beta_{d1}(Xd1) + \beta_{d2}(Xd2) + \beta_{d3}(Xd3) + \beta_{d4}(Xd4) + \ldots$ **}**

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 (α) 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.

Figure 1 - Model Calibration Process Schematic



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.*

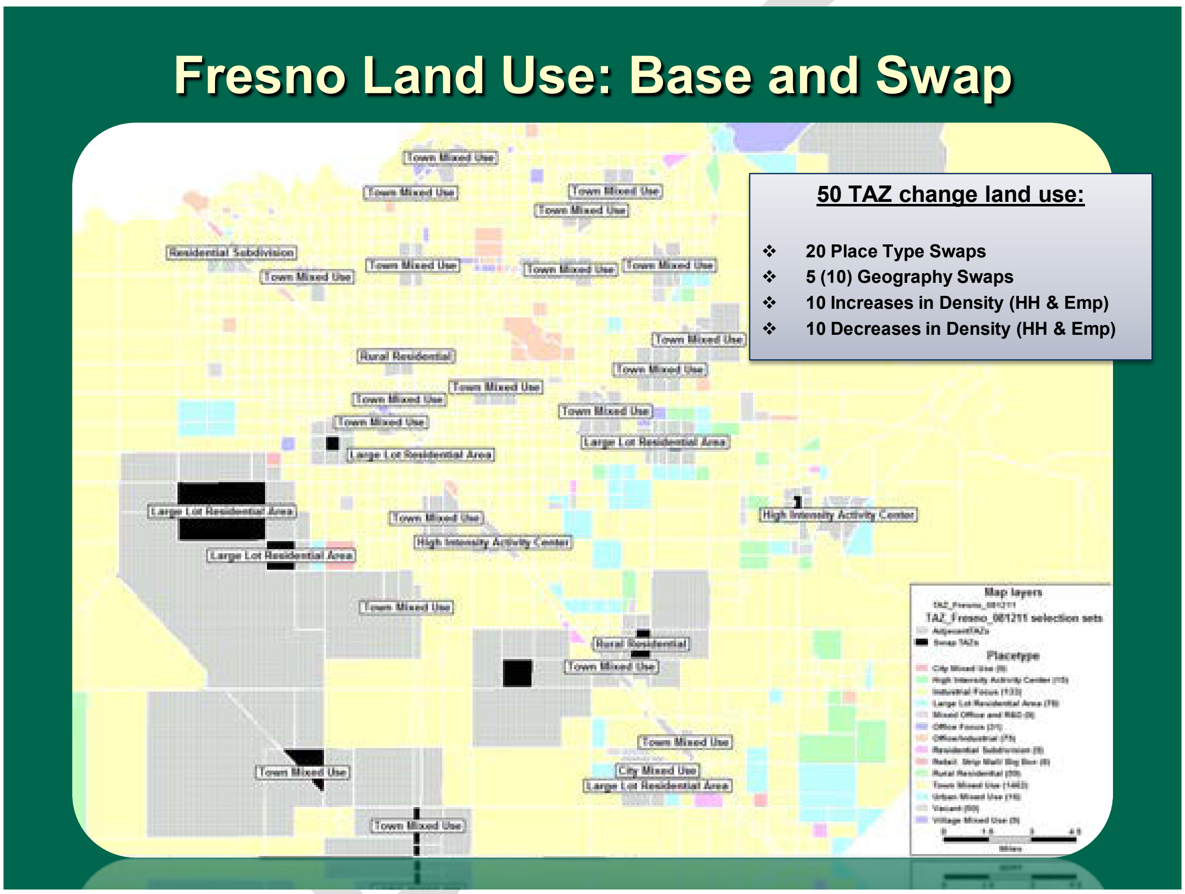
Model Testing and Ds Post-processor Development:

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

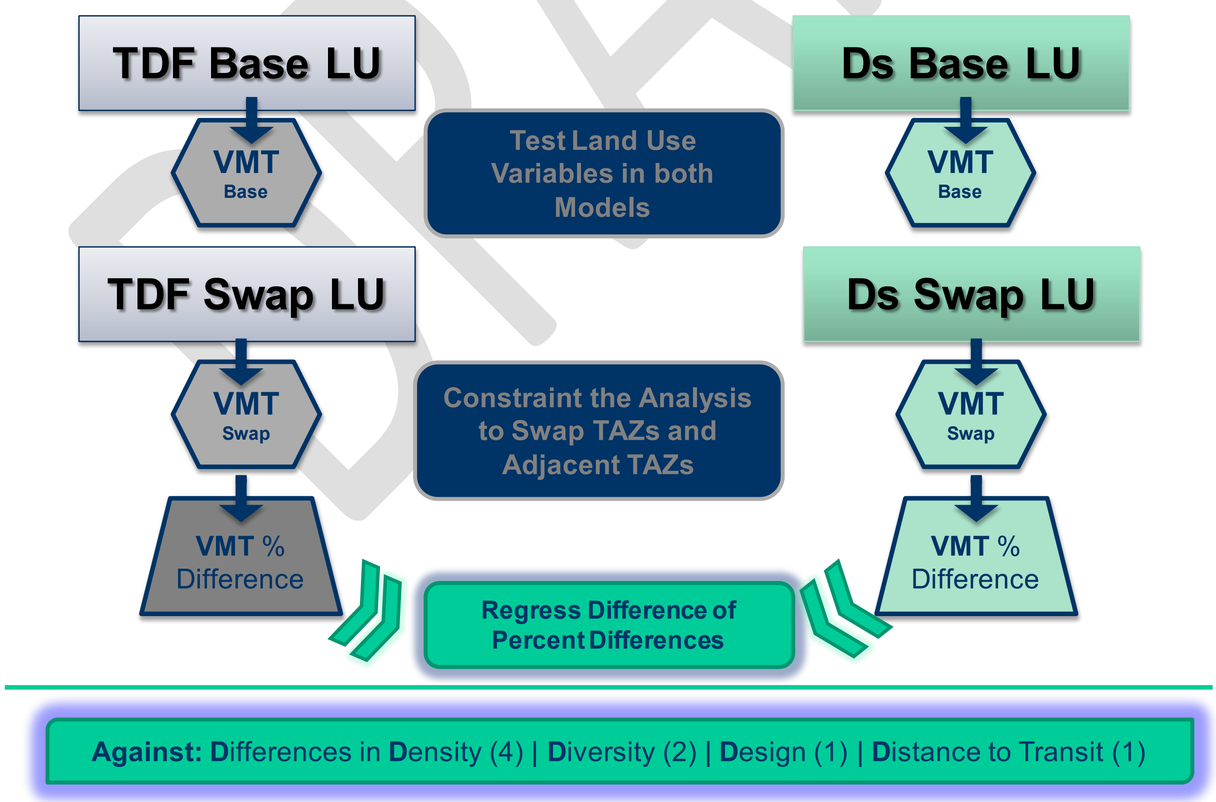


Table 1 (below) illustrates the best fitting regression equation developed for explaining the additional reduction in VMT found by the Ds Analysis Module in Fresno. The equation has an adjusted R^2 of 0.61 which means that the independent variables in the equation collectively explain about three-fifths 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

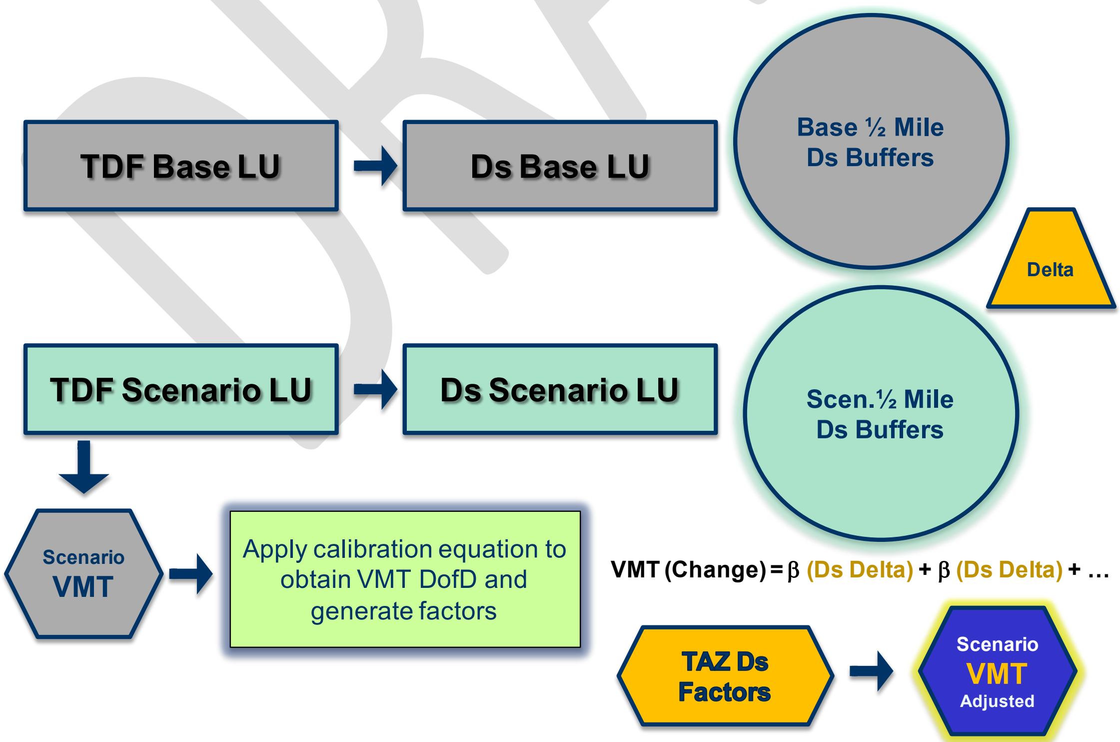
D Variables		Description Variables in terms of differences: (Scenario - Base)	Calibration Model B	 t (sig.)
	(Constant)		**1.773**	0.038
Demographics	**TOTHH**	Total Households per TAZ	**-0.045**	0.000
	HHVEH_CAT_0	Household Size	**-54.796**	0.099
	HHSIZE_CAT_1	Household Size	**-146.894**	0.000
	HHSIZE_CAT_2	Household Size		
	Income10K	Income by $10K increments	**-0.195**	0.068
	HHVEHCNT	Household Vehicle Count	**27.698**	0.000
Density	DEN_NetRes	Household population/residential acres within buffer		
	DEN_DevAcres	Sum of developed acres within half mile	**0.231**	0.000
	DEN_EmpAcre	Total jobs in 1/2 mile buffer		
	DEN_mi_acres	Minor commercial acres within buffer	**-1.488**	0.029
	DEN_inUrban	Record in Urban Area		
Diversity	DIV_JobsHH	Number of jobs/hh within buffer		
	DIV_LUEntropy	Land Use Mix within buffer (Entropy Index)	**-33.326**	0.068
Design	DSG_Street	Roadway density		
Dis. to Transit	DisT_RRstop	Nearest railroad station (converted to miles)		
		Number of "D" variables	**8**	
		2020 Concept Scenario VMT Reduction	**-1.98%**	
	R2		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



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

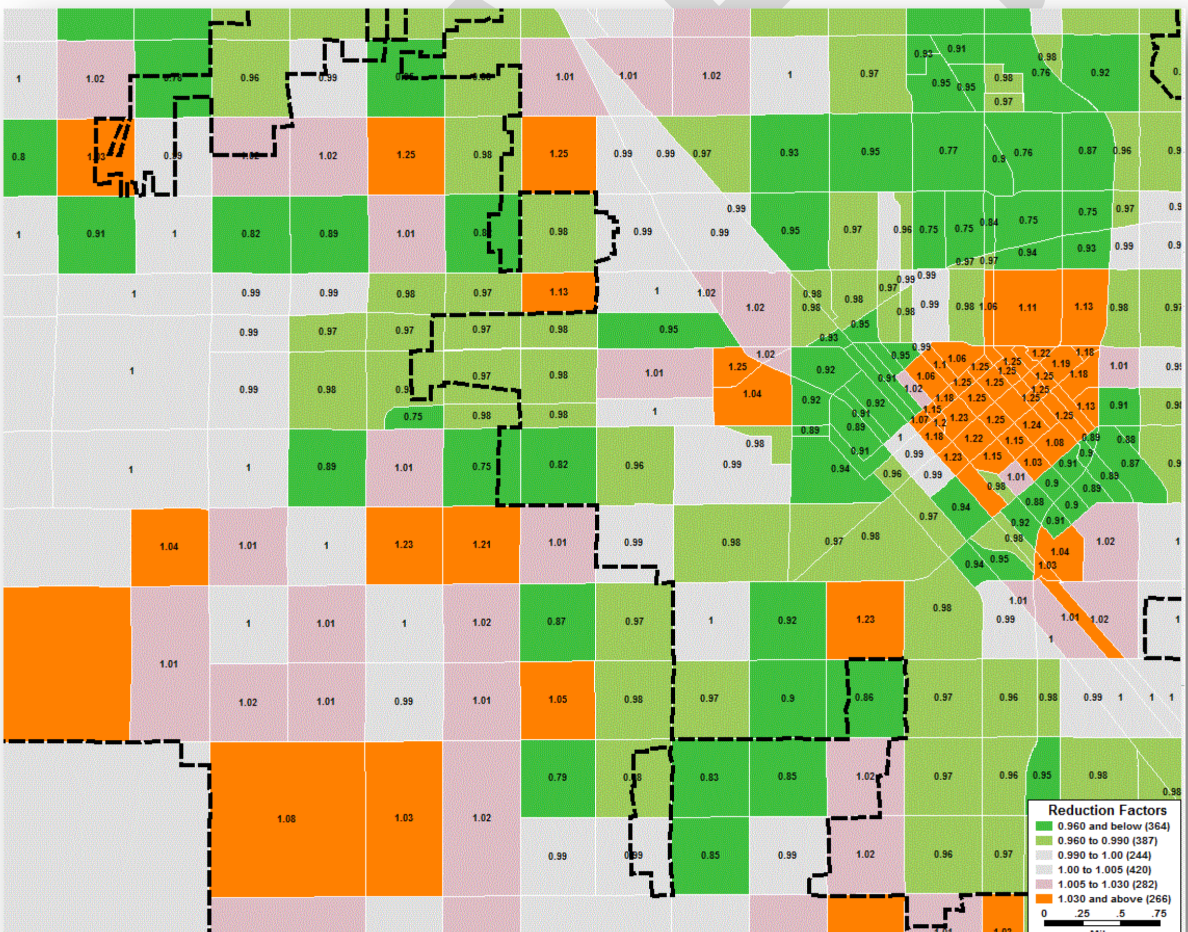


Figure 6 - Ds Analysis Module Reduction Factors

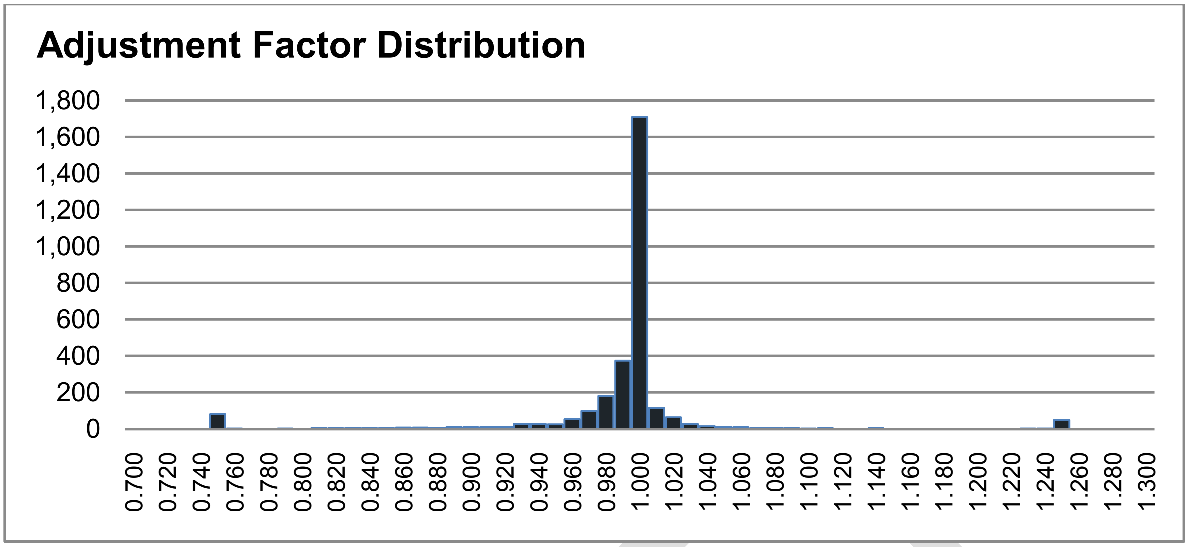
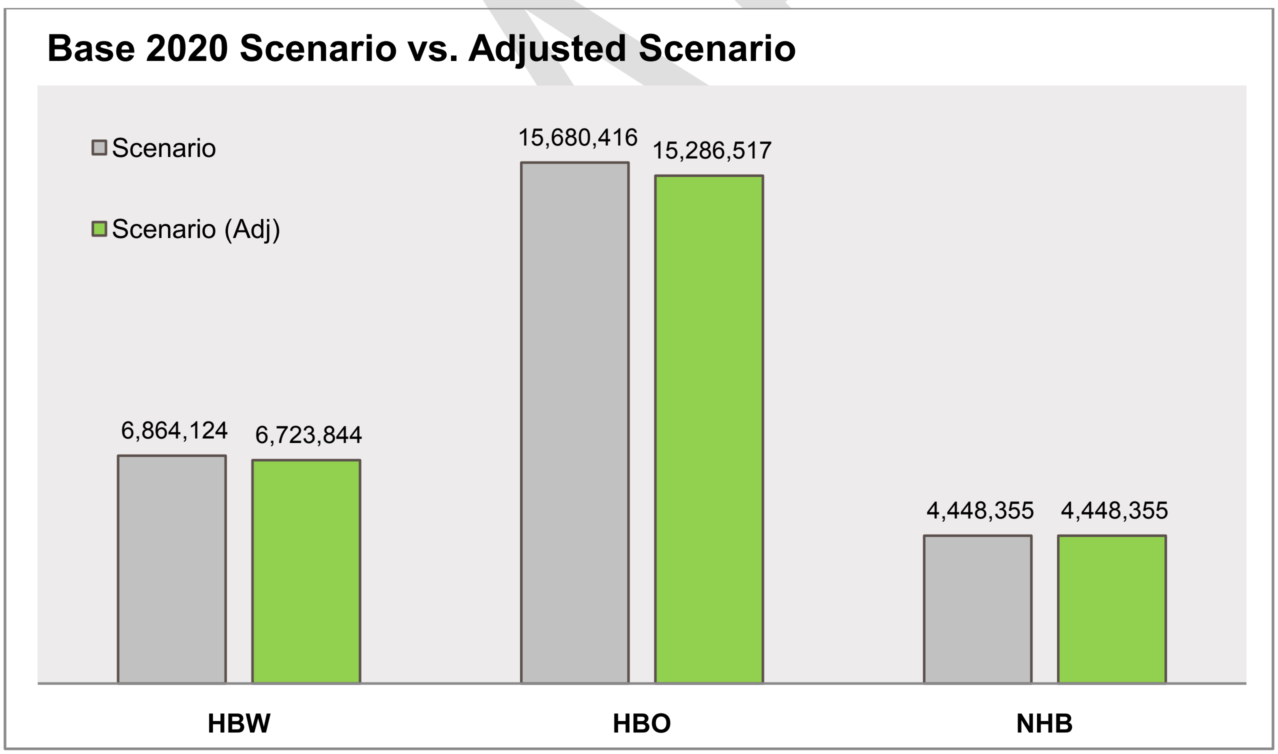


Figure 7 - Adjusted VMT for 2020 Conceptual Scenario



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

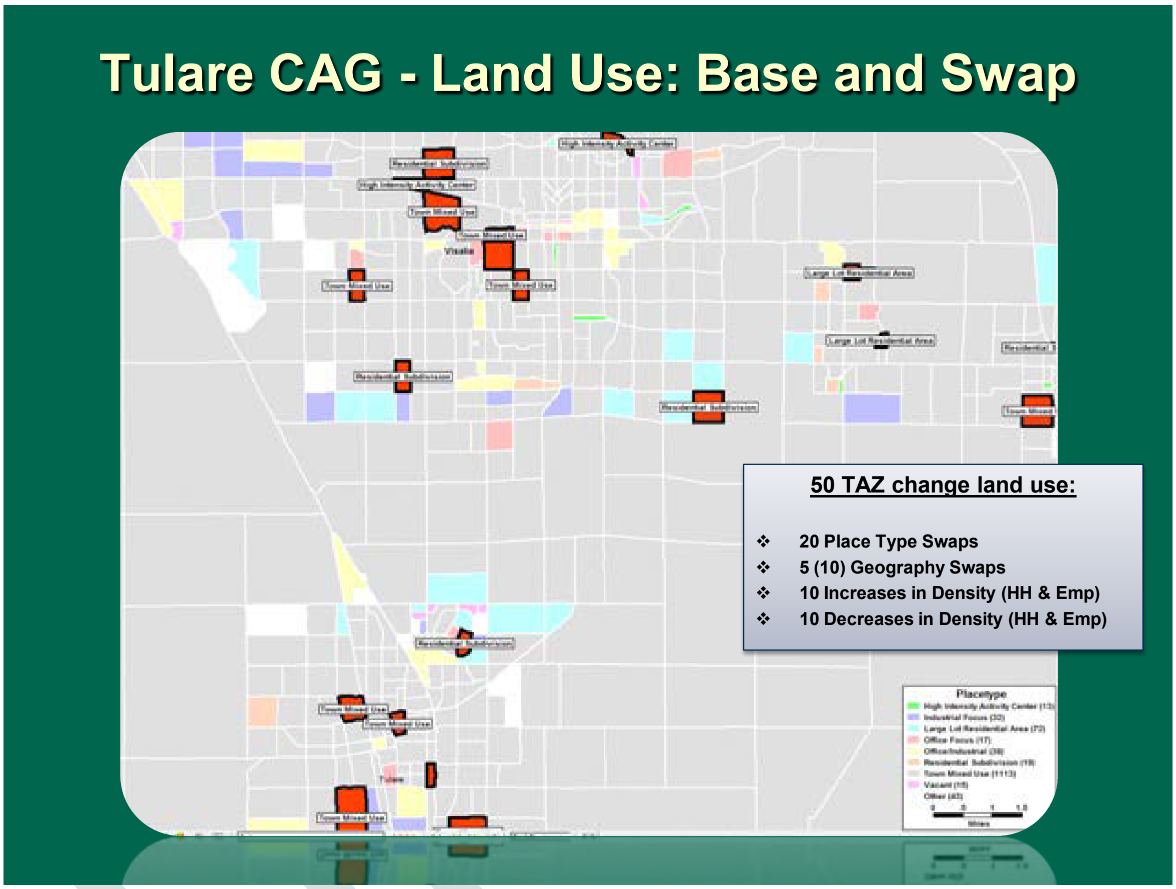


Table 2 (below) illustrates the best fitting regression equation developed for explaining the additional reduction in VMT found by Ds Analysis Module in Tulare County. The equation has an adjusted R^2 of 0.48 which means that the independent variables in the equation collectively explain about half of 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

D Variables		Description Variables in terms of differences: (Scenario - Base)	Calibration Model B	 t (sig.)
	(Constant)		**0.017**	0.994
Demographics	**TOTHH**	**Total Households per TAZ**	**-0.075**	0.000
	HHVEH_CAT_0	**Household Size**	**190.050**	0.014
	HHSIZE_CAT_1	Household Size		
	HHSIZE_CAT_2	Household Size		
	Income10K	Income by $10K increments		
	HHVEHCNT	**Household Vehicle Count**	**38.435**	0.000
Density	**DEN_NetRes**	**Household population/residential acres within buffer**	**-0.320**	0.414
	DEN_DevAcres	**Sum of developed acres within half mile**	**-0.749**	0.007
	DEN_EmpAcre	**Total jobs in 1/2 mile buffer**	**14.709**	0.062
	DEN_mi_acres	**Minor commercial acres within buffer**	**-1.118**	0.009
	DEN_inUrban	Record in Urban Area		
Diversity	DIV_JobsHH	Number of jobs/hh within buffer		
	DIV_LUEntropy	Land Use Mix within buffer (Entropy Index)		
Design	**DSG_Street**	Roadway density		
Dist. to Transit	DisT_RRstop	Nearest railroad station (converted to miles)		
		Number of “D” variables	**7**	
		2020 Concept Scenario VMT Reduction	**-1.24%**	
	R2		0.497	
	Adj R2		**0.481**	

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

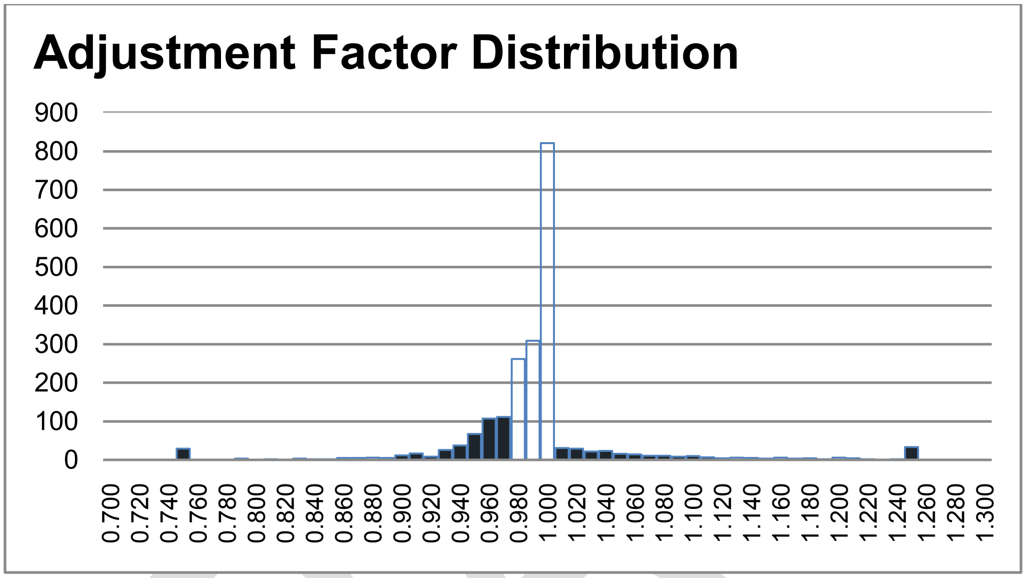
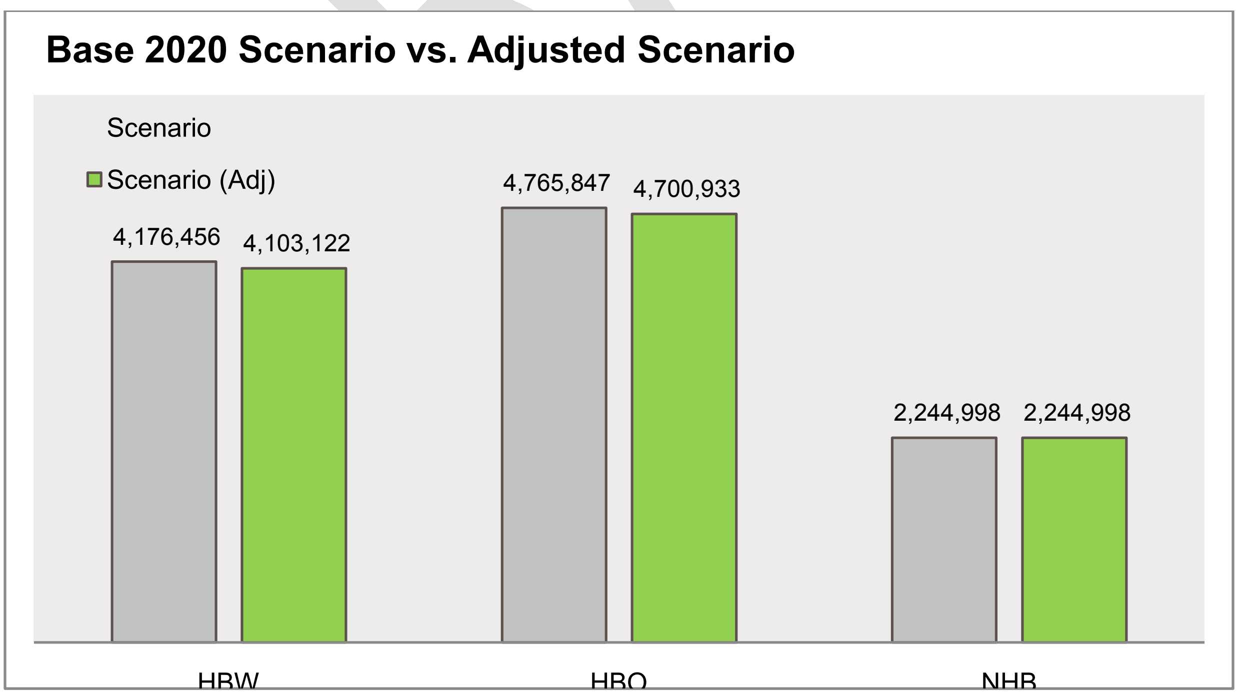


Figure 10 - Adjusted VMT for 2020 Conceptual Scenario for Tulare CAG



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

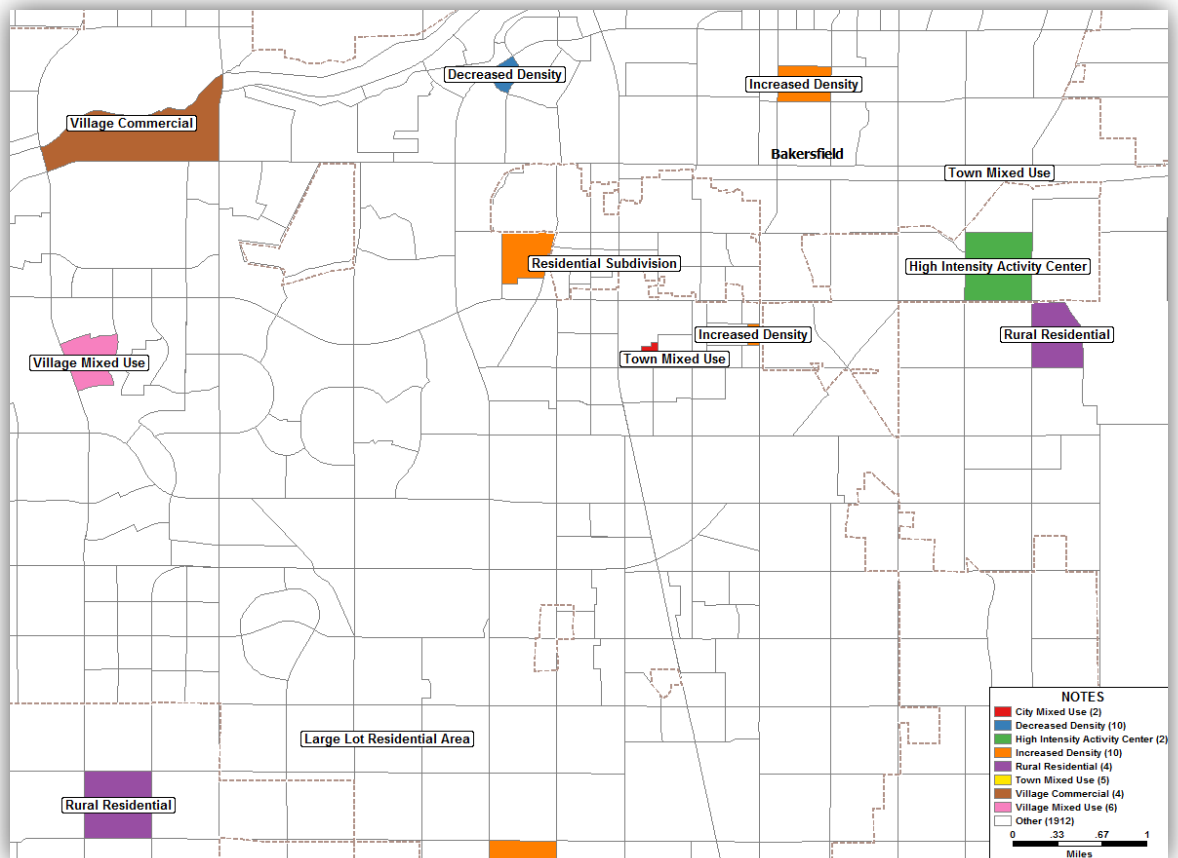


Table 3 (below) illustrates the best fitting regression equation developed for explaining the additional reduction in VMT found by Ds Analysis Module in Kern County. The equation has an adjusted R^2 of 0.59 which means that the independent variables in the equation collectively explain about three-fifths 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

D Variables		Description Variables in terms of differences: (Scenario - Base)	Calibration Model B	 t (sig.)
	(Constant)		**2.623**	0.015
Demographics	TOTHH	Total Households per TAZ		
	HHVEH_CAT_0	**Household Size**	**-397.062**	0.000
	HHSIZE_CAT_1	Household Size		
	HHSIZE_CAT_2	Household Size		
	Income10K	Income by $10K increments		
	HHVEHCNT	**Household Vehicle Count**	**34.702**	0.000
Density	**DEN_NetRes**	**Household population/residential acres within buffer**	**-0.194**	0.054
	DEN_DevAcres	Sum of developed acres within half mile		
	DEN_EmpAcre	**Total jobs in 1/2 mile buffer**	**-2.566**	0.001
	DEN_mi_acres	Minor commercial acres within buffer		
	DEN_inUrban	Record in Urban Area		
Diversity	DIV_JobsHH	Number of jobs/hh within buffer		
	DIV_LUEntropy	Land Use Mix within buffer (Entropy Index)		
Design	**DSG_Street**	**Roadway density**	**-3.778**	0.000
Dist. to Transit	DisT_RRstop	Nearest railroad station (converted to miles)		
		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

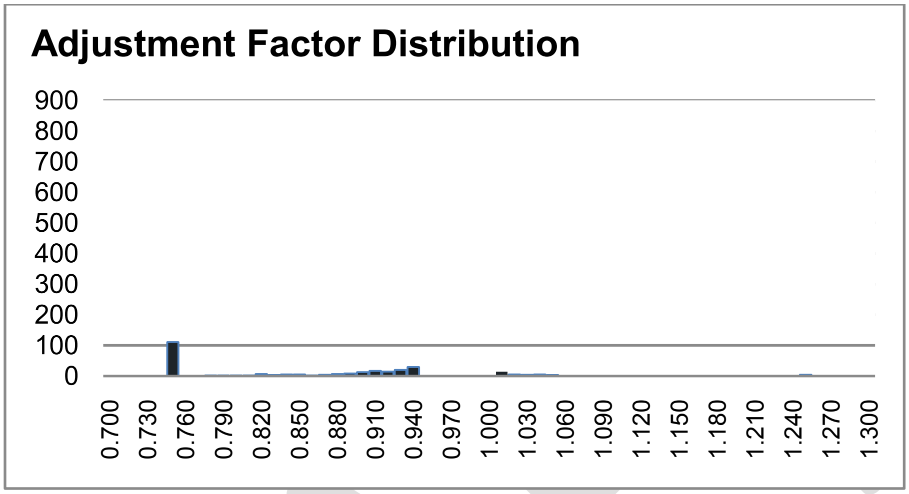
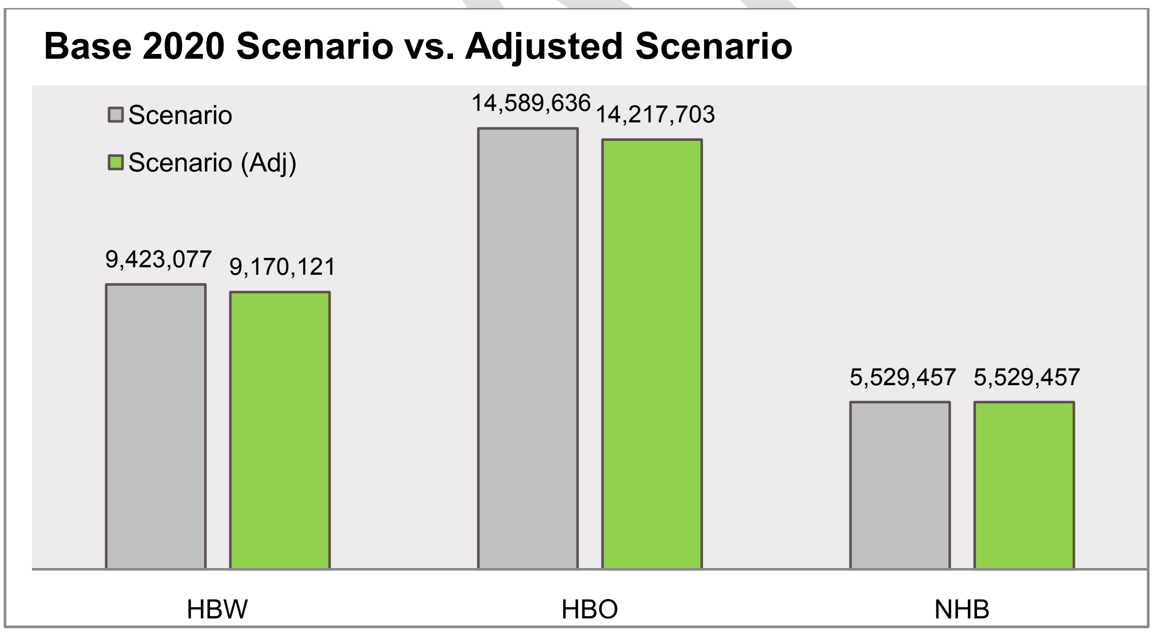


Figure 13 - Adjusted VMT for 2020 Conceptual Scenario for Kern COG



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

Stockton area.

Figure 14 – Three-County Land Use Swaps

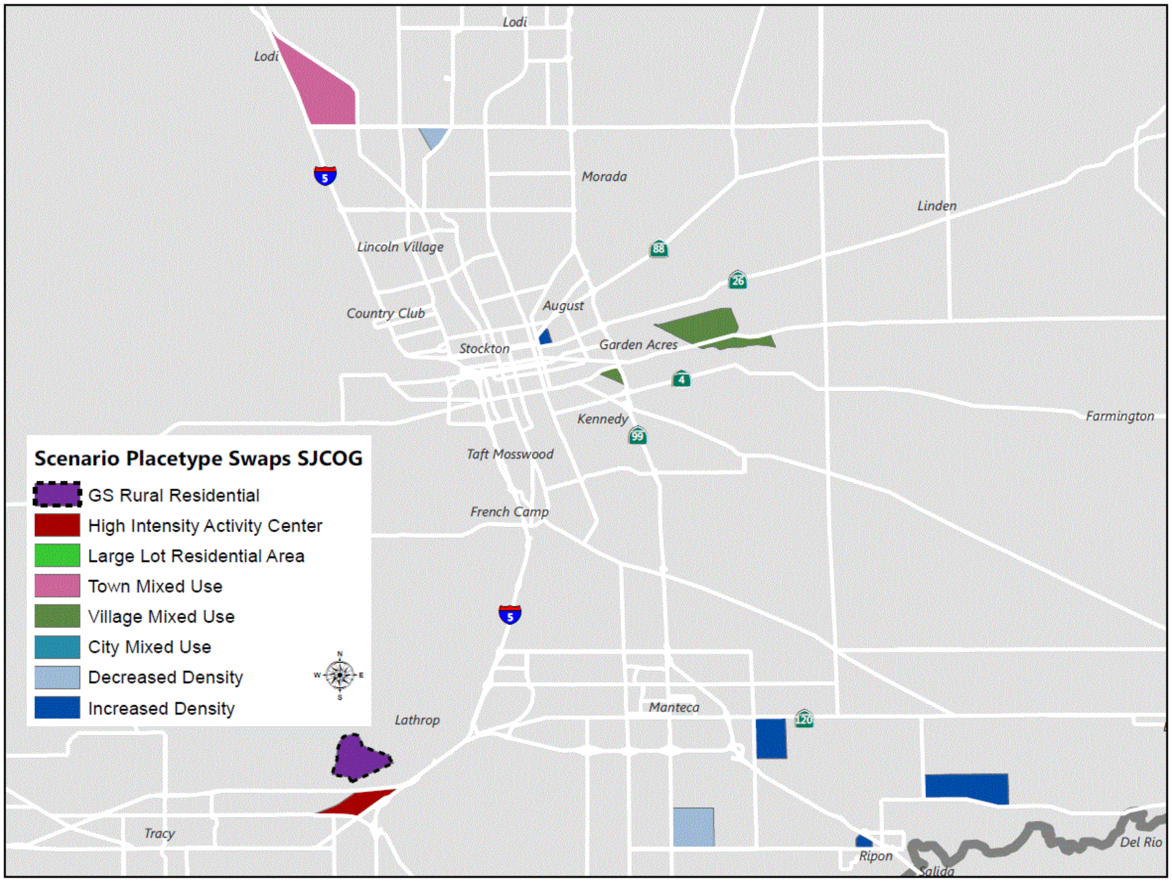


Table 4 (below) illustrates the best fitting regression equation developed for explaining the additional reduction in VMT found by Ds Analysis Module for the Three-County Model. The equation has an adjusted R^2 of 0.50 which means that the independent variables in the equation collectively explain about 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 spreadsheet calibration tool for adjusting TDF VMT forecasts.

Table 4 – Three-County Calibration Equation

D Variables		Description Variables in terms of differences: (Scenario - Base)	Calibration Model B	 t (sig.)
	(Constant)		**4.644**	0.000
Demographics	TOTHH	Total Households per TAZ		
	HHVEH_CAT_0	**Household Size**	**-126.363**	0.000
	HHSIZE_CAT_1	Household Size		
	HHSIZE_CAT_2	Household Size		
	Income10K	Income by $10K increments		
	HHVEHCNT	Household Vehicle Count		
Density	**DEN_NetRes**	**Household population/residential acres within buffer**	**-0.349**	0.060
	DEN_DevAcres	Sum of developed acres within half mile		
	DEN_EmpAcre	**Total jobs in 1/2 mile buffer**	**-2.445**	0.000
	DEN_mi_acres	Minor commercial acres within buffer		
	DEN_inUrban	Record in Urban Area		
Diversity	**DIV_JobsHH**	**Number of jobs/hh within buffer**	**0.943**	0.127
	DIV_LUEntropy	**Land Use Mix within buffer (Entropy Index)**	**-18.860**	0.001
Design	DSG_Street	Roadway density		
Dist. to Transit	DisT_RRstop	Nearest railroad station (converted to miles)		
		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

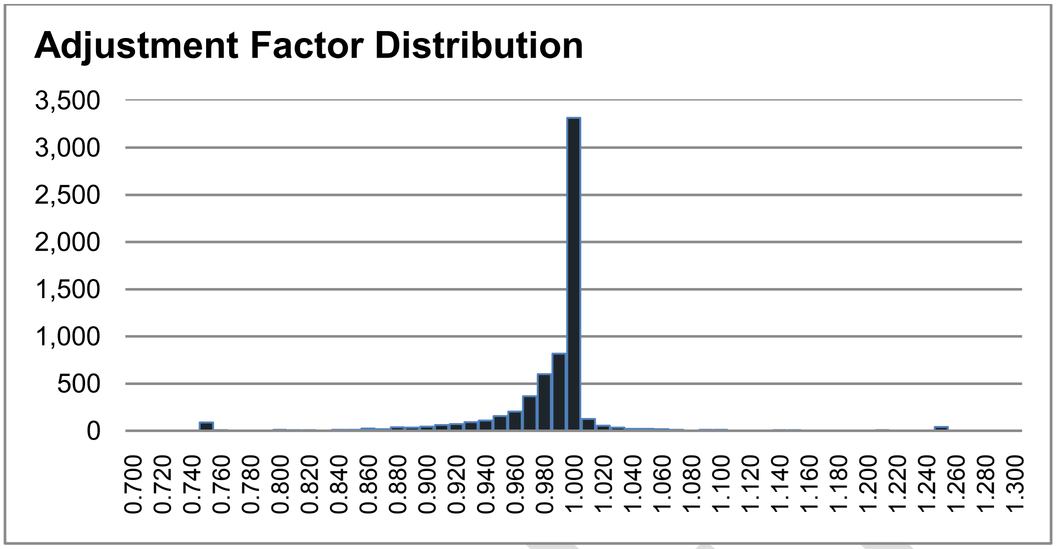
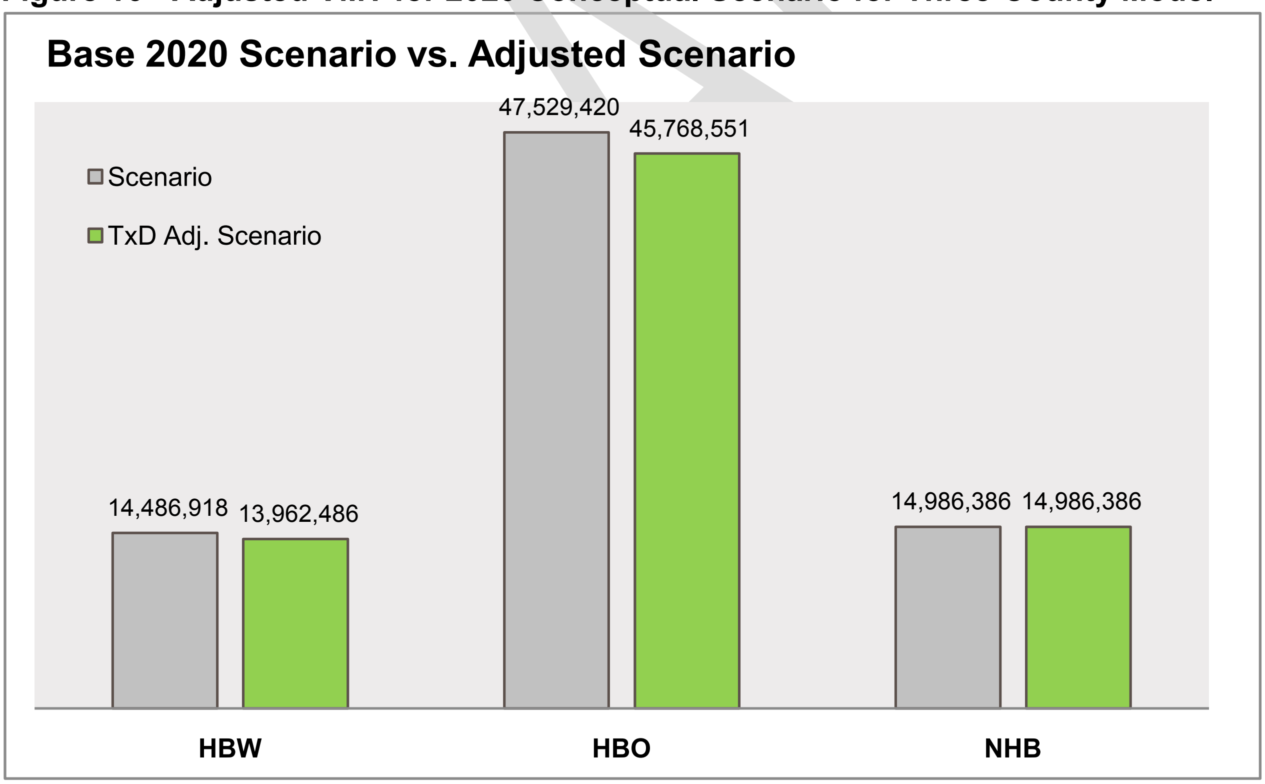


Figure 16 - Adjusted VMT for 2020 Conceptual Scenario for Three-County Model



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

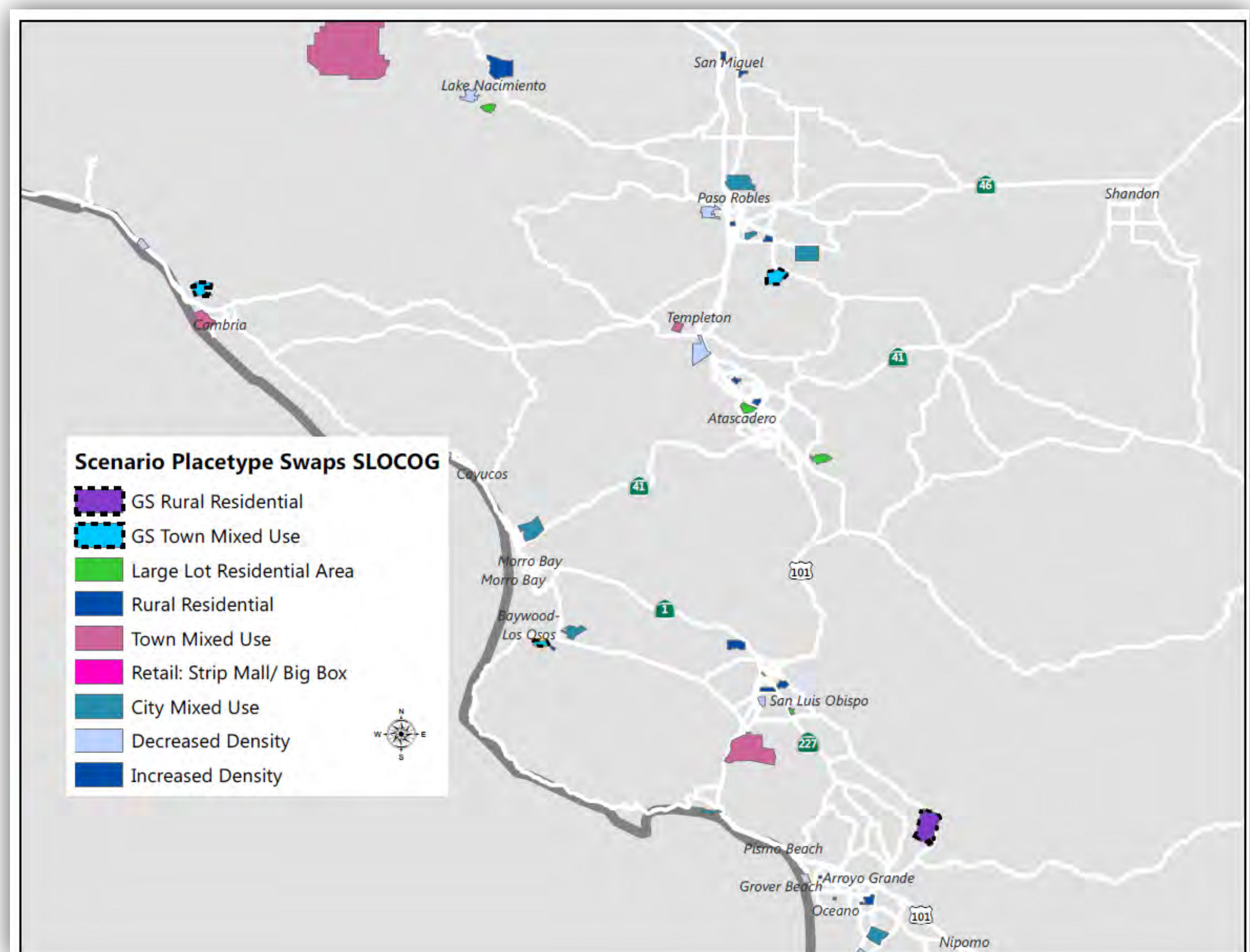


Table 5 illustrates the best fitting regression equation developed for explaining the additional reduction in VMT found by Ds Analysis Module in the SLOCOG area. The equation has an adjusted R^2 of 0.61 which means that the independent variables in the equation collectively explain about three-fifths 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

D Variables		Description Variables in terms of differences: (Scenario - Base)	Calibration Model B	t (sig.)
	(Constant)		-4.985	0.000
Demographics	**TOTHH**	**Total Household**	**0.736**	0.000
	HHSIZE_CAT_1	Household Size		
	HHSIZE_CAT_2	Household Size		
	Income10K	**Income by $10K increments**	**0.507**	0.000
Density	**DEN_NetRes**	**Household population/residential acres within buffer**	**-0.640**	0.115
	DEN_DevAcres	Sum of developed acres within half mile		
	DEN_EmpAcre	Total jobs in 1/2 mile buffer		
	DEN_mi_acres	Minor commercial acres within buffer		
	DEN_inUrban	Record in Urban Area		
Diversity	DIV_JobsHH	Number of jobs/hh within buffer		
	DIV_LUEntropy	**Land Use Mix within buffer (Entropy Index)**	**-36.480**	0.000
Design	**DSG_Street**	**Roadway density**	**-6.890**	0.000
Dist. to Transit	DisT_RRstop	Nearest railroad station (converted to miles)		
		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

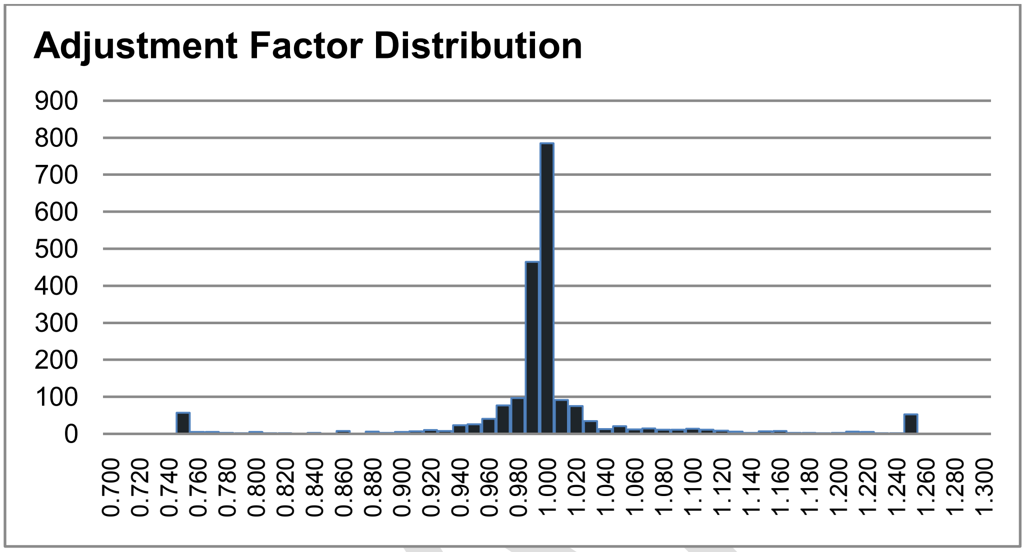
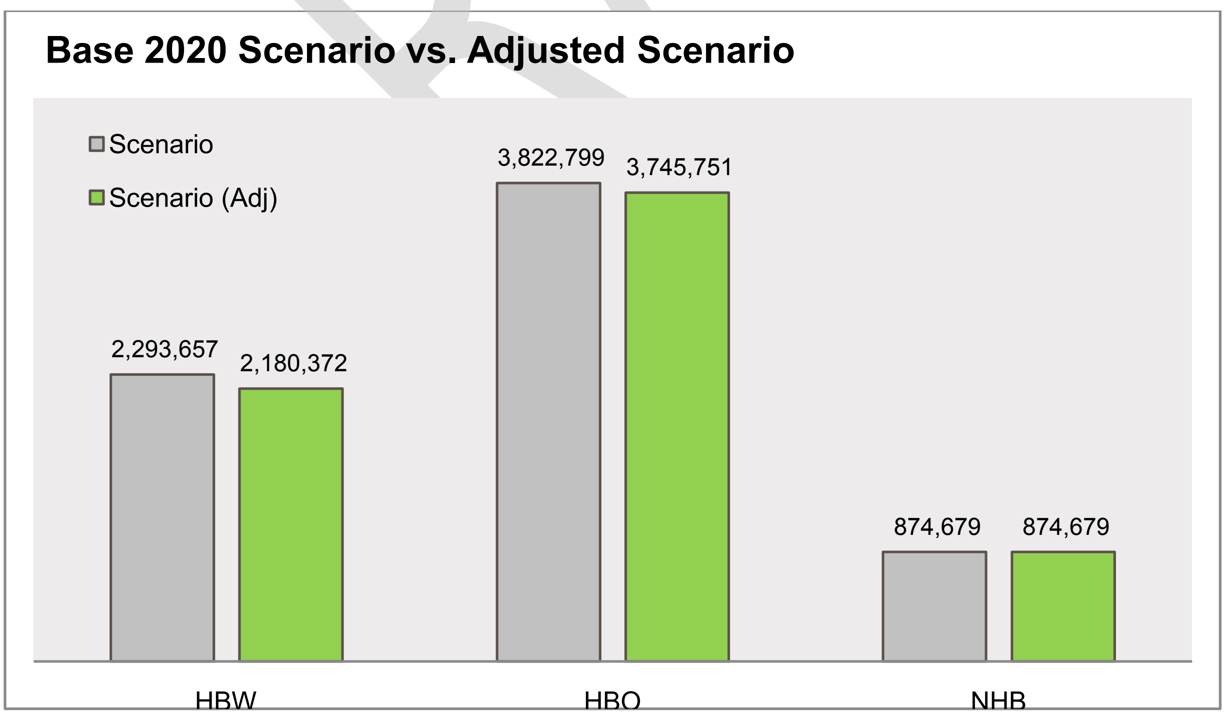


Figure 19 - Adjusted VMT for 2020 Conceptual Scenario for SLOCOG



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

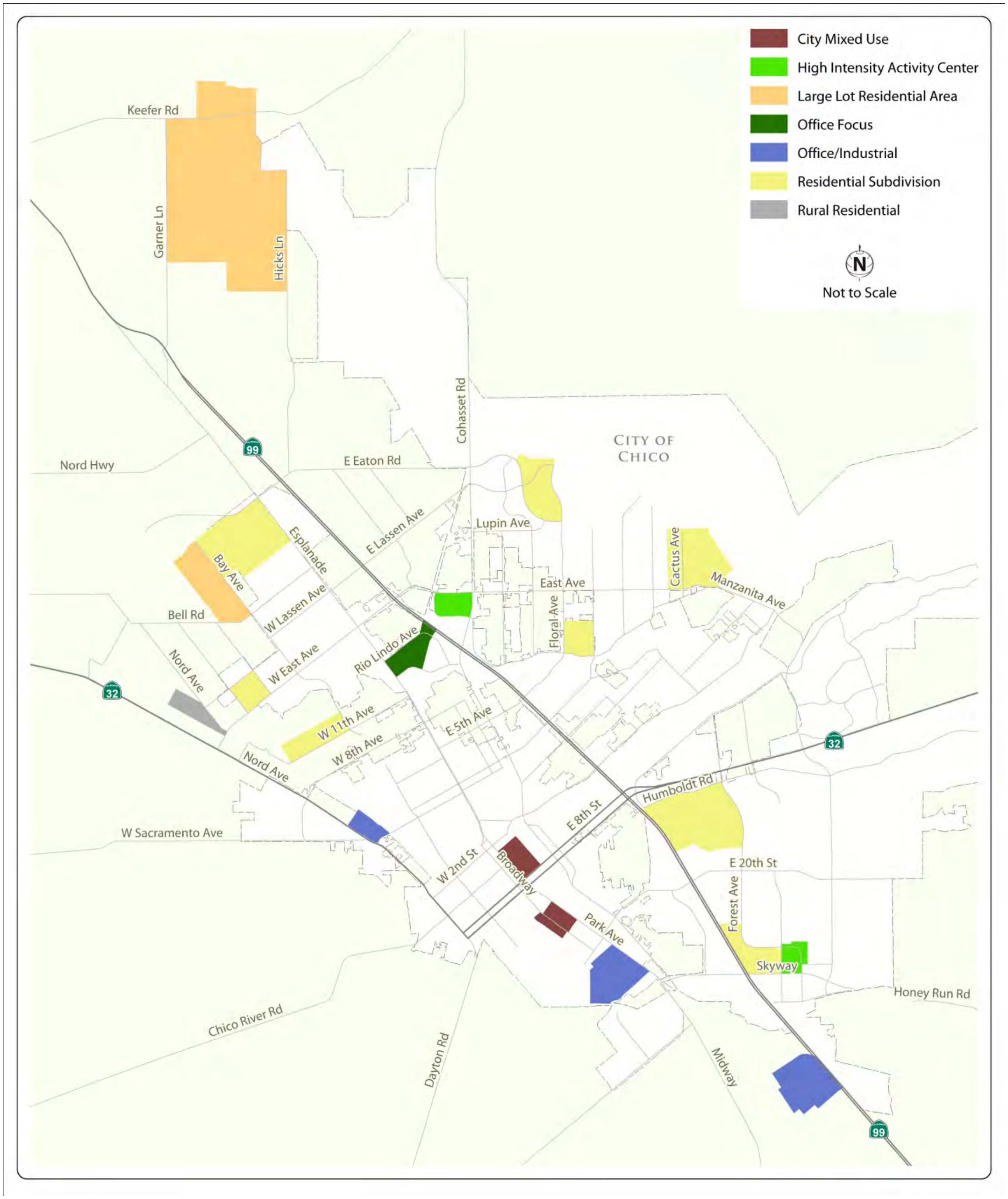


Table 6 - Butte CAG Calibration Equation

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

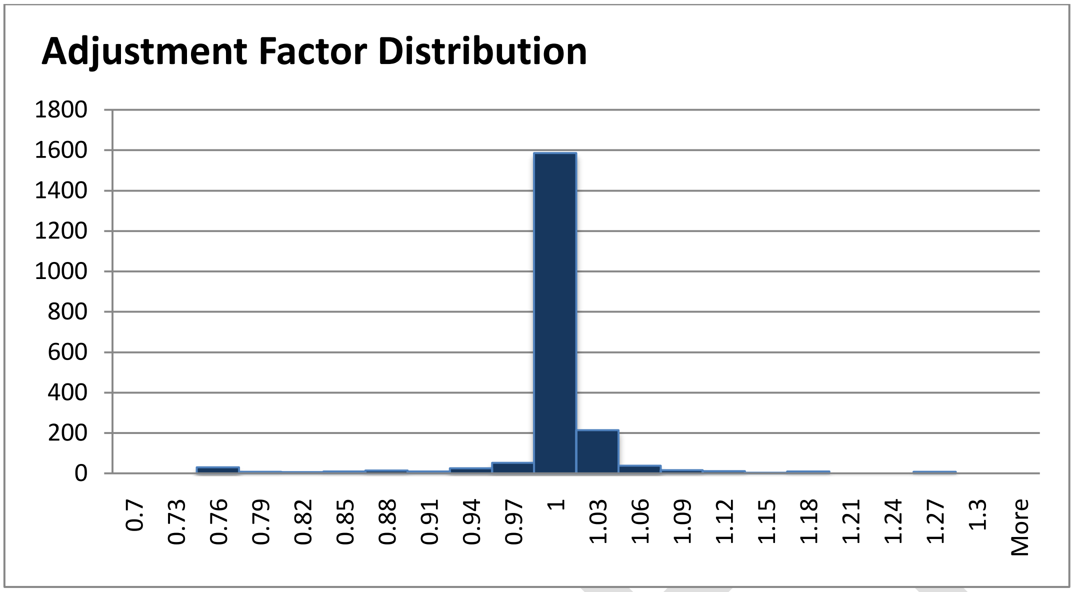
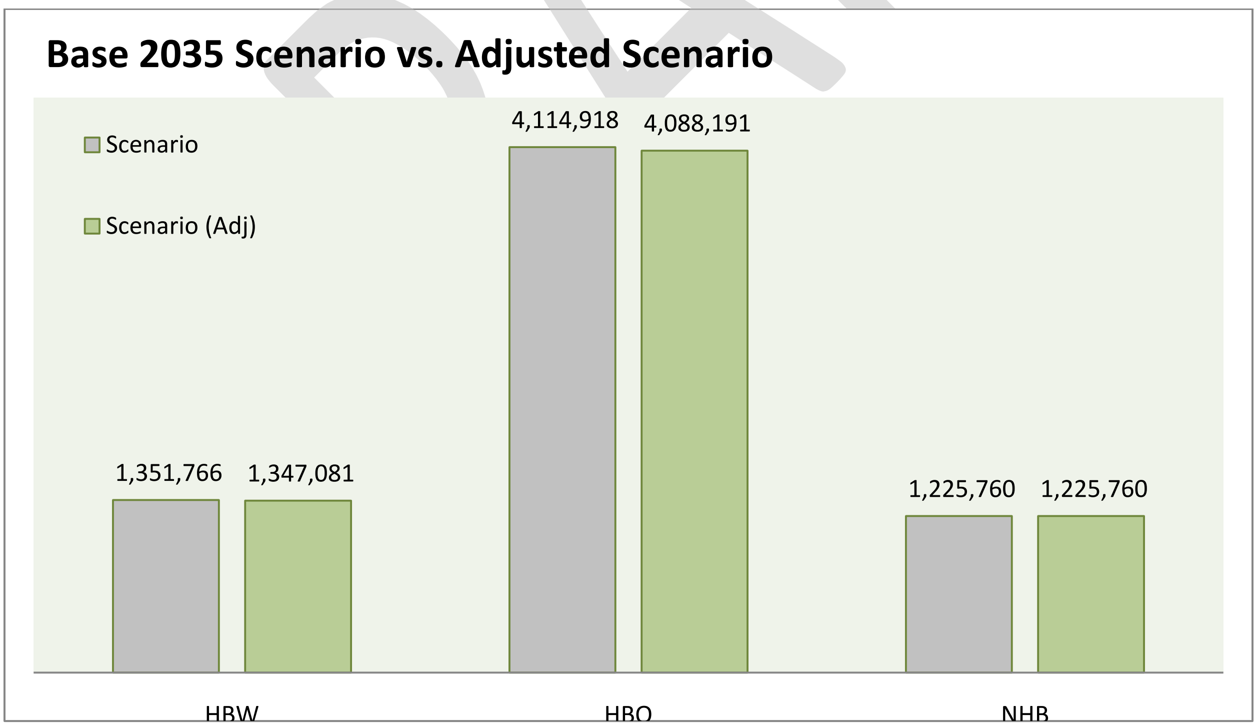


Figure 22 - Adjusted VMT for 2020 Conceptual Scenario for Butte CAG



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).

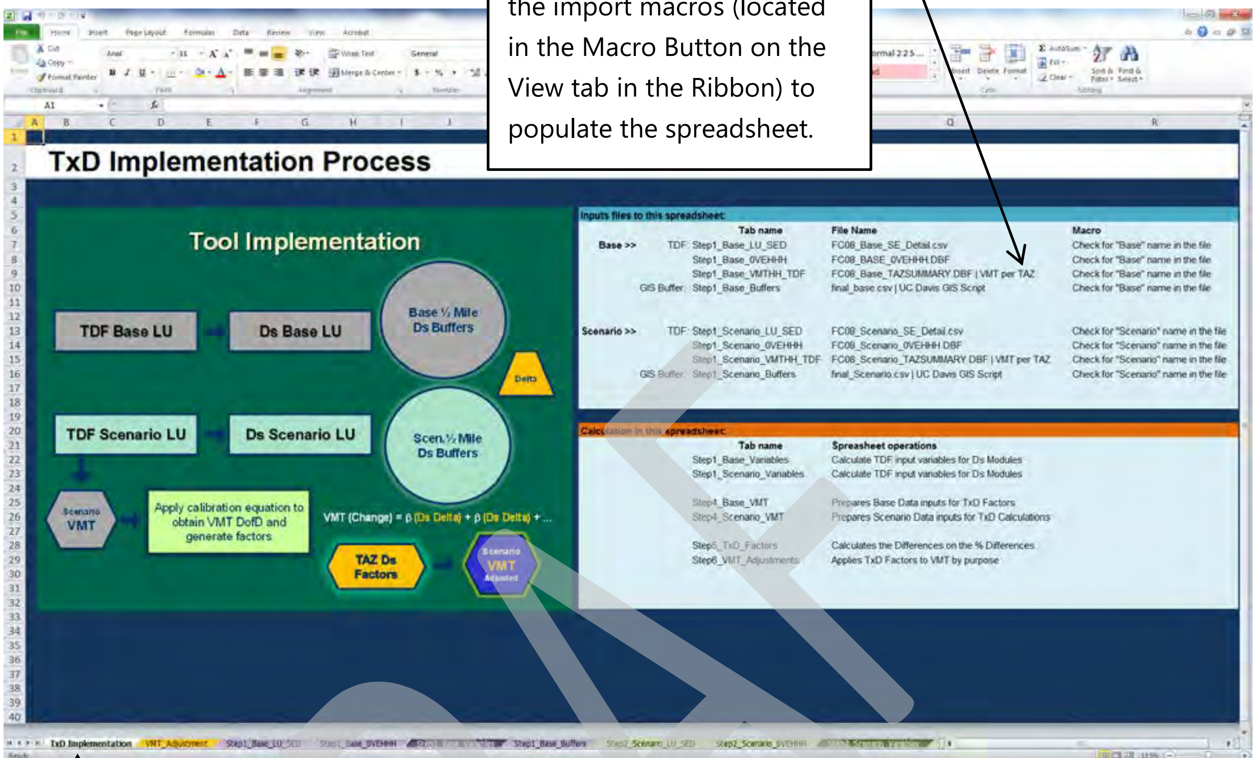
- The TDF model forecast of region-wide vehicle miles traveled (VMT) by trip purpose, to be adjusted by a separate data preparation script and the post-processor spreadsheet to take into account the effects of the built environment "D" variables.

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).

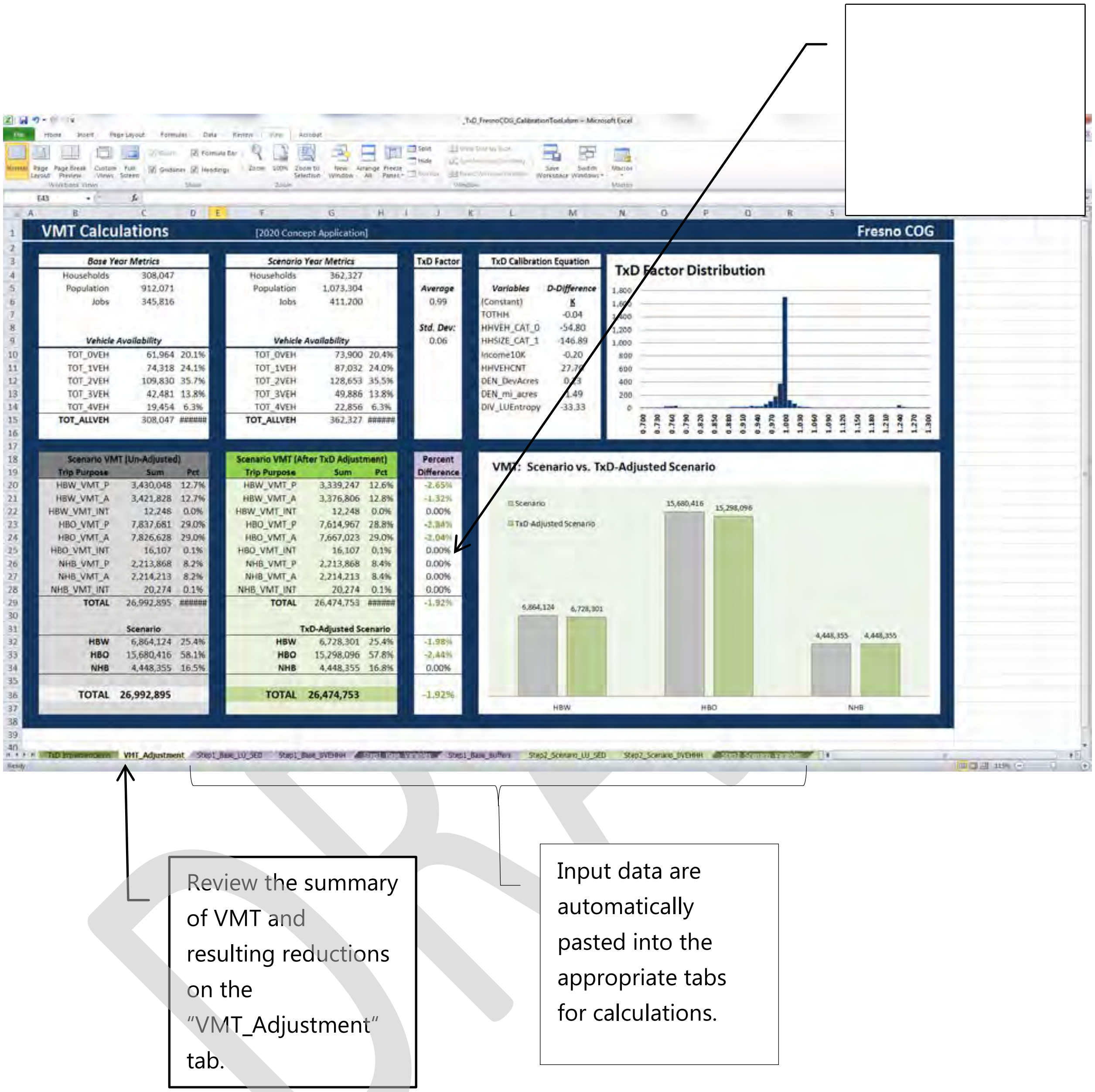
Figure 23 - Input Worksheet for Ds Adjustment Module

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



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.

FINAL REPORT – Improved Data & Tools for Integrated Land Use-Transportation Planning in California

APPENDIX F

Python Module and UPlan Implementation

TOPICS Include:

1. Overview
2. Appropriate Use Statement
3. Python Module
4. UPlan Implementation
5. Validation Test Plan and Results
6. Ancillary Products

- Nathaniel Roth, Urban Land Use and Transportation Center (ULTRANS), University of California, Davis

August 28, 2012

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1. Overview

Appendix “F” describes and documents three products of the “Improved Data and Tools for Integrated Land Use-Transportation Planning in California” funded by the California Department of Transportation (Caltrans). The broader goals and objectives of this study are described in the final report Overview.

One product described in this Appendix, the “python” module, is a building block component for using the study’s findings. (Note: “python” is a type of GIS programming code – see definitions below.) At its core, the python module is a specific-purpose calculator that utilizes the “Ds Analysis Modules” findings (which are described in Appendix “D” of the final report) and enables their application in GIS tools. The python module is not a standalone product and is not intended to exist without the support of other “helper” tools that prepare the inputs and record the outputs from it. In many ways, these helper functions are the more complex component of the tool kit and must be created and tested with care.

The second product described in this Appendix is the “UPlan Implementation.” (note: “UPlan” is a GIS scenario-planning tool that was developed by the University of California at Davis, which is used in a number of small and rural areas of California. Additional information about UPlan is provided in Section 5.) This process starts with the python module and then builds the “helper” functions that are needed to: prepare a baseline land use dataset, merge a UPlan growth projection with it, prepare all of the inputs to the python module, and record its outputs for further use and visualization.

Finally, an ancillary product is a prototype “placetype translation engine.” Written entirely in python, this translation module provides a structured “least distance” matching algorithm for converting one placetype with defined characteristics into the closest matching member of another placetype system based on matching characteristics. Like the python module, this component requires that “helper” functions be created to feed information into it and accept the outputs from it. But given those limits, it should be broadly usable in a wide range of other toolkits.

A. Programming Terms Used

Python: a free, open source, programming language in frequent use. ESRI has adopted python as the default scripting language for much of its business model. Python code can be edited by any text editor, though frequently an integrated development environment is used to speed the development process.

Integrated Development Environment (IDE): an application to assist with authoring programming code. These frequently include the automatic completion of commands and build in error and syntax checking. The code provided here was developed using the Pydev extension for Eclipse, a free and open source IDE.

Module: a unit of programming code distributed in a single python file. A module can take many forms, but in this case the module contains the classes and the code that enables them to be used. eg. "VMTEngine.py" is a module that contains the "main" classes VMT_2Step and VMT_3Step which make use of classes also included in VMTEngine that handle the binomial logistic and linear regression operations.

Class: the programming description of the properties and methods of an *object* intended to complete a task.

Function: a component of a class that defines how some task should be completed.

Object: an instance of a *class*. An object is a working copy of the "blueprint" laid out by the class that describes it. For example a simple class might describe an object that takes two numbers, adds them together and returns the result. An object created (formally "instantiated") from the class would be handed the two numbers by the program which would also receive the result.

In an OOP programming language all variables are objects. i.e. a string is an object as is a number either integer or floating point.

Object-oriented programming (OOP): A method of programming in which the applications are built by combining objects (described by classes) to complete a programming task. The advantages of are that each individual class can be self contained and can be built by linking other classes together. In OOP, the fundamental idea is that each individual class serves as a building block that can be reused, extended, tested, and debugged individually, and that if changes are needed they can be made only to the class, and those fixes will propagate through all instances of its use. There can also be multiple objects created from the same class simultaneously which allows, if the classes are defined to support it, for what is known as multi-threading or multi-processing allowing calculations to happen in parallel on modern computers. (note: The objects provided by ESRI for assembling GIS tools do not handle these muilti-processing tasks well.)

Reference Model: A working example of an algorithm or programming task with both the input and output values available that can be used as a model for subsequent development. In this case, a spreadsheet assembled by Fehr & Peers for this project that contained the needed algorithms and an application to data was used as the "reference model" for developing the python module. This also provided the initial accuracy testing for the python module as it replicated the results of the spreadsheet for identical input data.

List: an ordered set of objects (frequently an ordered set of text or number objects). You retrieve the desired object from a list by its position. i.e. the 3rd item in the list.

Dictionary: a key indexed set of objects. i.e. a set in which you find the item you're looking for by using a name for it rather than an order.

Comment: A comment is an inactive line or section of code that does not get executed. It is intended as a comment on what the code is intended to do or as a note to other users. In python, a "#" symbol indicates that the remainder of the programing line should be considered a comment.

Doc String: A specialized form of comment. Doc Strings are a unified block of comments, generally, at the beginning of a module, class, or function that describes the purpose and usage of that section of code. In python, a block of comments such as a Doc String is enclosed in a set of three sequential single or double quotes like:

```
“””
Comment here.
“””
```

2. Appropriate Use Statement

The following statement is appended to the beginning of all of the modules prepared as a result of the “Improved Data and Tools for Integrated Land Use-Transportation Planning in California”. It describes the intended use and discourages uses outside of its intended scope.

This is a land use-transportation scenario comparison tool. It conducts a "sketch" level analysis of land use and transportation relationships using "7 Ds": density (or intensity), diversity (mixture of uses), distance to transit, design (# of street intersections), destination (location within a metropolitan area), demographics, and development scale.

It assesses how a proposed scenario differs from an established or "base case" scenario, comparing them on built environment metrics such as the number and types of jobs and households, densities, and the mix of land uses. The tool also compares scenarios regarding travel behavior, and - depending on the scale of the project - can provide estimates of vehicle miles traveled (VMT).

This tool can be used at a jurisdictional or regional level for comparing different scenarios and evaluating consistency with large-scale plans (e.g., Sustainable Communities Strategies, General Plans, or large specific plans). It can also be used to compare alternatives for large-scale land use-transportation plans and projects.

These tools should not be used as a replacement for calibrated and validated travel demand models or for regulatory compliance, such as regarding air quality requirements, CEQA, or NEPA.

3. Licensing

The following license is being applied to all modules distributed under this section of the project. The intent is that the tools be freely available to all who wish to use them without restrictions that would pose difficulties for including them within either other commercial or open source tools. As a result, the Apache 2.0 license has been selected. The following licensing statement will be included in the header of each module distributed as part of this toolkit:

```
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```

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4. Python Module

This section will describe the components that, taken as a whole, form the "python module" products of the "Improved Data and Tools for Integrated Land Use-Transportation Planning in California" project.

The python module is available for download from: http://downloads.ice.ucdavis.edu/ultrans/statewidetools/Data_handler.zip

Any programmer who wishes to have "commit access" to the materials on this website may contact Nathaniel (Nate) Roth at neroth@ucdavis.edu to discuss their addition as a committing member of the project.

A user's guide that provides a discussion of the requirements for implementing the code will presented along with an example "helper" module that demonstrates feeding information to the tools and accepting results.

This is followed by a brief section documenting the code used will follow. The majority of the detailed documentation of the code is included in the code and that should be considered the authoritative source of documentation on the code.

A. User Guide

All uses of python module require the construction of a helper function that prepares the data, hands it to the VMT Engine and accepts the responses.

It should be noted that anyone planning to make direct use of the python module must be comfortable working with python prior to trying to do so. This document is not intended to provide sufficient background for a novice programmer to implement this toolkit.

Please see http://downloads.ice.ucdavis.edu/ultrans/statewidetools/Data_handler.zip for an example of a helper function that hands rows from a table into the VMT Engine and then accepts the response. This is the simplest case, one in which the GIS work has already been completed to create a single table that has the total number of housing units, the proportions of housing units in each household type, all of the parameters summarized by their half mile buffers, and any other calculations such as the entropy index already calculated.

The example helper function is contained within a module called Data_handler.py.

Within the helper function there are distinct sections:

a) A class called DataHandler which is instantiated into and object with a list “cats” that has the list of household categories, and “classmat” which is a dictionary that has the household type parameters for each of the households categories listed in cats.
    i) The Handler function: Loops through all of the rows in the input table, and assembles them into the dictionary that gets handed to the VMTEngine
    ii) And accepts the return values and prints them to the screen.
b) A section at the bottom that starts with “if __name__ = “__main__”:
    i) This section is used when running a module as a stand alone process. In this case, it contains the information to create the “cats” and “classmat” values that the Handler needs. It also reads the preprepared table into memory and does final preparation.
    ii) It then instantiates the DataHandler and hands to it each of the rows from the data table and prints the results to the screen
c) VMTEngine_2stage.py the module containing the 2 step VMTEngine that the datahandler uses to perform the calculations.

For a more complex example of a data handler, please see the discussion in the UPlan Implementation section. This will describe a method for preparing the GIS data for use in the model, handing it to the VMTEngine and recording the results.

B. Code Documentation

A spreadsheet provided by Fehr & Peers (http://downloads.ice.ucdavis.edu/ultrans/statewidetools/_TxD_CLEAN_RegressionBuilding.zip) served as the reference model for the python module. This spreadsheet provided a working example of the functions in use, their application to data, and the results produced.

The VMT Engine is the core calculation component of the python module. It is a self-contained python module that provides python classes called VMTEngine_2step and VMTEngine_3step. The intended use of this module is that a programmer can import it and then instantiate objects of type VMTEngine_2step or VMTEngine_3step as appropriate to their use (please refer to Appendices A-D for descriptions of the differences between the 2 and 3 step versions of the module). Our expectation is that the 2 step version will be the far more frequently used class. It is also the only version that has been applied and tested/validated as of this writing.

Two VMT Engine modules will be provided. The first, VMTEngine.py includes both the VMT_2Stage and VMT_3Stage classes and the classes that contribute to them (linear regression, binomial logistic, and some other helper classes). This module is intended for use in more complex modeling systems where either the two or three stage formulations of the tools may be called upon.

The second module contains only the 2 stage VMT Engine class and needed helper classes. This reduced set is not strictly speaking needed, but simplifies the process of using it in a modeling framework that will only use the 2 stage version.

Each of the two and three stage modules has the list of parameters needed and the coefficients that need to be applied included within the class as defaults. While a computer programmer can override these values, we do not anticipate that this will be done with any frequency unless these tools are extended to new areas or updated with revised research.

Upon instantiation of an object of either the two step or three step variety, the programmer must immediately provide that object with an identification of the geographic area the object will be used on. This brings the needed parameter list and coefficients to the forefront for immediate application to data fed into the object. Once the object has been instantiated, the helper functions need only hand it a “dictionary” containing the input values, appropriately named and receive the output.

The intended use case requires that the engine be handed the following sets of information:

2) The household type: which includes information about the households size, number of drivers, available vehicles, presence of children, and income. Both this and point 2 are combined into a parameterized dictionary of the inputs which is read in by the VMT_Engine Classes.
3) Geographic context: all of the variables either summarized by the half-mile buffer around the household's location (i.e. number of jobs, acres of retail, etc), direct measurements from the location (i.e. distance to rail station), or calculated values (i.e. jobs/hh, or an land use mixture measure such as the entropy index)
4) The number of households of the type described in point 1.

The results are then handed back in the form of a list, in which the first element is the total VMT, the second is the binary probability (0 or 1) that a household of the type passed in will make one or more trips on that day, and the last item is the VMT that will be generated by a single household of that type.

The 2 step parameters for small MPOs are presented here. The parameters for small mpo three step, or 2 or 3 step formulations for SACOG or SANDAG implementations should reference the appropriate appendices or the code.

There are several distinct form of parameters. Some parameters are Boolean meaning that they’re true or false these are identified with a # sign. Parameters flagged with a * are used in determining the properties of the household. All of these will be identical for the run on similar households. Unmarked parameters are considered to be continuous. Any reference to a buffered area is an area with a half mile (805m) radius (or 503 acres total area) from the center of the geometry being analyzed.

Table 1: Small MPO 2 Step Parameters

Constant	Constant: 0.6565 (step 1), 1.2171 (step2)
HHVEH_CAT_0	Household has 0 vehicles #*
HHSIZE_CAT_1	Household has 1 member #*
HHSIZE_CAT_2	Household has 2 members #*
HH_w0015	HH with children 0-15 years old # *
HH_w1621	HH with children 16-21 years old # *
WRKCOUNT	Workers in household
DRVRCNT	Number of Drivers in household
Income10K	Average HH income by $10k increments
DEN_NetRes	Household population/residential acres within buffer
DEN_DevAcres	Sum of Developed area within half mile
DIV_JobsHH	Number of jobs/hh within buffer
DIST_RRStop	Distance to nearest railroad station in miles
DEN_EmpAcre	Jobs per acre within the 1/2 mile buffer (total employment / 503 acres)
HHVEHCNT	Average Household Vehicle Count
DEN_inUrban	Record in urban area based on presence of the household in an Urban Area under US Census Definitions (This should be adjusted for future years) #
mi_acres	Minor commercial acres within buffer
DIV_LUEntropy	Land use mix within buffer (entropy index) see forumula below
DSG_Street	Number of Road miles within the half mile buffer

The land use entropy index is calculated as follows:

Employment Entropy = -E/(ln(N))
Where:
E=(b1/e)*ln(b1/e) + (b2/e)*ln(b2/e) + (b3/e)*ln(b3/e) + (b4/e)*ln(b4/e) + (b5/e)*ln(b5/e)
e = total active employment for five active employment categories present in buffer
b1= office employment

b2= retail employment
b3= service employment
b4= institutional employment
b5= school employment
N= number of the employment types with employment > 0

5. UPlan Implementation

UPlan is a simple urban growth model that predicts where new growth will occur using a simple set of user defined rules to allocate projected urban growth to available space. UPlan has been used at one point in all of the small MPOs, and many smaller counties in California, and has a some users across the rest of the United States, and several international users in Asia and Africa.

A common use case for UPlan is the examination of a set of scenarios for future urban growth and the evaluation of the likely consequences of that growth on infrastructure and the environment. In the past, UPlan results have been converted into inputs for traditional travel demand models for the analysis of VMT and infrastructure.

The products of the “Improved Data and Tools for Integrated Land Use-Transportation Planning in California” project open another alternative that will allow the relatively rapid analysis of VMT consequences in a scenario planning environment.

These tools are provided in a toolbox intended for use with the UPlan 2.6 family in ArcGIS10 (the most frequently used version of UPlan). This ArcGIS toolbox contains the UPlan_VMTTools.tbx, and the needed python modules to run the full suite of tools.

A. User Guide

This section will provide basic instructions on the use of the UPlan_VMTTools Toolbox. This toolbox is intended for use only in UPlan 2.6x versions being run in ArcGIS10. This is by far the most frequent user case, though all efforts will be make to keep the toolkit current as UPlan and ArcGIS are updated.

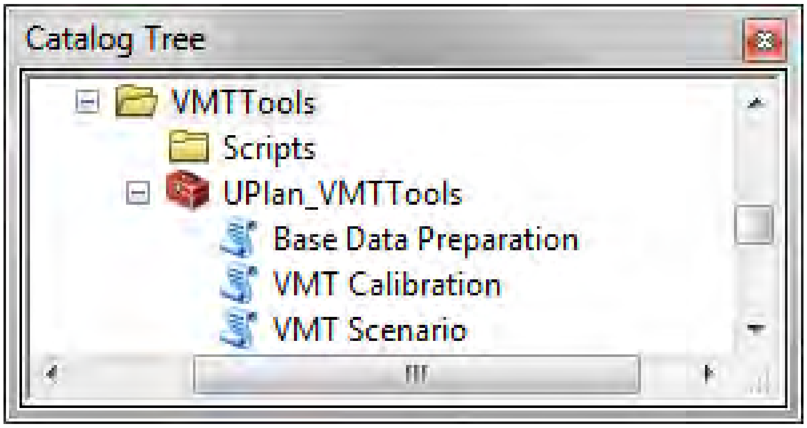

Figure 1: VMTTools Toolbox

The VMTTools toolbox will look much like Figure 1 though there are many ways to access the toolboxes. It will have a toolbox file (UPlan_VMTTools.tbx) which contains linkages to the python modules. There will also be a scripts folder that contains all of the python files used. The script folder and the toolbox (.tbx) must be kept in the same folder. The toolbox (.tbx) will be looking for a scripts folder immediately adjacent to itself in the directory structure that contains all of the python files.

Before attempting to use these tools, make sure that you have updated the numpy and scipy installations for the version of python installed with ArcGIS. This is a simple process if you have a simple installation of ArcGIS and only a single python installation on your computer. If you have multiple versions of python installed, you will need to make sure that numpy and scipy are installing for the ArcGIS installation of python.

Base Data Preparation:

To begin the base data preparation step, collect your existing land use, analysis boundary, roads, roads intersection, and railroad stop data in ArcMap (Figure 2). Ensure that all of the data is in the same projection as is used by your UPlan model.

Prior to beginning to run the base data preparation, please review the configuration settings embedded in VMTUPlan_Basedata.py for needed updates to reflect your base dataset.

Adjustments must be made to the __init__(self) section of the module using either a text editor or a python IDE.

```
self.lufield = "lu_f"
self.reslutypes = ['RM','RS','M'] # All land use types that are considered residential
self.sfdlutypes = ['RS'] # All land use types that are considered SFD
self.mfdlutypes = ['RM', 'M'] # All land use types that are considered MFD
```

```
self.emplutypes =
['I','O','R','M','ID','AP','RR','SC','ML','P','U','AP','MA','MI'] # All land use
types that are considered employment
self.retlutypes = ['R','RR','MI','MA'] # All land use types that are considered
retail
self.lretlutypes = ['R','MI'] # All land use types that are considered local
serving retail
self.serlutypes = ['S'] # All land use types that are considered service
self.offlutypes = ['O'] # All land use types that are considered office
self.indlutypes = ['ID', 'U','AP'] # All land use types that are considered
industrial
self.publutypes = ['I','ML','P'] # All land use types that are considered public
(non school)
self.edulutypes = ['SC'] # All land use types that are considered educational
self.poptypes = ['pop'] # All fields with totals that should be considered
population
self.sfdtypes = ['sfd'] # All fields with totals that should be considered sfd
housing units
self.mfdtypes = ['mfd'] # All fields with totals that should be considered mfd
housing units
self.rettypes = ['ret'] # All fields with totals that should be considered
retail employees
self.sertypes = ['ser'] # All fields with totals that should be considered
service employees
self.offtypes = ['office'] # All fields with totals that should be considered
office employees
self.indtypes = ['ind'] # All fields with totals that should be considered
industrial employees
self.pubtypes = ['inst'] # All fields with totals that should be considered
public (non-school) employees
self.edutypes = ['school'] # All fields with totals that should be considered
education employees

self.gridsize = 10 # grid size in acres
```

`self.lufield = "lu_f"` should be updated so that “lu_f” is replace with the name of the field containing the land use code.

`self.reslutypes` through `self.edulutypes` should be updated so that the contents of the “[‘R’,’S’]” (a python list constructor) contain the list of all land use codes that are considered SFD, MFD, Retail, Local Serving Retail and so on.

`self.poptypes,self.sfdtypes…` And following entries, need to be edited to include the list of all fields containing the total number of population, housing units, and employees of the respective indicated types.

If desired `self.gridsize = 10 # grid size in acres` may be edited to replace the numeric value with an alternate grid size. This will change the spatial resolution of the analysis. The default 10 acre size appears to be a reasonable compromise in computational speed and spatial resolution. There is an exponential relationship between processing time, storage space, and cell size. If you cut the cell size in half, you multiply the time and storage requirements by four.

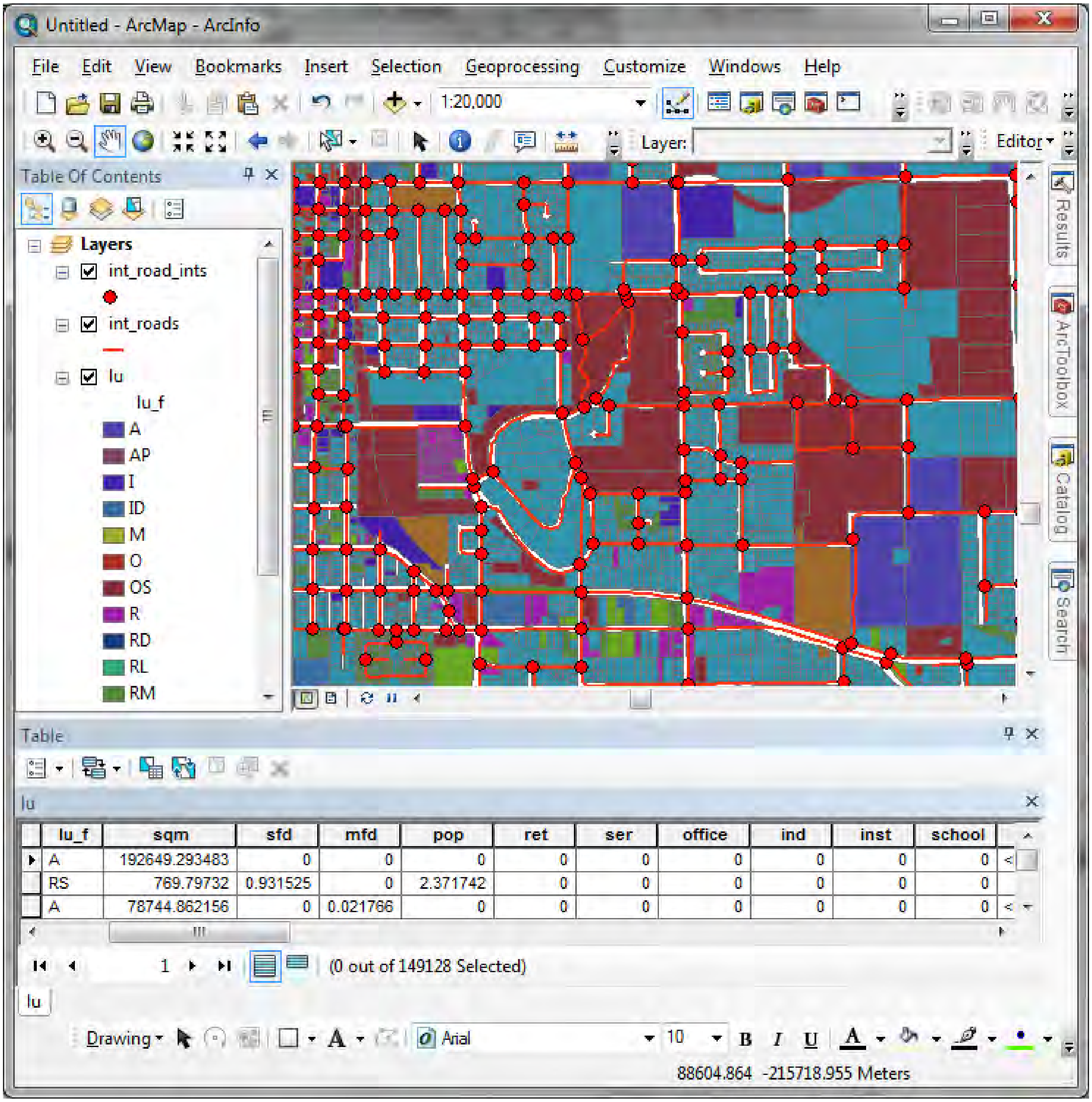

Figure 2: Initial data collection

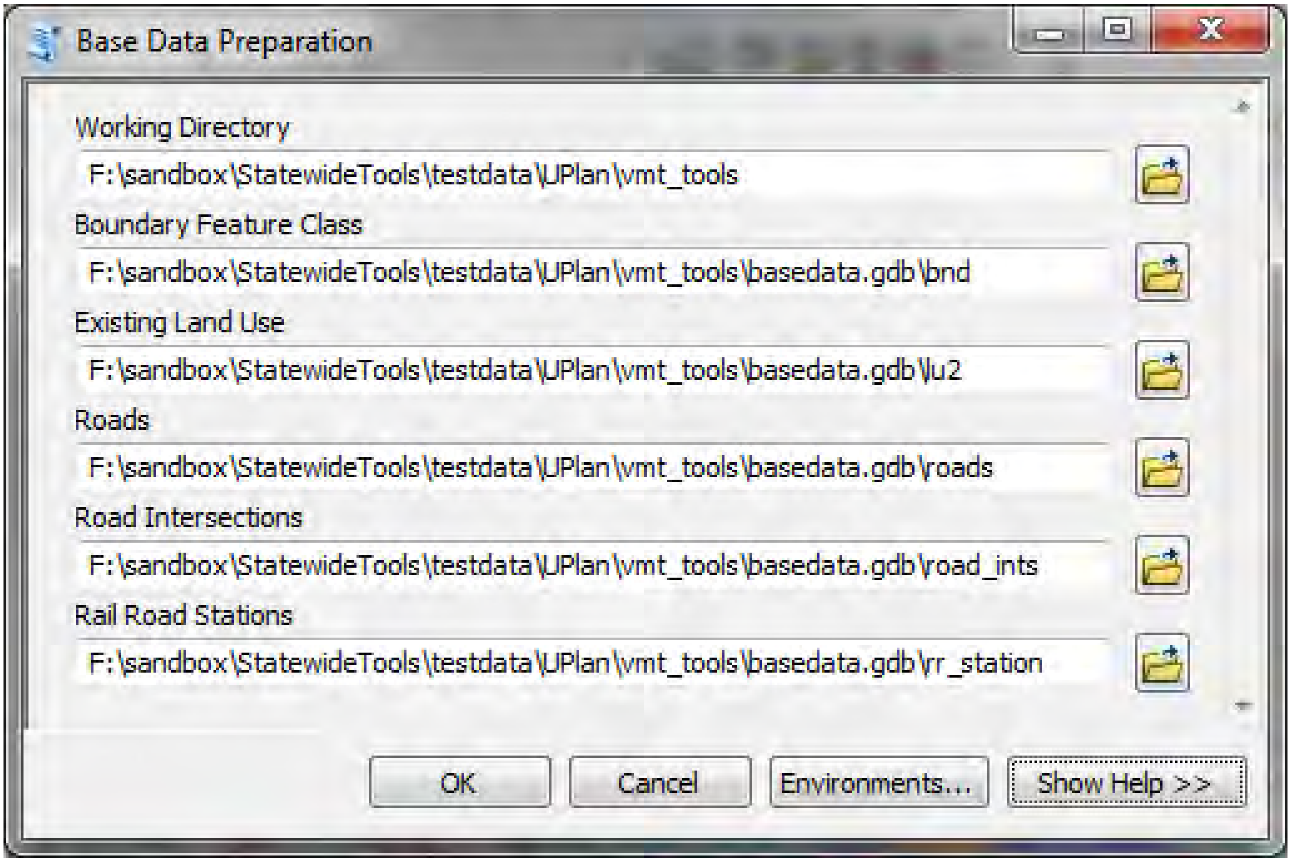

Figure 3: Base Data Preparation

On opening the Base Data Preparation tool from the toolbox you will be presented with a dialog box asking for the following items: (All feature classes should match the projection of the UPlan system).

1. A working director to place the results in. A file geodatabase called baselu.gdb will be created in this directory.
2. A polygon feature class that identifies the boundary of the analysis area
3. A polygon feature class with the existing land use. This dataset must have the following
    a. A field with the land use name
    b. A set of fields with the total number of population, sfd housing units, mfd housing units, retail employees, service employees, office employees, public (non-school) employees, education employees, industrial employees.
4. A line feature class with the road network for the area
5. A point feature class with the road intersections for the area

6. A point feature class with the railroad station locations

Click OK to begin the run. The run will probably take several hours to complete.

VMTUPlan Calibration:

Double clicking on the VMT Calibration Tool in the UPlan_VMTTools toolbox will open the dialog for running the calibration section of the tool (Figure 4). This will allow you to run the VMT tools on the existing land use to provide a base line and the ability to compare the results from scenarios to the present, and the present condition output to other sources of data.

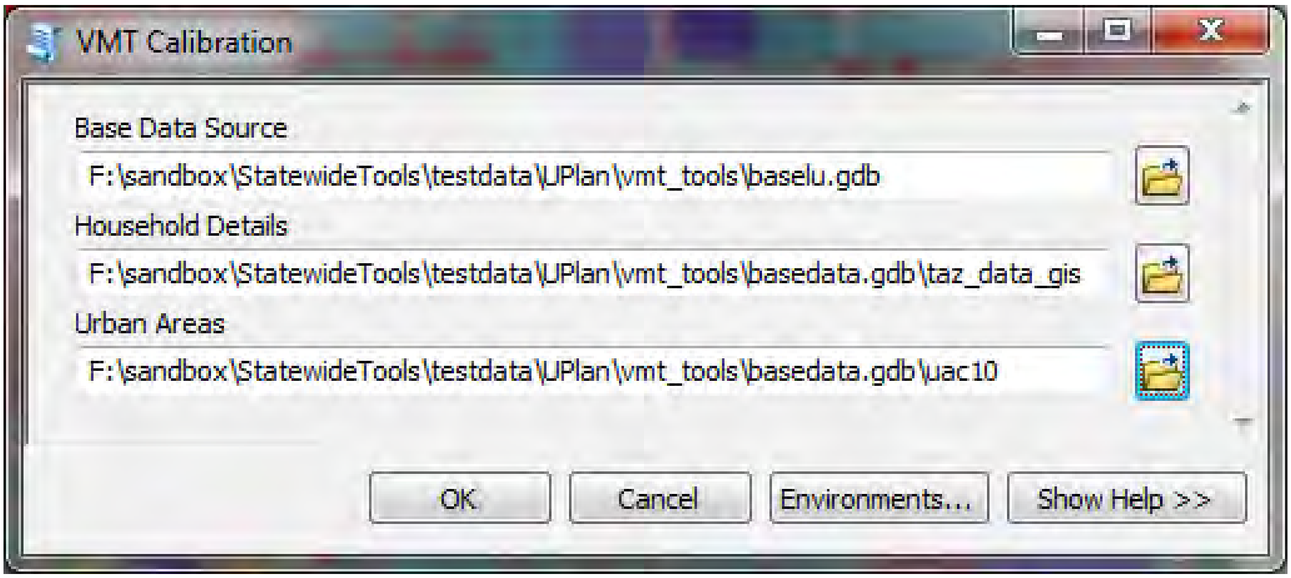

Figure 4: VMT Calibration tool dialog

You will be asked for the following inputs:

Base Data Source: The file geodatabase created by a successful Base Data step

Household Details: A polygon feature class with fields that conform to the naming conventions below. Each of these fields will contain the proportion of all housholds in that polygon that fall into the designated household type.

```
BaseModelHV_3p_NoKids # base = 3+ person household with a vehicle and no kids
BaseModel_HV_3p_w0015 # base + child 0-15
BaseModel_HV_3p_w11621 # base + child 16-21
HHVEH_CAT_0_NoKids # base + no vehicle
HHSIZE_CAT_1_NoKids # base + hhsize = 1
HHSIZE_CAT_2_NoKids # base + hhsize = 2
HHVEH_CAT_0_w0015 # base + no vehicle  and child 0-15
HHSIZE_CAT_1_w0015 # base + hhsize = 1 and child 0-15
HHSIZE_CAT_2_w0015 # base + hhsize = 2 and child 0-15
```

```
HHVEH_CAT_0_w1621 # base + no vehicle and child 16-21
HHSIZE_CAT_1_w1621 # base + hhsize = 1 and child 16-21

HHSIZE_CAT_2_w1621 # base + hhsize = 2 and child 16-21
```

Urban Areas: A polygon feature class that contains the urban areas. In the base year the 2010 US Census urbanized area definition was used as an example. The fields in the feature class do not matter. This is used only as a presence/absence test.

When you click OK, the process will run, and will take a minimum of 3 hours to complete.

On completion there will be three important tables in vmt.gdb

Vmt_by_uid: this contains multiple rows for each grid cell. One row will exist for each household type present in that grid cell. This table cannot be joined directly to the grid feature class also found in the vmt.gdb. However, it can be connected to the grid using the "relate" function. In this way you can select the grids you are interested an through the relationship established see the VMT generation by each household of each type in that grid cell.

To establish a relate, add both the grid and the table to a map document. Right click on the grid feature class, and select Joins and Relates→Relate…. Then select the "uid" field from the grid feature class (step 1), the name of the table to relate to the grid (step 2) , and then uid in step 3. The default name in 4 can be used.

To use the relate, open the attribute table of the grid, select the grid cells of interest, and then click on the table options icon at the top left of the attribute table, choose relates, and then the relate that you are interested in. The vmt_by_uid table will open and the rows connected to that grid cell will be selected.

Vmt_by_uid2: This table can be joined as normal with the join established between the uid in the grid feature class and the uid in vmt_by_uid2. This table contains the total VMT generated by all households in the grid cell, the number of households and the average VMT per household for the grid cell. After the join has been established, you can symbolize the results as you would any other data layer.

Combined: This table can also be joined to the grid feature class. It contains the grid level summaries of all variables fed into the VMTEngine for that grid cell and is usefull for reviewing the geographic context variables that apply.

Cfg_VMTUPlan:

Before running either the Scenario or Calibration tools please review cfg_VMTUPlan.py to ensure that all UPlan land uses are included and have appropriate proportions specified.

Lulist (a python list) must be updated so that it contains all of the land use names (short version) in use by the UPlan configuration (aka the land uses in the UPlan Variant).

Then ***luconfig*** (a python dictionary) must have an entry added for each UPlan land use that conforms to the following structure:

```
# Template for UPlan land use conversion
luc = {} # Establish an empty dictionary for the uplan land use
luc["sfd_ac"] = 0.0 # the number of acres of SFD for each acre of the uplan land use
luc["mfd_ac"] = 0.0 # the number of acres of MFD for each acre of the uplan land use
luc["ret_ac"] = 0.2 # the number of acres of retail for each acre of the uplan land use
luc["lret_ac"] = 0.05 # the number of acres of local serving retail for each acre of the uplan land use
luc["ser_ac"] = 0.1 # the number of acres of service for each acre of the uplan land use
luc["off_ac"] = 0.3 # the number of acres of office for each acre of the uplan land use
luc["pub_ac"] = 0.05 # the number of acres of public/institutional (non-school) for each acre of the uplan land use
luc["edu_ac"] = 0.05 # the number of acres of educational space for each acre of the uplan land use
luc["ind_ac"] = 0.0 # the number of acres of industrial for each acre of the uplan land use
luc["sfd_u"] = 0.0 # the number of SFD units for each residential unit of the uplan land use
luc["mfd_u"] = 1.0 # the number of MFD units for each residential unit of the uplan land use
luc["ret_u"] = 0.2 # the number of retail employees for each employee of the uplan land use
luc["lret_u"] = 0.05 # the number of local serving retail employees for each employee of the uplan land use
luc["ser_u"] = 0.25 # the number of service employees for each employee of the uplan land use
luc["off_u"] = 0.45 # the number of office employees for each employee of the uplan land use
luc["pub_u"] = 0.05 # the number of public (non-school) employees for each employee of the uplan land use
luc["edu_u"] = 0.05 # the number of education employees for each employee of the uplan land use
luc["ind_u"] = 0.0 # the number of industrial employees for each employee of the uplan land use
luc["du_or"] = 0 # NOT IMPLEMENTED allows the user to override the default UPlan densities
luc["emp_or"] = 0 # NOT IMPLEMENTED allows the user to override the default UPlan densities
luc["road_ints"] = 0.4 # the number road intersections per acre
luc["road_mi"] = 0.4 # the number of road miles per acre
luconfig["Lutype"] = luc # the additon of the configuration dictionary to the main lookup dictionary
```

VMTUPlan Scenario:

Double clicking on the VMT Scenario Tool in the UPlan_VMTTools toolbox will open the dialog for running the Scenario section of the tool (Figure 5). This will allow you to run the VMT tools on the combination of the existing land use and the UPlan scenario.

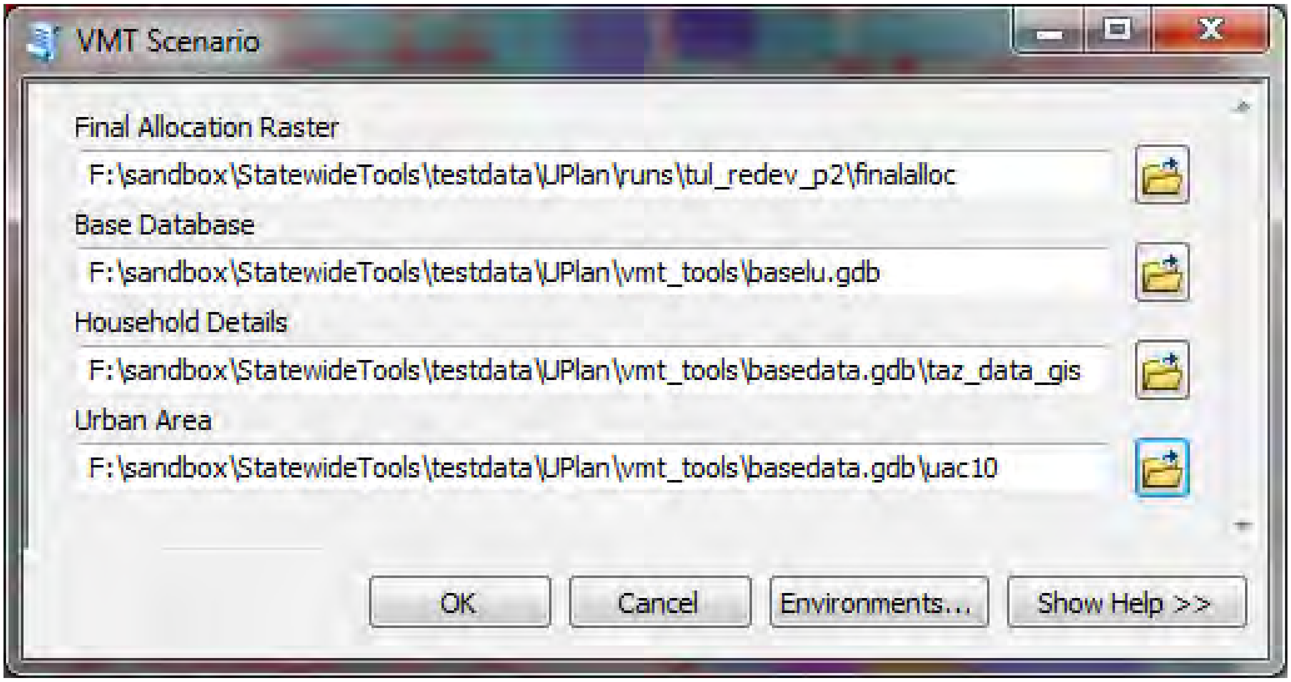

Figure 5: VMT Scenarios tool dialog

You will be asked for the following inputs:

Final Allocation Raster: This is the raster called “finalalloc” for the UPlan run of interest.

Base Data Source: The file geodatabase created by a successful Base Data step

Household Details: A polygon feature class with fields that conform to the naming conventions below. Each of these fields will contain the proportion of all housholds in that polygon that fall into the designated household type.

```
BaseModelHV_3p_NoKids # base = 3+ person household with a vehicle and no kids
BaseModel_HV_3p_w0015 # base + child 0-15
BaseModel_HV_3p_w11621 # base + child 16-21
HHVEH_CAT_0_NoKids # base + no vehicle
HHSIZE_CAT_1_NoKids # base + hhsize = 1
HHSIZE_CAT_2_NoKids # base + hhsize = 2
HHVEH_CAT_0_w0015 # base + no vehicle  and child 0-15
HHSIZE_CAT_1_w0015 # base + hhsize = 1 and child 0-15
HHSIZE_CAT_2_w0015 # base + hhsize = 2 and child 0-15
HHVEH_CAT_0_w1621 # base + no vehicle and child 16-21
HHSIZE_CAT_1_w1621 # base + hhsize = 1 and child 16-21
```

```
HHSIZE_CAT_2_w1621 # base + hhsize = 2 and child 16-21
```

Urban Areas: A polygon feature class that contains the urban areas. In the base year the 2010 US Census urbanized area definition was used as an example. The fields in the feature class do not matter. This is used only as a presence/absence test.

When you click OK, the process will run, and will take a minimum of 3 hours to complete.

On completion there will be three important tables in vmt.gdb

Vmt_by_uid: this contains multiple rows for each grid cell. One row will exist for each household type present in that grid cell. This table cannot be joined directly to the grid feature class also found in the vmt.gdb. However, it can be connected to the grid using the "relate" function. In this way you can select the grids you are interested an through the relationship established see the VMT generation by each household of each type in that grid cell.

To establish a relate, add both the grid and the table to a map document. Right click on the grid feature class, and select Joins and Relates→Relate…. Then select the "uid" field from the grid feature class (step 1), the name of the table to relate to the grid (step 2) , and then uid in step 3. The default name in 4 can be used.

To use the relate, open the attribute table of the grid, select the grid cells of interest, and then click on the table options icon at the top left of the attribute table, choose relates, and then the relate that you are interested in. The vmt_by_uid table will open and the rows connected to that grid cell will be selected.

Vmt_by_uid2: This table can be joined as normal with the join established between the uid in the grid feature class and the uid in vmt_by_uid2. This table contains the total VMT generated by all households in the grid cell, the number of households and the average VMT per household for the grid cell. After the join has been established, you can symbolize the results as you would any other data layer.

Combined: This table can also be joined to the grid feature class. It contains the grid level summaries of all variables fed into the VMTEngine for that grid cell and is usefull for reviewing the geographic context variables that apply.

B. Code Documentation

Like the python module all of the underlying code is programmed in python, though in this case almost all of the GIS functions are handled through calls to the "arcpy" module provided by ESRI as part of the standard ArcGIS 10.0 installation. Through arcpy, a programmer can make calls to almost all of the ESRI GIS tools and data manipulation methods in addition to those built into python and its extensions.

Numpy and Scipy

To use these tools with ArcGIS you **must upgrade** the Numpy and Scipy installations that are installed with the default ArcGIS installation.

Numpy and Scipy are open source extensions to python that support higher level numeric processing and some spatial analysis. In particular the newer versions of Scipy include the KDTree indexing algorithm that allows for dramatically improved calculations on the nearest neighbors between spatial features. In this case, the KDTree functions are used to build the lists of neighbors within the half mile buffer used for the toolkit. Through the use of KDTree, the processing time on these buffering operations is reduced from times measured in hours, to times measured in a few minutes or seconds depending on the geographic area being calculated.

The current versions of these can be downloaded from:

Numpy: https://sourceforge.net/projects/numpy/files/

Scipy: https://sourceforge.net/projects/scipy/files/

Make sure that you download the installation files for python 2.6 and 32 bit windows. Eg. numpy-1.6.2-win32-superpack-python2.6.exe

General Notes

Like the python module, a great deal of the documentation on what is going on within the code is contained within the code itself. The full details will not be repeated here, because doing so would effectively require the inclusion of all code to provide suitable context.

Instead, the general programming flow of each of the three main scripts will be described.

VMTUPlan_Basedata.py

This module contains the class BaseDataPrep which handles the preparation of all base data needed to build the "existing" conditions dataset used by the VMT calculator both as the calibration dataset and the base to which UPlan's projected land use change is added.

This class is instantiated by the concluding block of code:

```
if __name__ == "__main__":
    print "Starting Process"
    bd = BaseDataPrep()
```

```
    bd.bddebug = True
    bd.wdir =  arcpy.GetParameterAsText(0) # folder
    bd.ext = arcpy.GetParameterAsText(1) # boundary feature class
    bd.eluds = arcpy.GetParameterAsText(2) # existing land use dataset
    bd.roads = arcpy.GetParameterAsText(3) # roads dataset
    bd.road_ints = arcpy.GetParameterAsText(4) # road intersections with 3 or
more legs
    bd.rrstation = arcpy.GetParameterAsText(5) # point locations of railroad
stations

    bd.MainProc()

    print "Process Finished"
```

This code block instantiates an object of type BaseDataPrep called “bd” assigns the parameters passed in by Arcgis to the needed properties of the object and then calls the MainProc() function to run the entire process

The following parameters are required. **All spatial layers must be in the same projection as is used by UPlan**.

Wdir: the path for the working directory that you want to use. There are no formal requirements of this except that it be a folder that you have permission to create files in. However, it is recommended that you keep it close to the scenarios that you will be testing. The basedata.gdb geodatabase created by the BaseDataPrep process will be created in this folder, as will vmt.gdb for the calibration run.

Ext: A polygon feature class (shapefile or other feature class) that describes the boundary of the analysis. This will frequently be the full county.

Eluds: A polygon feature class containing the existing land use data. This has been modeled around the parcel level data prepared for this project and described in Appendix C(http://downloads.ice.ucdavis.edu/ultrans/statewidetools/Appendix_C_Data_Collection.pdf…

If the format changes from the default described in Section… Adjustments must be made to the __init__(self) section of the module using either a text editor or a python IDE.

```
self.lufield = "lu_f"
self.reslutypes = ['RM','RS','M'] # All land use types that are considered
residential
self.sfdlutypes = ['RS'] # All land use types that are considered SFD
self.mfdlutypes = ['RM', 'M'] # All land use types that are considered MFD
self.emplutypes =
['I','O','R','M','ID','AP','RR','SC','ML','P','U','AP','MA','MI'] # All land use
types that are considered employment
self.retlutypes = ['R','RR','MI','MA'] # All land use types that are considered
retail
self.lretlutypes = ['R','MI'] # All land use types that are considered local
serving retail
self.serlutypes = ['S'] # All land use types that are considered service
```

```
self.offlutypes = ['O'] # All land use types that are considered office
self.indlutypes = ['ID', 'U','AP'] # All land use types that are considered industrial
self.publutypes = ['I','ML','P'] # All land use types that are considered public (non school)
self.edulutypes = ['SC'] # All land use types that are considered educational
self.poptypes = ['pop'] # All fields with totals that should be considered population
self.sfdtypes = ['sfd'] # All fields with totals that should be considered sfd housing units
self.mfdtypes = ['mfd'] # All fields with totals that should be considered mfd housing units
self.rettypes = ['ret'] # All fields with totals that should be considered retail employees
self.sertypes = ['ser'] # All fields with totals that should be considered service employees
self.offtypes = ['office'] # All fields with totals that should be considered office employees
self.indtypes = ['ind'] # All fields with totals that should be considered industrial employees
self.pubtypes = ['inst'] # All fields with totals that should be considered public (non-school) employees
self.edutypes = ['school'] # All fields with totals that should be considered education employees

self.gridsize = 10 # grid size in acres
```

These lines will need to be updated as follows.

`self.lufield = "lu_f"` should be updated so that “lu_f” is replace with the name of the field containing the land use code.
`self.reslutypes` through `self.edulutypes` should be updated so that the contents of the “[‘R’,’S’]” (a python list constructor) contain the list of all land use codes that are considered SFD, MFD, Retail, Local Serving Retail and so on.

`self.poptypes,self.sfdtypes…` And following entries, need to be edited to include the list of all fields containing the total number of population, housing units, and employees of the respective indicated types.

If desired `self.gridsize = 10 # grid size in acres` may be edited to replace the numeric value with an alternate grid size. This will change the spatial resolution of the analysis. The default 10 acre size appears to be a reasonable compromise in computational speed and spatial resolution. There is an exponential relationship between processing time, storage space, and cell size. If you cut the cell size in half, you multiply the time and storage requirements by four.

Roads: A line feature class with all roads to be included for the road measurements.
Road_ints: A point feature class with all road intersections with 3 or more legs
Rrstation: A point feature class with point locations for all rail road stations.

The internal processing steps are as follows:

1. A file geodatabase called baselu.gdb is created to hold the modules products
2. The base grid is created to cover the entire extent with grid cells of the specified size (default = 10 acres)
3. A table containing the list of all grids with centers within a half mile of each cell's center is created (using Scipy)
4. The input land use feature class is prepared for intersection with the grid
5. The land use is intersected with the grid. The number of road miles and road intersections in each grid cell is calculated
6. The distance from each grid cell to the closes rail road station is calculated
7. The totals of land use (acres by type and housing units and employment by type) are calculated for each grid cell.

Cfg_VMTUPlan.py

This is a configuration file used to define the conversion of the UPlan land use categories into those needed by the VMTTools. The configurations provided here specify the mixture of SFD and MFD housing, and employment by type as understood by the VMTTools in each of the UPlan land uses. It also asserts a new density of roads and road intersections for each UPlan land use that will be used in the toolkit.

This file will need to be edited to support the UPlan configuration used.

Specifically:

Lulist (a python list) must be updated so that it contains all of the land use names (short version) in use by the UPlan configuration (aka the land uses in the UPlan Variant).

Then ***luconfig*** (a python dictionary) must have an entry added for each UPlan land use that conforms to the following structure:

```
# Template for UPlan land use conversion
luc = {} # Establish an empty dictionary for the uplan land use
luc["sfd_ac"] = 0.0 # the number of acres of SFD for each acre of the uplan land use
luc["mfd_ac"] = 0.0 # the number of acres of MFD for each acre of the uplan land use
luc["ret_ac"] = 0.2 # the number of acres of retail for each acre of the uplan land use
luc["lret_ac"] = 0.05 # the number of acres of local serving retail for each acre of the uplan land use
luc["ser_ac"] = 0.1 # the number of acres of service for each acre of the uplan land use
luc["off_ac"] = 0.3 # the number of acres of office for each acre of the uplan land use
luc["pub_ac"] = 0.05 # the number of acres of public/institutional (non-school) for each acre of the uplan land use
luc["edu_ac"] = 0.05 # the number of acres of educational space for each acre of the uplan land use
luc["ind_ac"] = 0.0 # the number of acres of industrial for each acre of the uplan land use
luc["sfd_u"] = 0.0 # the number of SFD units for each residential unit of the uplan land use
```

```
luc["mfd_u"] = 1.0 # the number of MFD units for each residential unit of the uplan
land use
luc["ret_u"] = 0.2 # the number of retail employees for each employee of the uplan land
use
luc["lret_u"] = 0.05 # the number of local serving retail employees for each employee
of the uplan land use
luc["ser_u"] = 0.25 # the number of service employees for each employee of the uplan
land use
luc["off_u"] = 0.45 # the number of office employees for each employee of the uplan
land use
luc["pub_u"] = 0.05 # the number of public (non-school) employees for each employee of
the uplan land use
luc["edu_u"] = 0.05 # the number of education employees for each employee of the uplan
land use
luc["ind_u"] = 0.0 # the number of industrial employees for each employee of the uplan
land use
luc["du_or"] = 0 # NOT IMPLEMENTED allows the user to override the default UPlan
densities
luc["emp_or"] = 0 # NOT IMPLEMENTED allows the user to override the default UPlan
densities
luc["road_ints"] = 0.4 # the number road intersections per acre
luc["road_mi"] = 0.4 # the number of road miles per acre
luconfig["Lutype"] = luc # the additon of the configuration dictionary to the main
lookup dictionary
```

The conclusion of the module contains some configuration information for the model overall, these include a list of household types used by the VMTEngine and a list of parameters that define each of those household types. **These setting should not be edited except following a discussion with Nathaniel Roth (neroth@ucdavis.edu)**

VMTUPlan_Calibration.py

The calibration module applies the VMTEngine to the base dataset generated by VMTUPlan_Basedata.py. This is intended to present a current conditions comparison to other sources. This enables some level of validation of the results against external real-world values.

There is a single class in the module called VMTUPlan. This is the equivalent of the Handler in the example Data_handler.py with the addition that it prepares all of the buffered values in GIS for handoff to the VMTEngine.

The object of type VMTUPlan is instantiated by the following code block at the bottom of the module:

```
if __name__ == "__main__":
    """
    Arcgis hooks in here and passes in the needed parameters before executing the full
model
    """
    basefgdb = arcpy.GetParameterAsText(0)
    hhdetails = arcpy.GetParameterAsText(1)
```

```
urbarea = arcpy.GetParameterAsText(2)
vmtup = VMTUPlan(basefgdb)
vmtup.hhdetails = hhdetails
vmtup.urbarea = urbarea
vmtup.MainProc()
```

The following parameters are passed into the module by ArcGIS:

Basefgdb: the path to the baselu.gdb prepared in by the BaseData step.

Hhdetails: A polygon feature class that contains the proportions of each of the household types. The fields for each of the proportions need to be consistent with the following list:

```
BaseModelHV_3p_NoKids # base = 3+ person household with a vehicle and no kids
BaseModel_HV_3p_w0015 # base + child 0-15
BaseModel_HV_3p_w11621 # base + child 16-21
HHVEH_CAT_0_NoKids # base + no vehicle
HHSIZE_CAT_1_NoKids # base + hhsize = 1
HHSIZE_CAT_2_NoKids # base + hhsize = 2
HHVEH_CAT_0_w0015 # base + no vehicle  and child 0-15
HHSIZE_CAT_1_w0015 # base + hhsize = 1 and child 0-15
HHSIZE_CAT_2_w0015 # base + hhsize = 2 and child 0-15
HHVEH_CAT_0_w1621 # base + no vehicle and child 16-21
HHSIZE_CAT_1_w1621 # base + hhsize = 1 and child 16-21
HHSIZE_CAT_2_w1621 # base + hhsize = 2 and child 16-21
```

Urbarea: A polygon feature class that contains a boundary of what is considered urban. For current conditions, the US Census definition of urban area has been used.

The processing steps used by this module are as follows:

1. Creation of a local file geodatabase (vmt.gdb) in the same folder with the baselu.gdb

2. Copy data from baselu.gdb to vmt.gdb for processing and to preserve provenance of the data

3. Prepare the household details dataset by intersecting it with the centroids of each grid cell to assign proportions of housing units in that grid cell to each household type.

4. Summarize the variable by half mile buffers, using the “Near Table” from baselu.gdb

5. Combine all needed components from the household details, summarized land use and railroad distance for each grid cell.

6. Loop through all household combinations for each grid cell and record the results

7. Aggregate results to from all households to create a household grid cell total VMT and average VMT per household

VMTUPlan_Scenario.py

The Scenario module applies the VMTEngine to a dataset created by merging the the base dataset generated by VMTUPlan_Basedata.py with outputs from a UPlan run.

There is a single class in the module called VMTUPlan. This is the equivalent of the Handler in the example Data_handler.py with the addition that it prepares all of the buffered values in GIS for handoff to the VMTEngine.

The object of type VMTUPlan is instantiated by the following code block at the bottom of the module:

```
if __name__ == "__main__":
    """
    Arcgis hooks in here and passes in the needed parameters before executing the full
model
    """
    far = arcpy.GetParameterAsText(0)
    basefgdb = arcpy.GetParameterAsText(1)
    hhdetails = arcpy.GetParameterAsText(2)
    urbarea = arcpy.GetParameterAsText(3)
    vmtup = VMTUPlan(far,basefgdb)
    vmtup.hhdetails = hhdetails
    vmtup.urbarea = urbarea
    vmtup.MainProc()
```

The following parameters are passed into the module by ArcGIS:

Far: the final allocation raster for the UPlan run to be tested. This must be from a full UPlan setup including the uplan.mdb for the run and the relative path to the initialization.mdb database in the "ini" folder for the UPlan installation. These databases are used in the conversion of the final allocation raster into the scenario tested for the VMT

Basefgdb: the path to the baselu.gdb prepared in by the BaseData step.

Hhdetails: A polygon feature class that contains the proportions of each of the household types. The fields for each of the proportions need to be consistent with the following list:

```
BaseModelHV_3p_NoKids # base = 3+ person household with a vehicle and no kids
BaseModel_HV_3p_w0015 # base + child 0-15
BaseModel_HV_3p_w11621 # base + child 16-21
HHVEH_CAT_0_NoKids # base + no vehicle
HHSIZE_CAT_1_NoKids # base + hhsize = 1
HHSIZE_CAT_2_NoKids # base + hhsize = 2
HHVEH_CAT_0_w0015 # base + no vehicle  and child 0-15
HHSIZE_CAT_1_w0015 # base + hhsize = 1 and child 0-15
```

```
HHSIZE_CAT_2_w0015 # base + hhsize = 2 and child 0-15
HHVEH_CAT_0_w1621 # base + no vehicle and child 16-21
HHSIZE_CAT_1_w1621 # base + hhsize = 1 and child 16-21
HHSIZE_CAT_2_w1621 # base + hhsize = 2 and child 16-21
```

Urbarea: A polygon feature class that contains a boundary of what is considered urban. For current conditions, the US Census definition of urban area has been used.

The processing steps used by this module are as follows:

1. Creation of a local file geodatabase (vmt.gdb) in the same folder with the baselu.gdb
2. Copy data from baselu.gdb to vmt.gdb for processing and to preserve provenance of the data
3. Covert the final allocation raster to a vector dataset with density figures for each land use. This utilizes the FAConverter.py module and inputs pulled from the run's uplan.mdb and the UPlan setup's initialization.mdb databases.
4. Intersect the final allocation vector dataset with the grid
5. Convert the densities from the final allocation raster back to acres and to housing or employee counts.
6. Aggregate the converted UPlan results to grid level totals
7. Prepare the household details dataset by intersecting it with the centroids of each grid cell to assign proportions of housing units in that grid cell to each household type.
8. Assemble the Base land use and UPlan outputs to a single dataset. This is done as a simple addition of the UPlan land use over and above the existing, both with respect to acrages and housing unit and employment totals.
9. Summarize the variable by half mile buffers, using the "Near Table" from baselu.gdb
10. Combine all needed components from the household details, summarized land use and railroad distance for each grid cell.
11. Loop through all household combinations for each grid cell and record the results
12. Aggregate results to from all households to create a household grid cell total VMT and average VMT per household

6. Validation Testing and Results

This section outlines the performance measures and comparisons of model results to externally available sources of data. A true validation of a model's outputs requires a data set that is either independent from or built from randomly selected data withheld from the original model estimation. This provides one of the limiting factors on a formal validation of these tools, particularly in the case of a predictive model where there is no real-world data to compare the results against.

This leaves us with a limited set of options. We can compare the results to those of an alternate model. We can compare the results to expected behavior (e.g., elasticities derived from the literature.) None of these are wholly satisfactory when one of the reasons for developing the tool kit is to answer concerns with validity of alternate models and methods.

We can, however compare a current conditions dataset to real world sources if quantified datasets exist. In this case, there is no clearly superior real-world dataset to which the numbers may be compared.

A. Testing Plan

The testing plan is as follows. Our demonstration area is Tulare County and all figures represent values for Tulare County or a subarea of it.

Python Module

The python modules will be compared against their reference model (which is the spreadsheet version of the Ds analysis modules provided by Fehr & Peers) to ensure that the same inputs produce effectively identical results. We mention "effectively identical" meaning that in a programming system different methods for storing the same numbers, specifically floating point decimal numbers, have a small but potentially noticeable set of rounding errors inherent in the calculations. In this case, we will consider results identical if the difference in outputs are less than one one hundredth of a percent (0.0001) of the expected value provided by our reference model. If the python module operating on an identical input dataset to the spreadsheet produces results that satisfy those requirements, both at the aggregate (full county) and in a selection of distinct subareas, the computational fidelity of the python module will be assumed.

UPlan Implementation

The results of the base case UPlan process (results from the VMTUPlan_Calibration.py) will be compared to the results of the reference model, an expansion of the 2009 National

Household Travel Survey, the regional travel demand model, and the HPMS values. These comparisons will be at the regional/county level with the exception of comparisons to the regional travel demand model which can be accomplished at the TAZ level.

The land use projections will be examined in comparison to expected values based on published elasticities. Regional comparisons of these elasticities are inappropriate given the scale at which the tool performs so these comparisons will be conducted at a TAZ level.

B. Python Module

The Reference Model spreadsheet produces a total of 6,476,062 household-generated VMT per day. The Python Module running against the identical input dataset and with the coefficients rounded identically produces 6,476,063 VMT per day. This is a difference of 0.0000003 (0.00003%) which meets our threshold.

Testing a selection of seven TAZs, chosen to represent a range from central urban to very rural areas, we see the following comparisons:

Table 2: Python Module compared to the reference model. (Numbers have been rounded.)

TAZ	Reference Model (VMT)	Python Module (VMT)	Difference	Percent Difference
392	5.2	5.2	0.0000024	0.000237
813	369.9	369.9	-0.0000172	-0.001725
1060	3930.5	3930.6	0.0000120	0.001197
1146	1413.3	1413.3	0.0000011	0.000114
1293	15624.1	15623.8	-0.0000160	-0.001601
1350	6575.3	6575.3	0.0000001	0.000014
1875	7203.2	7203.2	0.0000001	0.000007

C. UPlan Implementation

Current conditions comparisons:

There are no good direct comparisons between the household VMT generated in the toolkit and sources of data for formal validations. Instead we will present the values that are available for comparison and a brief discussion of why the differences may be expected.

First, in the aggregate comparison of the current conditions “Calibration” run of the existing land use through the same functions that will operate for the combined base conditions and UPlan projection run.

Reference Model Results: 6,476,062 household VMT

VMT Tools Result: 7,117,036 household VMT

Difference: 9.9%%

Given the difference in geographic scales being analyzed, we feel that this is a remarkably similar result. The input metrics used within the reference model were compiled based on land use summaries of the half-mile radius surrounding the centroid of each transportation analysis zone (TAZ) and assumed that each TAZ had a homogeneous land use and land cover mixture. The VMT Tools worked off of a grid of 10-acre cells, each of which was populated with land use information from a parcel level analysis. The half-mile radius around each cell then contains approximately 50 others of these cells. The fact that we can aggregate the results of some 311 thousand cells worth of calculations and get a result that is within 10% of that provided by a TAZ level analysis is interesting on several levels. First, it demonstrates that the assumption of homogeneity within a TAZ holds up well under examination. Second, it calls into question the need for parcel or fine geographic scale analyses in scenario tools, particularly in cases where a rapid response with a relatively accurate result is more important than a high precision answer.

Other County Level Comparisons:

Table 3: Comparison of aggregate totals

	Millions of VMT	Percent Difference
Current Conditions (VMT Tools)	7.117	0.0
Reference Model	6.476	-9.0
HPMS	9.965	40
2009 NHTS	4.724	-33.6
San Joaquin Valley Interregional Travel Model (SJVITM)	9.57	34.5
Tulare MIP Model	10.537	48.1
Tulare MIP Model (removing NHB trips)	5.907	-17.0

Many of the comparisons presented here are false comparisons. They are not directly equivalent. For example, the HPMS values contain through trips, commercial vehicles miles, and non-resident commuter trips as sources of VMT that are not accounted for in the VMT Tools figures. Tulare County, being on Highway 99 and in an area with extensive inter-county commuting, becomes a “poster child” for these issues. The same issues exist in the San Joaquin Valley Interregional Travel Model (SJVITM). These figures are derived from vehicle loadings on network links and include all modes and all purposes.

An expansion of the 2009 NHTS to create a daily VMT estimate is the lowest daily VMT total by a significant margin. Taken in isolation, this would be very concerning given that this study’s parameters and coefficients were estimated from the 2009 NHTS. However, the 2009 NHTS has demonstrated that it does not agree well with other applicable data sources, such as the HPMS. Joe Castiglione (RSG, Inc.) has noted that several travel demand model formulations (e.g., “activity based” and “4 step” models) have experienced difficulty with calibrating to both the NHTS and observed counts. In addition, Tulare County had a total sample size in the 2009 NHTS of only 173 households, which places a great deal of weight on each household sampled, whereby small discrepancies or biases in the sampling could result in substantial effects on the estimated VMT.

We also tested a suite of very simple UPlan scenarios using these tools. The “current conditions” test (VMTUPlan_Calibration outputs) will be used as a frame of reference. All of the tested scenarios assume the same total growth in households and employment and an end year of 2050. The three alternate scenarios are: A “base case” scenario, where growth continues much as it has in the recent past; a “smart growth” scenario with only modest infill but with modest density increases; and an aggressive “infill” and densification scenario.

Comparisons to most four step travel models on a TAZ level are of limited use because the VMT produced by households is not explicitly tracked throughout the day. This makes linking VMT to the home TAZ for the trip makers possible only through an estimation process.

Table 4: Comparison of UPlan Current Conditions Calculation to Local Travel Model. VMT/HH

TAZ	Current Conditions	VMT/HH (HB only)	VMT/HH (All)
392	41.4	34.5	39.1
813	71.3	149	216.9
1060	17.0	16.5	24.3
1146	76.9	24.3	28.1
1293	74.5	17.6	21.2
1350	18.9	16.8	24.7
1875	73.0	21.2	33.4

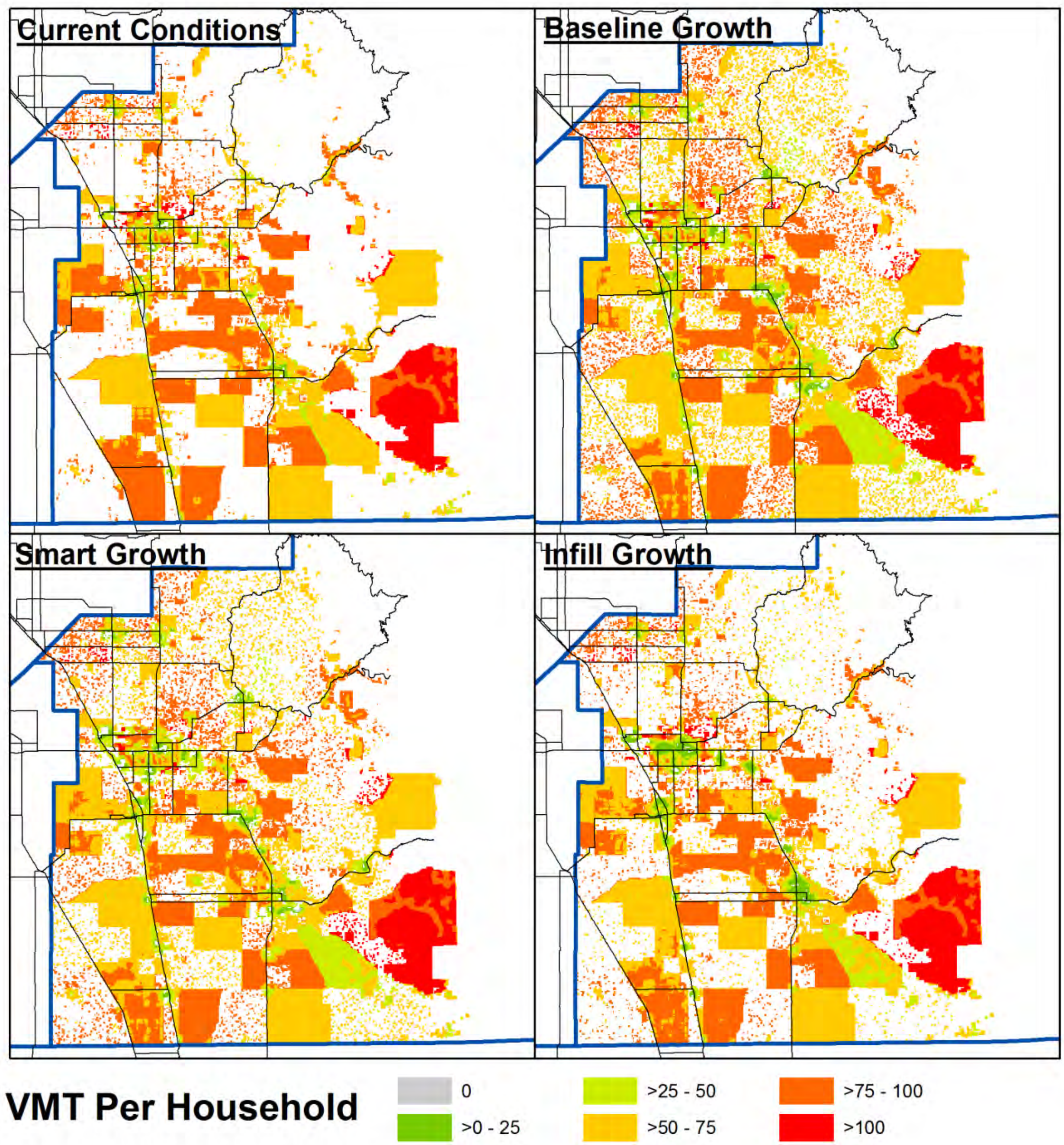

Figure 6: VMT per Per Household by Scenario

Table 5: Aggregate Scenarios Comparison

Scenario	Vehicle Miles Traveled	Household Count	Average daily VMT per Household	Percent difference from current conditions
Current	7,117,036	125,997	56.5	0
Base case	16,738,000	313,622	53.4	-5.5
Smart Growth	16,583,883	313,892	52.8	-6.5
Intensive Infill	12,776,831	313,829	40.7	-27.9

Several interesting features become apparent in the aggregate comparison. The most striking is that the intensive infill scenario produces significantly fewer VMT per household than the current conditions. This is caused largely because some of the core urban areas in this scenario have sufficiently high net residential densities, large enough developed acreages, and a sufficient number of jobs per household that the binary logistic equation to significantly reduce average daily rates of VMT per household. Effectively, the households in core urban areas are not making any privately owned vehicle trip on an average day; their needs are met through transit or non-motorized travel. Each future scenario has small areas that do this, but this is more prevalent in the intensive infill scenario. All of the future scenarios predict an urban mixture that benefits from reduced VMT per household. The "smart" growth scenario only benefits slightly more than the baseline growth, while the intensive infill scenario obtains roughly twice the benefit.

Table 6: Sample TAZ Reference

TAZ	Description of Current Conditions
392	Agricultural, immediately adjacent to a small town.
813	Industrial with large undeveloped parcels. On the edges of a medium sized city.
1060	A largely residential area, with some undeveloped space and modest commercial, adjacent to the downtown of a large city for the county.
1146	Agricultural with limited agricultural industrial development (dairy) and scattered rural residential. Approximately equidistant from two growing cities.
1293	Residential development near the center of the region's largest city. Relatively low density, with a golf course and some multi-family housing. Adjacent areas have significant office space and modest mixed retail/commercial.

1350	Residential near a core commercial/industrial office location, with included or immediately adjacent commercial space and containing large contiguous blocks of undeveloped space.
1875	Majority agriculture (orchard and row crop, with substantial dairy). A few rural residences. Distant from any major growth center.

Table 6 provides a brief description of the character of the example TAZs.

Table 7: VMT per HH Comparison by TAZ across scenarios

TAZ	Current VMT/HH	Baseline Scenario	% Change	Smart Scenario	% Change	Infill Scenario	% Change
392	41.4	35.6	-13.9	35.4	-14.5	28.0	-32.3
813	71.3	48.6	-31.9	50.0	-29.9	31.2	-56.2
1060	17.0	17.0	0.0	17.0	0.0	14.8	-12.9
1146	76.9	74.3	-3.4	76.0	-1.2	76.9	0.0
1293	74.5	74.5	0.0	74.5	0.0	24.5	-67.0
1350	18.9	19.0	0.4	19.4	2.5	3.2	-83.1
1875	73.0	54.2	-25.7	65.6	-10.2	72.1	-1.3

Within these scenario tests, access to rail transit and demographic mixtures were kept constant within each analysis unit. Considering demographics and distance to transit are fixed variables for each area, the other applicable “D” factors (density, diversity, destination accessibility, design and development scale) increase the total to seven “Ds” represented within the model.

The following tables 8-15 provide the average values assigned to each grid cell with a centroid in each TAZ for the current conditions dataset and the three scenarios.

Table 8: Total # of Households in the Half-Mile Buffer (Factor: Density)

TAZ	Current	Baseline Scenario	% Change	Smart Scenario	% Change	Infill Scenario	% Change
392	81	726	794.6	828	921.2	253	212.2
813	23	37	59.9	38	62.7	45	93.3
1060	293	293	0.0	293	0.0	483	65.0
1146	16	16	0.0	16	0.0	16	0.0
1293	249	249	0.0	249	0.0	757	203.5
1350	446	458	2.8	495	11.1	531	19.0
1875	78	441	466.1	114	46.0	87	11.8

Table 9: Net Residential Density in the Half-Mile Buffer (Factor: Density)

TAZ	Current	Baseline Scenario	% Change	Smart Scenario	% Change	Infill Scenario	% Change
392	3.3	4.0	19.4	4.6	37.1	4.8	42.8
813	3.3	3.6	10.7	3.0	-8.7	2.6	-21.5
1060	6.9	6.9	0.0	6.9	0.0	5.7	-17.7
1146	2.3	2.6	14.6	2.2	-5.7	2.3	1.4
1293	3.6	3.6	0.7	3.6	1.3	8.1	124.7
1350	5.8	5.8	0.0	6.0	3.7	7.1	22.0
1875	0.8	0.6	-18.4	0.5	-36.4	0.6	-29.9

Table 10: Employees per Acre in the Half-Mile Buffer (Factor: Density)

TAZ	Current	Baseline Scenario	% Change	Smart Scenario	% Change	Infill Scenario	% Change
392	0.24	0.94	292.2	0.95	296.1	1.39	477.3
813	1.22	1.75	43.0	1.76	44.4	8.96	633.9
1060	3.65	3.65	0.0	3.65	0.0	3.65	0.0
1146	0.05	0.06	1.3	0.06	3.7	0.05	0.0
1293	3.65	3.65	0.0	3.65	0.0	12.29	237.1
1350	5.20	5.32	2.3	5.32	2.3	18.28	251.3
1875	0.05	0.30	537.1	0.22	369.0	0.06	22.6

Table 11: Local Serving Retail in the Half-Mile Buffer (Factor: Destinations)

TAZ	Current	Baseline Scenario	% Change	Smart Scenario	% Change	Infill Scenario	% Change
392	6.5	22.1	240.0	22.1	240.1	16.5	154.7
813	10.6	21.2	99.6	21.7	104.3	83.7	687.9
1060	32.7	32.7	0.0	32.7	0.0	34.7	6.2
1146	0.0	0.1	NA	0.1	NA	0.0	NA
1293	4.4	4.4	0.1	4.4	0.1	81.9	1753.0
1350	34.0	34.1	0.4	34.1	0.4	136.4	301.2
1875	0.2	5.2	2334.2	3.5	1544.3	0.3	29.4

Table 12: Jobs per Household in the Half-Mile Buffer (Diversity)

TAZ	Current	Baseline Scenario	% Change	Smart Scenario	% Change	Infill Scenario	% Change
392	0.50	0.50	-1.1	0.48	-5.4	0.87	73.9
813	2.84	2.89	2.0	3.30	16.4	12.42	337.5
1060	1.71	1.71	0.0	1.71	0.0	0.98	-42.4
1146	3.88	1.74	-55.1	2.28	-41.3	2.94	-24.2
1293	3.31	3.28	-0.9	3.26	-1.4	3.17	-4.1
1350	2.60	2.64	1.4	2.54	-2.3	5.95	128.8
1875	16.63	8.67	-47.9	9.81	-41.0	11.70	-29.6

Table 13: Entropy Index in the Half-Mile Buffer (Factor: Diversity)

TAZ	Current	Baseline Scenario	% Change	Smart Scenario	% Change	Infill Scenario	% Change
392	0.395	0.589	49.3	0.603	52.8	0.538	36.3
813	0.629	0.695	10.5	0.664	5.6	0.794	26.3
1060	0.733	0.733	0.0	0.733	0.0	0.645	-12.0
1146	0.000	0.141	NA	0.066	NA	0.018	NA
1293	0.581	0.582	0.2	0.582	0.3	0.866	49.0
1350	0.672	0.659	-1.9	0.664	-1.1	0.845	25.8
1875	0.053	0.324	505.5	0.289	439.8	0.222	315.0

Table 14: Street Miles in the Half Mile Buffer (Factor: Design)

TAZ	Current	Baseline Scenario	% Change	Smart Scenario	% Change	Infill Scenario	% Change
392	4.8	9.4	97.1	9.1	90.6	6.6	38.6
813	5.0	6.0	21.1	6.3	25.7	11.1	122.7
1060	18.3	18.3	0.0	18.3	0.0	22.9	25.3
1146	1.7	1.9	13.3	1.7	3.2	1.7	0.1
1293	12.1	12.2	0.1	12.2	0.1	19.7	61.9
1350	14.9	15.0	0.8	15.0	0.9	23.5	57.9
1875	1.2	1.7	45.2	1.5	25.5	1.2	2.6

Table 15: Developed Acres in the Half-Mile Buffer (Factor: Development Scale)

TAZ	Current	Baseline Scenario	% Change	Smart Scenario	% Change	Infill Scenario	% Change
392	116.3	327.4	181.6	307.9	164.8	202.3	74.0
813	297.5	347.6	16.8	366.1	23.1	586.1	97.0
1060	267.7	267.7	0.0	267.7	0.0	474.2	77.1
1146	32.6	44.1	35.1	37.2	14.1	32.8	0.6
1293	266.5	266.9	0.2	266.9	0.2	588.8	120.9
1350	310.2	314.0	1.2	313.8	1.2	645.1	108.0
1875	76.0	122.9	61.8	102.4	34.7	83.0	9.2

Elasticity Comparisons

The comparison these results to elasticities is problematic for several reasons: 1) the interrelationship of independently estimated elasticities cannot be assumed to be linear, and 2) appropriate bounding limits on elasticites need to be defined because otherwise the elasticities have the potential to over-represent changes that may occur in scenarios with proportionally large changes.

Table 16(below) presents a comparison of changes in VMT predicted by the UPlan implementation of the Ds tools and the range of values that might be expected. The effects of applying elasticities to the measured average values for each of the TAZs in each of the three scenarios has also been calculated. The following assumptions were made in applying the elasticities (note: these guidelines and elasticities are adopted from the CAPCOA report.)[1]

1. The percent change in a measure would be capped at 500%
2. The maximum allowed percent change in the VMT from any particular measure would be 30%

The following elasticities were assumed.

- Density: 0.07
- Destination Accessibility: 0.2
- Diversity: 0.09
- Design: 0.12

[1] California Air Pollution Control Officers Association, August 2010, *Quantifying Greenhouse Gas Mitigation Measures*, http://www.aqmd.gov/CEQA/handbook/mitigation/greenhouse_gases/CAPCOA-Quantification-Report-Final1.pdf

Some of these elasticities are similarly challenging to apply to the measures used by this toolkit. Notably, Destination Accessibility is intended to measure the distance to desired destinations. In this case, the effects were calculated on the amount of local serving retail in a half-mile buffer.

Table 16: Percent Change from the UPlan Implantation, Mean, Minimum, Maximum and Summed Percent Changes by Elasticities in VMT by Scenario.

Baseline Growth Scenario

TAZ	% Change	Mean	Min	Max	Sum
392	*13.9*	14.0	-0.1	30.0	97.8
813	*31.9*	4.5	0.2	19.9	31.5
1060	*0.0*	0.0	0.0	0.0	0.0
1146	*3.4*	4.6	-5.0	30.0	27.7
1293	*0.0*	0.0	-0.1	0.1	0.0
1350	*-0.4*	0.1	-0.2	0.2	0.5
1875	*25.7*	17.1	-4.3	30.0	119.8

Smart Growth Scenario

TAZ	% Change	Mean	Min	Max	Sum
392	*14.5*	14.1	-0.5	30.0	98.5
813	*29.9*	4.7	-0.6	20.9	32.8
1060	*0.0*	0.0	0.0	0.0	0.0
1146	*1.2*	8.1	-3.7	30.0	56.5
1293	*0.0*	0.0	-0.1	0.1	0.0
1350	*-2.5*	0.2	-0.2	0.8	1.1
1875	*10.2*	12.3	-3.7	30.0	85.9

Intensive Infill Scenario

TAZ	% Change	Mean	Min	Max	Sum
392	*32.3*	13.2	3.0	30.0	92.4
813	*56.2*	16.0	-1.5	30.0	112.1
1060	*12.9*	0.4	-3.8	4.5	2.7
1146	*0.0*	4.7	-2.2	30.0	27.9
1293	*67.0*	11.6	-0.4	30.0	81.0
1350	*83.1*	10.2	1.3	30.0	71.3
1875	*1.3*	4.6	-2.7	28.3	32.2

The mean elasticity based calculation is not a perfect measure. It is an unequal combination of several factors including: several density, two diversity, a design, and a destination accessibility measure; but it is indicative of the measures being used in the tool, though of not their relative strengths.

The calculations presented are based on the percent change in the value measured and fed into the VMT calculator. A 100% change is a doubling of the value, 50% is an increase by half, and a -50% change would be cutting the value in half. The percent changes in per household VMT produced by the UPlan implementation fall within a reasonable range compared to the available literature.

It should be noted that he products of this project do not have the same maximum limitations imposed that are recommended by the CAPCOA report. With only three exceptions, the percent change presented by the UPlan implementation fall under the summed elasticity calculated value. That summed value would exceed the maximum change if all of the elasticities represented completely independent factors in VMT generation, which is not the case. In those cases where the % change exceeds the summed value, two are cases where the 30% maximum change is playing a role, and the last is an area of infill and redevelopment in a complex environment resulting in mixed elasticity based values that largely cancel each other's effects out.

Tables 17-23 present the expected effects of the change in the parameter as a percentage reduction in per household VMT based on each parameter's change. All values are calculated based on changes to the average value of the parameters within the TAZ, and each of those parameters is a summary of the land use within a half-mile.

Table 17: Elasticity Effects Based on Total Housing Units

TAZ	Baseline Scenario	Smart Growth Scenario	Intensive Infill Scenario
392	30.0	30.0	14.9
813	4.2	4.4	6.5
1060	0.0	0.0	4.5
1146	0.0	0.0	0.0
1293	0.0	0.0	14.2
1350	0.2	0.8	1.3
1875	30.0	3.2	0.8

Table 17: Elasticity Effects Based on Net Residential Density

TAZ	Baseline Scenario	Smart Growth Scenario	Intensive Infill Scenario
392	1.4	2.6	3.0
813	0.8	-0.6	-1.5
1060	0.0	0.0	-1.2

1146	1.0	-0.4	0.1
1293	0.1	0.1	8.7
1350	0.0	0.3	1.5
1875	-1.3	-2.5	-2.1

Table 18: Elasticity Effects Based on Employees Per Acre

TAZ	Baseline Scenario	Smart Growth Scenario	Intensive Infill Scenario
392	20.5	20.7	30
813	3.0	3.1	30.0
1060	0.0	0.0	0.0
1146	0.1	0.3	0.0
1293	0.0	0.0	16.6
1350	0.2	0.2	17.6
1875	30.0	25.8	1.6

Table 19: Elasticity Effects Based on Acres of Local Serving Retail

TAZ	Baseline Scenario	Smart Growth Scenario	Intensive Infill Scenario
TAZ	**Baseline**	**Smart Growth**	**Redevelopment**
392	30	30	30
813	19.9	20.9	30.0
1060	0.0	0.0	1.2
1146	30.0	30.0	30.0
1293	0.0	0.0	30.0
1350	0.1	0.1	30.0
1875	30.0	30.0	5.9

Table 20: Elasticity Effects Based on Jobs per Household

TAZ	Baseline Scenario	Smart Growth Scenario	Intensive Infill Scenario
392	-0.1	-0.5	6.6
813	0.2	1.5	30.0
1060	0.0	0.0	-3.8
1146	-5.0	-3.7	-2.2
1293	-0.1	-0.1	-0.4
1350	0.1	-0.2	11.6
1875	-4.3	-3.7	-2.7

Table 21: Elasticity Effects Based on Land use Entropy Index

TAZ	Baseline Scenario	Smart Growth Scenario	Intensive Infill Scenario
392	4.4	4.7	3.3
813	0.9	0.5	2.4
1060	0.0	0.0	-1.1
1146	NA	NA	NA
1293	0.0	0.0	4.4
1350	-0.2	-0.1	2.3
1875	30.0	30.0	28.3

Table 22: Elasticity Effects Based on Miles of Street

TAZ	Baseline	Smart Growth	Redevelopment
392	11.6	10.9	4.6
813	2.5	3.1	14.7
1060	0.0	0.0	3.0
1146	1.6	0.4	0.0
1293	0.0	0.0	7.4
1350	0.1	0.1	6.9
1875	5.4	3.1	0.3

Some interesting features arose that could be considered unintended consequences of the scenarios. In particular, the intensive infill scenario actually decreases the net residential density in many of the city edge TAZs because the rural residential areas surrounding the cities have not been diluted by the inclusion of large numbers higher density units. The core area TAZs do have density increases.

In summary, these tools work successfully and produce reasonable results given the inputs in the test area. However, it definitely would be preferable to conduct additional testing and deployment in other locations of California. Further, we do not recommend that absolute values of VMT be published from these tools because doing so is inconsistent with their intended application. Instead, users should consider the relative effects of each scenario, e.g. in TAZ 392, the baseline growth scenario reduced per household VMT by 13.9%, the smart growth by 14.5%, and the intensive infill scenario by 32.3%.

7. Ancillary Products

A. Place Type Translator

The project team determined that it was necessary to address the need for "place type translation" to provide a common set of terms and definitions for various local jurisdictions' land use zoning classifications and definitions. The following formulation for place type conversions evolved to meet some of those needs.

The underlying idea is that for a particular set of place types for which there is specific descriptive information and an expected range of values, it is possible to calculate the range-normalized "n-space" distance between a description of a location and all of the place types in the set regarding any other "place" description. If the place type that is "closest" to that location , it will provide the closest match between that particular place and the entire place type system.

This method has significant theoretical similarities to multiple linear regression methods or other supervised classification algorithms.

A prototype of this algorithm has been assembled and is available for use, or for refinement under the Apache 2.0 license.

The code and demonstration can be downloaded from:

http://downloads.ice.ucdavis.edu/ultrans/statewidetools/PT_Translator.zip

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FINAL REPORT – Improved Data & Tools for Integrated Land Use-Transportation Planning in California

APPENDIX G

VMT Spreadsheet Tool

TOPICS:

1. Overview of Tool
2. Code Documentation
3. User Guide
4. Validation Test Plan and Results

- Raef Porter, Sacramento Area Council of Governments (SACOG)

August 6, 2012

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1. Overview of VMT Spreadsheet Tool

The VMT spreadsheet tool is intended to give the user a sketch level comparison of different land use and transportation scenarios. It conducts a sketch level analysis of the land use and transportation relationships using 7 Ds: density, diversity, distance, design, destination, demographics, and development scale. It looks at how a land use scenario differs from an established or modeled land use scenario, comparing the two on land use metrics like number and types of jobs and households, densities, and the mix of uses. The tool also compares the scenarios on travel behavior, and - depending on the scale of the project - can provide estimates of vehicle miles traveled (VMT).

In the regional context, the tool provides VMT estimates that can be useful in scenario planning and evaluation. The project level evaluation compares land use variables as a "sketch" of whether an alternative scenario may perform better or worse than a base scenario. This level of use is not intended to replace the type of analysis better suited for more robust travel models or analysis tools, but to provide planners, developers, analysts, and elected officials a way of quickly comparing an alternative scenario to a base scenario.

The tool contains two parts. The main component of is a spreadsheet, Sketch7, built in Microsoft Excel. This is where all of the calculations take place. The other part is a web based GIS application, built in Microsoft Silverlight. The GIS portion is for making land use changes, and feeding the spreadsheet the appropriate land use data.

The rest of this documentation outlines the steps necessary to install, calibrate, and use the VMT spreadsheet tool.

2. Code Documentation

A. Silverlight Web GIS

A zip file with the custom GIS application, written in Silverlight, is available at http://downloads.ice.ucdavis.edu/ultrans/statewidetools/StatewideToolsWebFiles.zip. The contents of the file should be unzipped into a new folder. Visual Studio 2010 is required to open the project by selecting the *.sln file. Once the project is opened, the solution explorer will reveal a web section and a Silverlight section. All changes in the code should be performed in the Silverlight portion of the site. Finally, the site will need to be published to a web server using Visual Studio. To see an example of the application, please visit http://mapping.sacog.org/landusebuffer/.

B. Sketch7

This documentation is for the standalone “Sketch7” tool created for the “Improved Data and Tools for Integrated Land Use-Transportation Planning” study. It uses Microsoft Excel as the platform for conducting a series of calculations to derive travel behavior from a change in land use(s). The elasticities used in the calculations are derived from the “Ds analysis modules” that were produced in the study. While the tool is defaulted to use elasticities for the Sacramento region, a series of elasticities were produced for each region to be used in this tool, see Appendix D for a list of regions and related elasticities. Calibration of the tool should be conducted to local conditions.

Work flow

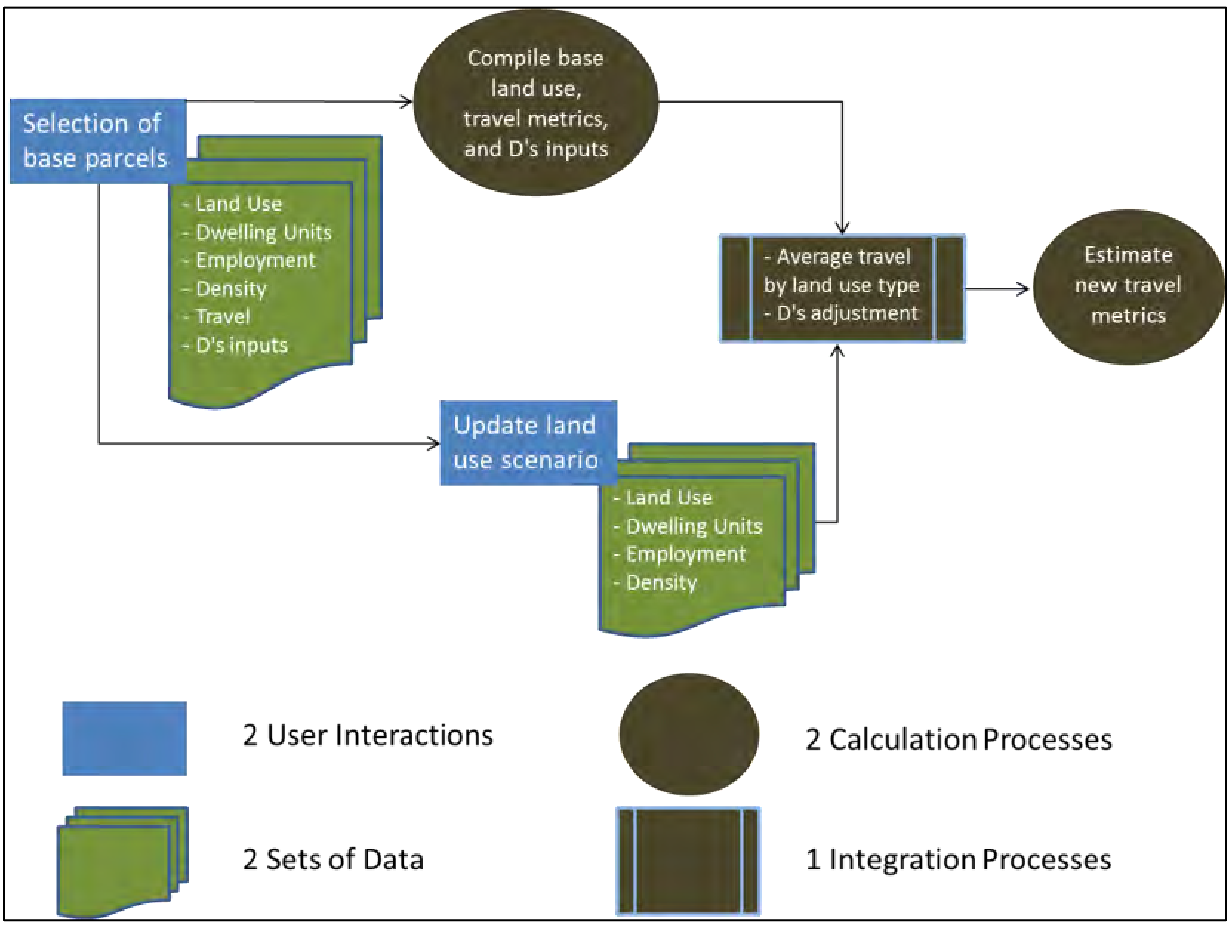


Figure 1

The figure above shows the flow of the process used in the estimation of travel based on a change in land use in the Sketch7 land use-transportation standalone estimation tool. It begins with the selection of a base set of parcels, the creation of a land use scenario, and estimation of final metrics. Between each step, the tool conducts several calculations to create base and context area averages for comparison purposes. The next sections of this document outline the steps within Sketch7, organized by tabs within the spreadsheet.

start

There are three user actions or options on the *start* tab:

Project Name,

A button labeled "Map", which opens the web based GIS application and allows the user to enter the land use scenario, and

A button labeled "Import", which allows the user to browse to the location of a saved version of the mapped land use scenario.

There are also three buttons that take the user to a screen to enter base data:

Regional Land Use and Travel Data

Elasticities

Place Types

The user first enters the name of the project. The user then clicks on the Map button to open the Silverlight GIS mapping application. Sketch7 opens a web browser for the Silverlight GIS mapping tool, which allows the user to select parcels, buffer them ¼ mile, change land uses, and export the new scenario to the spreadsheet tool (see prior documentation on this functionality). The Silverlight GIS map sets the context area for the analysis by assigning a transportation analysis zone (TAZ) to the project location. This TAZ becomes the base for all land use and travel metrics that are then adjusted using the elasticities set in the tool.

Once a land use scenario is created, the tool computes two sets of data. The first set is the place type average land use and travel metrics to be used for the base scenario and the newly created scenario. This includes the following:

Totals by Place Types:	Household Population, Households, Retail Jobs, Non-Retail Jobs,

HH-Generated Person Trips:	Transit, Bike, Walk, HOV, Vehicle Trips
HH-Generated Travel:	Household Generated VMT
Other:	Net Acres w/ Dwelling Units, Net Acres with Employment

The other set of data is the land uses and travel metrics for the context area. These data are used for the D variables to adjust the base travel metrics up or down. This includes the same set of data as the place type averages, but instead of data from the selected parcels, it estimates data from a larger context area. For the custom mapping application, these are buffered within the tool. For the spreadsheet option, these data are TAZ averages.

After the land use scenario is generated, and the base and context variables are estimated, the user has the opportunity to adjust a few of the Ds variables up or down. These include the level of transit, the street pattern, and income and age variables of the project.

Transit

The transit adjustment is simply "high, medium, and low" level of transit service, which are defined below. The adjustment made to the base travel metrics is from a comparison of the base to the context area. The context level is determined by the following: greater than 80% of the maximum average for percent transit of all trips in all RADs is High, lower than 20% of the minimum average for percent transit of all trips in all RADs is Low, everything else is Moderate.

- Low: Little or no transit service available within 1/4 mile. If available, it is infrequent service (1 hour +) with limited connections available.
- Medium: Some transit service available within 1/4 mile, but fairly infrequent (30 minutes +) headways.
- High: Multiple transit options available within 1/4 mile, with at least one frequent (~ 15 minutes) option.

Figure 7 below shows the default elasticities that are applied to the base VMT in order to estimate the new values.

Transit Access	-0.02

Figure 7

Street

Similar to the adjustment for transit service, street connectivity or Design is set to Low, Moderate, and High; see below for an explanation. These values are then compared to the context value, which is determined by the following: greater than 80% of the maximum average for percent walk and bike trips of all trips in all counties is High, lower than 20% of the minimum average for percent walk and bike trips of all trips in all counties is Low, everything else is Moderate.

- Cul-De-Sac style street design with limited 4-way intersections and large block faces.
- Mixed Block style street design with some 4-way intersections and some smaller block faces.
- Grid style street design with many 4-way intersections and smaller block faces.

Street Pattern	-0.13

Figure 8

Figure 8 above shows the default elasticities prior to updates resulting from the land use project.

Demographics

There are two demographic variables that the user can set for the area, age and income. How the variables are set for the project is described below.

Age:	**Income:**
Fewer people 55 and older	Fewer households above median income
Average amount of people 55 and older	Households near median income
More people 55 and older	More households above median income

Income	-0.02

Age	-0.01

Figure 9

Figure 9 above shows the default elasticities prior to updates resulting from the land use project.

The other Ds variables are set by the location and the combination of land uses selected by the user. These include: Destination (Accessibility), Density, Diversity, and Development Scale. These are described below.

There are two types of accessibility measures: transit and auto accessibility. Transit accessibility is defined by the number of jobs that can be reached with a 45 minute transit trip, and auto accessibility is the number of jobs accessible within a 20 minute drive. The context is defaulted to the RAD average, and the project adjusts that number up or down depending on the number of jobs added to the scenario.

Figure 10 below shows the default elasticities for the Accessibility variables.

Accessibility	-0.26

Figure 10

The Diversity adjustment is based on the difference between the context average for each specific component: Retail Employee per Dwelling Unit, Total Jobs per Dwelling Unit, and K-12 Employees per Dwelling Unit; and the optimal value in order to receive maximum travel benefit. Figure 11 shows the optimal value, and the elasticity used for each.

Diversity/Mix	-0.02

Figure 11

The Density adjustment is the gross density (jobs + dwelling units / gross acres) for the project area compared to the context area. The base is adjusted up or down depending on whether density in the project area increases density in the context area or not. The calculation is simply project divided by context – 1.

Density	-0.11

Figure 12

Figure 12 above shows the elasticity for this variable.

Development scale is the total amount of jobs and dwelling units within the project area. The higher the number, the bigger the adjustment will be on the travel metrics. Figure 13 shows the elasticities from the various scale of growth.

Development Scale	
Scale	Adjustment
0	0
500	0
1000	0
2000	0
5000	0
15000	-0.00001
50000	-0.0001
200000	-0.001
1000000	-0.01

Figure 13

<u>Input</u>

Once a user has created a land use scenario, adjusted Ds variables, and the tool has estimated travel demand, the user can alter the land uses to either optimize the scenario or better reflect observed results.

On this tab, the user simple adjusts the dwelling units, total employees, retail employees, and non-retail employees. The tool will automatically adjust the travel metrics to reflect the changes in land use.

These data are then compared to the TAZ averages calculated above to set the unadjusted land use and travel metrics for the scenario. The next step is for the user to adjust the "Ds" variables to estimate the change in travel.

The final report produced by this tool performs an assessment of each Ds variable for the project as compared to the context area and the region. Based on this assessment, the base travel metrics are adjusted up or down using the above-stated elasticities. The base travel metrics are shown alongside the non-adjusted numbers for the project, as well as the final adjusted travel estimates.

Figure 14 below is an example of the tool's final report.

Table 1. Assessment of Key Land Use and Travel Characteristics

Region	Context Area		Project Area Base Values	Assessment
1,212	2,795	Auto Accessibility (Jobs w/in 20 Minute Drive)	5,407	Higher than average in surrounding area, and higher than regional
453	1,637	Transit Accessibility (Jobs w/in 45 Minute Transit Trip)	4,249	Higher than average in surrounding area, and higher than regional
1.2	0.9	J/H Balance (Jobs per Household w/in 4 miles)	1.4	Higher than average in surrounding area, and near regional average
		Residential Mix (Entropy, 0.5 mile buffer)		
3.00	4.66	Residential Density (Dwellings per Net Res Acre, within a 0.5 mi buffer)	#DIV/0!	#DIV/0!
$60,000	$37,547	Income (Median income)		More households below median income
35	37	Age (Median Householder Age)		Lower median householder age
16.57	19.26	VMT per Capita	17.24	Near average in surrounding area, and near regional average
0.05	0.04	Transit Trips Per Capita	0.04	Near average in surrounding area, and near regional average
0.35	0.25	B+W trips per capita	0.21	Near average in surrounding area, and lower than regional

Table 2. Summary of Adjustments to Base Travel Metrics

	Destination		Diversity		Density	Demographics		Development	Design	Distance	
	Auto Access	Transit Access	J/H Balance	Res. Mix	Res. Density	Income	Age	Scale	Street Pattern	Transit Distance	TOTAL
VMT per Capita	-6.26%	-4.79%	0.76%		#DIV/0!	0.00%	-0.20%	0.00%	0.00%	-0.20%	#DIV/0!
Transit Trips per Capita											
B+W Trips per Capita											

Table 3. Final Project VMT

	Regional	Context Area	Non-Adjusted Project	Adjusted Project
VMT Per Capita	16.57	19.26	17.24	#DIV/0!
Total VMT (1000s)	36,699	560.4	75.2	#DIV/0!
Transit Trips per Capita				
B+W Trips per Capita				

Print

Start Over

Figure 24

In order for all calculations to take place, a set of land uses needs to be entered into the tool, and base set of data from a regional travel model using the same land uses needs to be loaded.

<u>place types</u>

The land uses, or place types within Sketch7, are defaulted to a generic set of land uses used in this study. The information that is needed within the place types tab includes:

Name	Order (sorting order)	Residential Density (dwellings per acre)
Employment Density (employees per acre)		% Retail (% of land for retail uses)

The place types used in Sketch7 must be consistent with those used in the Silverlight GIS mapping application as well as the travel model used to supply base metrics.

<u>regional data</u>

Regional data from a TAZ based travel model must be entered into the tool for each place type. By TAZ and place type, these data are:

Household Population	Dwelling Units	Employees	Retail Employees
Non-Retail Employees	Acres w/ DUs	Acres w/ Emps	Total Trips
Vehicle Trips	Walk Trips	Bike Trips	Transit Trips
VMT/HH	VMT/Capita	Jobs w/in 20 minute Drive	
Jobs w/in 45 transit trip			

B. Silverlight Web GIS

For the Sacramento region, the tool can be found by navigating to the following URL http://mapping.sacog.org/landusebuffer. The purpose of the website is to enable a user to select one or more parcel locations within the SACOG area on the map and produce a buffer from those points to retrieve all parcels within that buffer. A table then appears showing data for each parcel along with a highlighted selection of each parcels location. At this point the user can adjust the original data to fit the needs of a particular scenario. The **Employment**, **Dwelling Units**, and **Landuse Type** fields are all editable and can be changed to any value the user desires. Lastly, when all field value changes are completed the user can export the table into an xml spreadsheet onto their local computer to export into an Excel spreadsheet for further analysis.

Web server administrators have a few requirements to fulfill to host the application. The website utilizes ESRI's ArcServer GIS web mapping technology with data stored in an ArcSDE database for use over the internet. Data storage can also include shapefiles and file based geodatabases. A copy of Microsoft Visual Studio will be needed to change URL parameters and publishing of the website onto an IIS based web server. Users of the website also have the requirement of installing the Microsoft Silverlight browser plugin before they can view the web site. Upon navigating the site, a script checks to see if the browser contains the plugin, and if not provides a link to install. The shapefile or geodatabase must include the following fields:

Landuse Type (must be consistent with the place types in Sketch7)

Dwelling Units

Employees

TAZ

The initial screen shows a map view of the Curtis Park area in Sacramento, CA and various elements including a toolbar, map navigation tool, scalebar, and an overview map. The map is navigable in a similar fashion to Google or Bing maps. The scroll button zooms in and out while click and dragging pans the map view. The navigation tool at the lower left section of the web site allows the user to perform the same actions as using mouse activities. The overview window shows the current map extent using a red outlined box and the surrounding area. Clicking and dragging the red box will pan the window to that location. The bottom center of the screen displays a scalebar that adjusts itself when zooming in or out.

A toolbar containing three tools appears at the top right corner of the website. A user will select the point tool in order to select a parcel that will be used in buffering. It is recommended that an actual parcel be selected otherwise a message will appear explaining a parcel does not exist at that location. This point then becomes the location where the buffer will originate. If another point is desired in the overall selection, then the user will have to select the point tool again and place a second point on the screen. This process can be repeated for as many points on the map as desired. When all points are placed on the map, the **Buffer Parcels** button is selected and the buffer will take place. A table will appear on the upper left corner of the screen showing all parcels that were selected in the buffer. The selected parcels will also appear highlighted in blue on the map. When hovering the mouse over each record in the table, it will highlight to a cyan color as well as highlight the parcel that corresponds to that record on the map. This will help the user identify which record corresponds with the desired parcel. The table is now available for attributes to be edited. A permanent change to the underlying database is not being performed, changes will only be noted when the table is exported. After all changes are made to the scenario, the user will click the **Save Results** button on the table and export to an xml file onto their local desktop. This file will then be used in the next step of the process. If an undesirable buffer was performed or the user wishes to experiment with various buffers, the **Clear Tool** must be selected to reset the table and graphics in order to perform new buffers.

Navigation

Upon navigating to the website located at http://mapping.sacog.org/landusebuffer, a map appears showing the extent of the SACOG region. The map interacts similar to a Google map in that panning and zooming are controlled by the mouse and mouse wheel. An additional zoom tool exists as well by pressing the shift key and drawing a rectangle on the screen to zoom into the desired area. A navigation control is also available in the upper left corner of the map that interacts similar to Google maps.

Figure 3

Toolbar

The toolbar consists of 4 tools that include parcel selection, clear, buffer, and display help, respectively.

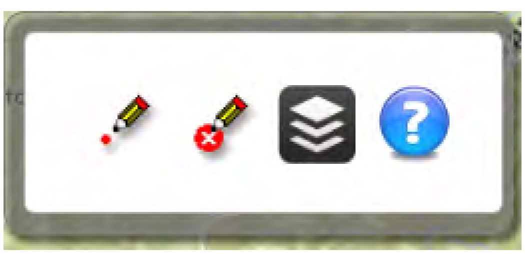


Figure 4

 **Parcel Selection** = When zoomed in within a close enough scale, parcels will display on the screen. The user will click the parcel selection tool and begin to select parcels on the screen whose values will then be changed later in a table for the simulation. Once the tool is initiated, as many parcels as desired will be selected.

 **Clear** = Clears all graphics and resets parcel selections from the screen. Useful if a parcel selection needs to be reselected to achieve a different buffer area.

 **Buffer** = Once parcels are selected on the map, a buffer of 0.5 mile will be performed and all parcels within that buffer will become selected and highlighted on the map. A table will then appear in the lower left screen showing the parcel(s) selected before the buffer occurred. These values can then be edited directly in the table.

 **Help** = Displays the help.

Basic Workflow – Below describes a basic workflow using the above tools

Zoom to desired area

Select parcel selection tool 

Select parcel(s)

Figure 5

Click the Buffer button 

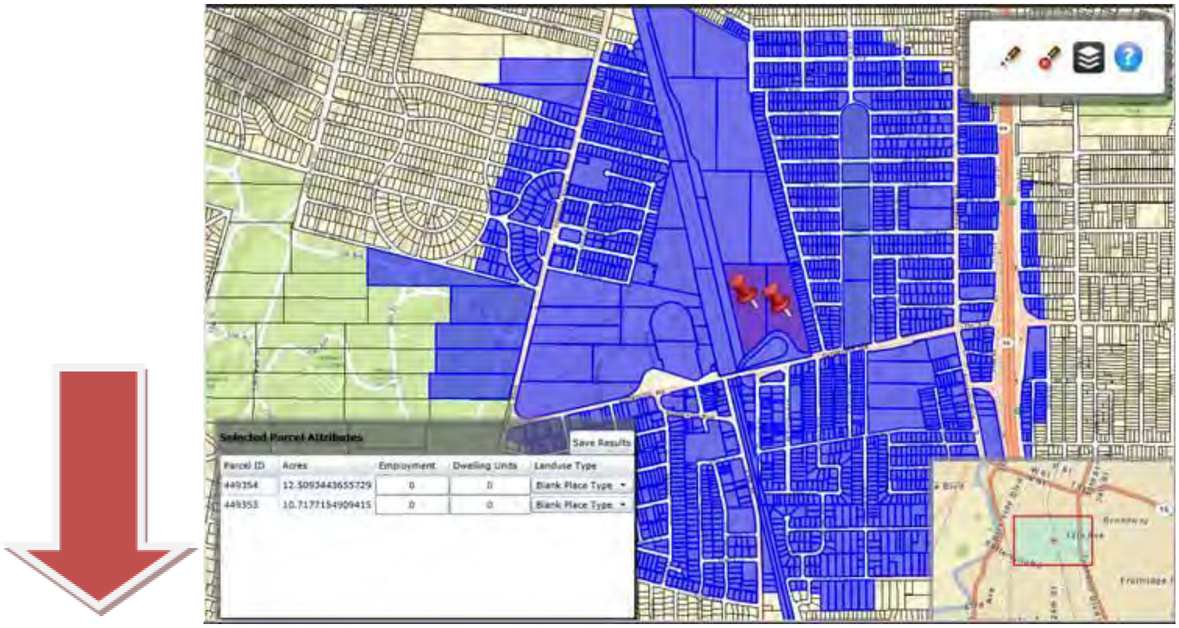
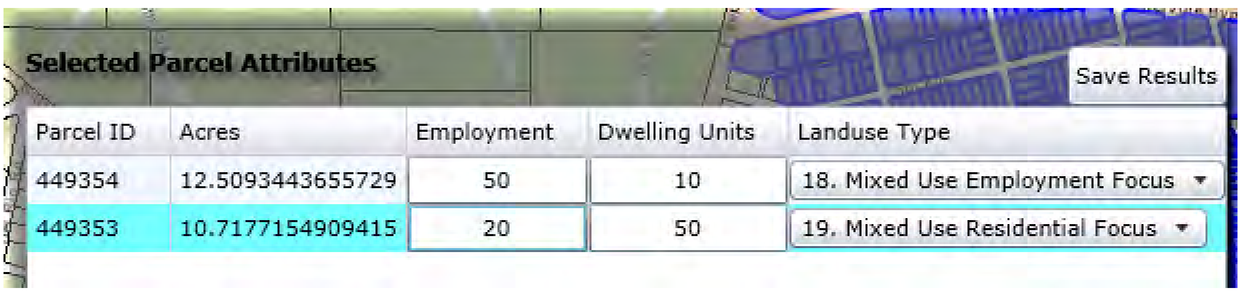


Figure 6

Edit values in the table



Selected Parcel Attributes

Save Results

Parcel ID	Acres	Employment	Dwelling Units	Landuse Type
449354	12.5093443655729	50	10	18. Mixed Use Employment Focus
449353	10.7177154909415	20	50	19. Mixed Use Residential Focus

Figure 7

Click the **Save Results** button to save the edited records in the table and the buffered surrounding parcels to an excel file.

4. Validation Test Plan and Results

In order to test the effectiveness of the tool, several tests were conducted. These are:

- Testing the accuracy of the calculations
- Testing the reasonableness of the results

These tests area appropriate levels of testing for sketch tools, which are not intended to provide specific numbers to be used in more rigorous evaluations, but rather to give users a sense of magnitude and direction between different planning scenarios.

A. Calculation Accuracy

The calculation tests are a simple way to check if the tool is functioning in the way it is intended. It is not meant to determine if results are accurate, just whether the calculations in the tool are working appropriately. A simple test would be seeing if 1 + 1 in the tool equals 2.

In order to conduct this test, the model was fed a simple land use scenario: 10 dwelling units and 10 employees, 5 of which were retail. Beginning from the results page, each formula was traced throughout the spreadsheet to see if the results were based on the correct input cells. Figure 15 below shows the outcomes from that test. Adding 10 employees increases the context plus project area accessibility measures by 10 employees. In addition, the jobs housing balance measure, with the addition of 10 employees and 10 dwelling units, stays the same.

Table 1. Assessment of Key Land Use and Travel Characteristics

Region	Context Area		Context Area with Project	Assessment
164,895	528,521	Auto Accessibility (Jobs w/in 20 Minute Drive)	528,531	Near average in surrounding area, and higher than regional
133,667	339,770	Transit Accessibility (Jobs w/in 45 Minute Transit Trip)	339,780	Near average in surrounding area, and higher than regional
1.2	2.2	J/H Balance (Jobs per Household w/in 4 miles)	2.2	Near average in surrounding area, and higher than regional

Figure 85

The test for calculations showed that the calculations were functioning correctly, and that spreadsheet portion of the tool was calculating as intended.

B. Reasonableness

Once the calculations were found to be functioning properly, the next test was to see if the results were reasonable. In order to conduct this test, three projects were entered into the tool, and the results examined to see if:

1. Estimated VMT was not higher or lower than expected,
2. Estimated mode shares were not higher or lower than expected, and
3. Given the land uses, the Ds variables and the adjustments they were making to the base VMT made sense.

The three projects tested were: Curtis Park Village in the city of Sacramento, La Valentina in Downtown Sacramento, and a non-geographically specific low density neighborhood.

Curtis Park Village was selected as SACOG had conducted analysis for the city of Sacramento and the Sacramento Air Quality Management District on this project. The project version evaluated contains approximately 530 dwelling units and 450 employees over 95 acres. The context area for the project is a typical inner-ring suburb in Sacramento with an abundance of mostly retail jobs, and medium density residential that is well-served by transit. The project is proposing a mix of uses, with slightly more residential units at a higher density. One portion of the project is designed for senior housing.

The test of the tool resulted in a VMT/HH of 44.3. SACOG's evaluation of the project using its SACSIM activity-based travel demand model resulted in a VMT/HH of 44.5, a difference of less than 1 percent. The share of trips resulted in increases in all non-auto modes from the regional average, including a 4% increase in walk/bike trips and a 4.4% increase in transit trips. Given the context area around the project, the existing and proposed demographics, and the proposed uses on the site, these slight increases aligned with our expectations.

La Valentina is an urban project that consists of two parcels totaling just over 1 acre in size. The proposed project used in this analysis is a mixed-use development that consists of 81 dwelling units and 30 jobs, 15 of which are retail. The context area immediately surrounding the project is urban, with an abundance of jobs, retail jobs, and fewer dwelling units, most of which are of medium to medium-high density.

The test of the tool resulted in a VMT per capita of 11.3, which seemed reasonable for an urban mixed-use project. A SACSIM analysis of the surrounding ½ mile area resulted in an average VMT per capita of 13.4. While this is 15% higher, given the mixed land uses and improved jobs-to-housing ratio with the addition of more housing, it makes sense to see an improvement over the surrounding area.

In order to find out if the improvements to the project warranted a 15% decrease in per capita VMT, the project was changed to reflect the typical development found in the area. The two parcels were set to medium-high density residential with no employment. As shown in Figure 16, this resulted in a VMT per capita almost identical to the context area.

Scenario	Res VMT/ Capita
La Valentina	13.5
Base	23.1
Context Area Avg:	*13.4*

Figure 16

For sketch level planning, the results of the two scenarios are reasonable and trend in direction that is expected. Although the models created for this tool are not intended to be used at this small scale, SACOG will continue to work on calibrating the tool to reflect travel at this level.

The Low Density Neighborhood scenario was created to reflect a standard suburban neighborhood that could occur anywhere. These areas typically are not served by transit, are not accessible to many jobs in a short drive, and are fairly homogenous in land use characteristics. For this test the project consisted of 100 single family dwelling units of approximately 4 dwelling units per acre. For this test, the VMT per capita was 35.6. Given the characteristics of the land use and lack of transit and accessibility to jobs, it seems reasonable the VMT per capita would be this high.

An additional test was done, setting the design, destination, and transit variables to those near the regional average. For this test, the per capita VMT was 27.5, which is still 19% above regional average. However, given that the project contained no employment and was at a slightly lower density than the regional average, it seems reasonable that the per capita VMT would remain slightly higher than the regional average.