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

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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:
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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.\(^3\)

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\(^1\) California Government Code Section 65080

\(^2\) CTC’s 2010 RTP Guidelines, Especially see Chapter 3 – Modeling.


Improved Data and Tools for Integrated Land Use-Transportation Planning in California
Final Overview Report
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.

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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. *(See Appendix B for details.)*
- 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).

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. 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.

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.

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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.
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. *(note: see Appendix E.)* 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.

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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.

Improved Data and Tools for Integrated Land Use-Transportation Planning in California Final Overview Report
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.

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

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). 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” 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.

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15 [CTC’s 2010 RTP Guidelines](#) Chapter 3 – Modeling.
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.
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):

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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.  


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.
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. 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, 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.

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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.
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).
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 \(\frac{1}{4}\) to \(\frac{1}{2}\) 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 \(\frac{1}{4}\) to \(\frac{1}{2}\) 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. Travel demand model post-processors

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.

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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. 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:

- 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.)

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.