Final Report

Assessment of Local Models and Tools for Analyzing Smart-Growth Strategies

Prepared for the

California Department of Transportation

Prepared by

DKS Associates
TRANSPORTATION SOLUTIONS

University of California, Irvine

University of California, Santa Barbara

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July 2007

DISCLAIMER

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State of California Business, Transportation and Housing Agency,
California Department of Transportation

By:

DKS Associates
and the
University of California, Irvine

In association with

The University of California, Santa Barbara
And Utah State University

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Abstract

There is a growing interest in California in "smart-growth" land- use and transportation strategies designed to provide mobility options and reduce demand on automobile-oriented facilities. This study focuses on models and tools available for use by cities and counties in California for assessing the potential effects of smart-growth strategies.

The majority of regional agencies and local jurisdictions in California currently use a version of the Urban Transportation Modeling System (UTMS), commonly referred to as the "four-step travel demand model." This study provides a review of the steps in the UTMS process to identify where sensitivity to smart-growth strategies may be limited during the modeling process, and suggests ways that improvements could be made.

The greatest degree of modeling smart-growth sensitivity was found among UTMS models used by larger Metropolitan Planning Organizations (MPOs) or Congestion Management Agencies (CMAs). Several larger MPOs in California are also implementing new types of models, such as activity-based travel models or integrated land use/economic/transportation models. Some local jurisdictions also already use advanced models or travel demand models with high levels of smart-growth sensitivity. The report suggests that if local jurisdictions are already using models with "moderate" to "high" levels of smart-growth sensitivity, they should continue to enhance their models.

However, many local jurisdictions' models have very little sensitivity to smart-growth land use or transportation strategies. In such cases, the study suggests the appropriate use of a planning tool and/or post-processing application that incorporates "4D elasticities" (e.g., Density, Diversity, Design and Destinations). The report finds that 4D elasticities tools can be used as part of local planning, public participation, and decision-making processes, such as: reviewing major land-use development proposals, preparing updates to city and county general plans and specific area community plans, and during regional "visioning" and other public participation processes. Therefore, local jurisdictions with low-sensitivity models should consider using a 4Ds methodology to gain increased sensitivity to smart-growth strategies, either applied in "sketch-planning" software (such as I-PLACE^{3}S, INDEX), or as a spreadsheet post-processor to a travel demand model.

However, before a decision is made to implement a 4D elasticities tool, the available travel demand model should first be tested to determine its sensitivity to smart-growth strategies. In addition, the report suggests that methods used to capture smart-growth sensitivity (either via improvements to a travel model and/or supplemental tools) should first be calibrated with local data and tested for reasonableness before being applied.

The report cautions against using 4D elasticities tools for conducting detailed corridor planning of streets or highways, for transportation impact studies of proposed land-use projects or traffic impact fee programs, or for CEQA or NEPA documentation - unless they are applied in specific ways (which are described). Other significant findings, conclusions, and recommendations are provided in Chapter 7.

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Technical Advisory Committee

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Executive Summary	**William Loudon**
Chapter 1 – Introduction	William Loudon
Chapter 2 – Overview of Travel Models and their Uses in Local Planning	William Loudon, Joe Story
Chapter 3 – Review of the Conventional Transportation Planning Model: Characteristics, Sensitivity to Smart-Growth Strategies, and Areas for Possible Improvement	Michael McNally, William Loudon, Joe Story, Michael Mauch, John Gibb
Chapter 4 - Overview of New Methods for Reflecting Smart-growth	Ming Lee, William Loudon
Chapter 5 - Travel Modeling Practice in California	William Loudon, Ming Lee, Miriam Leung, Kostas Goulias, Joe Story, Michael Mauch
Chapter 6 - Sensitivity Test of 4D Elasticities	Ming Lee
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Assessment of Local Models and Tools for Analyzing Smart-Growth Strategies

Executive Summary

Overview

There is a growing interest in communities across California and much of the rest of the nation in what is referred to as "smart-growth" - land development methods that can help reduce the amount of auto travel required to meet the needs of the people who live, work, shop or play in the development. By concentrating new development in existing urban areas where transit services are available or where more urban services are within walking or bicycling distance, smart-growth strategies seek to reduce the amount of automobile travel required by making it possible for more trips to be made by transit, bicycling, or by walking.

Smart-growth has been identified as a priority in ***Go California***, the Mobility Action Plan of the ***California Transportation Plan 2025***, and local communities are encouraged to explore smart-growth strategies in their land-use planning and development approval processes. To support the consideration of smart-growth strategies, the California Department of Transportation (Caltrans) funded this research to explore whether there are adequate travel-forecasting tools available to local jurisdictions to use in evaluating the potential vehicle trip reducing potential of smart-growth strategies.

The specific objectives of this study were as follows:

- To review the general adequacy of conventional travel demand models used at the local (city and county) level for sensitivity to smart-growth strategies
- To identify methods or tools that are available for use by cities and counties to add sensitivity for analyzing smart-growth strategies
- To review the current state-of-the-practice in travel-forecasting practice by local jurisdictions in California
- To produce recommendations for travel-forecasting practice to enhance smart-growth sensitivity

- To recommend additional research, development and training activities to improve the state-of-the-practice for travel forecasting for local land-use planning

Although there are different opinions about what constitutes smart-growth, the following principles of a smart-growth community as articulated by the U.S. Environmental Protection Agency (U.S. EPA)[1] capture the strategies most commonly included:

1. Mix land-uses
2. Take advantage of compact building design
3. Create a range of housing opportunities and choices
4. Create walkable neighborhoods
5. Foster distinctive, attractive communities with a strong sense of place
6. Preserve open space, farmland, natural beauty and critical environmental areas
7. Strengthen and direct development towards existing communities
8. Provide a variety of transportation choices
9. Make development decisions predictable, fair and cost-effective
10. Encourage community and stakeholder collaboration in development decisions

Smart-growth strategies can have an effect on travel behavior in a variety of ways. This study has investigated whether and how travel demand models and other assessment tools that local jurisdictions in California currently use to assess land-use plans and development projects may be "sensitive" to smart-growth strategies. This report also suggests types of improvements that could be made to the models and assessment tools to improve the evaluation of smart-growth strategies in local land-use planning and development processes.

The research team identified four key intended effects of smart-growth strategies as follows:

Providing opportunities to satisfy travel needs at nearby destinations with shorter vehicle trips, trip chaining, and/or non-motorized travel

- Clustering of potential non-home destinations such as daycare, cleaners, restaurants, stores, etc. near work sites
- Providing a higher level of diversity in mixed-use clusters
- Developing neighborhoods with more self-sufficient land-uses
- Providing more jobs-housing balance within sub-areas of regions that allows shorter commutes

[1] U.S. EPA's Smart-growth Network, http://www.epa.gov/smartgrowth/about_sg.htm

- Providing a more complete range of housing options and pricing near employment centers

Using land-use to create trips with origin-destination pairs that are more easily traveled by alternative modes

- Providing higher density residential and work sites near transit
- Providing higher density residential and work sites along bicycle routes and trails
- Location of schools along bicycle routes and trails
- Clustering potential destinations such as daycare, cleaners, restaurants, and stores near work sites and high density residential areas

Providing better and more attractive conditions for travel by alternative modes

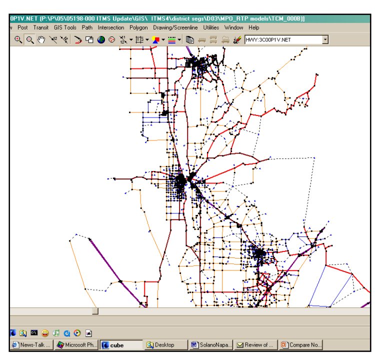
- Locating business entrances as close as possible to transit stops or stations
- Locating entrances to higher density residential buildings as close as possible to transit stops or stations
- Providing good pedestrian and bicycle access to transit stops or station
- Providing bicycle storage facilities at transit stops and stations
- Providing bicycle storage facilities at high density residential developments, work places, schools, and shopping areas
- Locating development on a grid street network
- Providing a high level of sidewalk coverage

Providing economic incentives for use of alternative modes

- Providing a limited supply of parking
- Charging separately for parking at multi-family residential, employment and shopping sites

These intended effects were used to develop a framework for assessing the sensitivity of alternative tools for evaluating smart-growth strategies.

Challenges with Current Travel Modeling Practice



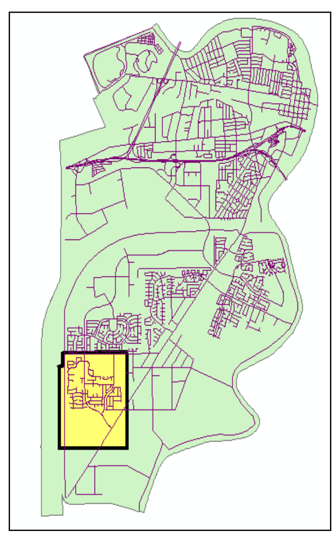
A review of the conventional travel-forecasting process used in California and throughout the U.S. identified a variety of limitations in the model systems regarding smart-growth analysis. A majority of local jurisdictions in California use a version of the Urban Transportation Modeling System (UTMS) - or "four-step" travel demand model - in its most basic form: a weekday travel model that forecasts only vehicle trips based on fixed vehicle trips rates

by land-use type. Models of this basic type typically cannot reflect changes in mode or vehicle occupancy that can result from smart-growth strategies or the possibility that trips will be made by bicycle, walking, or public transit instead of by automobile. This study's review of typical UTMS applications identified issues in all areas of current modeling practice that could potentially limit sensitivity to smart-growth strategies. The most significant limitations are:

- Trips not related (e.g., doesn't recognize "trip chaining")
- Consideration of only vehicle trips
- Limited or no transit modeling capability
- Limited or no modeling of walking and bicycling
- Fixed vehicle trip rates by land-use type
- Development design (building, street and sidewalk layout) not reflected in traveler choices
- Zonal aggregation of decision-maker characteristics
- Focus on travel during peak-periods
- Travel analysis zones often too large
- Land-use not affected by travel patterns

The time frame in which smart-growth strategies can be implemented or show benefit is also often beyond the ten- or twenty–year time frame of most local plans or models. This makes testing of long-range smart-growth strategies difficult. In addition, the amount of smart-growth development being tested in a model may be small in comparison to the quantity of other existing and future land-uses also represented in the model. As a result, the effects of the smart-growth may be un-noticeable in the aggregate vehicle trip and VMT output of the model.

Because of these and other limitations, it is generally very difficult for a local jurisdiction to adequately evaluate the potential benefits of smart-growth land-use practices regarding transportation efficiency. Therefore, those who may wish to implement smart-growth strategies often have no way to adequately assess or demonstrate the potential for reduced vehicle traffic volumes that may result from smart-growth implementation practices.

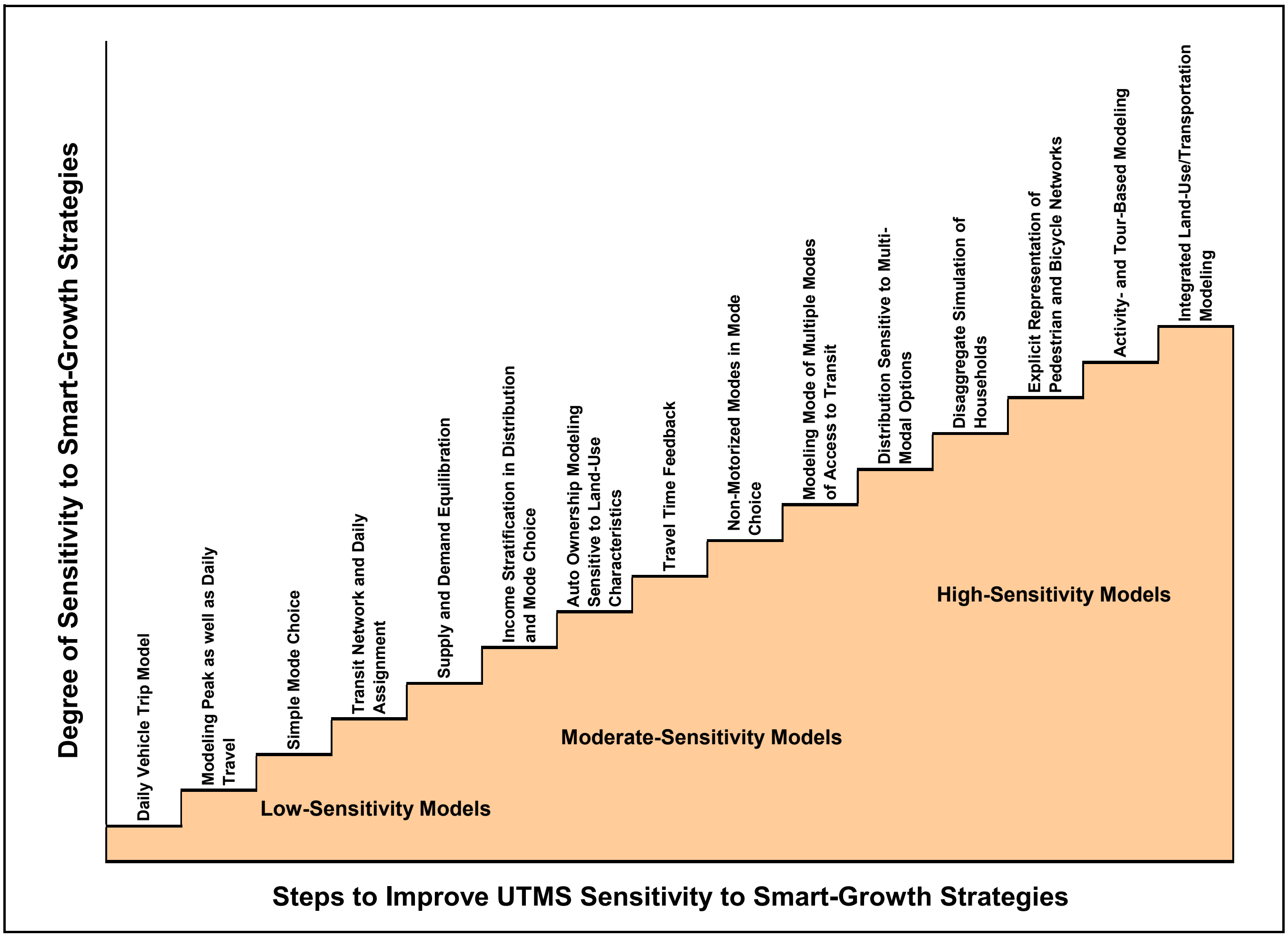


Options for Improving Travel Modeling Practice to Gain Smart-Growth Sensitivity

This study has identified numerous options for improving on the basic UTMS practice, and in most cases identified at least one or more agencies in California that are implementing each type of improvement. A summary of these options is presented in **Figure E-1**, which illustrates a progression in model improvement practice. **Figure E-1** roughly defines three ranges

of modeling improvement regarding sensitivity to smart-growth strategies: low, moderate, and high. Most of the modeling in the "moderate-sensitivity" and "high-sensitivity" ranges is currently done by Metropolitan Planning Organizations (MPOs) and/or Congestion Management Agencies (CMAs) located in the four major metropolitan areas of the state. When local jurisdictions are able to use focused versions of the MPO or CMA model, they also may have medium or high sensitivity. But the most common practice for local jurisdictions in the state is in the "low-sensitivity" range.

Figure E-1 Logical Progression of Steps to Improve UTMS Sensitivity to Smart-Growth Strategies



New Methods for Gaining Smart-growth Sensitivity

Because of the current lack of smart-growth sensitivity in many models, research has been conducted to develop supplemental tools to provide the missing sensitivity. Over the past 15 years, a series of studies have used cross-sectional analyses of variations in travel patterns for zones in major metropolitan areas.[2,3] These research efforts have documented how four key factors influence the rate of vehicle use per capita.

The four key factors[4] are often referred to as the "4Ds." They include:

- Density – population and employment per square mile
- Diversity – the ratio of jobs to population
- Design – pedestrian environment variables including street grid density, sidewalk completeness, and route directness
- Destinations – accessibility to other activity concentrations expressed as the mean travel time to all other destinations in the region

Research that resulted in the 4Ds characteristics also produced estimations of "elasticities" regarding vehicle travel per capita with respect to changes in each of the 4D variables.[5] These elasticities have been used in a variety of application tools to assess the potential vehicle travel reduction benefits of smart-growth land-use strategies.

Two GIS-based programs - INDEX and I-PLACE3S - have incorporated the 4D elasticities and have been used in land-use planning exercises to assess or demonstrate the transportation benefits of alternative smart-growth strategies. The 4D elasticities have also been applied as a "post-processor" with conventional travel-forecasting models, and also with other sources of "baseline" travel data (such as ITE trip generation rates).

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[2] Robert Cervero: "Travel Demand and the 3 Ds: Density, Diversity, and Design," *Transportation Research* D, 2, 3: 199-219, 1997; with K. Kockelmann. "Travel and the Built Environment: A Synthesis," *Transportation Research Record 1780*, pp. 87-113, 2001; with R. Ewing. "Built Environments and Mode Choice: Toward a Normative Framework," *Transportation Research D*, Vol. 7, 2002, pp. 265-284.

[3] INDEX 4D METHOD A Quick-Response Method of Estimating Travel Impacts from Land-Use Changes, Technical Memorandum, October 2001, Prepared for the U.S. Environmental Protection Agency. By Criterion Planners/Engineers and Fehr & Peers Associates.

[4] A 5th "D," "distance from heavy rail transit," has been developed and applied as a direct ridership model for predicting transit use associated with transit-oriented development. The 5th D is designed to respond to micro-scale influences around transit stations, such as higher density land uses around stations, station access modes, and parking availability.

[5] "Elasticity" is defined as the percentage change in one variable that results from a one percent change in another variable.

In California, I-PLACE3S has been used in the Sacramento area as an integral part of the regional "Blueprint" transportation and land-use planning effort. The City of Sacramento used the program for land-use planning around a light rail station and to assist in the City's recent General Plan update. The San Luis Obispo Council of Governments is using I-PLACE3S for regional land-use and transportation visioning and policy development. The San Diego Association of Governments began using I-PLACE3S in 2005 to assess various smart-growth planning options. The program is also being used by the County of Sacramento, Cities of Rancho Cordova and Ventura, as well as in several locations outside California.[6]

INDEX has been used by the City of Sacramento for pedestrian planning, by the County of Sacramento for comprehensive land-use/transportation planning, and by the Sacramento Metropolitan Air Quality Management District (SMAQD) for analysis of the benefits of alternative urban design strategies for reducing vehicle air pollutant emissions. INDEX has also been used by the Fresno and Madera Councils of Government as part of the San Joaquin Valley Growth Response Study.

The use of the 4D elasticities as a post-processor with a conventional UTMS model has been undertaken in several locations within California, including the following:

- Sacramento Region (SACOG) – for testing of alternative future land-use and growth scenarios
- San Luis Obispo (SLOCOG) – for testing of alternative future land-use and growth scenarios
- Contra Costa County (CCTA) – for long-range visions process "Shaping Our Future"
- Humboldt County – for County General Plan development
- Fresno and Madera Councils of Government – as part of the San Joaquin Valley Growth Response Study

(**Chapter 5** provides additional information about these efforts).

In addition, a 5th D, Distance to Rail Transit, has been used for analysis of transit-oriented land-use designs by the Bay Area Rapid Transit (BART) and Caltrain rail transit systems that operate in the San Francisco Bay Area. The 5th D is designed to estimate transit use, but does not estimate changes in vehicle trips or VMT.

The application of the 4D elasticities in these locations has demonstrated their usefulness as a planning aid in visioning or long-range planning processes. However, while the use of the 4D elasticities has added "sensitivity" for analysis of smart-growth strategies, a variety of issues have been identified that may limit the accuracy of the 4D methods, including the following:

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[6] Per email from Nancy McKeever, California Energy Commission, July 17, 2007.

- They are based on the aggregate characteristics of urban traffic analysis zones, and therefore the elasticities may reflect other unmeasured factors, such as income or cultural groupings that may be correlated with the 4D variables in those areas.
- The 4D elasticities capture some - but not all - of the potential influences of smart-growth strategies.
- Most 4D elasticities tools are not sensitive to the level of transit service or the availability of other "alternative" travel modes (such as bicycling) or demand management strategies (such as parking pricing) that could influence sensitivity of travel to urban design, density, and diversity.
- When used in conjunction with a local travel demand model that already has moderate or high sensitivity to smart-growth strategies, using the 4D elasticities may double-count some of the benefits of the smart-growth strategies, unless the 4D elasticities are calibrated to reflect sensitivity that is already provided by the travel model.
- The 4D elasticities are generally developed for daily vehicle trips and VMT and are not trip-purpose specific. As a result, it is difficult to relate the results to peak-periods of travel. There have been 4D elasticities developed for specific trip purposes, including a set developed for SACOG's Blueprint project,[7] which improved the capability to estimate changes in peak-period vehicle trips and VMT in that situation. However, most applications of the 4D elasticities have been for daily trips for all purposes.

Table E-1 provides a summary comparison of how well the potential UTMS improvements and the 4D elasticities are able to address smart-growth travel effects (that were identified above). This chart illustrates that increased sensitivity to more of the potential effects of smart-growth strategies can be gained through enhancement of UTMS models as compared to applying the 4D elasticities. However, upcoming research on a "5th D" (in another study) will likely increase the capability of the 4D elasticities to estimate benefits associated with a larger variety of transit service. This improvement will likely further increase the capabilities of 4D elasticities methodologies in the near future to estimate travel demand resulting from smart-growth strategies.

[7] Don Hubbard and Gerald Walters, Fehr & Peers, "Making Travel Models Sensitive to Smart-growth Characteristics," prepared for the ITE District 6 Conference, Honolulu, HI. July 2006.

Table E-1 Summary of 4D and UTMS Sensitivity to Smart-Growth Strategies

		Smart Growth Effect	Potential Options to Address UTMS Deficiencies	4D Sensitivity
1		**Providing opportunities to satisfy travel needs at nearby destinations with shorter vehicle trips, trip chaining or non-motorized travel**		
	1.1	Clustering of potential non-home destinations such as daycare, cleaners, restaurants, stores, etc. near work sites	Small Zones, More Purposes, Non-motorized Modes, Tour-based Modeling	Density, Diversity
	1.2	Providing a higher level of diversity in mixed-use clusters	Small Zones, More Purposes, Non-motorized Modes	Density, Diversity
	1.3	Developing neighborhoods with more self-sufficient land uses	Small Zones, More Purposes, Non-motorized Modes	Density, Diversity
	1.4	Providing more jobs-housing balance within sub-areas of regions that allows shorter commutes	Small Zones, Feedback to Distribution	Diversity, Destination
	1.5	Providing a more complete range of housing options and pricing near employment centers	Income Stratification in Distribution	Destination
2		**Using land use to create trips with origin-destination pairs that are more easily traveled by alternative modes**		
	2.1	Providing higher density residential and work sites near transit	Small Zones, Transit Modeling, Transit Access Modeling	Destination, Distance to a heavy rail station (not applicable for buses, and light rails)
	2.2	Providing higher density residential and work sites along bike routes and trails	Small Zones, Non-motorized Modes	
	2.3	Location of schools along bicycle routes and trails	Small Zones, Non-motorized Modes	
	2.4	Clustering potential destinations such as daycare, cleaners, restaurants, stores near work sites and high density residential areas	Small Zones, More Purposes, Non-motorized Modes	
3		**Providing better and more attractive conditions for travel by alternative modes**		
	3.1	Locating business entrances as close as possible to transit stops or stations	Small Zones, Transit Modeling, Transit Access Modeling	Distance to a heavy rail station (not applicable for buses, and light rails)
	3.2	Locating entrances to higher density residential buildings as close as possible to transit stops or stations	Small Zones, Transit Modeling, Transit Access Modeling	Distance to a heavy rail station (not applicable for buses, and light rails)
	3.3	Providing good pedestrian and bicycle access to transit stops or station	Small Zones, Transit Modeling, Transit Access Modeling	Design
	3.4	Providing bicycle storage facilities at transit stops and stations		
	3.5	Providing bicycle storage facilities at high density residential developments, work places, schools, and shopping areas		
	3.6	Locating development on a grid street network	Small Zones, More Purposes, Non-motorized Modes	Design
	3.7	Providing a high level of sidewalk coverage	Small Zones, More Purposes, Non-motorized Modes	Design
4		**Provide economic incentives for use of alternative modes**		
	4.1	Providing a limited supply of parking	Auto Ownership, Parking Constraint, Multimodal, Non-motorized Modes	
	4.2	Charging separately for parking at multi-family residential, employment and shopping sites	Incorporate Price in all Steps, Auto Ownership	

Conclusions and Recommendations

This study has led to a set of findings that can help guide choices of tools for analyzing smart-growth strategies by local jurisdictions (the cities and county agencies that are responsible for making local land-use decisions), and focus additional research and development activities to improve the tools currently available. The findings include conclusions in two areas:

- Local Model Sensitivity to Smart-Growth Strategies
- Supplemental Methods

Study recommendations are provided in three areas:

- Local Jurisdiction Practice Regarding Local Travel Modeling
- Local Jurisdiction Practice Regarding 4D Elasticity Tools
- Research, Development, and Training

The conclusions and recommendations are products of a cooperative effort by the research team and several participants in the study's Technical Advisory Committee.

Conclusions about Local Model Sensitivity to Smart-Growth Strategies

1. Few local jurisdictions in California use models that have sensitivity to smart-growth strategies. Most jurisdictions use models that: (a) lack the capability to estimate transit use or carpooling; (b) do not include representation of walking or bicycling trips; and/or (c) do not allow for variation in vehicle trip rates based on land-use density, mix, or design.
2. Local jurisdictions using Metropolitan Planning Organization (MPO) or Congestion Management Agency (CMA) travel demand models that have "moderate- to high-sensitivity" (**Figure E-1**) can capture some of the smart-growth sensitivity delineated in **Table E-1**, but to what degree is not clear.
3. GIS systems for local jurisdiction land-use and transportation system characteristics are making it possible to bring more information into the UTMS modeling process, and that has the potential to increase smart-growth sensitivity. This includes parcel-level land-uses and GIS layers for street systems, bicycle routes, sidewalks, topography, environmentally sensitive areas, etc. GIS systems are also facilitating the application of supplemental methods such as I-PLACE3S and INDEX.

Conclusions about Supplemental Methods

1. Local jurisdictions with low-sensitivity travel models (**Figure E-1**) can benefit from applying a 4D elasticities post-processor either as a spreadsheet supplement to the local model or applied in sketch-planning software, such as INDEX or I-PLACE3S, if used appropriately. It is also possible to integrate the 4Ds within the local jurisdiction model, but this effort requires more effort and should include calibration to local conditions.
2. For the 4D elasticities to function properly, it is necessary to follow the guidelines developed for their use (**Chapter 4**), and to calibrate them to local conditions.
3. The 4D elasticities are able to capture some - but not all - smart-growth sensitivity.
4. When the 4D elasticities are applied in conjunction with a travel model that already has "moderate" or "high" sensitivity to smart-growth, there may be double-counting of the smart-growth benefits -- unless the 4D elasticities are adjusted to reflect the local model's sensitivity. Therefore, it is recommended that the "moderate" or "high" model be tested to determine its actual degree of sensitivity, and that the 4D elasticities be calibrated, based on local data, to account only for the sensitivity unaccounted for in the travel model.
5. The 4D elasticities (or any "correction factors" that are based on aggregate cross-sectional data) most likely capture some unknown trip or VMT reduction effects as a result of correlations between smart-growth variables of interest (e.g., the 4Ds) and other factors not listed in the formula but related to how an area is developed. These factors may include:

    - Income
    - Race and cultural characteristics
    - Complementary land-uses
    - Quality and frequency of transit service
    - Parking costs and availability
    - Auto ownership

    However, developing locally estimated 4D elasticities can be done in a manner that controls for many of these variables. Doing so allows the 4D adjustments to predict trip reducing effects of smart-growth independent of, for example, income and race.
6. The 4D elasticities estimate reduced VT and VMT assumed to result from the use of transit, walking, or bicycling, with the assumption that basic transit and bicycling facilities are available. The 4D adjustments directly account for the presence or absence of sidewalks and pedestrian route connectivity, but do not explicitly account for bicycling facilities or bus or rail service. [8] If the study area

[8] While the 4Ds do not account for the presence of rail transit, if the smart-growth study area is expected to offer rail service, the 5th D (Distance to Rail Transit) or Direct Transit Ridership Modeling, can be used to assess the effect of rail proximity on the amount of transit ridership generated in an area.

has less than basic bus or bicycle facilities, the elasticities may overestimate the reduction in VT and VMT and assume a level of bus ridership that could not be accommodated by the planned bus service. However, if the smart-growth study area plans to offer basic bus service (similar to the service in other areas of the region with similar densities), and basic bicycle facilities (consistent with other areas of the region with similar densities and route connectivity), the 4Ds provide a reasonable approximation of the VT and VMT reductions resulting from pedestrian, bicycle, and bus availability.
7. It is possible to calibrate the 4D elasticities to account for complementary destinations (e.g., land-uses that provide opportunities for individual or household activity needs away from home, such as at work, to be met by non-motorized modes rather than solely by automobile) and their effect on VT and VMT reduction. This may be accomplished through developing locally validated 4D elasticities for non-home-based trip purposes, as several 4D studies have done.

Recommendations for Local Jurisdiction Practice Regarding Local Travel Modeling

1. Local jurisdictions that implement models that already have “moderate” to “high” smart-growth sensitivity (**Figure E-1**) should strive to continue to enhance their models regarding smart-growth sensitivity rather than to supplement them with 4D elasticities or other post-processing approaches. A model should be tested for its sensitivity to smart-growth, however, because the presence of the desirable features listed in **Figure E-1** does not guarantee sensitivity. The 4D elasticities research and other research on smart-growth effectiveness provide evidence of the expected range of sensitivity a model should have to smart-growth and can provide a benchmark for travel model testing. A model can be tested to determine whether it captures the expected range of sensitivity before a decision is made about how to add sensitivity. To perform this type of sensitivity testing, users need full access to travel demand models.
2. Due to the need to better understand and balance regional benefits associated with smart-growth strategies with localized traffic impacts, local jurisdictions that have access to a moderate- to high-sensitivity regional agency model should consider using it to assess proposed land-use plans and projects if such a model provides sufficient detail.
3. Local jurisdictions with low-sensitivity models should consider using a supplemental tool such as one of the 4D elasticities post-processors to evaluate smart-growth strategies in land-use planning efforts.
4. Methods used to capture smart-growth sensitivity (either improvements in the travel model or supplemental tools) should be calibrated with local data and tested for reasonableness before being used to assess land-use plans or projects.

Recommendations for Local Jurisdiction Practice Regarding 4D Elasticities Tools

1. There should be testing of an existing travel model to assess whether it already has smart-growth sensitivity and whether it estimates travel activity consistent with local travel survey results in order to determine whether a post-processor (such as the 4D elasticities) should also be used.
2. Local jurisdictions with low-sensitivity models should consider using a 4Ds methodology to gain some sensitivity to smart-growth strategies, either applied in sketch-planning software such as I-PLACE3S, INDEX, or as a spreadsheet post-processor to a local travel model.
3. It is recommended that 4Ds processes (whether in I-PLACE3S, INDEX, or as a spreadsheet post-process to a local travel model) can appropriately be used as part of local planning, public participation, and decision-making processes, such as:

   - Developing and/or updating city and county general plans and specific area community plans
   - Creating and communicating various land-use/transportation "scenarios" to workshop participants as part of these processes, and providing feedback to them regarding various potential benefits and impacts
   - Assessing land-use projects and plans regarding air quality benefits and impacts
   - As part of regional "visioning" processes (such as, for example, the SACOG Regional Blueprint Project) to gather input from participants and provide feedback to them regarding estimated benefits and impacts of their choices

   It is <u>not</u> recommended that 4D elasticities processes be used for conducting corridor planning of streets or highways (regarding numbers of lanes or other specific project-level details).

4. For transportation impact studies of proposed land-use development projects, for traffic impact fee programs, or for any CEQA or NEPA documentation, the 4Ds may be used but only if the following requirements are adequately met:

   - the 4Ds elasticities are applied in conjunction with a local travel model,
   - the 4Ds elasticities have been calibrated to local conditions using a local travel survey,
   - the 4Ds elasticities have been calibrated to reflect smart-growth effects and trip purposes that are captured directly by the local travel model (for models with moderate or high sensitivity), and
   - the project is at least 200 acres in size.

5. For the 4D elasticities to function properly, it is necessary to apply them according to the guidelines established by the developers of the elasticities and in

a way that reflects the conditions for which they were developed (**Chapter 4**). These include the following guidelines:

- Set minimum and maximum boundaries on the size of areas to be analyzed to reflect the general size of the analysis zones used in the estimation of the elasticities
- Limit the possible percentage change in the 4Ds to the range observed in the estimation data
- Calibrate to local conditions
- Use household travel surveys, if/when they are available, to determine actual elasticities appropriate for an area before conducting analyses of land-uses using a 4D elasticities post-processor
- Follow recommendations regarding the proper use of each tool (**Chapter 4**)

Recommendations for Research, Development, and Training

1. More research, development, and training should be conducted to support the use of more sophisticated modeling tools by local jurisdictions.
2. The diversity of case studies in this report indicates that "best practices" are emerging regarding use of models and tools to analyze smart-growth strategies. Training and education is needed in the form of documentation and technology transfer targeting the majority of local jurisdictions and smaller MPOs.
3. Procedures and standards should be developed for testing a travel model's sensitivity to smart-growth conditions and judging whether the model is within an acceptable range, or the degree to which adjustment is needed.
4. The most advanced model systems, including activity-based and tour-based models, should be used to conduct research on elasticities for post-processing or correcting less sensitive models, especially to capture the benefits of modeling all modes of travel, short and long trips, and the inter-relationship between trips.
5. Better documentation and explanation of supplemental methods such as the 4Ds methodologies (including, I-PLACE3S, INDEX, and 4D post-processors) should be developed and provided, along with parameters and recommendations for their appropriate use. Guidelines should also be provided that describe a calibration process for these tools.
6. An assessment should be undertaken of the benefits that improved regional modeling may have in assisting local governments' abilities to analyze smart-growth land use and transportation strategies at local and site-specific levels.
7. Additional research should be conducted to further support 4D elasticities and other post-processing methods to provide more direct sensitivity to smart-growth effects and to reduce correlation with other factors. There should also be research conducted on the elasticities for a broader range of area types. [9]

[9] Research currently underway includes: NCHRP Project 08-51, "Enhancing Internal Trip Capture Estimation for Mixed-Use Developments," is currently assembling data on vehicle trip generation rates in mixed-use developments. NCHRP Project 08-66, "Trip-Generation Rates for Infill Land Use

8. The 4Ds elasticities, outside of proprietary and copyrighted software, should evolve as "open architecture" freely available via the Internet.
9. The elasticities in proprietary and open source software should be tested periodically to verify their evolution over time and, most importantly, their transferability across California.
10. Additional research should be conducted with models from one or more case-study areas to assess how much sensitivity is added by different levels of improvement of UTMS modeling and by activity-based modeling. Comparison of results should be made with results from 4D methods to assess the effectiveness of 4D calibration to local model sensitivity. Sensitivity testing should also be used to provide insights regarding which smart-growth strategies are most effective in different types of locations and settings.

Developments in Metropolitan Areas" was recently approved. In addition, U.S. EPA is initiating a study that may provide the opportunity to update the 4D elasticities with more recent national data.

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Chapter 1
Introduction

1.1 Project Purpose and Objectives

In the past decade, frustration with increasing congestion, air pollution, and suburban sprawl has led to a resurgence of interest in land development patterns, often labeled as "smart-growth," including: mixed land-uses, urban and suburban infill, pedestrian and bicycle-oriented design, and transit-oriented developments. The features of smart-growth are generally designed to allow residents to be less dependent upon travel by automobiles. The purpose of this project has been to review the travel modeling methods used by local jurisdictions (e.g., cities and counties) in California to determine whether there is adequate sensitivity to smart-growth strategies to evaluate the potential impact on trip making and vehicular travel.

Interest in smart-growth strategies has been demonstrated in California by policy statements included in ***Go California***, the Mobility Action Plan of the ***California Transportation Plan 2025***. The document identifies as some of the key strategies to promote more efficient development patterns:

- Increasing densities and using design to facilitate effective transit service
- Promoting street and urban design to encourage walking and bicycling
- Providing information and technical assistance on transit-oriented design
- Encouraging localities to foster " smart-growth" development practices
- Promoting the revision of local zoning regulations to allow for higher density and mixed-use developments

Along with the increasing interest in new community design have come questions about whether the conventional Urban Transportation Modeling System (UTMS), or "four-step" travel demand model as it is commonly known, has the capability to effectively quantify the impacts and benefits associated with smart-growth characteristics, such as those listed below:

- Land-use location
- Land-use density
- Land-use diversity
- Transportation network configuration
- Non-motorized mode facilities (such as pedestrian and bicycle paths)

For example, clustering of services such as dry cleaning, day care, restaurants, and stores near major employment sites can provide the opportunity for workers to take care of personal errands on foot from work and possibly avoid unnecessary motor vehicle trips. Most travel models used by local jurisdictions in California do not reflect the differences in vehicle trip generation that result from such clustering of mixed uses. Transit ridership can also vary as a function of the difficulty in crossing streets at bus stops and the presence of waiting shelters and sidewalks, but these micro-scale design features are not recognized in most regional or local models. Building an ideal travel model to address these smart-growth issues would require the collection and interpretation of more data than has been used in current travel forecasting activities. The level of detail required for models of non-motorized modes is much finer than typically encountered in travel forecasting models in use today.

This report provides a review of current modeling practice in California and identifies applications that are designed to quantify the effects of smart-growth on local travel demand. In **Chapter 2**, the review begins with a brief overview of travel demand models and their use in local land-use decision-making. It is followed in **Chapter 3** by a detailed review of the conventional modeling process used by most local jurisdictions in California and the limitations of the approach for smart-growth sensitivity. Chapter 3 also identifies methods for improving the sensitivity of conventional UTMS modeling and provides examples of where innovative practices have been implemented in California.

Chapter 4 provides a review of several existing supplemental tools that are currently in use for gaining smart-growth sensitivity through the application of what are commonly called the “4D elasticities:” I-PLACE3S, INDEX, and a 4Ds Post-Processor. **Chapter 5** provides a review of current modeling practice in California. The review is intended to be a general overview of how travel models are used by local jurisdictions to support local land-use decision-making. Specific attention is given to the extent to which travel models have been used to make decisions about smart-growth strategies. Six case studies are included to illustrate the range of practice in California.

Chapter 6 provides the results of a sensitivity test of one of the 4Ds-based supplemental tools (INDEX) designed to increase smart-growth analysis sensitivity. The results from INDEX application are compared with the results from the baseline travel model. **Chapter 7** summarizes the conclusions and recommendations from the study and identifies directions for additional research.

Appendix 1 of this report provides a list of the members of the Technical Advisory Committee that provided guidance for the study, and of the research team. **Appendix 2** provides definitions for the acronyms used in the report, and **Appendix 3** is a glossary of terms used in transportation, modeling, and related topics.

1.2 Smart-Growth Strategies

Although there are different opinions about what constitutes smart-growth, the following design principles of a smart-growth community as articulated by the U.S. Environmental Protection Agency (U.S. EPA)[10] capture the elements most commonly included:

1. Mix land-uses
2. Take advantage of compact building design
3. Create a range of housing opportunities and choices
4. Create walkable neighborhoods
5. Foster distinctive, attractive communities with a strong sense of place
6. Preserve open space, farmland, natural beauty and critical environmental areas
7. Strengthen and direct development towards existing communities
8. Provide a variety of transportation choices
9. Make development decisions predictable, fair and cost-effective
10. Encourage community and stakeholder collaboration in development decisions

Transit-oriented development refers to land development patterns that place the development of various commercial and residential activities around a transit station. The design principles of transit-oriented development can be seen as a subset of those of smart-growth. Transit-oriented neighborhood design features typically include:

- Mixed land-use
- Compact development
- Destination within easy walking distance of transit
- Neighborhood focal point
- Pedestrian orientation

In the remainder of this report the term “smart-growth” is used to refer to all of the strategies identified above.

Smart-growth strategies can have an effect on travel behavior in a variety of ways. The ways in which they affect travel behavior have direct implications for whether travel models used by local jurisdictions are sensitive to the smart-growth strategies. They also have direct implications for what kinds of improvements to the models or supplemental methods might improve the local jurisdictions’ ability to evaluate smart-growth strategies in their land-use planning processes. The research team identified four key intended objectives of smart-growth strategies as follows:

Providing opportunities to satisfy travel needs at nearby destinations with shorter vehicle trips, trip chaining, or non-motorized travel.

[10] U.S. EPA’s Smart-growth Network: http://www.epa.gov/smartgrowth/about_sg.htm

- Using land-use to create trips with origin-destination pairs that are more easily traveled by "alternative" modes such as transit, walking, and/or bicycling.
- Providing better and more attractive conditions for travel by alternative modes.
- Providing economic incentives for the use of alternative modes.

The research team also identified examples of specific ways in which smart-growth strategies can produce these effects, and these are provided in **Table 1.1**. The assessment of local jurisdiction modeling practice and supplemental methods for their smart-growth sensitivity was conducted with these potential effects as the frame of reference.

1.3 Research Approach

This study was conducted through a combination of literature review, survey, case study analysis, and sensitivity testing of models. A Technical Advisory Committee (TAC) was formed to provide guidance and quality control for the project and also to provide technical input on the state of modeling practice in the state. A list of the TAC members and the other study participants is available in Appendix 1.

The research team performed a thorough review of conventional UTMS travel models that are used by most local jurisdictions to determine what limitations in the model influence sensitivity to smart-growth. Each major component of the four-step model was reviewed. Suggestions were generated regarding how the sensitivity of the conventional model could be improved.

The current state-of-the-practice of travel modeling for land-use planning and decision-making in California was characterized by conducting a survey of the TAC members and the professional experience of the research team. The review was designed to provide a profile of the range of travel-forecasting tools used, the applications of tools for land-use planning, and efforts made to gain smart-growth sensitivity. The range of practice is illustrated in more detail by a review of six case-study cities:

- Fresno
- Irvine
- San Diego
- San Jose
- San Luis Obispo
- West Sacramento

These case studies illustrate different local approaches to travel modeling and various approaches to analyzing land-use plans and projects, especially regarding smart-growth strategies.

Table 1.1 Intended Effects from Smart-Growth Strategies on Travel Behavior

Smart-Growth Effect and Smart-Growth Strategies Designed to Achieve the Effect		
1	**Providing opportunities to satisfy travel needs at nearby destinations with shorter vehicle trips, trip chaining or non-motorized travel**	
	1.1	Clustering of potential non-home destinations such as daycare, cleaners, restaurants, stores, etc. near work sites
	1.2	Providing a higher level of diversity in mixed-use clusters
	1.3	Developing neighborhoods with more self-sufficient land uses
	1.4	Providing more jobs-housing balance within sub-areas of regions that allows shorter commutes
	1.5	Providing a more complete range of housing options and pricing near employment centers
2	**Using land use to create trips with origin-destination pairs that are more easily traveled by alternative modes**	
	2.1	Providing higher density residential and work sites near transit
	2.2	Providing higher density residential and work sites along bike routes and trails
	2.3	Location of schools along bicycle routes and trails
	2.4	Clustering potential destinations such as daycare, cleaners, restaurants, stores near work sites and high density residential areas
3	**Providing better and more attractive conditions for travel by alternative modes**	
	3.1	Locating business entrances as close as possible to transit stops or stations
	3.2	Locating entrances to higher density residential buildings as close as possible to transit stops or stations
	3.3	Providing good pedestrian and bicycle access to transit stops or station
	3.4	Providing bicycle storage facilities at transit stops and stations
	3.5	Providing bicycle storage facilities at high density residential developments, work places, schools, and shopping areas
	3.6	Locating development on a grid street network
	3.7	Providing a high level of sidewalk coverage
4	**Provide economic incentives for use of alternative modes**	
	4.1	Providing a limited supply of parking
	4.2	Charging separately for parking at multi-family residential, employment and shopping sites

Researchers also conducted a review of existing tools for supplementing conventional models to gain smart-growth sensitivity by examining documentation of the tools. The review focused on how each of three 4D-based tools - I-PLACE3S, INDEX, and 4D post-processors - captured the additional sensitivity and the data used to provide that sensitivity. This report describes the structure of each of these tools, along with the equipment, data, and other resources and guidelines required for their appropriate application.

To gain a better understanding of how the existing tools for supplementing travel models work and the differences they produce for a sample urban environment, a "sensitivity test" was conducted using the 4D elasticities. The tests were conducted using the INDEX software applied to travel data available from West Sacramento.[11] The sensitivity tests were designed to assess how much reduction in travel demand that INDEX predicts would result from a variety of strategies. The sensitivity test also provided an assessment of the data and effort necessary to use the 4D elasticities in INDEX.

The research team and TAC members generated a set of conclusions and recommendations from the study based on the results of the activities described above. The focus of the conclusions and recommendations (Chapter 7) is on how local jurisdictions can, in the short run, make the most effective use of available models and tools to gain smart-growth sensitivity. Recommendations were also developed regarding additional steps that could lead to more smart-growth sensitivity in models and tools available to local jurisdictions.

[11] Sensitivity tests of I-PLACE3S or a 4D post-processor were not conducted due to insufficient time and other resources.

Chapter 2

Overview of Travel Models and Their Use in Local Planning

2.1 Uses of Models in Local Land-use and Transportation Planning

In California, as in most states, land-use planning and approval of development projects is the responsibility of the cities in incorporated areas and the counties in un-incorporated areas. Cities and counties in California have the responsibility to prepare a general plan as a statement of development policies setting forth objectives, principles, standards, and plan proposals for the coordination of land-use, circulation, housing, open space, conservation, environmental quality and safety. The general plan is usually developed with the aid of a travel model that can translate alternative land-use forecasts and configurations into travel patterns. Because of the availability of personal computers and fairly standardized software packages for applying travel models, most cities and counties have the ability to develop and use a local travel model for development of the general plan and for other uses.

Cities and counties also have the authority to review and approve land-use development projects. That review typically includes an assessment of the potential impact of the development on the transportation system. Again this review is frequently aided by the application of a travel model to assess the additional travel that could be generated by the development.

At a regional level, transportation planning is required in the United States as a conditional requirement to receive federal transportation funds for larger urban areas. Requirements for urban transportation planning emerged during the early 1960s. The Federal-Aid Highway Act of 1962 created the federal requirement for urban transportation planning largely in response to the construction of the Interstate Highway System and the planning of routes through and around urban areas. The Act required, as a condition attached to federal transportation financial assistance, that transportation projects in urbanized areas of 50,000 or more in population be based on a *continuing*, *comprehensive*, urban transportation planning process undertaken *cooperatively* by the state and local governments -- the birth of the so-called 3Cs, “continuing, comprehensive and cooperative” planning process.

Throughout the years, the requirements have been expanded and modified in subsequent legislation, through the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), the Transportation Efficiency Act (TEA-21), and the Safe, Accountable,

Flexible, Efficient Transportation Equity Act - A Legacy for Users (SAFETEA-LU) in 2006. ISTEA listed 15 specific factors that must be considered in urban transportation planning. These factors have led to regulations that require planning agencies to deal more directly with air quality issues, multi-modal planning, and better management of existing systems, expanded public input, and financial analysis requirements. Generally, they have led to a greater role for transportation planning in urban areas, and to the consideration of a wider range of alternatives and consequences of transportation investment choices.

In addition to national laws and regulations, California requires urban counties to develop and maintain travel models for use in the Congestion Management Program. This requirement originated from Proposition 111, passed by California voters in 1990. Proposition 111 added nine cents per gallon to the state fuel tax to fund local, regional, and state transportation projects and services. It also required 32 “urban counties” to designate a “Congestion Management Agency”, whose primary responsibility is to develop and maintain a “countywide transportation computer model: to coordinate transportation planning, funding and other activities in a congestion management program.” The codified task is in California Government Code Section 65089 (c):

> *The agency, in consultation with the regional agency, cities, and the county, shall develop a uniform data base on traffic impacts for use in a countywide transportation computer model and shall approve transportation computer models of specific areas within the county that will be used by local jurisdictions to determine the quantitative impacts of development on the circulation system that are based on the countywide model and standardized modeling assumptions and conventions. The computer models shall be consistent with the modeling methodology adopted by the regional planning agency. The data bases used in the models shall be consistent with the databases used by the regional planning agency. Where the regional agency has jurisdiction over two or more counties, the databases used by the agency shall be consistent with the databases used by the regional agency.*

The requirement for a Congestion Management Program does not apply in a county in which a majority of local governments that represent a majority of the population in the county adopt resolutions electing to be exempt from the congestion management program.

2.1.1 Policy Development (Sketch Planning)

Policy development often involves exploring potential outcomes in a broad-based way as a way of screening down options to identify strategies that are worthy of more investigation. Travel models can provide important information regarding some benefits and costs of various options and scenarios.

Policy studies often examine model results from prior studies as a point where trends and potential issues can be identified. If further system alternatives are to be considered, models can be used to test the effects of system changes. Some ways that travel models can be used vary depending on the policy choices being considered and also the model design.

Examples of the types of options and questions that travel models are typically used to assess include: whether and where traffic congestion levels may get worse, whether specific roadways will reach congested conditions, and the direct effects of land-use growth patterns on the transportation system. For example, if a travel model has sensitivity to transit service, that same model can be used to examine whether or not increases in transit service (resulting in increased transit service frequencies) or changes in transit fares may result in mode shifts. If the travel model has sensitivity to vehicle occupancy with HOV lanes, then different lane assumptions can be tested. Finally, area-wide measures such as aggregate vehicle miles of travel (VMT) or vehicle hours of travel (VHT) can be estimated to describe system performance.

2.1.2 General Plan

California communities must have an adopted General Plan, as defined in California Government Code 65300. A General Plan is a set of policies and maps designed to establish how the community will change should the community continue to experience development. General plans address various aspects of community planning including circulation, which is one of the core elements required by state law.

Travel models are used in General Plans, both in plan development as well as in the assessment of potential environmental impacts resulting from General Plan implementation. The procedure is to examine system performance and compare the consequences of leaving an existing General Plan intact or adopting an updated document.

2.1.3 Specific Plan

A Specific Plan is similar to a General Plan, but for a portion of the jurisdiction rather then an entire city or county. This planning concept is intended to set a series of area-wide improvements into motion, including possible set-asides for rights-of-way, exactions, and programming for new transportation facilities. This planning process is governed by California Government Code 65450 to 65457. A Specific Plan includes a text and a diagram or diagrams that specify all of the following in detail:

- The distribution, location, and extent of the uses of land, including open space, within the area covered by the plan.

- The proposed distribution, location, and extent and intensity of major components of public and private transportation, sewage, water, drainage, solid waste disposal, energy, and other essential facilities proposed to be located within the area covered by the plan and needed to support the land-uses described in the plan.
- Standards and criteria by which development will proceed, and standards for the conservation, development, and utilization of natural resources, where applicable.
- A program of implementation measures including regulations, programs, public works projects, and financing measures necessary to carry out the Plan.
- A statement of the relationship of the Specific Plan to the General Plan.

Travel models are used in Specific Plans to assess the potential consequences of various proposed actions. Traffic impact analyses (TIAs) are often conducted for Specific Plans as part of California Environmental Quality Act (CEQA) requirements.

2.1.4 Transportation Investment Study/Corridor Study

Studies and strategies are often performed to define potential transportation investments in major corridors. Special studies are often needed to reduce the number of alternative strategies, and/or to refine the content of alternatives. These studies then are used to inform decision-makers regarding more detailed environmental studies and design-related questions.

One key use of travel demand models is to assist in the development of investment strategies for transportation corridors. Depending on the type of model that is used and the alternatives being proposed, a travel model can provide responsive information on the demand that would result from different alternatives, providing one key piece of information in helping decision-makers reduce the number of alternatives. Travel models also provide input to micro-level traffic simulation models that are used in defining the geometric requirements of the roadway or intersection design based on an analysis of intersection "levels of service" and related queue lengths, or on segment level of service and related technical performance of merging, diverging, and weaving analysis.

2.1.5 Traffic Impact or Development Fee Program

Some jurisdictions have enacted traffic impact or development fee programs. Developer fees are dedicated assessments that are applied to new development in a district for the purpose of funding new transportation projects that would be needed as a result of growth. Such assessments help ensure that a community's transportation performance standards would continue to be met. Developer fees provide a "fair share" mechanism for funding transportation improvements on a proportional basis rather than requiring that a particular transportation project be funded through a single land-use development. In

California, development fees are enabled by California Government Code 66000 through 66008, which establishes the authority and procedures for creating and operating a program.

Travel models are often used as tools in developing and updating assessment fee programs. They represent one of the most defensible tools available for addressing many technical questions involved in fee studies. Travel models typically are used to estimate the proportion of traffic growth attributable to new development, identify the origins or destinations of the new traffic, determine an average forecasted trip length as a basis for the size of the fee district, and assess whether the proposed program to be funded by the fee will address the anticipated system deficiencies adequately.

2.1.6 Traffic Impact Analysis/CEQA Analysis for New Development

One current standard use of travel models is to analyze traffic impacts of new development, as required by the California Environmental Quality Act (CEQA), a California statute that became law in 1970. CEQA requires state, regional, and local agencies to identify and assess the significant environmental impacts of their actions and to avoid or mitigate those impacts, if feasible. The current CEQA law is found in the California Public Resources Code Division 13: Environmental Protection.

Each "lead agency" accepts an Environmental Impact Report (EIR), Negative Declaration, or Categorical Exemption regarding proposed new plans and development projects. Other communities or government agencies – and the public - can provide feedback during the initial stages of document preparation ("Notice of Preparation") or through a review of the draft EIR. The CEQA process includes a requirement to examine circulation issues. Forecast traffic volumes are also used in analysis of air quality and noise effects related to the proposed project (these are also studied through the CEQA process).

Travel models often provide a technical resource for preparation of CEQA studies. For example, travel models can be a source of background volumes, of trip and/or distribution of traffic generated by the development proposal, and of the aggregate impacts of new roadways or other improvements that may be contained in the development proposal. Typically, a travel model will provide traffic volume forecasts for cumulative "no project" and "cumulative plus project" conditions. These traffic volumes have a direct influence on the need and extent of mitigation.

Given this reliance on travel models by local agencies that control land-use decisions, clearly defining the "state-of-the-practice" for local modeling is an important first-step before recommending that local agencies invest in new or improved features that will increase the sensitivity of their models to smart-growth strategies.

2.1.7 Transportation Project EIS/EIR under NEPA/CEQA

Transportation projects that require construction and obtain federal funding must have an Environmental Impact Statement (EIS) as required by the National Environmental Policy Act (NEPA), passed in 1969. The adoption of the related CEQA in 1970 established a set of more specific rules that, if applied, typically also satisfy the NEPA process. Minor projects may be exempted from NEPA and CEQA depending on the urgency, nature and size of the project.

Often, transportation projects funded with Federal Highway Administration (FHWA) resources must be supported by an analysis of anticipated traffic conditions 20 years after project completion. Regional travel models are typically used to provide the necessary travel forecast. Forecast traffic volumes are also used in analysis of air quality and noise impacts, which are also studied through the NEPA/CEQA process.

Travel models are most often used to forecast future traffic volumes on area roadways. While models can be used to forecast some operational conditions on the roadways, they typically are not used in this way because models are not typically calibrated to operational attributes such as delay or travel time.

2.1.8 Transit New Starts Project Analysis

Federal funding for transit projects began in the 1960s. The popularity of transit projects began to rise in the 1970s, and a need emerged at that time for a better process to determine the relative benefits of making transit capital investments from the competitive Federal Transit Administration's (FTA) New Starts grant program. The appropriation of New Starts funding is now tied to a rating system established by FTA that includes existing and planned land-uses.

The adoption of TEA-21 in 1998 began to institutionalize the New Starts funding reports in a more comprehensive way. This federal act requires FTA to:

- Develop a rating for each criterion as well as an overall rating of "highly recommended," "recommended," or "not recommended" and use these evaluations and ratings in approving projects' advancement toward obtaining grant agreements; and
- Issue regulations on the evaluation and rating process.

TEA-21 directs FTA to use these evaluations and ratings to decide which projects to recommend to Congress for funding in a report due each February. These funding recommendations are also reflected in the U.S. Department of Transportation's (USDOT) annual budget proposal. In the annual appropriations act for USDOT, Congress specifies the amounts of funding for individual New Starts Program projects.

Travel model data are a key source of information for evaluating New Starts project proposals. Many calculations are based upon reports on rider demand, congestion, and impacts and benefits to other transit and transportation systems.

Because many travel models have not been adequately sensitive to transit demand, FTA has received many grant applications with potentially inaccurate transit rider forecasts. Consequently, the FTA has developed an evaluation process to closely review inputs, land-uses, and behavioral assumptions in travel models to determine whether New Starts program grant applicants have properly developed forecasts of rider demand.

2.2 Types of Transportation Planning Models

Travel demand models are used in the regional transportation planning process, which involves modeling and forecasting of the influences that various policies, programs and projects may have on travel in a region. The modeling and forecasting process also provides fairly detailed information, such as traffic volumes, transit ridership, and turning movements, to be used by engineers and planners in their designs. Travel demand forecasts typically include estimates of the number of cars on a future freeway or the number of passengers using a transit service. When properly designed and implemented, a regional travel model might also be able to predict the amount of reduction in auto use that could occur in response to central-area parking fee programs.

To decide which actions to implement, decision-makers need to understand how each potential improvement measure could affect the transportation system and the region as a whole. Models are used to estimate the number and types of trips that will be made on transportation system alternatives at future dates. These estimates are the basis for regional transportation planning and are used in major investment analyses, environmental impact analyses, and in setting priorities for infrastructure improvements. An understanding of modeling processes is therefore important to better understand how they are used in decision-making processes.

Several different techniques and models for travel demand forecasting are available depending on the requirements of the analysis. These techniques differ in complexity, cost, level of effort, sophistication and accuracy, but each has its place in travel forecasting. Each modeling technique is explained briefly below.

2.2.1 Sketch Planning Tools

Sketch planning involves the preliminary screening of possible configurations or concepts. It is used to compare a large number of proposed policies in enough analytical detail to support broad policy decisions. Useful in both long-range and short-range planning and in preliminary corridor analyses, sketch planning – that has minimal data costs - yields rough aggregate estimates of capital and operating costs, patronage,

corridor traffic flows, service levels, energy consumption, and air pollution. The planning process usually remains in the sketch-planning mode until comparisons of possibilities are completed or a strategic plan worthy of consideration at a finer level of detail is obtained.

Sketch-planning tools designed for smart-growth sensitivity have been used in California for charrette or workshop-style visioning exercises to assess the potential benefits of various strategies in a city, county, or region. The quick turnaround provided by the sketch planning models allows a group to test many options in a short period of time.

2.2.2 Conventional Models (4-Step Models)

Conventional models deal with many fewer alternatives than sketch planning tools, but in much greater detail. Inputs typically include demographic data, the location of principal roadway facilities, and delineated transit routes. At this level of analysis, the outputs are detailed estimates of number of lanes of a highway, transit fleet size and operating requirements for specific service areas, refined cost and patronage forecasts, and level-of-service measures for specific geographical areas. The cost of examining an alternative at the traditional level could be 10-20 times its cost in sketch planning, although default models - which dispense with many data requirements - can be used for a less expensive "first look." Potentially promising plans can be analyzed in detail, and problems uncovered at this stage may suggest a return to sketch planning to accommodate new constraints.

2.2.3 Activity-Based Models

Activity-based models represent a significant restructuring of modeling of travel demand. Instead of structuring the modeling around the trip as is done in UTMS, activity-based models structure the modeling around the activities that a household wishes to pursue during a day and how travel can occur to satisfy the activity desires. Travel is modeled in "tours" rather than trips and the decision-making unit is the household rather than all the households in a zone. Activity-based modeling is an emerging method that holds promise for improving smart-growth sensitivity because it recognizes that trips made by a household are not independent of each other but are often connected for efficiency or convenience. Many smart-growth strategies are designed to reduce vehicular travel by making it easier for individuals or households to chain trips together. Only two activity-based models have been developed to date in California: by the San Francisco County Transportation Authority and by the Sacramento Area Council of Governments. A brief overview of how these models can address some of the common deficiencies in UTMS models is provided in **Chapter 3**.

2.2.4 Micro-level Traffic Models

Micro-level or post-processing traffic models are applicable when actual implementation of a project grows near. They are the most detailed of all transportation planning tools. At this level of analysis, it is possible to make a detailed evaluation of the congestion levels of passenger and vehicle flows through a particular intersection, transportation terminal, or activity center. Final analysis may draw upon conventional traffic operations analysis using deterministic software programs such as HCS, TRAFFIX, or SYNCHO, or more complex stochastic micro-simulation traffic operations software programs such as CORSIM, SIMTRAFFIC, PARAMICS, or VISSIM.

Micro-level traffic operations analyses usually draw upon traffic volume output from a relevant travel demand model as direct inputs to the traffic operations models. This may take the form of trip tables, link volumes, or intersection turning movement volumes. Near-term planning is most effective when traffic volumes from actual counts can be used for the micro-simulation inputs, but it is sometimes necessary to use the traditional longer-range planning model to forecast future count data.

2.3 The Conventional (UTMS) Transportation Planning Model

The history of demand modeling for passenger travel has been dominated by the modeling approach, which has come to be referred to as the Urban Transportation Modeling System (UTMS). Travel has always been viewed in theory as derived from the demand for activity participation, but in past practice has been modeled with trip-based rather than activity-based methods. Trip origin/destination (OD) surveys, rather than activity surveys, form the principle database. As the sequence of modeling steps in the conventional forecasting process proceeds, there is less attention to the activities that the travel satisfies and more attention to the point-to-point trips that are made. The application of this modeling approach is currently nearly universal.

UTMS might best be viewed in two stages. In the first stage, various characteristics of the traveler and the land-use activity system (and to a varying degree, the transportation system) are "evaluated, calibrated, and validated" to produce a non-equilibrated measure of travel demand (or trip tables). In the second stage, this demand is loaded onto the transportation network in a process that amounts to formal equilibration of route choice only, not of other choice dimensions - such as destination, mode, time-of-day, or whether to travel at all (feedback to prior stages has often been introduced, but not in a consistent and convergent manner). Although this approach has been moderately successful in the aggregate, it has failed to perform in most relevant policy tests, whether on the demand or supply side.

Transportation modeling developed as a component of the process of transportation analysis, which came to be established in the United States during the era of post-war development and economic growth. Initial application of analytical methods began in the

1950s. The initial development of models of trip generation, distribution, and diversion in the early 1950s led to the first comprehensive application of the four-step model system in the Chicago Area Transportation Study. The focus was decidedly highway-oriented with new facilities being evaluated versus traffic engineering improvements.

The 1960s brought federal legislation requiring "continuous, comprehensive, and cooperative" urban transportation planning, fully institutionalizing the UTMS. Further legislation in the 1970s brought environmental concerns to planning and modeling, as well as the need for multimodal planning. It was recognized that the existing model system might not be appropriate for application to these emerging policy concerns. In what might be referred to as the "first travel model improvement program," a call for improved models led to research and the development of disaggregate travel demand forecasting and equilibrium assignment methods that integrated well with the UTMS and have directed modeling approaches for most of the last 25 years. The late 1970s brought "quick response" approaches to travel forecasting and independently the start of what has grown to become the activity-based approach.

A growing recognition of the misfit of UTMS regarding relevant policy questions in the 1980s led to the Federal Travel Model Improvement Program in 1991. As a result, much of the last decade has been directed at improving the state-of-the-practice relative to the conventional model, while also fostering research and development regarding new methodologies to further the state-of-the-art, such as disaggregate simulation of households and activity-based models. (Many of the limitations of UTMS specifically for modeling smart-growth strategies are identified in a review of the conventional UTMS model in **Chapter 3**. The chapter also identifies some innovations in practice that can increase sensitivity of UTMS models to smart-growth strategies and provides examples of applications in California where such innovations have been incorporated.)

2.3.1 Limitations of Travel Demand Models

Travel demand modeling was developed primarily for highway planning. As the need to examine other issues such as transit, land-use planning, and air quality analysis has arisen, the modeling process has been modified to add additional techniques to attempt to deal with these needs. Travel models provide forecasts only for those factors and alternatives that are explicitly included in the equations and data of the models. If the models are not sensitive to certain polices or programs, the models' outputs will not include the effect of these policies or programs. More specifically, these policies and programs cannot be formulated as input variables into the models. For example, travel-forecasting models usually do not include pedestrian and bicycle trips; therefore, plans or programs that include bicycle or pedestrian system improvements cannot be evaluated with the conventional modeling procedure if the models ignore these types of trips. However, it would not be correct to conclude that pedestrian or bicycle improvements are ineffective. The actual impact is unknown. Therefore it is critical that the assumptions used in the modeling process and the model limitations be explicitly stated and considered before decisions are made based on their results.

One concern in modeling of smart-growth strategies by local jurisdictions with available travel models is the time it takes for many of the strategies to have a significant impact within an area. In older parts of urban areas where some of the best opportunities exist for in-fill development and development near transit services, the time required to achieve a significant amount of smart-growth development may be long. In some cases this may be beyond the forecast time frame of the local model and beyond the time frame of the jurisdictions general plan. Even when the smart-growth is occurring in more suburban areas where the developments may be larger, full build-out of the developments may be staged over a long period of time and the effects from the smart-growth of the developments may not be present in the earlier stages of the development.

The amount of new development in higher density urban areas may also be small compared to the existing land-use in an area. As a result, the vehicle trip and VMT rates per capita for the new development may be lower in the high-density area than in a corresponding development in a less dense suburban area, but the impact on an area-wide scale may be virtually un-noticeable when only the area-wide vehicle trip or VMT is used as the measure. Using a travel model to test smart-growth strategies in a development can mask the potential benefits of the strategies unless care is taken to examine the vehicle trip and VMT reduction benefits to, from and within the proposed smart-growth development.

2.4 New Methods of Reflecting Smart-growth

A variety of new methods have been developed in recent years to add sensitivity to the conventional UTMS model, and the methods span a broad spectrum in terms of complexity, resources required for implementation, and resources required for maintenance. There is also significant variation in how the different methods can be used in support of land-use planning for local jurisdictions. These methods can be categorized in four general approaches:

- Post-processor to UTMS for application of smart-growth trip and VMT elasticities
- Stand-alone tools for aggregate application of smart-growth trip and VMT elasticities
- Enhancement of UTMS models
- Integrated land-use/economic/and transportation models

Methods in the first two categories involve the application of vehicle trip and VMT "elasticities" for smart-growth strategies estimated on the basis of cross-sectional comparison of areas with smart-growth characteristics to areas without these characteristics. In both of the first two categories, the elasticities are applied to baseline travel data provided by a travel model. A progression of research efforts have contributed to the development of what are referred to as the "4D Elasticities" because they reflect

the potential reduction in vehicle trips and VMT associated with changes in land-use characteristics that reflect smart-growth strategies.

In the first category – 4D elasticities post-processor to UTMS - methods are designed to directly supplement the UTMS model by factoring trip ends in the model to account for the effects of smart-growth strategies with the capability to produce assignments that reflect the factored trip ends. Methods in the second category – stand-alone tools - apply the elasticities to aggregate measures of travel to estimate what the area-wide effect of smart-growth strategies may be. These methods are designed primarily for interactive planning in a workshop or charrette setting during which alternative land-use strategies can be tested by participants. Two of the specific tools that have been used in California for this purpose are I-PLACE3S and INDEX. The results of a detailed review of the methods in these first two categories are provided in **Chapters 4** and **6**.

The final category - integration of land-use, economic, and travel data and models - provides more direct linkages between these complex systems and how they interactively affect one another. In a fully integrated modeling process, travel demand is a function of existing and future land-uses and economic activities. In turn, future land-uses and economic activities are also functions of the transportation system as well as demand on the system. These interactive analytical processes are replicated through numerous iterations. This interactive analysis system provides smart-growth sensitivity because it recognizes the synergistic effects that such strategies can have over time. For example, the economic and travel response to the implementation of smart-growth strategies can result in greater market demand for smart-growth projects and programs. The state-of-the-practice and advancements in this category are the subject of another Caltrans-funded study, *Assessment of Integrated Land-use/Transportation Models.*[12]

[12] "Assessment of Integrated Transportation/Land Use Models Final Report," Robert Johnston & Michael McCoy, UC Davis, May 31, 2006. http://www.ice.ucdavis.edu/um/ (Final Report)

Chapter 3

Review of the Conventional Transportation Planning Model: Characteristics, Sensitivity to Smart-Growth Strategies, and Areas for Possible Improvement

3.1 General Characteristics

The Urban Transportation Modeling System (UTMS), commonly known as the travel demand model, is the primary tool used for forecasting future demand and performance of a transportation system, typically defined at a regional or sub-regional scale. This chapter provides a review of UTMS, including a description of its features and the process by which travel forecasts are produced. The chapter also provides an assessment of some of the limitations of UTMS, as it is commonly applied, for assessment of smart-growth strategies. A summary of the limitations of UTMS for smart-growth analysis and the improvement options is provided in **Table 3.1** at the end of this chapter.

There are several examples of UTMS applications in California that have addressed one or more of the limitations with an approach that increases the smart-growth sensitivity, and some of these examples are provided. The most sophisticated applications of UTMS are generally those by Metropolitan Planning Organizations (MPOs) for large urban areas, and so many of the examples provided in this report for improvement options come from the large MPOs in the state. Because it is becoming common for local jurisdictions within a major metropolitan area to use a focused version of an MPO model, advanced practices are (or could be) available to the local jurisdictions in the region as well.

For UTMS to be optimally useful, models must be suitably policy-sensitive to allow for the comparison of alternative programs, policies, and projects to influence future travel demand and performance. However, the model system was developed primarily for evaluating large-scale infrastructure projects, and not for more subtle and complex policies involving management and control of existing infrastructure or introduction of programs that directly influence travel behavior.

Application of travel-forecasting models is a continuous process. The period required for data collection, model estimation, and subsequent forecasting exercises may take years, during which time the activity and transportation systems change, as do policies of interest - often requiring new data collection efforts and a new modeling effort.

A study area can be defined to encompass the area of expected policy impact; a cordon line defines this area. The area within the cordon is composed of Traffic Analysis Zones (TAZs) and is subject to explicit modeling and analysis. Interaction with areas outside the cordon is defined via external "stations" which effectively serve as gateways for trips into, out of, and through the study area. The Activity System for these external stations is defined directly in terms of trips that pass through them, and the models that represent this interaction are separate from and less complex than those that represent interactions within the study area (typically, growth factor models are used to forecast future external traffic).

The internal Activity System is typically represented by socio-economic, demographic, and land-use data defined for TAZs or other convenient spatial units. The number of TAZs (usually based on purpose for the model, size of analysis area, data availability, and model vintage) can vary significantly from a few hundred to several thousand. The unit of analysis, however, can vary over stages of the UTMS and might be at the level of individual persons, households, TAZs, or some larger aggregation for different steps. In the majority of models, TAZs are derived from US Census geographical subdivisions. Data releases follow the Decennial Census lagged by a few years for data packaging to develop TAZs in a form known as Census Transportation Planning Package (CTPP).

The Transportation System is typically represented via network graphs defined by links (one-way homogeneous sections of transportation infrastructure or service) and nodes (link endpoints, typically intersections or points representing changes in link attributes). Both links and nodes have associated attributes (for example, length, speed, and capacity for links and turn prohibitions or penalties for nodes). The activity system is interfaced with the Transportation System via centroid connectors which are abstract links connecting TAZ centroids to realistic access points on the physical network (typically mid-block or at points where minor collector streets meet the arterial streets represented in the model, usually not connected to nodes representing roadway intersections). Different networks may be used to represent different modes. If a transit network is included, it will define routes, stops, schedules and fares for service as well as the links that the service can use.

The UTMS provides a mechanism to determine capacity-constrained flows. For elementary networks, direct demand functions can be estimated and, together with standard link performance functions and path enumeration, can provide the desired flows (i.e., traffic volumes on roadway segments represented by links in the modeling network). For any realistic regional application, an alternative model is required due to the complexity of the network. The UTMS was developed to deal with this complexity by formulating the process as a sequential four-step model.

First, in Trip Generation, measures of trip frequency are developed providing the propensity to travel for different reasons or purposes. Trips are represented as trip ends: the production trip end and the attraction trip end are estimated separately but their totals must eventually match.

Second, in Trip Distribution, the trip productions are distributed across the trip attractions whereby each trip production is matched to a trip attraction. The distribution (or linkage) of the productions to attractions is modeled using empirically obtained travel impedance relationships (connecting the likelihood of making a trip to the travel time and/or cost associated with the trip). The result is a set of trip tables (person-trips or vehicle-trips, depending on the model) that satisfy the demand for travel given travel options and costs.

Third, in Mode Choice, logit mode choice models developed and calibrated from household survey data are used to determine trip mode (i.e. drive alone, carpool, transit, bicycle or walk). These calibrated model parameters are assumed to hold constant over time – that is, the same model parameters are used in both the existing conditions models and in the 20 and 30-year horizon models. However, in many of the locally developed travel demand models, the trip tables are essentially factored (using the mode split and auto occupancy factors from a regional model, if one is available) to reflect relative proportions of trips by alternative modes.

Fourth, in Route Choice, modal trip tables are assigned to mode-specific networks (if provided in the model) incrementally or via a multi-iteration equilibrium assignment scheme.

The time dimension (time-of-day) is typically introduced after trip distribution or mode choice where the production-attraction tables are factored to reflect observed distributions of trips in defined periods (such as the AM or PM travel peaks). Performance characteristics of the transportation system are first introduced in route choice and so UTMS in its most basic form only equilibrates route choices. Total "demand" as specified through generation, distribution, mode choice, and time-of-day models, is fixed with only the route decision to be determined. Many applications of UTMS now include feedback of equilibrated link travel times from route choice to the mode choice and/or trip distribution models for a second pass (and occasionally more) through the last three steps, but no formal convergence of the travel times used in the different steps is guaranteed in most applications. Because integrated activity-location procedures (combined land-use and transportation models) are absent in most U.S. applications, the future activity system is forecast independently with no feedback from the UTMS.

The UTMS has significant data demands in addition to those required to define the activity and transportation systems. The primary need is data that defines travel behavior, and this is gathered via a variety of survey efforts. Household travel surveys with travel/activity diaries provide much of the data that is required to calibrate the UTMS. These data and observed traffic studies (counts and speeds) provide much of the data needed for model calibration and validation.

Household travel surveys provide:

- household and person-level socio-economic data (typically including income and the number of household members, workers, and cars);

- activity/travel data (typically including activity type, location, start time, and duration and, if travel was involved, mode, departure time, and arrival time for each activity performed over a 24-hour period); and
- household vehicle-ownership data.

The survey data are used to validate the sample's ability to represent the resident population, to develop and estimate trip generation, trip distribution, and mode choice, and time-of-travel models.

3.2 Representation of the Traveler/Decision Maker and the Unit of Travel

3.2.1 General Approach

UTMS applications generally use aggregate characteristics for populations within a Traffic Analysis Zone (TAZ) rather than the characteristics for actual decision-making units, such as an individual or a household. As a result, the travel choice behavior represented in a UTMS model must be based on correlation between observed aggregate travel patterns and average characteristics for the aggregated population within a zone. While this method has proven to be an efficient method for developing approximate forecasts of travel activity for a large area, it has limited the ability of models to represent the influence of how individual or household characteristics can influence travel choices or how different individuals or households within a zone would be influenced by differences in the nature of the transportation system or land-use within the various parts of the zone.

UTMS is also designed to predict the decisions about travel on the basis of a trip, with each trip independent of any other. This method works fairly well for trips that are simple round trips from one zone to another and back, but does not work well for trips that are part of a tour that includes multiple stops.

3.2.2 Common Limitations and Improvement Options

Aggregation of zonal characteristics

The loss of sensitivity brought on by aggregation of the characteristics of the population within a zone is particularly troublesome when there are non-linear relationships between traveler characteristics and how the traveling populations respond to characteristics of the transportation system. This non-linearity is common in how income affects travelers' responses to changes in travel costs.

Numerous efforts have been made to reduce the biases that are introduced by the aggregation of decision makers into zones. Sample enumeration is one method for "synthesizing" households in a zone based on the aggregate characteristics and then predicting travel behavior for each of these synthesized households. The results are then aggregated after the forecasts are produced. This avoids the bias introduced by non-linearity, and by representing all travelers in a TAZ as a homogenous group (e.g., all having the same value of time, and the same propensity toward walking versus driving). The Metropolitan Transportation Commission of the San Francisco Bay Area (MTC) and the Sacramento Area Council of Governments (SACOG) use stratification of households by household characteristics including income, number of autos owned and number of workers. MTC has also used sample enumeration as a technique for simulation of individual households based on aggregate zonal characteristics. The newly developed SacSim model, which is designed to work with I-PLACE3S, is the first synthetic population generator that reproduces the resident population at a fine parcel level of spatial resolution.

Trip-based methods do not recognize the linkage between trips

Travelers may often combine a variety of purposes into a sequence of trips as they run errands and link together activities. This is called trip chaining and is a complex process. The standard UTMS trip-based modeling process treats such trip combinations in a very limited way. For example, non-home-based trips are calculated based only on employment characteristics of zones and do not consider how members of a household coordinate their errands. Because many of the smart-growth concepts are designed to group activities so that multiple functions (work, daycare, shopping, dry cleaning, workout, etc.) can be satisfied in single tour rather than multiple trips, the deficiency inherent in the trip-based method of the UTMS makes analysis of smart-growth strategies difficult, at best.

Travel models are now being developed that consider the activities that a household typically undertakes during a day and then predict "tours" to achieve the desired activities. These activity- or tour-based models provide greater sensitivity to strategies that encourage trip chaining or satisfying multiple activity goals in a single location. For example, activity-based models have been developed by the San Francisco County Transportation Authority (SFCTA). MTC and the Southern California Association of Governments (SCAG) have recently embarked on the development of activity-based models. One of the most complete and sophisticated tour-based models that incorporates synthetic population generation is the "SacSim" model currently being developed for the Sacramento Area Council of Governments (SACOG). The SacSim model also targets smart-growth and transit policies.

3.3 Representation of Land-uses

3.3.1 General Approach

Before travel demand forecasts are made, it is necessary to develop forecasts of future population and/or households, economic activity, and land-uses. Forecasted transportation demand is directly linked to projected land-uses. Trips are assumed to follow future land-use patterns; if land-use forecasts are changed, travel demand and travel patterns will likewise change. Local land-use plans, however, typically only project to 10 years, while regional transportation plans are required to project out 20 years. As a result, there is often at least a ten-year period for which transportation planning is not linked to local land-use planning. In the absence of local land-use plans for the period, regional agencies develop land-use forecasts based on extrapolation of development and economic trends.

Planning agencies may prepare study area population and/or household forecasts, or they may rely on forecasts prepared by others (such as a state or regional agency). Forecasts of economic activity (commercial development) are done in conjunction with the population forecasts, since the two are highly interrelated. Subsequently, population and economic growth have to be distributed to different locations in order to conduct travel forecasts because it is necessary to know where people will live, work, shop and go to school in the future to estimate future trip-making.

Land-use plans prepared by cities and counties establish quantities, types, amounts, and locations of land for various uses to meet projections of population and employment as part of the General Plan and Specific Plan development processes. These plans are then also reflected in regional travel demand forecasts. Alternative plans can be developed to reflect different goals, land-use policies and assumptions. For example, land-use plans could be developed to continue current trends; to reduce low-density urban development; or to concentrate development along major corridors, in satellite communities, or in undeveloped portions of existing urban areas. Different assumptions could be made regarding the extent to which environmentally sensitive areas and prime agricultural land will be protected.

Once the quantities and types of land are estimated for the future, those uses must be allocated to specific locations for transportation modeling. A regional allocation is important since local communities often overestimate their growth. For example, individual community zoning often allocates far more commercial and industrial land-use than may actually be demanded when examined from a regional marketplace perspective. Regional allocation addresses situations in which communities attempt to limit their growth as the regional allocation can account for the effects of shifting the growth to other locations within the region. Land-use allocation can be done either through a judgment technique or through a modeling process. The judgment technique involves the

allocation of growth in steps to smaller and smaller geographic areas considering past trends, recent development approvals, availability of open land for future potential development, and available local plans and zoning ordinances. It is sometimes done with the use of an “expert panel” that includes local planners, developers, financiers, and real estate brokers. An allocation is made following rules and guidelines established in available land-use plans.

Once the volumes of land-use activities within all areas are allocated (including those not currently addressed by local government plans), transportation modelers will further split the areas based on the boundaries of the Traffic Analysis Zones (TAZs). Then various economic and residential activities will be used to forecast future trips generated. (Recently, models of land-use allocation have been used to forecast future land-use patterns; however, this approach is relatively new and has only been used in limited locations.)

3.3.2 Common Limitations and Improvement Options

No feedback to the transportation plans

Land-use plans and forecasts are usually developed before transportation plans. It is often assumed for the purpose of modeling tractability that no land-use changes will occur as a result of transportation improvements. In reality, improved transportation conditions often trigger a market for additional or different land development. Many smart-growth strategies are designed to provide mutually reinforcing land-use and transportation systems so that (for example) transit-oriented development, higher density, and mixed land-uses would improve accessibility to transit. In response, increased transit use and service would lead to more transit-oriented development. The same is true for pedestrian-oriented design and use of non-motorized modes.

Land-use simulation models can be added to the sequence of models to help determine how a proposed transportation system and related travel patterns will lead to land-use changes, and vice-versa – how land-use changes affect changes in travel. For example, the San Diego Association of Governments (SANDAG) links the economic and demographic allocation model to the travel model in an iterative process. And SACOG has developed land-use simulation models that are being linked to the travel model.

Existing developments are assumed to be unchanging

Land-use plans often deal with new growth on vacant land and assume that current development will be unchanged. However, effects of redevelopment programs, urban infill, and changing land-uses in existing neighborhoods are usually not considered. Many smart-growth strategies use redevelopment opportunities to produce more compact and mixed-use developments with more travel opportunities close-by and accessible by walk, bicycle, and transit modes.

There is a growing movement to using local parcel data in transportation planning models. A direct mapping of parcels to TAZs allows for better monitoring of changes in land-use and for conducting analyses of micro-scale environments (and how they may affect trip-making behavior). Geographic Information Systems (GIS) have made this type of direct connection much easier, and most local jurisdictions are adopting GIS-based parcel databases. For example, the City of West Sacramento has used parcel data directly to update baseline zonal land-uses in their most recent model update.

Mixed-use and pedestrian-oriented developments are not explicitly considered

Land-use patterns that facilitate walking and non-auto travel are generally not considered in the transportation modeling process. Most models do not distinguish developments with good pedestrian facilities, mostly because no variables for pedestrian environment factors are included in the model. The lack of sensitivity to mixed use and good pedestrian orientation results to a large extent from the use of TAZs to represent land-uses. The TAZ is usually the construct of a model developer and may be made up of Census blocks or tracts, but generally does not relate to the land-use data structure of the local agency charged with land-use planning. Model land-use data sets may be constructed with local government parcel data, but there is rarely a direct linkage established to enable the tracking of growth on a parcel-by-parcel basis.

The increased speed and computing power of computer equipment available to local jurisdictions have made it more practical to operate with more zones in the travel model and still have reasonable run times. The linkage of GIS with travel models has also resulted in much greater use of parcel data in the development of zonal data, and has enabled the development of baseline information for more detailed zone systems (e.g., smaller zones). For example, to address the issue of pedestrian-friendliness, SACOG has developed a fine-zone system and uses a pedestrian-friendliness factor in their trip-based model. SACOG also uses GIS-based urban detail variables in their new activity-based model to reflect the characteristics that lead to more intra-zonal travel.

Land-uses are often represented by employment rather than floor area

One typical barrier to the use of the local jurisdiction's parcel data consists of the variables that are used in the travel model to reflect non-residential land-use. Most MPO and CMA models use employment to represent non-residential land-use, but parcel data are based on floor area or acreage.

To maintain the connection to the parcel data as a source of information for modeling, many local travel models use floor area or acreage by land-use type - rather than employment - which potentially breaks a link with the MPO or CMA model. Factors are often developed to allow for converting from one form to the other. For example, the model for Solano and Napa Counties uses customized conversion tables for each community as a pre-processor for trip generation. One of the major drawbacks to using highly disaggregated land-use data is the forecasting of the land-use 20 to 30 years into the future at the parcel (disaggregate) level. Models that produce high-level (i.e.., city, county, or region level) population and employment forecasts are generally considered

reliable. However, long-range (e.g. 20 to 30 year) parcel level land-use forecasts, especially in high growth areas, are considered extremely speculative, at best (unless integrated land-use/transportation models are used in the forecast, which is rare).

Density of activity centers may not be accurately represented in large zones

Use of large TAZs can often misrepresent the density of activity centers or residential areas if the zones also include parks, open space or other undeveloped land. Even though the overall density of the TAZ might not be high, density within an activity center or residential area may be high enough to provide more opportunities for travel needs to be satisfied by intra-zonal trips, or may provide greater opportunities for ridesharing or transit service.

Use of smaller zones can usually increase the sensitivity to density in activity centers, but variables can be included that reflect the density characteristics and avoid reliance on the zonal system to calculate the density. For example, SANDAG uses roughly 4000 zones for some portions of its modeling. MTC uses employment density in its work mode choice model.

3.4 Representation of the Transportation System

3.4.1 General Approach

The travel options available for trip makers are represented in the UTMS model by one or more transportation networks. Roadway networks are a series of links and nodes that define pathways that travelers can traverse in getting from their origin to their destination. However, while there is always a network replicating roadways used for vehicular travel, networks for transit, ferry, or other public transportation services may or may not be replicated in the models. Moreover, walk & bicycle link variables and/or networks are seldom developed, and - even if present - are rarely given the attention necessary to accurately reflect walk and bicycle paths and streets with bicycle lanes and/or adequate sidewalks.

Roadway networks have information about each link that defines the type of roadway (e.g., freeway, arterial, or collector streets) and other relevant roadway characteristics, such as free-flow (or posted) speeds, number of lanes, and capacity. Transit links can be separate from and supplemental to the roadway network (as is typical for modeling light rail and/or commuter rail). Or predefined transit “routes” can be modeled on the roadway network, which is more typical for bus service that operates on and shares the roadway with passenger vehicles.

Freeways and major arterial streets are typically included in regional travel demand modeling networks. Freeway ramps and freeway-to-freeway connections might, or might not, be represented with any level of detail that matches their geometric configurations

and/or capacity limitations. Minor arterials may be included in the modeling depending upon their regional significance. Traditionally, centroid connectors are used to represent one or more local or collector streets that feed traffic onto the arterial street system, and neighborhood collector streets are rarely in the networks. Typically, when city and local agencies build their models from regional MPO models, many disaggregate the zone system, especially in areas or sub-regions of interest, accompanied by additional network detail such as including more of the minor arterial, collector, and neighborhood streets.

UTMS applications that are used for transit planning or for assessing the effects of transit improvements on travel patterns and air quality must have a network to describe the transit service provided under different scenarios. Transit networks consist of a description of the modes (bus, light rail, heavy rail, commuter rail, ferry, etc.), the lines that provide the service, a description of the routing of each line, the stops and transfer points, the service schedule, and the fare structure. These characteristics of the transit services are often referenced to the roadway network, and changes in predicted roadway travel times as a result of congestion will also affect transit travel times on those links. More advanced transit networks also provide information about the modes of access to the transit services (walk, bicycle, bus, kiss-and-ride, park-and ride, etc.).

3.4.2 Common Limitations and Improvement Options

Inadequate representation of transit options (in some but not all models)

In most modeling software packages, transit (bus) stops must be at nodes; multiple stops cannot be replicated on a single network link. So, to accurately model a transit route that has bus stops every two blocks, the links must be terminated every two blocks to provide nodes as necessary to replicate transit stops at this density. Modelers have used short walk links (representing average walk distance to transit stops), and/or modified other transit parameters to emulate multiple stops on long links.

Shuttle buses around college campuses, downtown trolleys, other circulator buses, and infrequent bus routes (e.g., those that serve suburban areas with 60-90 minute headways) might not be modeled at all, as they can be seen as having little impact on regional traffic patterns. Additionally, most regional models, and models developed by county and city agencies, do not explicitly model park-and-ride lots. As such, it is difficult to forecast changes in the drive-to-transit trips associated with park-and-ride lots at new Bus Rapid Transit and/or light rail stations and/or multi-modal centers.

The Santa Clara Valley Transportation Authority (SCVTA) uses a more refined zone system around transit stations to provide better representation of walk times to stations. SCVTA also models park-and-ride options explicitly and uses capacity constraint to reflect limits of availability of park-and-ride at the stations.

Lack of representation of non-motorized options for short trips (most models)

Most travel demand models (regional and local models alike) are insufficiently detailed to adequately represent households' shorter trips or to reliably model walk and/or bicycle trips. Foremost, modeling networks typically do not contain many of the local neighborhood/collector streets, many of which have sidewalks. Bicycle paths are often located on minor streets, along parks, rivers, and other public lands that are not of regional significance from the traditional travel demand standpoint. It is extremely difficult to model infrastructure improvements affecting walk and bicycle trips when these routes and links are not part of the modeling network. SACOG and MTC both perform estimated walk and bicycle times by recognizing which portions of the roadway network are available for walking and bicycling, and which are not. Both also use "pedestrian friendliness" factors to recognize good walking conditions in some TAZs.

Zone system too coarse for the network representation

The zone system in most models is coarse compared to the spacing of bus stops along major bus routes. For example, traffic analysis zones may be on the order of census tracts where two to three hundred acres (or more) might be represented as a single zone, while bus stops might be spaced only a few blocks apart; and walk trips might be only a few hundred yards or less. This relatively large zone system does not lend to reliable replication of relatively short non-motorized modes of travel (e.g. walk and bicycle trips). To address the issues of zone size, SACOG has disaggregated their zone system in recent updates, and in its new activity-based model's mode choice module uses disaggregate simulation of multiple points with each TAZ.

Inaccurate transportation network data

Many networks in older model systems were developed without the benefit of electronic map systems and GIS files. Link lengths in the older networks were often estimated by the modeler by hand or estimated on the basis of the coordinates of nodes. These methods often lead to inaccuracies in the lengths of links. The inaccuracies can be a significant problem in representing shorter trips, which are important components of many smart-growth strategies.

GIS mapping systems are now available to provide much more accurate network lengths. For example, the new Alameda County Congestion Management Agency (ACCMA) model is based on GIS layers, and as a result is better able to simulate short travel distances. The networks could also be further improved by digital elevation models (DEMs) to ensure that topographic effects are considered in distance and speed estimates.

Inaccurate speed and/or capacity assumptions

Other network inaccuracies can also cause problems in network representations. When the free-flow speed or speed limit is not accurate or the capacity of a link is misrepresented, the estimation of congested speeds and travel times will be affected. Inadequate representation of congested roadway speeds can decrease sensitivity to smart-growth strategies that encourage walk, bicycle and transit trips to avoid congested roadway networks.

New global positioning technologies and software make the collection of travel time inventories much easier. For example, the Association of Monterey Bay Area Governments (AMBAG) based their model on GPS sampling of major routes for free-flow speeds.

3.5 Trip Generation

3.5.1 General Approach

The objective of this first stage of the UTMS process is to define the magnitude of total daily travel in the model system, at the household and zonal level, for various trip purposes (activities). This first stage also explicitly translates the UTMS from activity-based to trip-based daily activity, and tabulates each trip at its production end and its attraction end. This effectively prevents network performance measures from influencing the frequency of travel in most applications. Travel demand models with feedback loops to trip distribution and/or mode choice can shorten trips in areas of heavy congestion and/or shift modes due to congestion. These are not the only potential responses to congestion, however, and a more complete feedback system is necessary if the full effect of congestion is to be recognized in the model.

The trip generation stage of UTMS essentially defines total travel in the region. The generated trips are usually determined solely on zonal-based land-use, socio-economic, and/or demographic data (and the trip rate factors), independent of the roadway and transit networks and other model parameters. The remaining steps (distribution, mode-choice, and route assignment) effectively distribute the fixed set of trips to destinations, modes and routes. Separate generation models are estimated for productions and attractions for each trip type.

Virtually all model applications are for discrete spatial systems typically defined by between 100 and 2,000 traffic analysis zones. Typically, at least three different trip purposes are defined, often home-based work trips (HBW), home-based other (or non-work) trips (HBO), and non-home-based trips (NHB). The majority of trips are typically home-based, having “home” as either their origin or their destination. HBO trips are often divided further to estimate different travel patterns for shopping, recreation, school, and university trips. NHB trips have neither trip end at home. These trips could be independent (unlinked) trips such as a lunchtime work-to-shop trip. Or, these trips could be one leg of a linked trip (i.e. part of a home-based trip chain), although these distinctions are usually ignored in the UTMS. Trip ends are modeled as productions or attractions. The home-end of a trip is always the production -- it is the household and its activity demands that gives rise to (or produces) all trips; the non-home end is the attraction (for NHB trips, the origin is the production and the destination is the attraction).

Trips can be modeled at the zonal, household, or person level, with household level models most common for trip productions and zonal level models most common for trip attractions. For household production models, all trips are initially generated at the home location, and NHB trips must be re-allocated to be "produced" in the actual origin zone of the trip. Such production models can reflect a variety of explanatory and policy-sensitive variables (such as car ownership, household income, household size, or number of workers per household). Cross-classification models are more common than regression-based models and provide a reasonably accurate measure of trip frequency at the household level and, once aggregated, at the zonal level (person-level models are similar in structure).

The independent modeling of trip ends has limited the ability to integrate measures of accessibility into generation models. Few, if any, models have achieved significant inclusion of accessibility variables despite the intuitive appeal that such variables should affect trip frequency. This eliminates potential feedback from route choice models.

Trip attraction models serve primarily to scale the subsequent destination choice (trip distribution) problem. Essentially, these models provide a measure of relative attractiveness for various trip purposes as a function of socio-economic and demographic (and sometimes land-use) variables. The estimation is more problematic, first because regional travel surveys sample at the household level (thus providing for more accurate production models) and not for non-residential land-uses, and second because the explanatory power of attraction variables is usually not as good. For these reasons, factoring of survey data is required prior to relating sample trips to population-level attraction variables, typically via regression analysis. Subsequent attraction levels, while typically normalized to production levels for each trip purpose, should nonetheless be carefully examined if the totals vary significantly from the totals for productions. Special generators are sometimes introduced to independently model trips at locations that are not well represented in the standard models (such as major recreational destinations or airports).

The above discussion refers to internal trips (resident trips with both ends in the study area). Non-residential trips within the study area and external trips (including both through trips and trips with one end outside of the study area) are modeled separately (but must not double-count resident trips already reflected in the regional travel survey). External-internal trips typically are modeled with the production at the external station and attractions scaled to total internal attraction. Growth factors, often reflecting traffic counts at the external stations, are used to factor current external totals for forecasting purposes. External and external-internal trips, typically vehicle trips, are integrated in the vehicle trip tables prior to route assignment. As a final adjustment, the sums from the production model and the attraction model must equal the same number of trips. To achieve this, one or the other type of trip end may be factored slightly to achieve this equalization.

3.5.2 Common Limitations and Improvement Options

Limited trip purposes
With no more than four to eight trip purposes, a simplified trip pattern results. All shopping trips are treated the same whether shopping is done for groceries or lumber, although some local models contain highway, commercial, or regional shopping as separate purposes in recognition of the different trip generation and trip distribution characteristics of these land-uses. Home based "other" trip purposes cover a wide variety of purposes - medical, visit friends, banking, etc. which are influenced by a wider variety of factors than those used in the modeling process.

Additional trip purposes (market segments) may provide a way to get a better representation of complex household trip patterns and trip chaining. This would also provide trip generation procedures that are sensitive to more factors that would follow from travel management techniques. For example, the Greater Eureka Model was expanded from three to six internal trip purposes in a recent update. SCAG and the Orange County Transportation Agency (OCTA) each use 13 trip purposes.

Limited variables
Trip making is found in travel models as a function of only a few variables, typically: auto ownership, household size, and employment. Other potentially influential factors, such as the quality of transit service, ease of walking or bicycling, fuel prices, congestion levels, land-use design, and so forth are not typically included. To address this problem, SACOG's new trip-based model also uses accessibility measures in trip generation that capture the number and proximity of potential destinations for trips from a particular zone and the level of service on the network connecting the zone with those destinations.

Independent decisions
Travel behavior is a complex process in which decisions of household members are often dependent on others in the household. For example, childcare needs may affect how and when people travel to work and whether or not there is an interim stop or some out-of-direction travel involved. This interdependency for trip making is not considered in traditional UTMS travel models.

Lack of representation of non-motorized travel
Most local travel models estimate only vehicle trips and are not sensitive to strategies that reduce vehicle travel by substituting transit, ridesharing, bicycling or walking. More sophisticated modeling addresses this issue by initiating the model with estimation of person trips and then including steps for predicting mode (including non-motorized modes) and vehicle occupancy. For example, the Fresno Council of Governments, SACOG, SCAG, OCTA, MTC, Silicon Valley Transportation Agency (VTA), and the San Diego Association of Governments (SANDAG) all begin with person-trips and include non-motorized modes.

3.6 Trip Distribution

3.6.1 General Approach

The objective of the second stage of the process is to recombine trip ends from trip generation into trips. The trip distribution model is essentially a destination choice model and generates a trip matrix or trip table for each trip purpose as a function of activity system attributes and network attributes (typically, inter-zonal travel times). For internal trips, the most common model is the so-called gravity model that distributes the trips produced in one zone to all the zones in the model based on the size of the attraction in each zone and some measure of distance to the zone. Discrete choice models also have occasionally been utilized for destination choice. Growth factor models are used primarily to update existing matrices for external trips but are not used for internal trips since measures of level of service are not incorporated.

While various intuitively and empirically-supported functional forms have been used to calibrate trip distribution models, for many years the most common estimation technique involved the iterative fitting of "friction factors" that reflect the observed travel frequency distributions from the household travel survey. Free flow automobile travel times are most often used for the initial (and sometimes only) pass through UTMS to represent the “impedance” of the travel time between zones. Ideally, these impedance values would reflect generalized costs appropriately weighted over all modes in subsequent steps. Only inter-zonal impedances are directly computed. Intra-zonal impedance is estimated via a weighted average of inter-zonal impedance to one or more neighboring zones. The skim matrix is usually updated to reflect terminal time for access and egress at either end of the trip.

The calibration process is driven by the underlying trip length frequency distribution. In the basic process, either this distribution or its mean is used to judge calibration. The relative distribution of trip interchanges (matrix cells) is not directly considered. Individual cells can be adjusted via estimation of K factors, but opinions vary as to the use of what are essentially “fudge factors.” On one hand, it is difficult to relate any policy variables to these factors; thus, it is difficult to assess their validity in the future. On the other hand, the resultant base trip matrix will more closely reflect observed behavior.

The trip matrices are at this stage defined as production-to-attraction flows. Depending on the treatment of mode choice, these matrices may be converted from Production-Attraction (P-A) format to Origin-Destination (O-D) format (which is required in the route choice step). Conversions may also be made at this stage to reflect time-of-day, particularly if the subsequent mode choice models are period dependent. P-A to O-D conversion typically reflects the observed travel data. When surveys are analyzed to develop base distributions of observed trips by purpose, the proportion of trips from the production zone to the attraction zone is also computed.

3.6.2 Common Limitations and Improvement Options

Use of automobile travel times only to represent 'distance'
The gravity model requires a measurement of the distance between zones. This is almost always based on automobile travel times rather than transit travel times and leads to a wider distribution of trips (they are spread out over a wider radius of places) than if transit times were used. This process limits the ability to represent travel patterns of households that locate on a transit route and travel to points along that route. This may be particularly important if a rail transit system is being analyzed.

If trip distribution models used a generalized measure of distance that includes costs of travel by different means, as well as parking costs, then they would better show the sensitivity of travel patterns to cost changes. Some agencies incorporate mode choice "logsums" into trip distribution that reflects a weighted average of the generalized costs (all time and cost components) of all available modes, where the weight is the probability of the mode being used. SCAG and OCTA use such a multimodal composite impedance measure that captures time and cost. And MTC has developed special starting matrices for distribution based on multi-modal peak-period speeds.

Limited effect of socio-economic-cultural factors
The gravity model distributes trips only on the basis of size of the trip ends (trip productions, trip attractions) and travel times between the trip ends. Thus the model would predict a large number of trips between a high-income residential area and a nearby low-income employment area, or between neighborhoods consisting of different ethnic residents. However, in reality, the actual distribution of trips is affected by the nature of the people and activities that are involved and their socio-economic and cultural characteristics, as well as the size and distance factors used in the model. Factors that are typically not considered include: differences in income, crime conditions, and attractiveness of the route. Furthermore, groups of travelers might avoid some areas of a city and favor others based on socio-economic-cultural reasons. Adjustments are sometimes made in a model to account for such factors, but this is difficult since the effects of such factors on travel are difficult to quantify, much less to predict over time.

The most common method for addressing this issue is to stratify the population in each zone by one or more of the household characteristics that are believed to influence trip distribution. For example, MTC uses four income quartiles in modeling of work trip distribution.

Feedback problems
Travel times are needed to calculate trip distribution; however, travel times depend upon the level of congestion on streets in the network. The level of congestion is not known during the trip distribution step since that is found in a later calculation. Normally, travel times are assumed and then checked later. If the assumed values differ from the actual values, the model should be iterated a number of times to get the inputs and outputs of the model to balance.

Feedback of congested travel times from assignment to earlier parts of the model system has become common practice for the larger MPOs in California because the practice was required by the Federal Clean Air Act of 1990 as part of the air quality conformity process in serious non-attainment areas. The procedure is designed to equilibrate speeds and travel times within the model process. Feedback from assignment to trip distribution and mode choice is used by MTC, SCVTA, SCAG, OCTA, SANDAG, and SACOG.

Abstract representation of local travel conditions
Regional model networks do not describe the detail of the local circulation and land-use pattern. By generalizing local conditions, they are unable to represent street connectivity, local travel speeds, and routes and amenities available to pedestrians and cyclists. Smart-growth planning places an emphasis on local mixing of compatible land-uses and creating walkable connections. Smart-growth plans also emphasize interconnected street systems, such as grid patterns and dense networks with small block sizes to encourage walking and biking and to reduce the travel distance and vehicle miles generated by auto trips. Even in local city models, the relatively large TAZ sizes and use of zone centroid connectors as abstract representations are unable to capture the actual degree of intra-zonal connectivity and the connectivity among neighboring zones. As a result, trip distribution is generally insensitive to the distinction between smart-growth neighborhood design and the design of conventional suburban neighborhoods with disconnected local networks and homogenous land-uses. Consequently, UTMS models are insensitive to the ability of smart-growth neighborhoods to distribute trips locally rather than to more distant destinations, to attract local trips into non-motorized modes, and to reduce the vehicle miles traveled per auto trip. This abstract and coarse representation of local land-use and travel conditions reduces the models' ability to capture the benefits of smart-growth development patterns to trip distribution and mode choice.

3.7 Mode Choice

3.7.1 General Approach

Mode choice is one of the most critical parts of the travel demand modeling process. It is the step in which trips between a given origin and destination are split into trips using walk, bicycle, transit, trips by carpool or as automobile passengers, and trips by automobile drivers. Automobile trips are converted from person trips to vehicle trips using an auto-occupancy model. Mode-split and auto-occupancy analysis can be two separate steps or can be combined into a single step, depending on how a forecasting process is set up.

Mode choice effectively factors the trip tables from trip distribution to produce mode-specific trip tables. These models are now almost exclusively disaggregate models that are often estimated on separate choice-based samples and reflect the choice probabilities of individual trip-makers. While in U.S. applications transit is a less important factor,

many recent mode choice models reflect current policies such as carpooling choices resulting from high occupancy vehicle facilities and the presence of tolls on automobiles. The most common mode choice model is the nested logit model. These mode choice models can reflect a range of performance variables and trip-maker characteristics, but produce disaggregate results which must then be aggregated to the zonal level prior to route choice.

Due to resource limitations, in lieu of a formal mode choice model, local transportation agencies often use a simplified factoring of the person trip tables to allow for the development of vehicle trip tables. Essentially, average vehicle occupancies reflecting total person trips versus total vehicle trips are used to produce the trip table of automobile trips while ignoring trips by other modes. This, of course would only be valid if the proportion of trips by other modes was very small, but it does allow for the illustration of how vehicle trip tables are then assigned to the highway network; transit trips, if computed, would be assigned to the corresponding transit network. Some software allows for the simultaneous equilibration of true multimodal networks and these methods should be utilized when significant choices exist.

3.7.2 Common Limitations and Improvement Options

Mode choice is only affected by time and cost characteristics
An important concept to understand about mode choice analysis is that shifts in mode usage would only be predicted to occur if there are changes in variable reflected in the model, most often characteristics of the modes (i.e., there must be a change in the in-vehicle time, out-of-vehicle time, or cost of the automobile or transit for the model to predict changes in demand). Thus, if one substitutes a light rail transit system for a bus system without changes in travel times or costs as compared to the bus system, the travel model would not show any difference in transit demand.

People are assumed to make travel choices based only on the factors in the model. Factors not in the model will have no effect on results predicted by the models. Factors that are not included in a model, such as smart-growth strategies and transit-oriented developments, therefore have no effect. They are assumed to be included as a result of the calibration process. However, if an alternative has different characteristics for some of the omitted factors, no change will be predicted by the model. Such effects need to be factored in by hand and require considerable skill and assumptions.

An example of a strategy to address this issue is that SACOG, MTC, and SCVTA use pedestrian friendliness factors in their trip-based models.

Access times are simplified
No consideration is given to the ease of walking in a community or the characteristics of transit stops and waiting facilities in a travel model's choice process. Strategies to

improve local access to transit or the quality of a place to wait for a transit vehicle do not have any effect on common travel models.

Improved methods are available to measure the impedance or "cost" associated with the access portion of transit and highway trips. Such methods involve the calculation of an index that is sensitive to the ease of access and waiting for transit vehicles in areas characterized by transit/pedestrian/bicycle-friendly design. Such indices have been used for mode choice by MTC and SACOG. SANDAG uses special walk-access adjustments based on topography and street pattern.

Disaggregate simulation of points within a zone or a similar randomizing process can also improve the representation of access times. SACOG's new activity-based model's mode choice process uses disaggregate simulation of multiple points with each TAZ.

Weights for time and cost remain constant
The importance of time, cost, and convenience is assumed to remain constant for a given trip purpose. Trip purpose categories are very broad (i.e. "shop", "other"). Differences in the importance of time and cost within these categories are ignored. To recognize the differences in value of time and sensitivity to cost for trip-makers for particular purposes, MTC uses four income groups to stratify the households in each zone.

Limited representation of pedestrian and transit friendliness
Improved representation of bicycle and pedestrian travel can be achieved by incorporation of factors in trip generation models that relate trip making to pedestrian or bicycle amenities or land-use characteristics that are supportive of bicycling and walking. Also, methods of mode choice could be expanded to include these types of trips. For example, models developed for SACOG include a Pedestrian Environment Factor (PEF), which can reflect the effects of the existence of pedestrian facilities on auto travel demand reduction. The factor is based on four separate indices that rate the availability of sidewalks, street continuity, topography, and the ease of crossing streets. Fresno COG, SACOG, SCAG, OCTA, MTC, and SCVTA all include walk and bicycle in mode choice.

Auto occupancy is a fixed factor by purpose
Current auto occupancy procedures tend to be insensitive to a wide range of policies that may lead to more or less carpooling. Auto occupancy procedures need to be sensitive to the cost of parking and costs of travel, as well as the number of trips that occur between an origin and destination.

Better estimation of auto occupancy can be achieved by mode choice procedures that recognize household characteristics as well as differences in the cost of travel and parking in the choice between "drive alone," "drive with passenger," or "carpool" - which dictates auto occupancy rates.

For example, MTC stratifies the zonal households by income, number of autos owned, and number of workers in the work mode choice model, and determines each HOV type (2, 3+) in mode choice for all trip purposes.

3.8 Route Choice and Assignment

3.8.1 General Approach

Once trips have been split into roadway and transit trips, the specific path that they use to travel from their origin to their destination must be found. These trips are then assigned to that path in the step called "traffic assignment." Although some local jurisdictions do only daily traffic assignments, such assignments are often done for peak-hours travel. When peak-hours assignments are performed, a ratio of peak-hours travel to daily travel is needed to convert daily trips to peak-hour travel (for example it may be assumed that ten percent of travel occurs in peak-hours). Numbers used for this step are very important in that a small change in the values assumed will make a considerable difference in the level of congestion forecast on a network. Normally the modeling process does not deal with how traffic congestion dissipates over time.

In this last of four major steps of the UTMS, an equilibration of demand and performance is given consideration. Modal O-D trip matrices are loaded on the modal networks, usually under the assumption of "user equilibrium" where all paths utilized for a given O-D pair have equal impedances (for off-peak assignments, stochastic assignment has been used, which tends to assign trips across more paths thus better reflecting observed traffic volumes in un-congested periods).

The basic user equilibrium solution is obtained by the "Frank-Wolfe algorithm," which involves the computation of "minimum paths" and "all-or-nothing" assignments to these paths. Subsequent all-or-nothing assignments (essentially linear approximations) are weighted to determine link volumes and thus link travel times for the next iteration. The estimated trip tables are fixed, that is, they do not vary due to changing network performance.

3.8.2 Common Limitations and Improvement Options

Intersection delay is ignored

Most traffic assignment procedures assume that delay occurs on the links rather than at intersections. This is a good assumption for through highways and freeways, but not for major roadways with extensive signalized intersections. Intersections involve highly complex movements and signal systems. They are very simplified in traffic assignment, and the assignment process does not modify control systems in reaching equilibrium. Use of sophisticated traffic signal systems, freeway ramp meters, and enhanced network control of traffic cannot be easily analyzed with conventional traffic assignment procedures.

Some limited efforts have been made to incorporate intersection delay into travel time estimates by route. Some of the software vendors have introduced algorithms into their packages to calculate intersection delay, but they required detailed data on signal timing

and may introduce route time bias if the intersection delay is not included for all intersections. SANDAG uses a simplified method that incorporates the Volume/Capacity ratio of intersections into the delay estimation and also a delay per traffic signal.

Capacities are simplified
To determine the capacity of roadways and transit systems requires a complex process of calculations that considers many factors. In most travel forecasts this is greatly simplified. Capacity is estimated based only on the number of lanes of a roadway and its facility type (freeway or arterial). Most travel demand models used for large transportation planning studies do not consider other factors, such as truck movement, highway geometry, and other important factors affecting capacity in their calculations.

The software packages that are used to apply UTMS models will allow use of more complex procedures to estimate link capacity, but the data needed to improve the capacity estimate are normally not included in the model database. The Association of Monterey Bay Area Governments (AMBAG) has implemented more complex capacity calculations based on ***Highway Capacity Manual*** (HCM) adjustments.

Route choice does not reflect cost
Route choice and assignment in most local models is a function of congested travel times but usually does not reflect costs. As the interest in toll facilities and the use of pricing to manage demand has increased, the importance of including cost in route choice has also increased.

Transit route choice limited to "best" route
For most transit assignments, transit route choice is limited to a "best" route and ignores "good" alternate routes and their timesaving opportunity. This can result in uneven representation of transit utilization and loadings. Most of the software packages available for application of UTMS have good "multi-path" or "optimal-strategy" transit path and assignment algorithms, but they are seldom used.

Travel only occurs on the network
It is assumed that all trips begin and end at a single point in a zone (the centroids) and occur only on the links that are included in the network. However, not all roads and streets are included in networks, nor are all possible trip beginning and end points included. Therefore, the zone/network system is a simplification of reality and necessarily excludes some travel - especially shorter (intra-zonal) trips. To estimate total travel (e.g., for air pollution analyses), a certain percentage of off-network travel must be added to assignment results.

Any modification of a travel model from forecasting only trips by motorized modes to one that also includes non-motorized modes would need to consider whether the intra-zonal trip method that was previously used would require modification to reflect motorized and non-motorized trips.

As the interest in smart-growth strategies increases, more attention is also being given to representation of short trips that show up only as intra-zonal travel in a travel model. In some cases, this has been addressed by more explicit representation of "off-network" travel, including intra-zonal travel, with variables for street continuity and connectedness, using GIS when possible. For example, SACOG uses pedestrian and bicycle friendliness factors to improve the representation of the environment for non-motorized travel when forecasting these types of trips.

3.9 Time of Travel

3.9.1 General Approach

The time of travel can be reflected in UTMS models in a variety of ways. Time of travel can be reflected in trip generation, with productions and attractions being generated for specific time periods. This is often the case when compiled land-use trip rates are used, since these rates are typically defined by time-of-day. Time-of-day adjustments, however, are more common after the trip generation and distribution steps are performed.

The most common practice is to use household travel survey data to develop factors for the percentage of travel for each trip purpose in different time periods. The factors indicate what percent of the daily trip for a trip purpose are from the production zone during each time period and what percentage are from the attraction zone to the production zone during each time period. When there is considerable variability in the time of travel by purpose within a region, the percentages that are applied can vary by the location of the production zone, the location of the attraction zone - or both. More sophisticated approaches are also sometimes used that adjust the percentage of travel that occurs in a peak-hour or peak-period based on the estimated level of congestion on a link or in a corridor.

3.9.2 Common Limitations and Improvement Options

Lack of sensitivity to time-of-day variations
Traffic varies considerably throughout the day and during the week. The travel demand forecasts are made on a daily basis for a typical weekday and then converted to peak-hour conditions. Daily trips are often multiplied by an "hour adjustment factor" (for example 10%) to convert them to peak-hour trips. Many model systems use different factors for each trip purpose developed from household travel surveys.

Most UTMS models in California have some level of representation of the time of travel, but it is seldom a function of travel conditions by time-of-day or the travel needs of the trip-makers. Most travel-time modules apply fixed percentage factors to daily travel by trip purpose for each time period specified. In comparison, the activity-based models that

are now being developed have more direct acknowledgment of the activities that are being satisfied by travel and when they occur. This allows a better connection estimation of the time of travel and one that is more sensitive to the transportation system level of service. Activity-based models have been developed by the San Francisco County Transportation Agency and SACOG.

Lack of sensitivity to land-use and travel options
A limitation of the available methods for estimating the time of travel for the assessment of smart-growth strategies is that the time of travel is rarely - if ever - based on the nature of the land-use in the production or attraction zone. Nor do the available methods base time of travel on the transportation services available.

Time-of-day choice models have been developed that predict the time period of a trip based on the transportation system level of service and cost in different time periods and the number of retail opportunities near workplace zones. MTC, SCVTA, and the new SACOG activity-based model include time-of-day choice models that are a function of zonal and travel level of service characteristics.

Emphasis on peak-hour travel
As described above, forecasts by local jurisdictions are often done for A.M. and/or P.M. peak-hours on a typical weekday, but a forecast for the peak-hours of the day does not provide any information on what is happening during the remaining hours of the day. Therefore, the duration of congestion beyond peak-hours (e.g., “peak spreading”) is not determined. In addition, travel forecasts are made for an “average weekday.” Variations in travel by time of year or day of the week are usually not considered. Sensitivity to travel by time-of-day is most often addressed in MPO models by assigning travel to at least four periods that in total represent 24 hours. Almost all of the MPO models reviewed and many of the local jurisdiction models follow this practice.

3.10 Conclusions

The review of the conventional UTMS modeling practice indicates that there is a range of smart-growth sensitivity in UTMS modeling and many options to improve the sensitivity. **Figure 3.1** provides a graphic representation of the most significant steps that can be taken to improve a UTMS model from a “low-sensitivity” model to “moderate-sensitivity” or “high-sensitivity” model. The graphic is not intended to be an accurate representation of the amount of sensitivity that is gained by each step, but is instead designed to show reasonable progress of steps to improve the sensitivity of a model system. While the most basic level of UTMS modeling has almost no sensitivity to smart-growth strategies, models with all of the improvements listed in the figure can achieve significant sensitivity.

Figure 3.1 Logical Progression of Steps to Improve UTMS Sensitivity to Smart-Growth Strategies

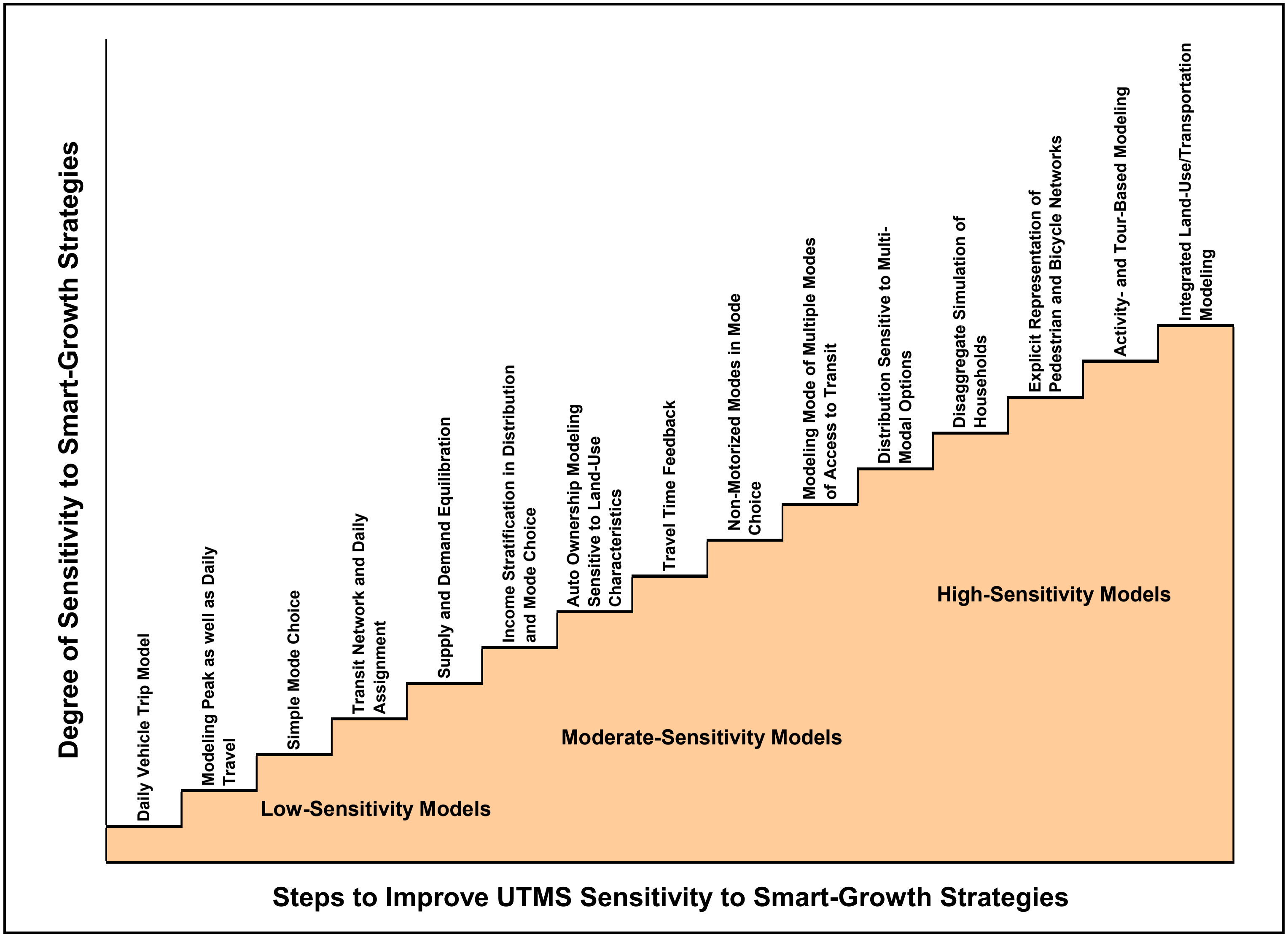


Table 3.1 UTMS Limitations and Areas for Improvement

Limitations of UTMS	Improvement Options	Example Applications
Aggregation of zonal characteristics leads to bias in representation of trip-maker characteristics.	Use sample enumeration, disaggregate simulation of households, or cross-classified market segments.	MTC has used sample enumeration for analysis of pricing options. SACOG, SCAG, OCTA and MTC have used multiple-cross-classification of households by income and other household characteristics.
Trip-based methods do not recognize linkage between trips.	Use tour-based and activity-based modeling.	San Francisco Transportation Authority and SACOG have developed activity-based models that simulate individual households and predict tours to accomplish household activities.
3.3 Representation of Land-Uses		
No feedback to transportation plans - land-use is not sensitive to the transportation system and level of service.	Attach a land-use simulation model; run model with iterative "feedback loop" to equilibrium.	SANDAG links the economic and demographic allocation model to the travel model. SACOG has developed land-use simulation models that are being linked to the travel model.
Existing developments are assumed to be unchanging.	Periodically update the baseline land-use with new inventory information from parcel or other data.	West Sacramento has used parcel data directly to update baseline zonal land-uses.

Table 3.1 UTMS Limitations and Areas for Improvement

Limitations of UTMS	Improvement Options	Example Applications
Mixed-use and pedestrian-oriented developments are not explicitly recognized.	Use mixed-use variable and pedestrian friendliness factors to characterize land-uses with complimentary mixed uses and strong pedestrian orientation.	SACOG uses a pedestrian-friendliness factor in their trip-based model, and GIS-based urban detail variables in their activity-based model.
Land-uses are often represented by employment rather than floor area like the parcel data.	Use variables that are floor area or acreage based like the parcel data with conversion factors that allow comparison to MPO model variables.	Solano/Napa model utilizes customized conversion tables for each community as a pre-processor for trip generation.
Density of activity centers may not be accurately represented in large zones.	Either use smaller zones or include density of activity centers as a land-use variable (e.g. floor area ratios, FARs).	SANDAG uses roughly 4000 zones for some portions of its modeling. MTC uses employment density in its work mode-choice model.
3.4 Representation of the Transportation System		
Inadequate representation of transit options.	Improved representation of mode of access to transit. More detailed representation of transit network and/or bus stop density, transit quality factors.	SCVTA uses more refined zone system around transit stations and uses park-and-ride capacity constraint.
Lack of representation of non-motorized modes.	Explicit representation of walk and bicycle networks including quality of walk/bicycle path indicators not simply travel-time estimates.	SACOG and MTC both perform estimation of walk and bicycle times by recognizing which portions of the roadway network that are available for walking and bicycling.

Table 3.1 UTMS Limitations and Areas for Improvement

Limitations of UTMS	Improvement Options	Example Applications
Zonal aggregation of walk distances to the centroid point.	Disaggregate simulation of multiple points within each zone. More disaggregate zone system.	SACOG activity-based model's mode choice uses disaggregate simulation of multiple points within each TAZ.
Inaccurate transportation data misrepresents effects of congestion.	Use of GIS street layers and DEMs for network development.	New Alameda Countywide model based on GIS layers better able to simulate short travel distances.
Inaccurate speed and/or capacity assumptions misrepresent travel time by auto.	Use of GPS technology to verify roadway travel speeds and related capacity variations.	AMBAG model based on GPS sampling of major routes for free-flow speeds.
3.5 Trip Generation		
Limited trip purposes - do not allow adequate differentiation of the trips that are most likely to use modes other than driving alone or that can chain trips.	Use more trip purposes - to differentiate the types of trips that might be most likely to choose options other than drive alone.	Greater Eureka Model expanded from three to six internal trip purposes. SCAG and OCTA use 13 trip purposes.
Limited variables - omit factors such as quality of transit service, ease of walking or bicycling, and land-use design.	Develop person-trip based trip generation that is a function of travel options, level of service and smart-growth features.	SACOG's trip-based model uses accessibility measures in trip generation.
Independent decisions - trips are not related for an individual and across different members of a household.	Activity-based or tour-based models that represent the travel of a household as a series of related tours to achieve desired activities.	San Francisco Transportation Authority and SACOG have implemented activity-based models that represent the travel of a household as a series of related tours to achieve desired activities.

Table 3.1 UTMS Limitations and Areas for Improvement

Limitations of UTMS	Improvement Options	Example Applications
(Most local models). Estimate only vehicle trips are not sensitive to strategies that reduce vehicle travel by substituting transit, ridesharing, bicycling or walking.	Beginning the model with estimation of person trips and then including steps for predicting mode (including non-motorized modes) and vehicle occupancy.	Fresno COG, SACOG, SCAG, OCTA, MTC, VTA and SANDAG all begin with person trips and include non-motorized modes.
3.6 Trip Distribution		
Use of automobile travel times only to represent "distance".	Incorporate mode choice "logsums" into trip distribution; include parking and other costs in auto modes.	SCAG and OCTA use a multimodal composite impedance that captures time and cost. MTC developed special starting matrices for distribution based on multi-modal peak-period speeds.
Limited effect of socio-economic and cultural factors.	Incorporate income and other socioeconomic or cultural characteristics in trip distribution.	MTC uses four income quartiles in work trips.
Feedback problems - trip distribution often does not use the same speeds and travel times as the final assignment produce.	Apply model in a correctly designed iteration system to converge toward fully consistent equilibrium. Some "feedback" schemes fail to converge.	Feedback from assignment to trip distribution and mode choice is used by MTC, SCVTA, SCAG, OCTA, SANDAG, and SACOG.
Abstract representation of local travel conditions – use of abstract centroid connectors to represent local street and sidewalk network.	Smaller zones, more detail in the transportation network, coding of the sidewalk and bicycle path networks, calibrating distribution to reflect non-motorized trips.	SACOG and MTC both perform estimation of walk and bicycle times by recognizing which portions of the roadway network that are available for walking and bicycling.

Table 3.1 UTMS Limitations and Areas for Improvement

Limitations of UTMS	Improvement Options	Example Applications
3.7 Mode Choice		
Mode choice is only affected by time and cost characteristics.	Include household demographics, transit and pedestrian friendly quantifiers, and land-use variables replicating effects of Smart-growth.	SACOG trip- and activity-based models use pedestrian friendliness factors as do the MTC and SCVTA trip-based models.
Access times are simplified.	Disaggregate simulation of points within zone, or similar randomizing process. Better replication of walk paths, including quality of path and safety indicators. More disaggregate zone system.	SACOG activity-based model's mode choice uses disaggregate simulation of multiple points with each TAZ. SACOG, MTC, and SCVTA use pedestrian friendliness factors. SANDAG uses special walk-access adjustments based on topography and street pattern.
Weights for time and cost remain constant.	Disaggregate simulation with randomly generated values-of-time. Cross-classifications of weights representing different groups of the population (e.g. low-income, medium-income, high-income).	MTC uses four income groups for work trips.
Non-motorized modes are generally not explicitly modeled.	Include bicycle and pedestrian travel modes.	Fresno COG, SACOG, SCAG, OCTA, MTC, VTA all include non-motorized modes in mode choice.
The characteristics of the roadway system, sidewalks and trails that make access by walk, bicycle and transit easiest	Improved representation of access (particularly the pedestrian and bicycle friendliness); include bicycle and	SACOG has special indicator for bicycle-friendly Davis.

Table 3.1 UTMS Limitations and Areas for Improvement

Limitations of UTMS	Improvement Options	Example Applications
are generally not represented in local models.	pedestrian-only links.	
Auto occupancy is generally a set value by trip purpose in most local models and does not reflect the costs of travel and parking.	Better auto occupancy models that recognize the cost of travel, parking, and household demographics in the drive alone, drive with passenger, or carpool mode choice, which dictates auto occupancy rates.	MTC determines each HOV type in mode choice for all trip purposes.
3.8 Route Choice and Assignment		
Intersection delay is ignored.	Incorporate intersection delay into travel time estimates by route.	SANDAG incorporating the V/C ratio of intersections into the delay estimation and also a delay per traffic signal.
Capacities are simplified.	Incorporate more variables in the evaluation of V/C ratios and the resulting congested speeds.	AMBAG has implemented complex capacity calculations based on HCM adjustments.
Route choice and assignment in most local models is a function of congested travel times but usually does not reflect costs.	Incorporate travel costs in route assignment.	
Transit route choice limited to a "best" route ignores "good" alternate routes and their timesaving opportunity.	Use a good "multipath" or "optimal-strategy" transit path and assignment algorithm.	

Table 3.1 UTMS Limitations and Areas for Improvement

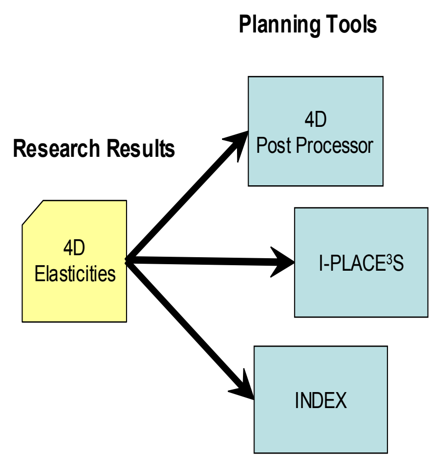
Limitations of UTMS	Improvement Options	Example Applications
Off-network travel simplified.	Represent off-network, including intra-zonal travel, with variables for street continuity and connectedness, from GIS if possible.	SACOG uses pedestrian and bicycle friendliness factors.
3.9 Time-of-Travel		
Lack of sensitivity to land-use and travel options.	Use activity or tour-based models.	SACOG and SFCTA have implemented activity-based models that represent the travel of a household as a series of related tours that reflect activity and travel options.
Lack of sensitivity to time-of-day variation.	Use time-of-day choice models.	MTC, SCVTA and the new SACOG activity-based model include time-of-day choice models that are a function of zonal and travel level-of-service characteristics.
Emphasis on peak-hour travel.	Assign at least four periods that in total represent 24 hours.	Most MPO models and many local models forecast trips for four periods.

Chapter 4

Overview of "4 D Elasticities" Methods for Analyzing Smart -Growth Strategies

4.1 Introduction

Results from the early stages of this study[13] suggested that efforts were needed to investigate the potential of applying a new generation of planning tools to estimate the impacts of smart-growth strategies on travel demand. These three tools are all based on what are commonly referred to as the "4D elasticities." Two of the tools are stand-alone software packages that often use input from a local travel model: I-PLACE3S and INDEX. A third tool is commonly referred to as a "4D post-processor" that uses a spreadsheet to link the 4D elasticities methodology directly with a local planning model or to apply the elasticities to other estimates of travel.



Both I-PLACE3S and INDEX were designed to address a wide spectrum of impacts and benefits resulting from various growth and alternative scenarios, and transportation impacts are only a part of what they can address. The 4D post-processor was designed specifically to give local travel models more sensitivity to smart-growth strategies. Although these three tools were designed for slightly different applications, they are similar to one another because a version of the 4D elasticities is now embedded in all three to generate approximate indicators of trip reduction due to smart-growth land-use strategies.

None of these three tools fits the conventional definition of a travel demand model. They are not designed to forecast or estimate travel as a function of land-use and transportation system characteristics. They are designed to estimate changes in travel based on changes in the 4D variables, which are described below. Inputs from an applicable travel model are required to use these tools. For example, to estimate the reduction in vehicle travel due to land-use plans, application of the 4D elasticities (whether in INDEX, I-PLACE3S, or the 4D post-processor) requires data on vehicle trips (VT) and vehicle miles traveled

[13] Early stages included the first meeting of the study's Technical Advisory Committee and a survey of modeling practice in California

(VMT) provided by a travel model of the study area. If such travel model data are not available, it is necessary to make informed assumptions about VT and VMT.

This study's efforts to investigate the three tools began with the collection of documentation and – in the case of INDEX - actual software and application data. This chapter summarizes findings based on this qualitative investigation of the three tools. The findings illustrate the features of the tools and suggest ways that each tool could be applied in the local assessment processes. A summary of the processes and data required to use the tools is then provided, which is intended to assist local agencies in using them. Finally, another program – URBEMIS – is introduced and briefly described that can be used to evaluate land use projects up to 40 acres in size. (URBEMIS does not incorporate the 4D elasticities, but uses a similar type of post-processing methodology).

4.2 The "4D Elasticities"

The 4D elasticities were developed to estimate the travel demand impacts associated with various smart-growth land-use and urban design changes. The method's name derives from the four factors used to characterize the land-use and transportation infrastructure: Density, Diversity, Design, and Destinations. The method originates from a series of land-use and travel-behavior studies led by Robert Cervero, a Professor at the University of California at Berkeley.[14] Over forty studies related to the relationships between changes in land-use characteristics, such as density, and changes in travel as measured by vehicle trips and vehicle miles of travel, were used in the development of the 4D elasticities[15.]

The 4D methodology uses a set of "elasticities" that quantitatively relate the built environment and accessibility characteristics to travel rates and modes. These elasticities are used to estimate the percentage changes in vehicle trips (VT) and vehicle miles traveled (VMT) that may be associated with various land-use plans and urban designs.

The methodology for applying the 4D elasticities as part of a planning tool was originally developed by Fehr & Peers Associates for Criterion Planners. This methodology was originally used in INDEX models, including U.S. EPA's Smart-growth INDEX[16]. Since then, 4D elasticities tools have gone through a series of revisions and improvements. "Pilot" copies of Smart-growth INDEX (Version 1.0, released in July 2000) contained the

[14] Cervero, Robert, "Travel Demand and the 3 Ds: Density, Diversity, and Design," *Transportation Research* D, 2, 3: 199-219, 1997; with K. Kockelmann. "Travel and the Built Environment: A Synthesis," *Transportation Research Record 1780*, pp. 87-113, 2001; with R. Ewing. "Built Environments and Mode Choice: Toward a Normative Framework," *Transportation Research D*, Vol. 7, 2002, pp. 265-284.

[15] "INDEX 4D METHOD A Quick-Response Method of Estimating Travel Impacts from Land-Use Changes," Technical Memorandum, October 2001, Prepared for the U.S. Environmental Protection Agency. By Criterion Planners/Engineers and Fehr & Peers Associates.

[16] "INDEX ® 3D METHOD A Quick-Response Method of Estimating Travel Impacts from Land-Use Changes," Technical Memorandum Prepared for the U.S. Environmental Protection Agency, Criterion Planners/Engineers With Fehr & Peers Associates, July 2000.

original version of the methodology, which at that time had only "3Ds" - density, diversity, and design. The second version of the method in Smart-Growth INDEX Version 2.0 (October 2001) contained 4Ds: density, diversity, design, and destinations.[17]

In the most recent version of *INDEX PlanBuilder*, the 4D method is expanded to include a 5th D: Distance from heavy rail transit station.[18] The effects of distance from heavy rail transit are treated differently from the other 4Ds, since heavy rail transit use is a subset of the various types of transportation alternatives to private vehicle use. The 5th D can only be applied in areas that are served by heavy rail transit service.[19] The 5th D is not elasticity-based like the 4 Ds. Instead, the 5th D employs a regression equation to predict "the change in the likelihood of heavy rail transit use between a base-case and a scenario-case due to differences in development density in proximity to rail transit stations as well as changes in rail and feeder bus service levels." Because the 5th D does not predict changes in vehicle trips or VMT as a result of land-use changes, it has not been included in the remaining discussion of the 4D methodology or software tools.

To develop elasticities for the 4Ds methodology, relationships between rates of vehicular travel (VT and VMT) and primary descriptors of the built environment and accessibility were derived from studies that provided valid, comparable results. Then, individual study results were synthesized into a unified matrix of partial elasticities. These express percentage changes in VT and VMT as a function of percentage changes in each of the 4Ds:

1. **Density**: population and employment per square mile;
2. **Diversity**: the ratio of jobs to population;
3. **Design**: pedestrian environment characteristics including street grid density, sidewalk completeness, and route directness; and
4. **Destinations**: Accessibility to other activity centers, expressed as the mean travel time to all other destinations within a region.

Figure 4.1 shows the formulation used to calculate the 4Ds. The resultant table of elasticities - **Table 4.1** - was created as a tool for assessing the relative benefits of one land-use pattern compared with another.

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[17] "INDEX ® 4D METHOD A Quick-Response Method of Estimating Travel Impacts from Land-Use Changes," Technical Memorandum prepared for the U.S. Environmental Protection Agency, by Criterion Planners/Engineers with Fehr & Peers Associates. October 2001.
[18] "5D Method Technical Memorandum INDEX PlanBuilder Release 9.1.9 User notebook," Criterion Planners, August 2006.
[19] "Heavy rail" is rail transit that does not mix with street traffic and includes commuter rail (including diesel multiple unit trains) and rail rapid transit, such as Bay Area Rapid Transit - BART. "Heavy rail" excludes light rail and street railways that share a significant portion of right-of-way with other traffic.

Figure 4.1 4D Formulation

Density	=	Percent Change in [(Population + Employment) per Square Mile]
Diversity	=	Percent Change in {1 - [ABS(b * population - employment) / (b * population + employment)]}
where: *b*	=	regional employment / regional population
Design	=	Percent Change in Design Index
Design Index	=	0.0195 * street network density + 1.18 * sidewalk completeness + 3.63 * route directness
Destinations (accessibility)	=	Percent Change in Gravity Model denominator for study TAZs "I": Sum[Attractions(j)*Travel Impedance(i,j)] for all regional TAZs "j"

where:

street network density = length of street in miles/area of neighborhood in square miles

sidewalk completeness = total sidewalk centerline distance/total street centerline distance

route directness = average airline distance to center/average road distance to center

Source: INDEX 4D METHOD A Quick-Response Method of Estimating Travel Impacts from Land-Use Changes Technical Memorandum

Table 4.1 4D Elasticities

	Daily Vehicle Trips	Daily Vehicle Miles Traveled
Density	-0.04	-0.05
Diversity	-0.06	-0.05
Design	-0.02	-0.04
Destinations (Accessibility)	-0.03	-0.20

Source: INDEX 4D METHOD A Quick-Response Method of Estimating Travel Impacts from Land-Use Changes Technical Memorandum

A travel demand model is generally needed to provide accurate baseline inputs for vehicle travel (i.e., VT and VMT) for operating the 4Ds elasticities, as well as for characterizing existing and future accessibility levels. If a travel model is not available, it

is advised that the method be carefully applied with the assistance of a qualified transportation planner using professional judgment based on experience in the geographic area.

The density, diversity, and design elasticities listed in **Table 4.1** are applied in cases where only land-use alternatives (no transportation network changes) are being considered for the same site. In such a case, the accessibility elasticities (destinations) do not need to be applied because a single site's relative accessibility would not vary from one land-use alternative to another. However, even when only one site is under consideration and accessibility is not expected to change over time or as a function of different transportation alternatives, it is still important to start the analysis with realistic baseline trip rates as influenced by the site's location within its region and its relative level of accessibility. The accessibility elasticities listed in **Table 4.1** should be applied when considering possible changes to transportation systems or services to a site. In addition, a travel demand forecasting model should also be used in such cases in order to estimate differences in accessibility that may result from such transportation changes.

Because the effects of the 4Ds on auto travel and trip length are primarily due to the proximity of supportive and well-designed land-uses to one another and the opportunity this provides for walk and bicycle travel between them, the developers of the 4D tools provide guidance on the maximum size of zones for which the elasticities should be applied. They advise that the areas to which the 4D elasticities are directly applied should be less than two miles in diameter or 2,000 acres. They suggest that if larger areas are under study, the 4Ds should be sampled within two-mile sub-areas of the larger area, and the results averaged. For example, a large area with employment clustered at one end and residential uses at the other should not be considered as diverse as an area with block-by-block mixing of land-uses. Therefore, the sampling and averaging technique is recommended to better capture the 4Ds effects in large study areas.[20]

4.3 4D Elasticities Post-Processor

The 4D elasticities can also be applied as a "post-processor" to a travel demand model or to other sources of baseline vehicle travel estimates to reflect the potential vehicle trip reduction that may result from smart-growth strategies. In such applications, the elasticities are applied directly to measures of vehicle trips or VMT. This has been done by application of the elasticities to aggregate measures by sub-area such as the area containing a new development, but has also been done by applying the elasticities to vehicle trip ends in a model trip table to adjust the number of trips. The revised trip table can then be used in the travel model for assignment of traffic to a roadway network to see how the trip reduction affects travel on specific links.

[20] Information provided by Eliot Allen, Criterion Planners, and Jerry Walter, Fehr & Peers (Emails, 2007).

Because the elasticities have only been developed for daily travel and not by trip purpose or by time-of-day, post-processors are generally used only for daily traffic assignments. Time-of-day factors in the travel model can be used to estimate peak-period assignments, but there is no available research that provides assurance that smart-growth strategies affect travel by time period in the same proportions as the time-of-day factors in the travel model. In certain instances, 4D elasticities have been developed for specific trip purposes, including a set that was developed for use in SACOG's regional Blueprint planning effort. These factors improved the ability to estimate changes in peak-period vehicle trips and VMT .[21] However, most other applications of the 4D elasticities have been only for daily trips for all purposes.

A 4D post-processor with a local travel model can be used to compare growth scenarios for an entire city, county, or region; or for multiple development sites scattered throughout an analysis area. Area-wide analyses include comprehensive assessments of development patterns over a large, relatively homogeneous area, or a large area consisting of multiple communities. "Growth scenarios" can comprise comparisons of existing versus future conditions, comparisons of "trend" versus "smart-growth" scenarios, and/or comparisons of several alternative community plans or specific plans.

Fehr & Peers Consultants has used the 4D post-processor method in a variety of applications, including assessment of large development projects and as a method for adjusting trip tables in a travel model. Based on their experience, Fehr & Peers developed guidance on the application of the 4D elasticities in planning practice. **Table 4.2** presents some "Do's and Don'ts" of 4D applications. **Table 4.3** suggests guidelines regarding when, where, and how it may be appropriate to use 4Ds tools for various purposes.

[21] Don Hubbard and Gerald Walters, Fehr & Peers, "Making Travel Models Sensitive to Smart-growth Characteristics," prepared for the ITE district 6 Conference, Honolulu, HI. July 2006.

Table 4.2 Fehr & Peers "Do's and Don'ts" for Use of 4D Elasticities

Stated simply: *the 4D's are intended only to predict relative changes in regional vehicle trips and VMT per capita resulting from large scale changes in density, diversity, design and destinations.* They are not intended for analysis of small or medium development projects, nor to be used as the sole means of forecasting project-generated traffic. When considering using the 4D's, please adhere to the following rules.	
Do's	
1	Compare two or more land use alternatives to one another in the same forecast year.
2	Pivot from one "baseline" alternative to predict the relative trips for the second alternative.
	The baseline case should fully analyzed using a validated model or other standard practice, and the impacts of the second alternative should be predicted via a 4D comparison of the two alternatives.
3	Compare large projects (at least 200 acres) or regional plans.
4	Use (or assume) the same transportation network for each alternative.
5	Compare in terms of vehicle trips per capita and VMT per capita.
Don'ts	
1	Do not apply to projects that are less than 200 acres.
2	Do not apply to special generators: colleges, hospitals, regional warehouse/distribution centers.
3	Do not apply if difference between base case and land use alternative results in trip generation under the alternative that falls below other locations in the region with similar densities.
4	Do not apply to projects whose land use mix consists of incompatible uses, such as blue-collar employment with executive housing.
5	Do not compare cases where the regional transportation system differs between them.
6	Do not apply in NEPA or CEQA traffic studies, unless you've tested the available local traffic models to avoid double-counting 4D benefits, validated the factors for local use, addressed the other "Don'ts" in this list, and cleared the approach with the lead agency and reviewing agencies.
Only With Care	
1	Apply to sites where density, diversity or design vary by over 400% from one alternative to another. Such cases are beyond the comparison limits that the 4D data supports. They requires testing of boundary effects, and possible borrowing of baseline trip rates from regional averages or from other comparable areas of the region.
2	Approximate the "design" variable – When complete sidewalk or route-tracing is not available, we have experience using a quasi-subjective rating system for quantifying design. Check with an experienced user to review how it's done.
3	Plug 4D adjustments into a conventional process, such as a 4-step model, or ITE/TRAFFIX analysis.
4	For TOD's, combine 4D's with Direct Ridership transit ridership forecasting.

Table 4.3 Fehr & Peers' Guidelines for Application of 4D Elasticities

Results Obtainable from 4D Applications Employing Different Levels of 4D Calibration and UTMS (Travel Demand) Model Use					
	Applications *without* a UTMS Model			**Applied in Conjunction *with* a UTMS Model**	
TYPE OF STUDY	4D Values: **Generic** values from National Studies (1)	4D Values: **Borrowed** from Other Regions or **Generic** from National Studies (2)	4D Values: **Calibrated** Using Local Household Travel Survey (2)	4D Values: **Borrowed** from Other Regions or **Generic** from National Studies (2)	4D Values: **Calibrated** Using a Local Household Travel Survey and **Adjusted** to Reflect Effects Captured by the Model (2)
Sketch Plan for Regional Scenarios	VT, VMT	VT, VMT	VT, VMT	MTP, AA	MTP, AA
General Plan	VT, VMT	VT, VMT	CEQA/ NEPA	MTP, AA	CEQA/ NEPA
Corridor Plan	VT, VMT	VT, VMT	VT, VMT	MTP, AA	CEQA/ NEPA
Specific Plan	NA	VT, VMT	VT, VMT	MTP, AA	CEQA/ NEPA
Project Site >200 acres	NA	VT, VMT	VT, VMT	VT, VMT	CEQA/ NEPA
Project Site < 200 acres	NA	NA	NA	NA	NA

NOTES:
(1) As employed in INDEX and I-PLACE3S.
(2) Must be applied with professional guidance on ceiling and floor values

Definitions:
NA = Not applicable
VT, VMT = Acceptable for quantitative estimation of land-use effects on VMT/capita and VT/capita. Should be used as comparative information only and not as the basis for impact analysis contained in a CEQA or NEPA document.
MTP, AA = Acceptable for quantitative estimating of travel corridor volumes for use in master transportation plan (MTP) or transportation alternatives analysis (AA). Also provides quantitative estimation of land-use effects on VMT/capita and VT/capita. Should be used as comparative information only and not as the basis for impact analysis contained in a CEQA or NEPA document.
CEQA/ NEPA = Acceptable for quantitative estimation of land-use effects on VMT/capita and VT/capita, and link volumes and may be used as the basis for master transportation plan (MTP) or transportation alternatives analysis (AA) and impact analysis in a CEQA or NEPA document.

4.4 I-PLACE^{3}S

PLACE3S, which stands for Planning for Community Energy, Economic and Environmental Sustainability, is both a planning *method* and a planning *software*.[22] PLACE3S was designed to provide information to decision-makers so that the implications of their choices can be assessed and visualized.

The PLACE3S *method* is in the public domain and consists of five steps. In general, the five steps can be applied to most local planning applications, but adjustments may need to be made for special circumstances. These five steps are:

- **Start-up** - the geographic scope of the project to be assessed using PLACE3S is established, along with other planning projects in the vicinity of the study area.
- **Establish "Business-as-Usual" Alternative -** the existing conditions or a plan is projected to a future year (the planning horizon) to create the Business-as-Usual Alternative.
- **Analyze Alternatives -** alternatives improving upon the Business-as-Usual plan are developed.
- **Create "Preferred Alternative" -** the Preferred Alternative is selected, normally including a mixture of elements containing attributes from alternatives evaluated.
- **Adopt, Implement, Monitor, and Revise -** the Preferred Alternative is adopted and a process is developed for implementing, monitoring, and revising the development program.

The PLACE3S *software*, which supports the PLACE3S method, is a land-use and urban-design analysis tool that was created to help communities better understand the potential benefits and impacts of local development decisions. PLACE3S is generally a data-intensive analysis tool, but in small communities a moderate amount of data and manual calculations can support a PLACE3S study. Other than in small communities, however, facilitators of the planning process need to use computers to assemble and analyze a large amount of data.

PLACE3S was originally developed cooperatively during the 1990s by the State energy offices in California, Oregon, and Washington, and private consultants Criterion Planners and McKeever/Morris, with financial support from the U.S. Department of Energy.

In 2002, the California Energy Commission (CEC) funded the development of an Internet-based version of PLACE3S, referred to as "I-PLACE3S". At the same time, the Sacramento Area Council of Governments (SACOG), which is comprised of 28 member cities and counties, partnered with a local organization, Valley Vision, to conduct the Sacramento Region Blueprint Transportation/Land Use planning effort. The Blueprint was a major planning effort that used I-PLACE3S (among other tools) to envision and

[22] "The Energy Yardstick Using PLACE^{3}S to Create More Sustainable Communities," California Energy Commission, Oregon Department of Energy, and Washington State Energy Offices. August 1996.

assess various future growth scenarios for the region.[23] SACOG volunteered to test and use the newly developed I-PLACE3S software in its Blueprint process, and also funded additional modules and augmentations of the I-PLACE3S program.[24]

Both PLACE3S and I-PLACE3S can be used to estimate the type and extent that a development may have in the vicinity of a community. I-PLACE3S can be used to show the estimated effects of a development decision to a number of participants during planning workshops for immediate feedback and response.

During the Blueprint process, SACOG found I-PLACE3S to be much more flexible than the original desktop version of PLACE3S for both community workshops and staff work. Both desktop and Internet versions of the PLACE3S software require GIS capability for staff-level work. Unlike the desktop version of PLACE3S, which requires high-powered computers or laptops to function, I-PLACE3S only requires a computer or laptop with an Internet connection and a web browser. For this reason, SACOG was able to use it extensively in more than thirty public workshops during the regional Blueprint planning process.

In the SACOG application of I-PLACE3S, land-use scenarios were modified during workshops and their impacts were measured instantly. For example, in a community planning workshop, a group of participants who opted to change the land-uses around a light rail station were able to get instant feedback regarding resulting changes in the jobs/housing balance, total dwelling units, and number of employees, as well as land-use density.

In addition to these land-use indicators, a set of 4D elasticities measures imbedded within I-PLACE3S estimates the potential changes in Vehicle Trips per Household (VT/HH), Vehicle Miles Traveled per Household (VMT/HH), and Mode Choice resulting from the various types, locations, and configurations of land uses.[25] Another SACOG application of I-PLACE3S allows workshop participants to select highway, street, and transit projects that are also modeled with a streamlined version of SACOG's regional travel model. This I-PLACE3S module allows users to isolate the impacts of transportation investments, including VMT/HH, VT/HH, VH/HH, Congested VMT/HH, and Mode Choice.

Table 4.4 lists the major functions of I-PLACE3S (called "Modules"), their required inputs, and resulting outputs. Many of the data items needed for I-PLACE3S can be obtained from regional and local planning agencies, such as (for example) the number, size, and location of dwelling units. The method uses GIS to make the planning process efficient and easy to understand for the public and decision-makers.

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[23] Sacramento Regional Blueprint Transportation/Land Use Study, http://www.sacregionblueprint.org/sacregionblueprint/the_project/technology.cfm

[24] "I-PLACE[3]S Program Overview - Geospatial Technology for Community Planning and Local Government" by Nancy McKeever. The Rural Geospatial Innovations in America Conference. October 24, 2003.

25 "San Luis Obispo County Place Making Workshops," Presented by: Steve Devencenzi, Corinne Rosenblum, San Luis Obispo. February 3, 2004.

Table 4.4 I-PLACE3S Modules and Examples of the Indicators, User-defined Inputs, and Formulas of each Module.

MODULE	RESULTS/INDICATORS	USER-DEFINED INPUTS	FORMULAS
Land Use	Number of Dwelling Units & Jobs - by Land Use Type Density Acreage of each Land Use Amount of development within walking distance of transit Acres of land set aside for environmental resources (vernal pools, wetlands, etc.) Building Square Footage for Employment Sectors (Retail, Office, Industrial, Public)	Land Use Development Types (Building or Land Use Prototypes) - Building Square Footage - Mix of Uses - Number of Stories - Landscape and setback requirements - Parking ratios - Levels of parking - Square feet per parking space - Average lot size (single family detached - Residential Type (attached or detached) Environmental Resources - Set rules for resource set-aside	Development yield (number of jobs and dwelling units by type) Development density (Dwelling units/Acre, FAR) Land Consumption (Residential and Employment Acres)
Transportation/ Land Use Impacts	Change in Vehicle Miles Traveled/Household Change in Vehicle Trips/Household Change in Mode Split (Percent of all trips that are Bike/Ped and Transit) Change in Light Rail Boardings	Land Use indicators (see Land Use Module) Transportation network - Street pattern/connectivity - Level of transit service	Formulas that calculate travel performance from land use pattern and transportation characteristics (comparison of Base Case land use and transportation network to new scenarios).
Regional Transportation/Travel Model – Transportation Impacts	Number and/or Change from Base Scenario of: -Vehicle Miles Traveled per Household -Vehicle Trips per Household -Vehicle Hours of Travel per Household -Congested Vehicle Miles Traveled per Household -Mode Choice (Auto, Transit, Walk/Bike)	Add/subtract/ modify road projects. Add/subtract/ modify transit routes.	Regional travel model connected to I-PLACE3S. Runs mode choice and assignment modules. Other components of full regional travel model are available.
Return on Investment* (I-PLACE3S)	Return on Investment	Land Use Development Types - Operating Costs - Rents & For Sale Costs per Sq. Ft. - Occupancy Rates - Hard Costs - Soft Costs - Permit Fees - Impact Fees - Land Value - Structure Value	Method of Calculating ROI (Net Annual Income/Total Project Cost)

MODULE	RESULTS/INDICATORS	USER-DEFINED INPUTS	FORMULAS
Energy Module *(UNDER DEVELOP-MENT)*	Total and by sector electricity demand Feasibility of multiple energy efficiency options Feasibility of multiple alternative energy generation technologies, including renewable energy sources Environmental effects of energy demand	Energy efficiency programs to implement Levels of energy efficiency by sector to achieve Energy generation technologies to deploy Amount of demand to serve with local generation	Electricity demand is applied to existing buildings, factored by efficiency standard in place at year of construction, and new buildings in alternative developments. Options for reducing demand can be introduced, with percent market penetration, to determine net benefit. Energy generation technologies are matched with energy demand curves for feasibility. Emission, noise, size and other parameters are matched for compatibility with surrounding uses.

Source: Information provided by Gordon Garry of SACOG, July 20, 2007.

4.5 INDEX

INDEX is a GIS-based sketch-planning tool that was introduced by Criterion Planners in 1994. It was first designed as a tool to automate many tasks that are optimally involved in developing long-range land–use plans and evaluating major land–use project proposals.[26] Through the years, INDEX has undergone several phases of development.

The U.S. Environmental Protection Agency (EPA) sponsored the development of a version entitled "Smart-Growth INDEX" as part of its national smart-growth program.[27] Smart-Growth INDEX is a customization of the INDEX software series. In a pilot study that applied and tested Smart-Growth INDEX, EPA distributed the software to 20 communities. EPA documented the performance strengths and difficulties encountered during these pilot applications, which led to improvements to the program in Version 2.[28] EPA provides Smart-Growth INDEX as public-domain software.

The most recent versions of INDEX are "PlanBuilder 9.2" and "Paint the Region," which contain features not available in EPA's Smart-Growth INDEX. Criterion Planners provides INDEX Planbuilder as a commercial product.

INDEX inputs differ depending on whether it is being used for long-range forecasting or to develop a "snapshot" of current conditions to be used in scenario testing. In both cases, there are certain minimum requirements for model operation, listed below:

[26] Criterion Planners Website at: http://www.crit.com/index/index.html
[27] Smart-growth Index Website: http://www.epa.gov/livablecommunities/topics/sg_index.htm
[28] "EPA's Smart-growth INDEX In 20 Pilot Communities: Using GIS Sketch Modeling to Advance Smart-Growth," EPA 231-R-03-001, February 2003.

GIS Coverages:

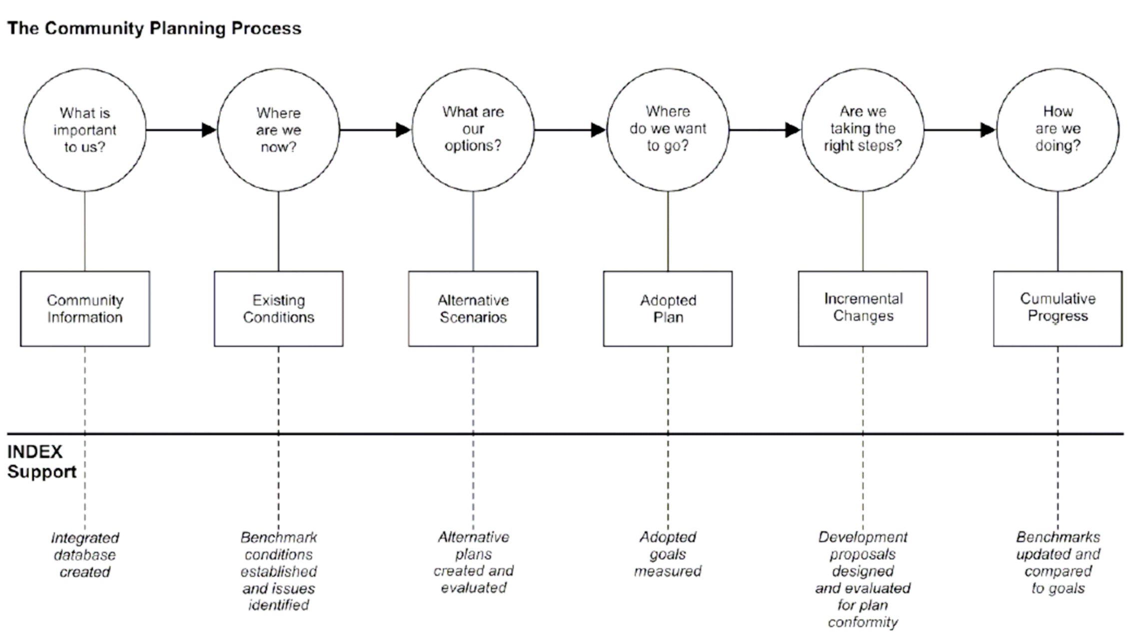
- Existing housing by type
- Existing employment by type
- Land-use plan designations by class
- Existing land-use with housing by type (single-family or multiple-family)
- Street centerlines attributed by functional class, numbers of traffic lanes on each segment if available, and sidewalk presence (for snapshots)
- Transit routes by type (bus, rail) for forecast sketches; transit stops by type for snapshot sketches

User-Defined Parameters:

- Growth projection
- Urban size category
- Commute shed population
- Transit rail availability
- Levels of service
- Vehicle trips and miles traveled
- Average number of lanes by functional class and year of service
- Allowable densities for each land-use class (maximum) in dwellings per acre for residential uses, and floor-area ratios for non-residential uses
- Ratios of non-residential floor area to number of employees for non-residential land-use classes
- Ratios of residential to non-residential uses for mixed-use land-use classes (if a jurisdiction has such classes)
- Percent of maximum allowable infill dwelling units within existing residential areas
- Transportation fuel consumption rates
- Climate region and building energy demand coefficients
- Transportation and building air pollutant and greenhouse gas emission coefficients
- Residential water consumption rates

INDEX incorporates a set of "indicators" that are used to identify existing conditions, evaluate alternative scenarios, and/or track changes over time. Indicators are measurements of neighborhood and environmental characteristics that provide information about potential impacts of planning decisions. **Figure 4.3** illustrates a community planning process using INDEX.

Figure 4.3 Support of Community Planning with INDEX



Source: INDEX PlanBuilder User Notebook

The most recent version of INDEX Planbuilder has a menu of 73 indicators for users of ArcEditor/ArcInfo, and 53 indicators for ArcView users that can be used to evaluate various alternatives.

Table 4.5 lists the INDEX Planbuilder indicators related to travel. Five of the indictors that are of significance in transportation planning processes are generated by INDEX using the 4D Elasticities. These indicators (which are italicized in Table 4.5 that follows) are: *Home Based Vehicle Miles Traveled, Non-Home Based Vehicle Miles Traveled, Home Based Vehicle Trips, Non-Home Based Vehicle Trips, and Personal Vehicle Energy Use.*

Table 4.5 INDEX Travel Indicators

TRAVEL
Internal Street Connectivity
External Street Connectivity
Street Segment Length
Street Centerline Distance
Street Network Density
Street Network Extent
Transit Service Coverage
Transit Service Density
Transit-Oriented Residential Density
Transit-Oriented Employment Density
Light Rail Transit Boardings
Heavy Rail Mode Shift
Pedestrian Network Coverage
Pedestrian Crossing Distance
Pedestrian Intersection Safety
Street Route Directness
Pedestrian Setback
Pedestrian Accessibilities
Bicycle Network Coverage
Residential Multi-Modal Access
Home Based Vehicle Miles Traveled
Non-Home Based Vehicle Miles Traveled
Home Based Vehicle Trips
Non-Home Based Vehicle Trips
Personal Vehicle Energy Use
Parking Lot Size
Parking Requirements

Source: INDEX PlanBuilder User Notebook

4.6 Another Tool: URBEMIS

Other software tools have been developed to evaluate smart-growth strategies. Among these is URBEMIS, which stands for “Urban Emissions.” URBEMIS was originally produced by the California Air Resources Board to easily estimate air quality emissions associated with land-use development projects from: motor vehicles (light-duty cars and trucks), area sources (such as water heating, lawn mowing), and during construction. Since the late 1990s, URBEMIS has been updated, maintained, and distributed by a consortium of air districts in California. It is often used for CEQA assessments of land-use developments up to 50 acres in size (but should not be used for larger plans or projects). URBEMIS does not require GIS or other specialized software to operate.[29]

URBEMIS contains a module – the "Mobile Source Mitigation Component" – that can be used to estimate changes in vehicle, transit, and non-motorized trips (and related emissions) resulting from a variety of smart-growth land-use and transportation strategies.[30] Although this module does not specifically incorporate the “4D Elasticities,” it can also be used to assess land-use projects. (A Users’ Manual provides detailed documentation of the Mobile Source Mitigation Component.) The main types of strategies that the URBEMIS Mobile Source Mitigation Component can assess are:

- Net residential density
- Mixture of land-uses
- Local-serving retail
- Parking supply (based on ITE’s *Parking Generation* manual)
- Parking pricing
- Proximity to various levels and types of transit service
- Bicycle and pedestrian accessibility
- Telecommuting and other Transportation Demand Management (TDM) programs

URBEMIS first estimates “baseline” vehicle travel rates associated with various types and amounts of land-uses utilizing vehicle trip generation rates obtained from the most recent version of the Institute of Transportation Engineers (ITE) *Trip Generation*. Users can then operate the Mobile Source Mitigation Component to estimate reductions in daily vehicle travel associated with the project’s attributes. The program then estimates the percentage benefit of each factor that is selected for a land-use development project. It limits the total amount of reduction estimated to reasonable levels.

After URBEMIS has been operated for a selected project, the program produces a written report documenting the results that lists the estimated numbers of vehicle trips and VMT for both the “before mitigation” and “after mitigation” versions of the project. It also provides air quality data for each. In addition, the program’s report output lists and describes each of the mitigation measures that were selected during operation of the Mobile Source Mitigation Component so that these are clearly documented.

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[29] The URBEMIS software and Users’ Manual can be downloaded (free of charge) from the Internet at: http://www.aqmd.gov/ceqa/urbemis.html

[30] Jones & Stokes Associates, “Software User’s Guide. URBEMIS 2002 for Windows on the Enhanced Construction Module,” prepared for the South Coast Air Quality Management District, April 2005

Chapter 5

Travel Modeling Practice in California

5.1 Transportation Planning and Modeling Requirements in California

The first real demand for transportation system analysis in California came in the mid-1940s. At that time, both population and automobile ownership increased at such a rapid rate that the demand for intercity and urban area mobility could no longer be ignored. The Federal-aid Act of 1944 first provided Federal funds for the construction of urban area highways and advocated urban transportation planning. Almost 20 years later, the Federal-aid Act of 1962 required transportation planning for all urban areas of more than 50,000 in population and formalized the Urban Transportation Planning Process. This included the 3-C Process for planning: that it be cooperative, comprehensive, and continuing.

This new process provided the framework within which all levels of government (local, regional, state, and federal) began conducting transportation planning. That framework included inventories, data and model analysis, forecasts, transportation system analysis, plan development, plan evaluation, plan selection, and plan implementation, followed by continuing reevaluation. This new process was a significant departure from the simplistic "rule-of-thumb" methods that provided for an estimate of the future based upon past experience (trend line, for example). Rule-of-thumb methods were limited to the point at which the estimate was made on the existing or proposed network. Urban travel demand forecasting provided for an analysis of the entire system based upon alternative networks and service (supply side) and alternative estimates of socioeconomic data such as housing, population, income, employment, etc. (demand side). This process provided answers to the following questions for each of the alternatives:

- Where are the activities located?
- How many trips will be generated?
- Where will the trips go?
- By which mode?
- By which route?

The Urban Transportation Modeling System (UTMS) was designed specifically to answer these questions. After the 1960s, UTMS became the primary tool used to quantify travel demand in regional transportation planning in California. (A detailed description of UTMS is provided in **Chapter 3**.)

Transportation planning is a cooperative effort between different units of local, state and federal governments. In areas with a population over 50,000, an agency is designated as a Metropolitan Planning Organization (MPO) to conduct regional planning projects. This is usually an agency such as a council of governments (COG) or a regional transportation planning agency (RTPA). The MPO works cooperatively with local governments and units of state government, such as the California Department of Transportation (Caltrans) in preparing regional transportation plans.

As indicated in **Table 5.1**, there are 17 MPOs in California. Many MPOs in California incorporate large rural areas as well as urban areas. Most MPOs maintain a travel forecasting model for their entire area to aid them in meeting Federal regulations requiring a long-range transportation plan for the region. Substantial funding and resources are dedicated to the development and maintenance of these models. State and local governments also engage in transportation planning for specific issues that relate to their jurisdictions. In rural areas or smaller urban areas that are not out of compliance with Federal air quality standards, transportation planning still occurs but it usually follows a simpler process than in larger urban areas. There is less emphasis on growth and congestion issues, and consequently not as much need for detailed travel demand models.

California Government Code §29532 also requires that regional transportation planning be conducted in each county and has designated a Regional Transportation Planning Agency (RTPA) in each county. Thirty-nine of California's counties are in areas that are also covered by the 17 MPOs. Of the counties in multi-county MPOs, Placer, El Dorado, San Benito, Monterey, and Santa Cruz Counties also have an RTPA. Some of the RTPAs also maintain travel models.

Because of limited resources for modeling, many of the smaller MPOs and RTPAs have chosen to maintain and update models that were initially developed 10 to 20 years ago rather than develop new models. Such modeling systems are often termed "legacy" systems. The model structures are primarily UTMS and were developed under existing software packages such as EMME/2, MINUTP, and TRANPLAN. As a result, many of the advanced functions available in new software (such as TransCAD and CUBE) that are designed to address the limitations of conventional UTMS models are not widely used in practice in California. Lack of training, lack of familiarity with new methods, and funding for model improvements are some of the reasons.

Table 5.1 MPOs in California

MPO	Area Covered	Web Site
Association of Monterey Bay Area Governments (AMBAG)	Monterey and Santa Cruz Counties	www.ambag.org
Butte County Association of Governments (BCAG)	Butte County	www.bcag.org
Fresno County Council of Governments (Fresno COG)	Fresno County	www.fresnocog.org
Kings County Association of Governments	Kings County	www.countyofkings.com
Kern Council of Governments (Kern COG)	Kern County	www.kerncog.org
Madera County Transportation Commission	Madera County	www.maderactc.org
Merced County Association of Governments (MCAG)	Merced County	www.mcag.cog.ca.us
Metropolitan Transportation Commission (MTC)	Alameda, Contra Costa, Marin, Napa, Santa Clara, San Francisco, San Mateo, Solano, and Sonoma Counties	www.mtc.ca.gov
Sacramento Area Council of Governments (SACOG)	Sacramento, Placer, El Dorado, Yuba, Sutter, and Yolo Counties	www.sacog.org
San Diego Association of Governments (SANDAG)	San Diego County	www.sandag.org
San Joaquin County Council of Governments (SJCOG)	San Joaquin County	www.sjcog.org
San Luis Obispo Council of Governments (SLOCOG)	San Luis Obispo County	www.slocog.org
Santa Barbara County Association of Governments (SBCAG)	Santa Barbara County	www.sbcag.org
Southern California Association of Governments (SCAG)	Los Angeles, Orange, Riverside, San Bernardino, Imperial, and Ventura Counties	www.scag.ca.gov
Shasta County Regional Transportation Planning Agency	Shasta County	www.scrtpa.org
Stanislaus Council of Governments (StanCOG)	Stanislaus County	www.stancog.org
Tulare County Council of Governments	Tulare County	www.tularecog.org

Individual counties within multi-county MPOs may also develop and maintain travel demand models of their own. This has become more common since the State in 1990 began requiring that a Congestion Management Program (CMP) be developed for each county by a Congestion Management Agency (CMA). Although a separate model is not required for each CMA, most CMAs that include urban areas have developed their own

models to assess how land-use and transportation decisions in the county will affect transportation level of service in future years. The designated CMA can be either the county or another existing agency within the county. The designation is made by County Boards of Supervisors and the City Councils of a majority of the cities representing a majority of the population in the incorporated areas of each county. A CMA travel model is usually based on the travel model of the MPO in which the county is a member because the model is required to be consistent with the MPO model. For most single-county MPOs in California, the CMA and the MPO are the same organization, and thus they use the same model structure.

The modeling network of a CMA model may cover a planning area as large as the MPO model, but is typically more detailed within the county border. For example, Orange County, which is a member of the Southern California Association of Governments (SCAG), maintains the Orange County Transportation Analysis Model (OCTAM). The OCTAM network includes networks of other counties in the SCAG membership but is more detailed within Orange County.

Because resources are usually limited at the county level, additional household travel survey efforts beyond those conducted by MPOs are rarely performed. Thus, critical variables and parameters for each model component are usually taken from the MPO models, which are typically supported by actual household travel surveys. Some adjustments to the model parameters may take place to ensure the results of the model can approximate existing traffic counts within the county border.

Many cities also develop their own travel model. A city model is often based on the MPO model or the CMA model with additional focus on the area within the city border. For example, the City of Irvine in Orange County has its own Irvine Transportation Analysis Model (ITAM), which is based on the OCTAM model.

5.2 Common Practice by Local Jurisdictions

Travel modeling for land-use planning by local jurisdictions in California is most often a function of size of the metropolitan area in which the local jurisdiction is located and the modeling capabilities of the MPO (if one exists for the area). In the largest metropolitan areas covered by major metropolitan MPOs - MTC, SANDAG, SACOG, and SCAG - sophisticated multi-modal travel demand models are available for the region. Parameters for these models are estimated from detailed local data (i.e., household travel surveys, roadway traffic counts, and transit ridership data). Within these major metropolitan areas, the county CMAs and the counties generally use the MPO model or a derivative of it, although this is not uniformly true.

The cities within a region usually also draw on the regional or county model as a basic framework for their modeling, although often with simplification of one or more of the steps. The city models typically are focused on or enhanced for the areas of interest, usually the area within their city boundaries and immediately surrounding areas. Within this focus area, city models tend to split the traffic analysis zones (TAZs) into smaller

more refined zones, taking advantage of more detailed land-use data. These smaller zones with disaggregate land-use are usually accompanied by a roadway network that contains considerably more detail (such as minor arterial, collector, and neighborhood streets) than the original regional models.

Some of the local jurisdiction models use an approach called “focusing”, whereby only a sub-region centered on the city or on the areas of interest is modeled in detail. Less detail is maintained outside of the area of interest. This dramatically reduces the size and complexity of the local jurisdiction model. This also enables the use of traffic simulation software to examine micro-improvements in the traffic network.

Most common among the simplifications that a local jurisdiction typically makes to a regional or county model is the elimination of mode choice analysis and transit assignment. The most common practice for modeling by local jurisdictions that use a model derived from an MPO or CMA model is to assume a fixed mode-share and vehicle-occupancy rate by trip type and/or origin-destination combination. Models developed using the “focused” approach, generally use auto-occupancy mode share factors. Therefore, it is rare for a local jurisdiction to have the ability to analyze alternative transit scenarios, and this type of analysis is usually left to the CMA, the MPO, or a transit authority. If a local jurisdiction does have transit modeling capability, it most probably is using the CMA or MPO model directly or in a focused form.

Most local jurisdictions also do not have the ability to estimate the proportion of travel that is made by non-motorized modes: walk or bicycle. This capability generally exists only in the model systems of the larger MPOs and CMAs. For those, non-motorized mode travel is usually predicted as a function of zone size and density and possibly a “pedestrian friendliness factor” that may be developed for each zone. The prediction of non-motorized travel mode is generally not based on modeled pedestrian facilities or bicycle networks. Micro-scale characteristics capturing the quality of the walking or bicycling environment are currently not included in model networks or in the trip generation, trip distribution, or mode-share parameters of any MPO, CMA, or local jurisdiction models in California.

Even when an MPO or CMA model with moderate or high sensitivity (based on the model features) is available in a region, many local jurisdictions choose to use their own model for analyses to support land-use decision-making. This may be because the local model has more zonal or network detail or because it uses land-use variable that are more common in land-use planning – floor area for commercial uses rather and than employment. But the reluctance to use a more regional MPO or CMA model may also be a result of a history of using the local model for local land-use decisions such as general plans, specific plans, traffic impact studies and development impact fee programs and using MPO and CMA models only for regional transportation planning efforts. Over time, the features in MPO and CMA models often filter down into the local models as updates of the local model are performed. New versions of local models are now frequently developed as focused versions of the regional model, capturing all the features of the regional model while also maintaining greater detail within the local jurisdiction boundaries.

The amount of effort to develop and maintain local jurisdiction models is a function of the size and population of the area being modeled and of the amount of growth occurring there. Local jurisdictions in areas that do not have the benefit of a MPO or CMA model as a resource most often perform modeling with a simplified approach - if they use travel models at all. Most often, this is done with a model developed using "borrowed" model coefficients and parameters. In these situations, modeling is usually done with the help of a consultant and involves the use of vehicle trip rates that are often based on the Institute of Transportation Engineers (ITE) land-use-based trip generation rates,[31] or on model coefficients from a model developed for a similar area.

Because most local jurisdictions use travel models to evaluate the impacts of land-use decisions on traffic level of service and roadway capacity needs, most of these models consider a representative travel weekday and predict vehicle trips for a peak-period or a peak-hour. Some of the more sophisticated models provide forecasts for different periods of the day and also output a total daily travel forecast. The local jurisdictions that use this type of approach are generally those that use an MPO model directly or a derivative of the MPO model. Many local jurisdictions that do not use an MPO or CMA model produce forecasts for one time period only - such as daily, peak-period, or peak-hour - and for vehicle trips only.

5.3 Application of Smart-Growth Sensitive Methods in California

As a result of the growing awareness of smart-growth principles and their potential benefits, some planning agencies in California have undertaken steps to apply methods and tools that provide analysis sensitivity to smart-growth strategies. These efforts have included enhancement of conventional travel models, development of micro-level activity-based models, and use of supplemental tools such as the 4D elasticities, INDEX, and I-PLACE3S.

5.3.1 Sophisticated Conventional Planning Models

Most of the larger MPOs in California have undertaken model enhancements over the past twenty years largely for the purposes of transit forecasting and for air quality planning and conformity analysis. All four of the major metropolitan areas have pursued federal funding for new rail starts and have adopted new modeling practices that give greater sensitivity to how access to transit services affects use of the new systems. The improvements that have been implemented in some (but not all) of California's major MPO models include most of those identified in **Chapter 3** as areas for potential improvement to the conventional UTMS model:

[31] Institute of Transportation Engineers, *Trip Generation*.

- Modeling Peak as well as Daily Travel
- Simple Mode Choice
- Transit Network and Daily Assignment
- Supply and Demand Equilibration
- Income Stratification in Distribution and Mode Choice
- Auto Ownership Modeling Sensitive to Land-Use Characteristics, Household Characteristics, and Travel Options
- Travel Time Feedback
- Non-Motorized Modes in Mode Choice
- Modeling Multiple Modes of Access to Transit
- Distribution Sensitive to Multi-Modal Options
- Disaggregate Simulation of Households
- Explicit Representation of Pedestrian and Bicycle Networks
- Activity- and Tour-Based Modeling
- Integrated Land-Use/Economic/Transportation Modeling

5.3.2 Activity-Based Planning Models

The development of activity-based transportation planning models has been undertaken (so far) by four agencies in California: the San Francisco Transportation Authority (the CMA for the City and County of San Francisco), SACOG, MTC, and SCAG. Although only four agencies are exploring the use of activity-based models, they cover a large proportion of the most urbanized portions of the state, representing roughly 70 percent of the state's population.

The San Francisco Transportation Authority was the first to develop this type of model in 2002. SACOG began developing an activity-based model in 2004, and currently has an operational model that is being tested for its sensitivity to smart- growth strategies. MTC began the development of an activity-based model in 2005 that is scheduled for completion in 2007. It is expected to have many of the same features of the San Francisco Transportation Authority's model. SCAG began a model design project in 2007 to explore possibilities for the Southern California region. and is planning to commence model development.

5.3.3 4D Elasticities

As discussed in **Chapter 4**, the use of the 4D elasticities as a post-processor with a conventional UTMS model has been undertaken in several locations within California, including:

- Sacramento Region (SACOG) – for testing of alternative future land-use and growth scenarios

- San Luis Obispo Region (SLOCOG) – for testing of alternative future land-use and growth scenarios
- Contra Costa County (CCTA) – for long-range visions process "Shaping Our Future"
- Humboldt County – for General Plan development
- Fresno and Madera Councils of Government - as part of the San Joaquin Valley Growth Response Study

In addition to the 4D elasticities, a 5th "D" - "distance from rail transit" - has been developed. It has also been applied as a "direct ridership model" for predicting rail transit use associated with transit-oriented development. The 5th D is designed to respond to micro-scale influences such as higher density land-uses around stations, station access modes, and parking availability. BART and Caltrain (two rail transit agencies in the S.F. Bay Area) have used the 5th D to analyze transit-oriented development designs.

5.3.4 I-PLACE3S

The software package I-PLACE3S has been used in California for a variety of purposes since it was first developed with sponsorship of the California Energy Commission. I-PLACE3S has been used in the Sacramento area as an integral part of the regional "Blueprint" transportation and land-use planning effort. The City of Sacramento has used it to conduct land-use planning around a light rail station, and for a recent General Plan update. The San Luis Obispo Council of Governments used I-PLACE3S for regional land-use and transportation "visioning." (**Chapter 4** provides more information.)

5.3.5 INDEX

The software package INDEX has been applied to test the benefits and impacts of smart-growth strategies in a variety of locations in California. For example, INDEX has been used in the Sacramento area by the City of Sacramento for pedestrian planning, by the County of Sacramento for comprehensive land-use/transportation planning, and by the Sacramento Metropolitan Air Quality Management District for analysis of the benefits of alternative urban design strategies for reducing vehicle air pollutant emissions. INDEX has also been used by the Fresno and Madera Councils of Government as part of the San Joaquin Valley Growth Response Study. (**Chapter 4** provides more information.)

5.4 Case Studies of Local Travel Modeling Practice

This case study review of travel models in California is intended to provide a sampling of the range of approaches by local jurisdictions in California to forecast travel demand and traffic - with a focus on the models' abilities to reflect land-use configurations, such as the smart-growth strategies. Cities were selected for these case studies to ensure that the role of the travel modeling could be examined in the context of decision making related

to land-use and development decisions. Although counties also have the same land-use responsibilities as cities for unincorporated areas, only cities were chosen for these case studies because more development typically occurs within cities (with some exceptions, such as in unincorporated portions of Sacramento County).

The case studies were selected based on a combination of factors: geographic locations, urban forms/development patterns, use of travel models for local land-use planning, and the applications of smart-growth and transit-oriented development strategies in the communities. Six locations were selected:

- City of Irvine
- City of Fresno
- City of San Diego
- City of San Jose
- City of San Luis Obispo
- City of West Sacramento

In each of the following case studies, the relationship between the city, the county, and the MPO regarding travel modeling is explored and described. A summary of the information provided in the case studies is provided in **Table 5.2**.

Table 5.2 Summary of Six Case Study Cities

City	Uses of Model in Land-use Planning	Relationship of Model to CMA or MPO Model	Maintenance of Model	Transit Modeling Capability	Smart-Growth Sensitivity
Irvine	General Plan, Development Analysis	Uses derivative of OCTA (CMA) and SCAG (MPO) model	In-house staff at the City with assistance from MPO/CMA staff	Performed at the CMA level	Plans to incorporate 4Ds
Fresno	General Plan, Development Analysis	Uses Fresno COG MPO/CMA model directly	MPO/CMA staff	Full transit modeling capability	Existing modes include walk, bicycle and transit. Uses 4Ds post-processor
San Diego	General Plan, Development Analysis	Uses derivative of SANDAG (MPO) model	In-house staff at the City with assistance from CMA staff	Full transit modeling capability	Existing modes include walk, bicycle and transit. Smart-growth development patterns and transit focus areas tested.
San Jose	General Plan, Development Analysis	Uses CMA model which is derivative of the MTC MPO model	In-house staff at the City with assistance from CMA staff and MPO staff	Full transit modeling capability	Existing modes include walk, bicycle and transit. Incorporates MTC's features for auto ownership and income stratification.
San Luis Obispo	General Plan, Development Analysis, Impact Fee Calculations, Identification of Suitable Areas for Development	Submodel of the MPO model	City with input from the MPO	Only auto-trips modeled	MPO/CMA has tested use of 4Ds for visioning
West Sacramento	General Plan, Development Analysis, Impact Fee Program	Uses derivative of SACOG MPO model	Consultants, with assistance from MPO/CMA staff	Full transit modeling capability	Existing modes include walk, bicycle, and transit. Incorporates 4Ds as post-processor. MPO is testing an Activity-Based Model

5.4.1 Irvine[32]

Land-Use Planning Practice

How Land-Use Decisions are made

Like other cities in California, the City of Irvine General Plan provides guidance regarding land-uses for the area within the City's boundaries. The City's policy is to "promote land-use patterns that maintain safe residential neighborhoods, bolster economic prosperity, preserve open space, and enhance the overall quality of life in Irvine."

In addition to the City General Plan, land-use decision-making in Irvine is also heavily influenced by countywide and regional planning. A countywide plan establishes development targets that are reflected in long-range forecasts of population and employment. The forecasts are consistent with regional plans developed by SCAG for the six-county region that also includes Los Angeles, Orange, Riverside, San Bernardino, Ventura, and Imperial Counties. The Orange County Projections provide a common and consistent forecast for all local and regional agencies within the county as inputs into local transportation modeling and planning.

How Traffic Forecasts are Used in Land-Use Decisions

An EIR of the City's updated General Plan was prepared in accordance with CEQA. The Irvine Transportation Analysis Model (ITAM) was used in the EIR to assess the compatibility between the General Plan land-use element and circulation element, and to model the future traffic conditions and assess the development projects' impacts on the City's circulation system. The ITAM is also used for subarea studies.

The City also utilizes ITAM to establish "fair share" contributions from developers for needed improvements to the existing transportation system through mitigation measures. The "fair share" contributions are determined by estimating the percentage of the additional traffic (Average Daily Trips, or "ADT") that will be generated by the individual proposed developments compared to the cumulative ADT generated by all proposed or approved projects within the jurisdiction. This percentage of the cumulative mitigation payment established by the mitigation fee program is the "fair share" that the City requires each developer to pay.

Modeling Capability

Characteristics of the Travel Model Used for Land-Use Decisions

[32] Information for the Irvine case study was based on a telephone interview with Jimmy Chen of the City of Irvine and model documentation for the models of the City of Irvine, OCTA, and SCAG.

The current Irvine Transportation Analysis Model (ITAM 3.01) is a “focused” version of the Orange County Transportation Analysis Model (OCTAM). ITAM has approximately 600 zones covering the city and its “sphere of influence” area. The model roadway network was coded to be consistent with the OCTAM in terms of facility types, area types, and speed/capacity assumptions.

ITAM is a vehicle-based model without multi-modal modeling capability. The trip generation component of this model is based on the socioeconomic characteristics of each TAZ within the City. The socioeconomic characteristics are derived from data in the City’s land-use databases and Census data. The same five trip purposes in OCTAM are considered in the ITAM, as listed below:

- Home-Work
- Home-Elementary/High School
- Home-Other
- Other-Work
- Other-Other

Trip distribution in ITAM is based on the trip distribution in the OCTAM model. The trips from the regional trip table are aggregated into growth-factoring districts. Based on the changes in local land-use, growth factors based on trip rates associated with socioeconomic data are developed for each district and applied to the compressed trip tables. These compressed and factored trip tables are then disaggregated to ITAMs TAZs through a factoring process based on ITAM socioeconomic trip generation developed for each zone. Vehicle trips from the trip tables generated from the trip distribution components are then assigned to the roadway network using equilibrium highway modules based on minimum travel time and cost.

Four time periods are analyzed in the ITAM:

- Morning Peak (6:00AM-9:00AM)
- Midday Off-Peak(9:00AM-3:00PM)
- Evening Peak (3:00PM-7:00PM)
- Night Off-Peak (7:00PM-6:00AM)

The City of Irvine has used ITAM to forecast future traffic volumes for selected horizon years, which are subject to changes. For example, one modeling scenario may include a near-term projection (five to seven years out), a year 2025 projection, a post-2025 projection, and City build-out projection post 2040. In order to prepare the best possible estimate of future traffic conditions, a post-processing is performed using existing count data. Refined ADTs and peak-hour intersection turning movement volumes are the two main products of the post-processing procedures.

Relationship to County and MPO Models

As mentioned above, ITAM is a "focused" version of OCTAM, and is designed to meet county model consistency requirements in accordance with the "Sub-Area Modeling Guidelines Manual" developed by OCTA in 1998. The OCTAM model, in turn, is also a focused version of the regional travel model developed and maintained by the Southern California Association of Governments (SCAG). The OCTAM model varies from the SCAG model only in the zonal and network detail within Orange County. The structures of the two models, ITAM and OCTAM, are basically the same except that the ITAM model has a focus area approximating the boundary of the City. The ITAM roadway network coding procedure follows the OCTAM coding conventions in terms of facility types, area types, and speed/capacity assumptions.

For the area within Irvine, the ITAM model uses a zone structure that is more refined than that in the OCTAM. For regions outside the City boundary and within Orange County, the traffic analysis zoning system is exactly the same as the OCTAM. Outside of Orange County but within the SCAG boundary, each county or a Regional Study Area (RSA) is defined as a TAZ.

The City of Irvine has a comprehensive land-use database that is updated periodically when new information regarding development patterns and roadway improvements becomes available. The land-use data are converted to socioeconomic data in the trip generation component of the model. The conversion factors from floor area-based data to employment data are calibrated to match the regional socioeconomic data for the City, and to obtain consistent trip generation estimates between the local and the regional models.

Sensitivity to Smart-Growth and Transit Strategies

The current ITAM model has not been modified to incorporate smart-growth sensitivity in any of its modeling components, and no post-processing tools have been applied to assess smart-growth land-use or transportation strategies. The models maintained by OCTA and SCAG have some degree of smart-growth sensitivity. Both the OCTA and SCAG models include the following features:

- mode choice and transit modeling capabilities
- use multimodal composite impedances that capture travel time and cost in the trip distribution
- contain a feedback loop that uses travel times from assignment in distribution and mode choice in subsequent iterations of the model
- differentiate between linked and unlinked trips in the journey-to-work for better discernment of the likelihood of transit or ride-share mode choice
- provide a degree of income stratification for work trips, for better differentiation between worker and job type.

Incorporating Sensitivity to Smart-Growth Strategies

Incorporating smart-growth sensitive modeling in their travel models is still in the research stage for both the City of Irvine and OCTA regarding ITAM and OCTAM, and no tools or techniques have yet been applied by the two agencies in regard to this aspect. The City is planning to undertake an effort to include smart-growth elements in the next stage of local model updates by incorporating a 4-D post-processor and by making changes in the base travel model. The City also plans to modify the trip generation rates in the current model to reflect a new set of socioeconomic and neighborhood characteristics. Some of the socioeconomic characteristics being considered include auto ownership and household income. Some of the neighborhood features include: sidewalk width, distance between building and curb, parking availability (on- and off-street), and handicap ramp availability. A more detailed zone system and a finer roadway network will also be used within the city boundary. In addition, the City will include new mode choice and transit assignment procedures in the new ITAM model.

5.4.2 Fresno[33]

Land-Use Planning Practice

How Land-Use Decisions are Made

The City of Fresno General Plan contains many policies that provide direction regarding land-use decision-making. The City also encourages and promotes regional cooperation among local jurisdictions because land-use and planning decisions made by a local jurisdictions impact neighboring counties and cities. Some of the other agencies that have land-use and planning responsibilities include: Fresno County, the Fresno Local Agency Formation Commission (LAFCO), and the Fresno County Council of Governments (Fresno County COG).

The roles of these agencies are described below:

- Fresno County: To establish adequate spheres of influence and maintain the integrity of the County's General Plan - particularly in fringe areas.
- LAFCO: To review and approve proposals for annexation, district formation, city incorporation, and sphere of influence amendments.
- Fresno County COG: To foster intergovernmental coordination, undertake comprehensive regional planning with emphasis on transportation, provide for

[33] Information for the Fresno case study was based on telephone interviews with Darrell Unruh of the City of Fresno, Michael Bitner of the Fresno Council of Governments, and Marc Birnbaum of Caltrans District 6; also from documentation for the Fresno COG model and the final report of the San Joaquin Valley Growth Response Study.

citizen involvement in the planning process, and provide technical services to its members.

How Traffic Forecasts are Used in Land-Use Decisions

The Fresno COG is responsible for maintaining and operating the regional travel demand model that represents Fresno County**.** All modeling work and traffic forecasting activities for the local cities or county are being handled by Fresno COG**.** The regional model has been used in various EIRs and traffic impact studies. It is also being used in regional land-use planning to assess future traffic growth and impacts. The cities in Fresno County, including Fresno, use the regional travel model to assess traffic impacts for General and Specific Plans and for specific land-use development proposals. Some of the examples are listed below:

- General Plan modeling for the City and County of Fresno
- Regional corridor studies
- Traffic impact analyses
- EIRs
- Freeway efficiency modeling study

Modeling Capability

Characteristics of the Travel Model Used for Land-Use Decisions

The Fresno COG model uses the traditional UTMS modeling process. The roadway network in the current model consists of the roadway system as defined in adopted General Plans of the Cities of Clovis and Fresno, and the County of Fresno.

The model contains approximately 1,600 TAZs, which are the land-use analysis units of the model. Land-use information in terms of type, intensity, and location are used in the trip generation process to estimate the number of person trips that a household or employer will produce. The trips are then distributed between zones using a gravity model.

Five trip purposes are defined in the model:

- Home-Work
- Home-Shop
- Home-Other
- Work-Other
- Other-Other

A mode-choice module predicts how the trips will be divided among seven modes of travel:

- Walk
- Bicycle
- Motorcycle
- Auto
- Bus
- Train
- Plane

Trips are then assigned to the network separately for the six analyzed time periods: Daily, AM 1-hr, AM 3-hr, PM 1-hr, PM 3-hr, and Off-peak.

Relationship to County and/or MPO Model

The City of Fresno uses the regional travel model that Fresno COG maintains and operates.

Sensitivity to Smart-Growth and Transit Strategies

Modeling smart-growth and transit land-use strategies using the travel model for Fresno County is under development. Due to the large size of many of the TAZs, the current model is insensitive to many local growth characteristics. One of the model modifications is to develop a more detailed zone system.

Prior to the model update process, a Caltrans-funded study entitled the San Joaquin Valley Growth Response Study[34] was conducted for identifying innovative strategies to assess smart-growth strategies in the Fresno/Madera area. Phase III of this study involved a demonstration of the implementation of various "toolboxes" developed in Phase II of the study. A brief summary of this effort is provided in the following section.

Incorporating Sensitivity to Smart-Growth Strategies

The City of Fresno's experience with smart-growth sensitive modeling is limited. But because of the rapid population growth in that portion of the San Joaquin Valley and a vision to promote smart-growth in the region, a series of studies was conducted to identify innovative modeling processes to assess the effectiveness of smart-growth on reducing travel demand.

The San Joaquin Valley Growth Response Study had three primary goals:

1. To create a toolbox for local jurisdictions in Fresno and Madera Counties that would provide decision-makers better information regarding potential land-uses;
2. To integrate land-use, transportation, environmental, and market conditions; and
3. To identify the potential benefits of various smart-growth concepts.

[34] VRPA Technologies Inc, San Joaquin Valley Growth Response Sturdy – Phase II Final Study Report, June 24, 2005. http://www.dot.ca.gov/dist6/planning/sjvgrs/phaseIII/sjvgrs3_final.pdf

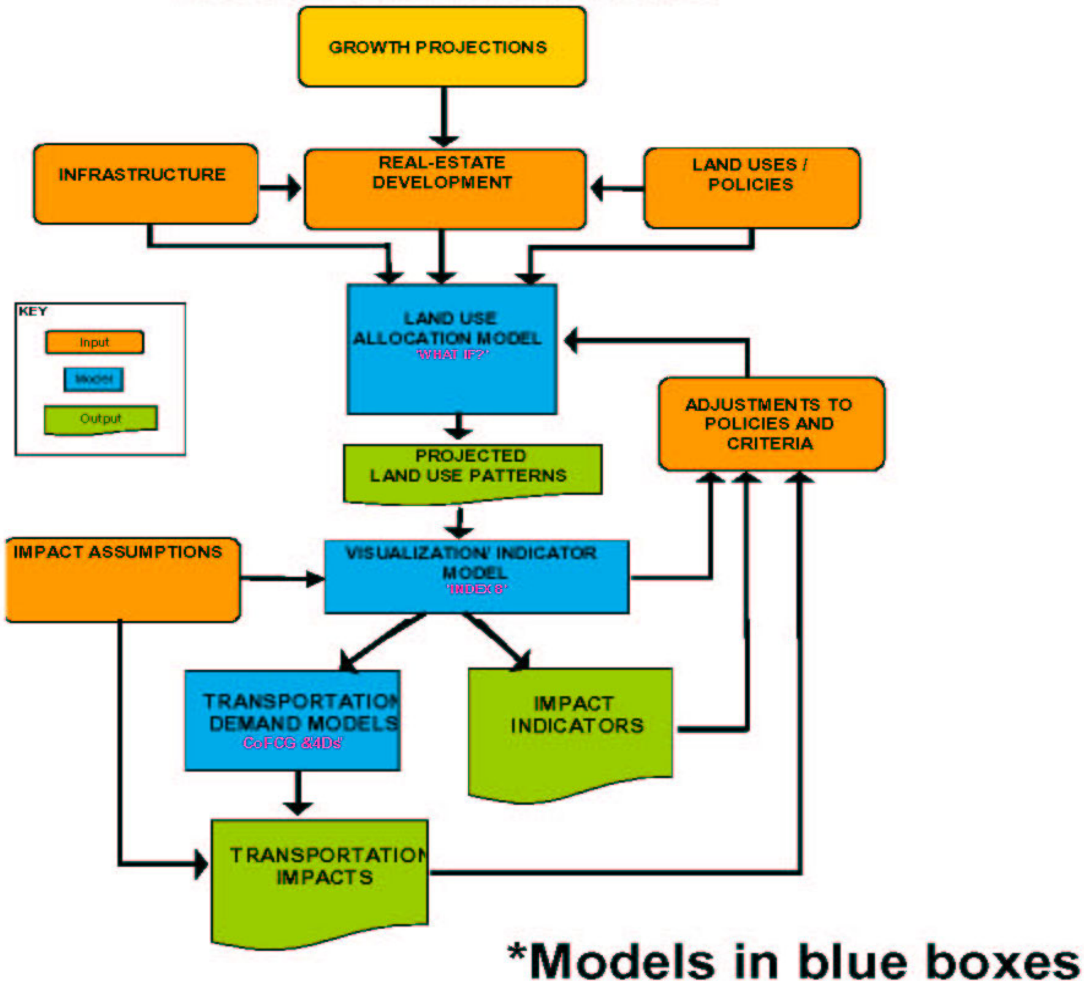
Phase III of the study introduced innovative modeling processes that added three new modeling components to the conventional UTMS Fresno County COG model. **Figure 5.1** provides an illustration of the San Joaquin Valley Growth Response Study modeling process. The first tool is *"What If?"*- a land-use allocation model, which was used to: map existing and future land-use and transportation patterns, define additional assumptions and directions for growth, provide comprehensive and coordinated mapping of existing and future land-uses, and develop demographic projections.

The second tool, INDEX, was used to develop various land-use and transportation scenarios, to estimate the effects of alternative development scenarios, and to assess land-use and demographic patterns. This information helped stakeholders understand how variations in land-use mix, intensity, and transportation may affect travel demand. These tools also provided more comprehensive land-use information for subsequent travel forecasting than was previously available.

The third new modeling component is the "4D post-processor" that enables the county travel demand model to more fully capture the effects of land-use Density, Diversity, Design, and access to regional Destinations by modifying the trip generation rates to reflect local changes in the 4D variables. (This process is described in **Chapter 4**.) The 4D post-processor begins by computing the differences between the initial model run and each alternative scenario regarding TAZ land-use characteristics such as: residential density, retail/non-retail job mix, sidewalk completeness, block size, and route directness. Elasticities for each of these TAZ characteristics were computed from household survey data and applied to the percentage differences in density, diversity and design between the Initial Run and each scenario being tested. The results are adjustment factors for the person trip generation for each TAZ and for each trip purpose. The final model translates the results from alternative scenarios into travel demand estimates compatible with the Fresno COG and Madera County Transportation Commission (MCTC) travel demand models.

In the course of implementing Phase III of the San Joaquin Valley Growth Response Study, several obstacles were overcome in order to run scenarios through the models and gauge their relative success at meeting performance indicators and goals that were defined by stakeholders who attended workshops. Many of these challenges were related to the state of the GIS data for both Fresno and Madera Counties. Some problems were related to the lack of correspondence between data acquired from the various planning authorities, while others were related to the function and interface of the models.

Figure 5.1 San Joaquin Valley Growth Response Study Model Process



Source of diagram: VRPA Technologies Inc, "San Joaquin Valley Growth Response Study – Phase II Final Study Report," June 24, 2005

A significant amount of time was spent during Phase III of the San Joaquin Valley Growth Response Study researching, translating, modifying, standardizing, and reconciling the various land-use, demographic, and environmental datasets. For example, scenarios were developed based on parcel-level data because this level of detail was needed for the INDEX indicators to be as meaningful as possible. However, demographic projections and inputs for the TP+ traffic models use a TAZ geography, which cannot be easily reconciled back to the parcel level. The lack of detail in the TAZ files for existing and 2025 future data made it challenging to engage the understanding of the local jurisdictions on issues such as the potential for revitalization and redevelopment. This is of prime importance if an area is looking to preserve valuable agricultural land while maintaining its preference for low-density development and encouraging higher-density, highly accessible housing development.

The Phase III Study utilized four modeling tools, which required the preparation of data in different ways. If such tools are to be used on a regular basis, a procedural standard should be developed to convert the collected data into the input formats needed for each of the models. A checklist of inputs required for the models should be maintained before data collection. This will help focus the acquisition of data from different sources. If efforts are made to provide a comprehensive, standardized, and detailed GIS data set, the majority of issues that were encountered during this effort would be minimized, and the power of these models could be more fully realized and result in a more streamlined process.

Study Conclusions

The study team concluded that the What If?, INDEX, and transportation model/4D post-processor tools provide an opportunity to improve the understanding of the interrelationships between land-use and transportation and the benefits of smart-growth strategies. The study team expects that, over time, required data and data gathering practices will ease the functionality of the models for the Study Area and the local jurisdictions interested in applying the models to further enhance their planning processes and help the jurisdictions make better informed decisions regarding growth and development. Two new planning efforts are expected to use these modeling tools.

5.4.3 San Diego[35]

Land-Use Planning Practice

How Land-Use Decisions are Made

Land-use decisions in the City of San Diego are guided by the policies or regulations in the City's General Plan, which is designed to complement and support long-range growth-management strategies throughout the region. As part of the City's General Plan, a number of Community Plans specifically designate the distribution and location of land-uses at smaller geographic levels of community or neighborhood areas throughout the City. The General Plan also provides recommended density or intensity ranges for each category of land-use.

The City of San Diego recently updated its General Plan to include a new mobility section that presents a wide range of policies to advance a strategy for congestion relief and increased transportation choices, and to target future growth to areas that are or will be served by the regional transit system.

The San Diego Association of Governments (SANDAG) has had an encouraging role on land-use planning, and the City General Plan reflects the policies and recommendations in the SANDAG Regional Comprehensive Plan. The City has also had a leading role in regional planning, and continues to coordinate and work closely with SANDAG in refining the regional land-use structures and transportation networks for the region.

How Traffic Forecasts are Used in Land-Use Decisions

The City of San Diego uses its local travel model to analyze General Plan and Community Plan Updates, Capital facilities planning, development project traffic impact assessments, and EIRs.

As part of these processes, travel forecasts are used to:

- Identify a circulation system that provides sufficient mobility options.
- Assess various future land-use alternatives.
- Help guide future roadway and circulation system decisions.
- Project future locations and volumes of automobile and transit travel based on future land-use assumptions.
- Identify potential locations of future traffic congestion and evaluate roadway and transit improvements in conjunction with various land-use alternatives.
- Forecast the character of service for streets and help define their design characteristics.

[35] Information for the San Diego case study was based on telephone interviews with Linda Marabian of the City of San Diego and Bill McFarlane of SANDAG, as well as documentation for the SANDAG model.

Travel forecasting has also been used in a Development Impact Fee Program for new land-use projects in the region. The travel model is used to assess additional ADT or traffic volumes on roadway networks associated with proposed land-use developments in different communities of the City. These forecasted volumes are then assessed to determine the amount of traffic impact fees that developers are required to pay. Traffic impact fees vary among different types of land-uses and in different locations in the City.

Modeling Capability

Characteristics of the Travel Model Used for Land-Use Decisions

SANDAG currently uses four models to produce regional travel forecasts: (1) the Demographic and Economic Forecasting Model (DEFM), (2) the Interregional Commuting Model (IRCM), (3) the Urban Development Model (UDM) and (4) the Transportation Forecasting Model (TransCAD).

The City of San Diego operates a local travel model that is based on SANDAG's regional transportation forecasting model that has the same structure as SANDAG's model. The SANDAG travel model is a conventional four-step model that has two iterations or stages. In the first stage of application, the model generates person trips by applying trip generation rates to households stratified by household type, and the amount of non-residential land stratified by land-use type. Ten trip purposes are considered in the model:

- Home-work
- Home-college
- Home-school
- Home-shop
- Home-other
- Work-other
- Other-other
- Serve passenger
- Visitor
- Regional airport

The model then determines trip destinations using a gravity-based model, which distributes trips according to a mathematical relationship between the number of trips generated from, or attracted to, an area and its travel time from other areas. It then allocates trips to various modes as follows:

- Drive alone
- two-person carpools
- three-or-more-person carpools
- local bus
- trolley

- commuter rail
- bicycle and walk

Finally, the trips are assigned to highway and transit segments that provide the shortest travel time between TAZs.

In the second stage, the congested travel times from the first stage traffic assignment are fed back to the second-stage trip distribution and subsequent steps, in which the trips are redistributed and assigned in a more rigorous manner.

SANDAG's transportation model was calibrated to data collected in 2000. During this process, model parameters were adjusted so that model-estimated transit and highway volumes would match year 2000 observed data based on year 2000 demographic, land-use, and transportation network inputs.

Three time periods are analyzed in the model: AM peak-period, PM peak-period, and off-peak. Traffic volumes are forecasted for the year 2020, and recently, year 2030 traffic forecasts have also been accomplished.

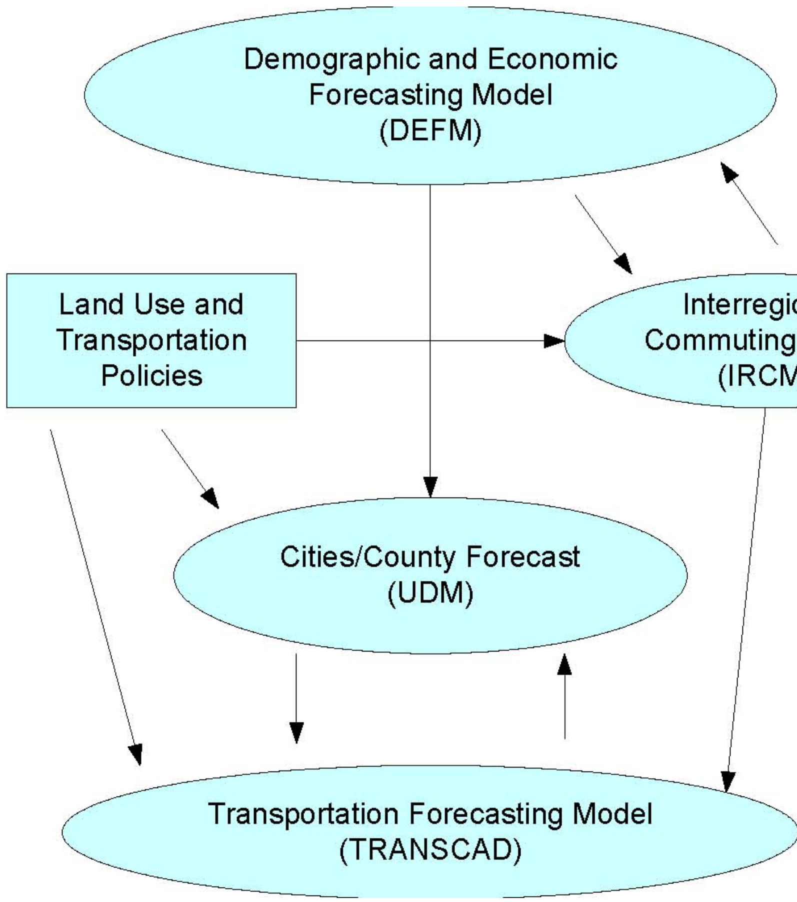
Relationship to County and/or MPO Model

The City of San Diego's travel model is a "focused" version of the SANDAG regional travel model. The model structures and components are exactly the same between the two models. The City of San Diego coordinates closely with SANDAG regarding any land-use element changes to make sure that both models consistently incorporate the latest land-use data available.

In order to model roadway details down to the City level, the regional model roadway network was revised to include more refined information that closely matches the City's roadway systems. For example, the City modified the number and location of nodes and also added some attributes to individual links including speed and the number of lanes to its model. The entire model, with the updated roadway network and elements, was then calibrated based on traffic counts and survey data collected.

Figure 5.2 illustrates the modeling process and the flow of information from model to model. A feature of the modeling system is the feedback of information from one model to another, particularly between the travel models and the economic/land-use models.

Figure 5.2 Final 2030 SANDAG Forecast Models



Source: SANDAG, Final 2030 Forecast Process and Model Documentation, March 2004.

Sensitivity to Smart-Growth and Transit Strategies

Both SANDAG and the City of San Diego have a vision of promoting smart-growth land-use and encouraging the use of public transit and non-motorized travel. SANDAG's 2020 forecast is the first forecast to consider smart-growth development patterns in the region. Smart-Growth assumptions used in the model were not meant to be consistent with the existing local land-use plans, but were developed to simulate increased densities in transit corridors. In the 2030 forecasts, however, adopted general plans and policies for the various incorporated jurisdictions within the County were used as land-use inputs for the model. Concurrent to the introduction of smart-growth inputs was the revision of the transit network coding of the model. The new transit network was designed to accommodate Regional Transit Vision concepts and better reflect improved "walkability."

Incorporating Sensitivity to Smart-Growth Strategies

The City of San Diego has worked closely with SANDAG on promoting transit-oriented land-uses and mobility in the region. The smart-growth land-use policies adopted by the City of San Diego are incorporated as the land-use input of the regional model. These policies, presented in the Mobility section of the City General Plan, provide for an allocation of a higher concentration of development density near highly active transit areas. Under the new policies and regulations, auto travel is no longer considered the highest priority; instead, other modes of transportation are comprehensively considered.

SANDAG has taken many steps to incorporate smart-growth sensitivity in the regional model. Some of the key features that improve the model sensitivity include the following:

- Use of small zones
- Inclusion of non-motorized modes
- Use of walk-access adjustments for transit based on topography and street patterns
- Linkage of the economic and demographic forecasting models with the travel-forecasting model

Both the SANDAG and the City of San Diego travel models reflect an increase in transit ridership, and both agencies are satisfied with the travel forecasts from the models. The City of San Diego has completed a test and validation for the local model that has the smart-growth land-use policies incorporated. The population growth and transit ridership were compared for both the existing year and a future forecast year. The City found that its model provided a noticeable and reasonable increase in the use of transit and walk trips with the smart-growth land-use inputs. The City also purposely selected one transit line for model checking/validation, and again the model reflected the expected change in transit ridership.

5.4.4 San Jose[36]

Land-Use Planning Practice

How Land-Use Decisions are Made

Land-use decisions in the City of San Jose are guided by the policies and regulations in the City General Plan. For some sub-areas, Special Strategy Areas (i.e., Area Development Policy, Planned Community, and Specific Plan) provide more detailed direction such as land-use, development, urban design, and neighborhood revitalization.

Each proposed land-use development project goes through a Development Review Process. Included in this process are several different review categories: zoning, planned development permits, site development permits, and environmental review.

How Traffic Forecasts are Used in Land-Use Decisions

The City uses its travel model for a variety of purposes, including General Plan Amendments, comprehensive General Plan Updates, and corridor studies. Traffic forecasts are also used in Traffic Impact Studies (TIS) and EIRs to assess the level of traffic impact anticipated for proposed new developments.

The City of San Jose maintains a land-use database with information on the future dwelling units and employees projected in each of the TAZs. This is used as the basis for distribution of trips on the transportation network and analysis of long-term traffic patterns in the City. The City updates this database annually or as warranted to reflect the build-out of land-use in the General Plan or for updates to the General Plan.

For North San Jose, the City's travel demand model is used to determine traffic impact fees for new developments in the area. The number of additional trips projected to be added to the roadway network by planned or proposed developments is forecast using the travel model. A cost per vehicle trip for the anticipated growth is calculated by dividing the total package cost of improvements by the increase in PM peak-hour trips. This cost per trip is then multiplied by the land-use trip rates estimated by the travel model to determine the applicable impact fee for each land-use. This Impact Fee Program only applies to North San Jose. For other parts of the City, all new developments are required to pay the cost for improvements as established by specific mitigation measures.

[36] Information for the San Jose case study was based on a telephone interview with Paul Ma of the City of San Jose and documentation for the models of the City of San Jose, SCVTA and MTC.

Modeling Capability

Characteristics of the Travel Model Used for Land-Use Decisions

The City of San Jose's travel model is based on the MTC regional model with a focus within the Santa Clara County boundary. MTC's regional model, BAYCAST-90, is a conventional UTMS model that encompasses the nine-county San Francisco Bay Area. It is used to develop Regional Transportation Plans and to prepare travel forecasts for major regional corridor studies. The AMBAG (Monterey) and San Joaquin region are added to the south and southeast of the MTC region to more accurately estimate interregional trips attracted to the Santa Clara County sub-region.

MTC's model has two extra main models: "workers in household" and "auto ownership choice." These extra models generate market segment estimates of the number of households by household income, by workers in household, and by auto ownership level for each travel analysis zone (TAZ).

The trip generation components of MTC's regional model include both trip production and trip attraction models. Except in the home-based school trip generation model, all of the trip generation models use multiple regression analysis. The home-based school trip model is a hybrid of a cross-classification model and a multiple regression model.

The five trip purposes considered in trip generation are as follows:

- Home-Based Work
- Home-Based Shop/Other
- Home-Based Social/Recreation
- Home-Based School
- Non-Home-Based

Home-Based school trips are further broken down into:

- Home-Based School: Grade School
- Home-Based School: High School
- Home-Based School: College

Trip distribution models are a gravity form with friction factors. Data from the 1990 Census-based "observed" home-based work trip tables were used in calibrating these friction factors. In addition, socioeconomic adjustment factors are used in calibrating and validating trip distribution models.

The mode-choice model for each of the trip purposes mentioned above is a nested logit model except for home-based grade school trips. A unique characteristic of the travel model is that both AM peak and off-peak-period travel times and trip cost are used in the model application so that the trip purposes are sensitive to changes in both the peak and off-peak-periods.

There are in total seven modes of travel considered in MTC's mode-choice model:

- Drive Alone
- Shared Ride 2+
- Shared Ride 3+
- Auto Access Transit
- Walk Access Transit
- Bicycle
- Walk

Transit is further broken down into commuter rail, bus, express bus, and light rail inside Santa Clara County.

The trip tables generated from the mode-choice models are used for trip assignment. Auto person trips are factored using peaking factors derived from household travel surveys. The trips are then divided by appropriate vehicle occupancy levels to convert to vehicle driver trips before assigning to networks.

Trip assignment is done separately for the following five analyzed time periods: AM 1-hr, PM 1-hr, AM 3-hr, and PM 3-hr. In each of these time periods, volumes by mode of travel are produced.

Although a time-of-day choice model is included in the MTC regional model, the City of San Jose's model uses a conventional approach of diurnal factoring derived from the travel survey to estimate peak-hours and peak-periods travel demands.

Year 2030 travel forecast is available for both MTC's BAYCAST and the Silicon Valley Transportation Agency model. In addition, travel forecasts for year 2020 are prepared for the City of San Jose's purposes.

Relationship to County and/or MPO Model

San Jose's model components, model parameters, and procedures are exactly the same as the MTC model, except that the zonal system and network inside the Santa Clara County sub-region have been enhanced for finer detail. Within that sub-region, smaller TAZs are defined in order to better reflect walk trips to transit in high transit activity zones. More sub-modes of transit and constraints for parking at transit stations were also introduced in the San Jose model network.

The trip generation, trip distribution, and mode-choice model components of San Jose's model were re-calibrated due to the introduction of new zones and a new mode-choice structure. The model forecast was validated against highway counts and transit ridership data to ensure that the model maintains consistency with the original MTC base model validation.

Sensitivity to Smart-Growth and Transit Strategies

Some of the new components and features that are included in San Jose's travel model allow better reflection of smart-growth land-uses and transit-oriented development strategies in the region. Because transit is a significant mode of travel in the City, especially for home-based work trips, the mode choice component of the local model was enhanced to estimate ridership for more sub-modes of transit: light rail, bus, express bus, commuter rail, and heavy rail. The mode-choice model results were calibrated against observed trips for each of the transit sub-modes.

Another unique feature added to the local travel model was the transit station park-and-ride constraint in the home-base work mode-choice models. This constraint takes into account the fact that parking capacity and demand at transit stations would affect mode choice selection of other modes of travel by introducing a "shadow" parking cost variable to relate parking demand and capacity.

Experience with Modeling for Smart-growth and Transit

San Jose has used the current local travel model to study smart-growth and transit-oriented land-uses. The City, in general, has had a positive experience with the model's performance. With new land-use, new projections inputs, and network modifications, the model has added sensitivity regarding how smart-growth strategies affect vehicle travel. One example is the 2000 BART Extension Study in which the results generated from the City's model projected a reasonable reduction in vehicle travel in the area.

The City of San Jose has no specific plans to add additional supplemental tools or techniques to the current model to enhance its smart-growth sensitive modeling capabilities. The City has indicated that - if MTC makes major changes to the regional model - the City would probably also adopt those changes.

In 2003, a set of short- and long-term strategies were proposed for assessing effects of smart-growth and transit-oriented development in the MTC model.[37] These include:

- Strategy #1: Update zonal allocation procedures to incorporate new Census 2000 journey-to-work data. That is, the proportion of households and jobs within a census tract may need to be adjusted to account for development shifts.
- Strategy #2: Update the future year zonal allocation procedures in MTC's "split tract" zones to incorporate smart-growth allocation of jobs and housing.
- Strategy #3: Apply improved procedures to predict the proportion of multi-family dwelling units for all travel analysis zones
- Strategy #4: Review and update single family and multi-family household data in smart-growth neighborhoods

[37] Duruis, Charles, "Incorporating the Effects of Smart-growth and Transit Oriented Development in San Francisco Bay Area Demand Models: Current and Future Strategies," for the Metropolitan Transportation Commission, November 2003

MTC has also proposed three short-term and two long-term strategies for adjustments to travel model networks:

- Short-term Strategy #1: Adjust auto network to reflect higher density compact development
- Short-term Strategy #2: Adjust transit network walk access connector links to reflect higher density, compact development.
- Short-term Strategy #3: Adjust intra-zonal travel times for auto, transit and non-motorized networks to reflect higher density, compact development within smart-growth neighborhoods
- Long-term Strategy #1: Produce a geographic market segmentation of zones to represent portions of zones with very short walks (< 0.25 miles), moderate walks (0.25-0.50 miles), long walk (0.5-1.00 miles) and not walkable (> 1.00 miles) to transit.
- Long-term Strategy #2: Create distinct and different networks and intra-zonal travel time calculations for walk and bicycle travel modes.

5.4.5 San Luis Obispo[38]

Land-Use Planning Practice

How Land-Use Decisions are Made

The City follows its General Plan and related zoning directives while taking into consideration San Luis Obispo Council of Governments (SLOCOG) and County projections. Decisions regarding proposed land-use projects and modifications to the General Plan and zoning ordinance are first assessed by advisory committees that make recommendations to the City Council.

Surrounding San Luis Obispo is a buffer geographical area - the "sphere of influence" - in which decisions are contingent upon City approval. The sphere of influence is based on a Memorandum of Agreement between the City and the County of San Louis Obispo for urban services that identifies urban boundaries, discourages sprawl, and helps preserve open space between communities.

The City uses a GIS zoning map and a detailed listing of properties to help direct development to specific sites for office space, retail, industrial, and shopping land-uses.

How Traffic Forecasts are Used in Land-Use Decisions

The City has modeled traffic since the early 1990s. In 2000, traffic model information was converted to a GIS-based software application (TRANSCAD) to increase detail and compatibility with other City GIS systems. The Public Works Department maintains a GIS suite of models that potentially could perform analysis on a parcel-by-parcel basis.[39]

Approximately 90% of model applications are to estimate traffic impacts of proposed land-use development projects and to analyze potential impact fees. The remaining 10% is for assessment of major capital improvements. A small amount of time and effort is dedicated to using the model for long- range visioning and planning. In the next two years, the City expects to update the model that may include more detailed land-uses, socioeconomic variables, travel and modal assignment integration, and better coordination with the SLOCOG travel model.

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[38] Information for the San Luis Obispo case study was based on telephone interviews with Tim Bochum, Kim Murry, and Brian Leveille of the City of San Luis Obispo and documentation for the SLOCOG model.
[39] http://maps.slocity.org/website/zoning/viewer.htm

Modeling Capability

Relationship to County and/or MPO Model

The City model predates the SLOCOG model by about ten years. There have been significant differences between the models primarily because the City has detailed land-use information that may not be available in other areas of the county. SLOCOG completed an update of its travel model in December 2006 that included sub-regional integration of the two models. The new SLOCOG model includes all of the zonal detail of the City model and all City streets. There is an ongoing exchange of information and data for model calibration between the City and County.

Sensitivity to Smart-Growth and Transit Strategies

The City embraces smart-growth principles; however, it does not use a travel model with smart-growth sensitivity for land-use decisions. In its most recent model update, SLOCOG incorporated application of three of the 4D elasticities: Density, Diversity and Design. However, this model is a vehicle trip-based model and does not include mode choice or travel by non-motorized modes.

Experience with Modeling Smart-Growth and Transit Strategies

SLOCOG has undertaken a 2050 visioning effort using the I-PLACE3S planning tool. The City also ultimately expects to use I-PLACE3S, but some key discrepancies in method and data first need to be worked out. The City has provided key data to the County for the I-PLACE3S travel component.

City officials are participating in visioning exercises that make use of the UPLAN GIS-based planning tool (provided by UC Davis) and also anticipate using I-PLACE3S. City staff have expressed concern with the data quality and content because some of the data required for the types of scenarios analyzed do not exist at the county level.

From the SLOCOG viewpoint and from experience with the Visioning 2050 effort (via the Caltrans Blueprint Planning Grant Program), many details still need to be determined, including roles and responsibilities as well as decision-making domains. Conceptually, there is support for this type of visioning using modeling, but practically there are many barriers to implementation. Uncertainty about the usefulness of model outputs exists due to concerns about data input and model assumptions. Model outputs and how the information may be used are difficult to communicate to decision makers. There is general consensus that collaboration in model development is occurring, and that dialogue will eventually lead to a modeling platform that exchanges information between various modeling software used for forecasting purposes.

5.4.6 West Sacramento[40]

<u>**Land-Use Planning Practice**</u>

How Land-Use Decisions are Made

West Sacramento is located across the Sacramento River from downtown Sacramento. The City of West Sacramento is addressing many issues, including: improving transit service, industrial development related to water- and highway-based goods movement, and redevelopment of major tracts. The City and its leaders have also been active supporters of the SACOG regional Blueprint initiative that is promoting smart-growth through infill development in the urban core.

How Traffic Forecasts are Used in Land-Use Decisions

The City of West Sacramento updated its travel model in May 2005. Like the previous version, the model is used for:

- General Plan and Specific Plan amendments and updates
- Development-related traffic studies
- Traffic Impact Fee assessments and updates
- Scenario analyses of land-use policies and programs
- Transportation improvement projects
- Transit studies

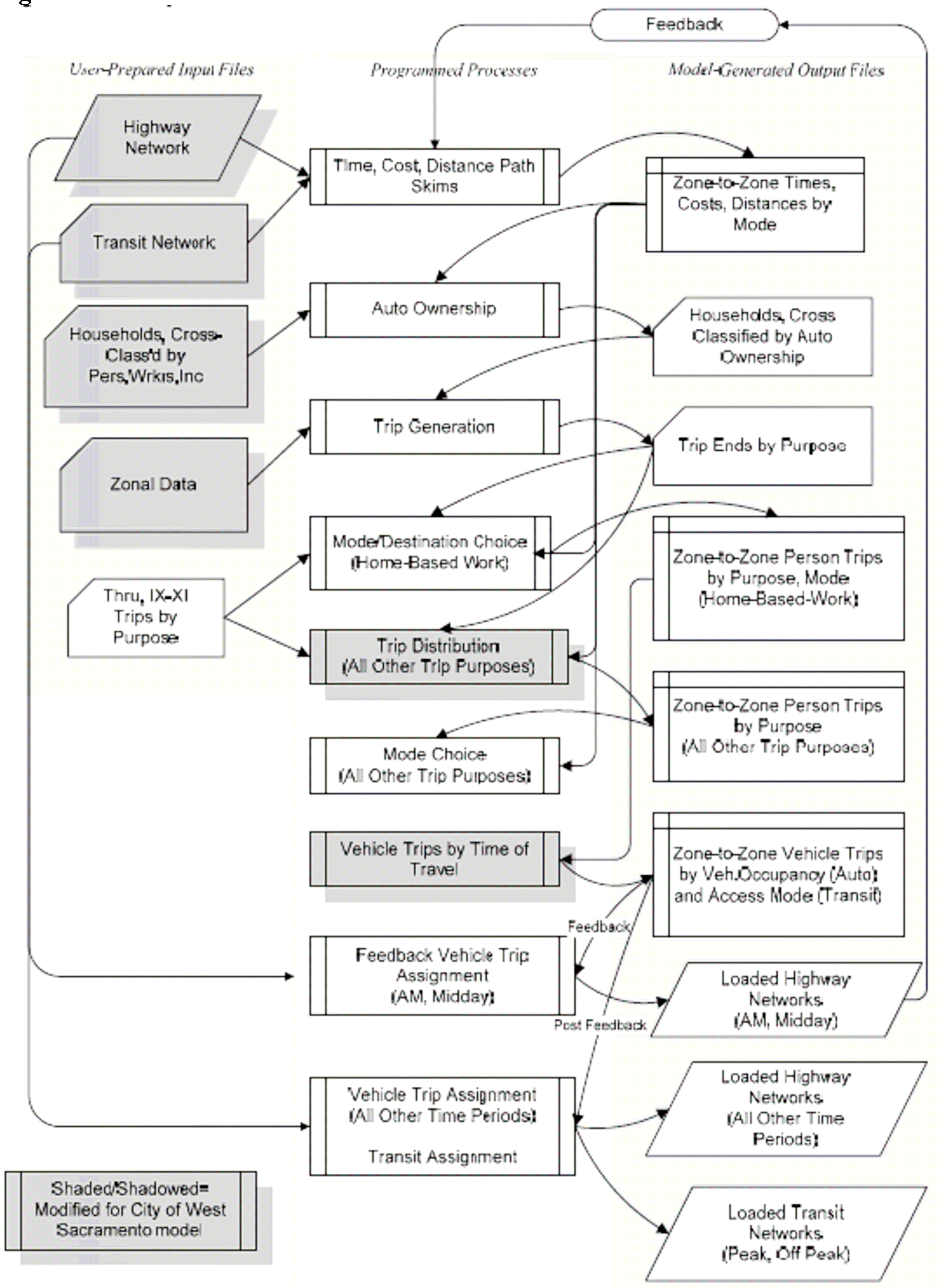
<u>**Modeling Capability**</u>

Characteristics of the Travel Model Used for Land-Use Decisions

The West Sacramento uses a windowed version of SACMET, the regional travel model developed and maintained by the Sacramento Area Council of Governments (SACOG). The City's model has most of the capabilities of this sophisticated regional travel model. The model structure is illustrated in **Figure 5.3**.

[40] Information for the West Sacramento case study was based on telephone interviews with Bruce Griesenbeck of SACOG and documentation for the models of West Sacramento and SACOG.

Figure 5.3 West Sacramento Travel Demand Model Structure



Source: DKS Associates, 2004 *Traffic Demand Model Update Final Report*, prepared for the City of West Sacramento, May 2005.

Shaded/shadowed boxes in Figure 5.3 indicate model elements that are significantly modified from SACOG's regional travel model for use in the City model. West Sacramento's model includes the SACMET looping structure to ensure that key model components, such as trip distribution and assignment, "converge" (i.e., that the results of final model outputs for network "skims" are equal to the skims used for trip distribution and mode choice).

The West Sacramento model includes the following trip purposes:

- Home-based work
- Home-based shop
- Home-based school
- Home-based other
- Work-other
- Other-other

Mode choice analysis is conducted for the following modes:

- Drive alone
- Shared ride, 2 occupants
- Shared ride, 3 or more occupants
- Transit, walk access
- Transit, drive access (park and ride)
- Walk
- Bicycle

Assignments are conducted for the following time periods:

- 3-Hour AM Peak-period
- 3-Hour PM Peak-period
- 5-Hour Midday
- 13-Hour Evening/Nighttime
- AM Peak-hour
- PM Peak-hour

Some of the key features of the West Sacramento and SACMET models that enhance their sensitivity to smart-growth strategies include the following:

- Modeling of all person trips
- Mode choice for all travel modes, including non-motorized modes and transit by mode of access
- Incorporation of a "pedestrian friendliness factor" in prediction of walk mode share
- Inclusion of number of workers in household stratification
- Inclusion of housing type in trip generation rates

- Use of an accessibility measure in trip generation
- Use of GIS and parcel data for land-use detail
- Feedback of congestion auto travel times from assignment to trip distribution and mode choice.

Relationship to County and/or MPO Model

The West Sacramento model is based on SACOG's SACMET travel demand model structure. To fully meet the City's needs, major refinements to SACMET were performed:

- The zone system, roadway network, and transit network contain more detail within the City of West Sacramento.
- The SACMET rule-based household cross-classification process was replaced with a cross-classification system based on dwelling unit type.
- The SACOG minor zone land-use data within the City of West Sacramento were replaced with GIS-generated data for both the base year and future years.

Table 5.3 provides a tabulation of the key model elements and their relationships to the SACMET model.

Table 5.3 Comparison between West Sacramento and SacMet Models

Model Element	Within City	Outside City Areas
Zone System	New system of 138 zones	1112 SACMET zones
Roadway Network	Refined roadway network, corrected to geograhy	SACMET roadway network
Transit Networks	Refined routing and service frequencies	SACMET routing and service frequencies
Zonal Data--Population	Generated from GIS and Other Sources	SACOG Projections
Zonal Data—Employment	Generated from 2002 SACOG/InfoUSA Survey and Other Sources	Carried over from SACMET
Through Trip, External Trip Files	n/a	Carried over from SACMET
Household Cross-Classification System	Developed from 2000 Census, differentiated by residential structure type	Carried over from SACMET (1990 Census, differentiated by area)
Schools Data	Developed from WUSD Data and Plans	Carried over from SACMET
Validation Data	Developed Available City and Caltrans Counts	n/a
Source: DKS Associates, March 2005.		

Sensitivity to Smart-Growth and Transit Strategies

When undertaking the update of its travel demand model, the City also requested that the new model account for smart-growth effects not likely to be captured directly by the travel model. A test application of the 4Ds post-processor developed by SACOG for use in SACOG's "Blueprint" land-use/transportation education and planning process was adapted for use with the City model. The 4Ds post-processor utilized elasticities for adjusting SACMET model output. The post-processor was developed based on the following assumptions:

- The SACMET travel demand model reflects part, but not all, of the 4Ds factors' effect on trip-making behavior.
- The smart-growth effects that SACMET does not account for can be observed in the Year 2000 Household survey.
- Elasticities were estimated using a form of regression analysis by Fehr & Peers using the regional travel survey. Separate elasticities were estimated for each of the 4Ds factors by trip purpose.

Some modifications to the SACOG 4Ds spreadsheets were made for the City of West Sacramento model application. The SACOG post-processor was developed in large measure to account for aggregation bias in the SACMET regional travel model. Because the TAZs are quite large in the regional model, travel interactions within TAZs were poorly modeled. The SACOG post-processor was designed to compensate for this.

Because the City model TAZs were already split into smaller areas (25 SACMET TAZs were split to 138 City TAZs), the need to compensate for this aggregation bias was reduced, and so the elasticities estimated for the SACOG spreadsheet were reduced. Land-use data to support the calculation of the 4D variables were derived from parcel data rather than from model zonal data, thus providing greater disaggregation.

The resulting vehicle trip adjustment factors were applied to the cumulative peak-hour vehicle trip tables and re-assigned. However, the adjustments did not result in any change in level of service deficiencies or the need for additional transportation improvements.

Experience with Modeling for Smart-growth and Transit

Since the updated model was completed, it has been used in the evaluation of several major development proposals in West Sacramento. In these assessments, the 4D post-processor has been tested but not used for decision making about the development projects. This is because City staff and the City's modeling consultant (DKS Associates) have raised concern that the application of the 4D elasticities may be double-counting some of the benefits of smart-growth strategies because the City's basic model already accounts for some of these effects. These effects potentially include: diversion of auto trips to transit and non-motorized modes due to transit-oriented or pedestrian-oriented design; reduction of trip length when higher density or mixed land-use provides

convenient, close destination opportunities; and the diversion of trips to transit that results from improved service and development of higher densities near transit.

Development of the 4Ds post-processor for use with the SACMET model has continued by SACOG for project applications in the region. For several major projects in other areas of the Sacramento region, DKS has used SACMET and the 4D elasticities with a dampening of the effects to acknowledge the degree to which the baseline model is already capturing some of the effect.

SACOG is also developing an activity-based model, and testing of the model is underway. While the results of the analysis of the results are not yet final, it appears that the new activity-based model has added more sensitivity to smart-growth strategies for the Sacramento Area Regional travel model.

Chapter 6

Sensitivity Test of 4D Elasticities

6.1 Overview of the Sensitivity Tests

This chapter presents the results of sensitivity tests conducted with the 4D elasticities to a case-study data set. The sensitivity tests were conducted to provide an illustration of how the 4D elasticities can be used, the difference they can make in assessing the potential benefits of smart-growth strategies, and the steps that are necessary to ensure proper application of the elasticities.

The sensitivity tests were conducted using the INDEX tool in a sample application using a database from West Sacramento. The INDEX application is created using GIS data downloaded from the City's website. The application contains hypothetical development scenarios intended to test the software's ability to reflect travel impacts of various mixed-use and transit-oriented development patterns**.** It is important to note that these sensitivity tests represents one user's application of INDEX with one data set, and results may vary in other situations, using other applications, and with different users.

Although the software INDEX is chosen for the study, the testing is essentially focused on the use of 4D elasticities. For travel impact assessment (i.e., VMT and VT per capita measurement), INDEX implements the 4D elasticities that are represented in **Table 4.1**.

6.2 Development of INDEX Sensitivity Tests

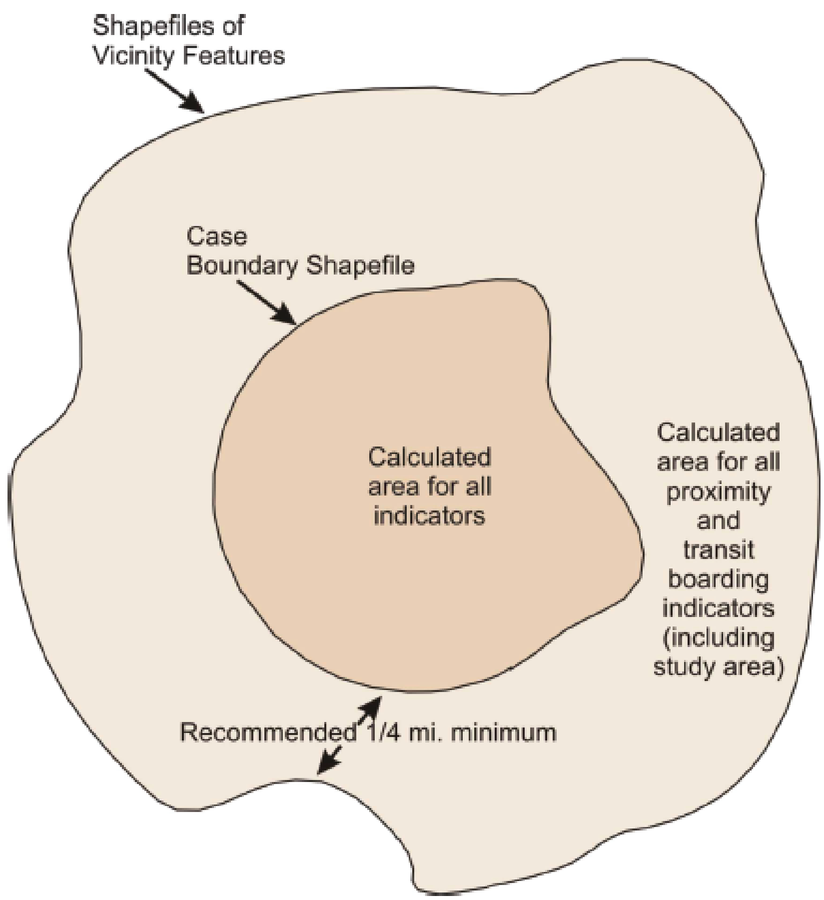
An INDEX study requires a series of GIS layers representing natural and man-made features in a study area. The number and combination of layers will depend on the context and extent of the study. For example, if storm water management is of concern for a community, GIS layers of slope and storm-water management practice need to be included. For this case study, the main objective is to evaluate travel impacts; thus all of the layers included are related to the multi-modal facilities for traveling in the study area. The GIS layers included for the study are: Case Study Area, Land-use Parcels, Street Centerlines, Pedestrian Routes, Transit Lines, Transit Stops, and Points of Interest.

6.2.1 Case Study Area

The case study area defines the geographic area for which indicators are calculated and mapped. **Figure 6.1** illustrates a typical study area configuration. The case study area should be derived from the study's scope and objective. Sizing of the case study area in

relation to the subject being studied is important because it can affect the magnitude of change that is estimated. For example, a small development proposal inside a large study area will not significantly change baseline scores versus the same proposal measured in a smaller study area that would produce major baseline changes. The case study area should be set to capture the logical spatial extent of a project's impact.

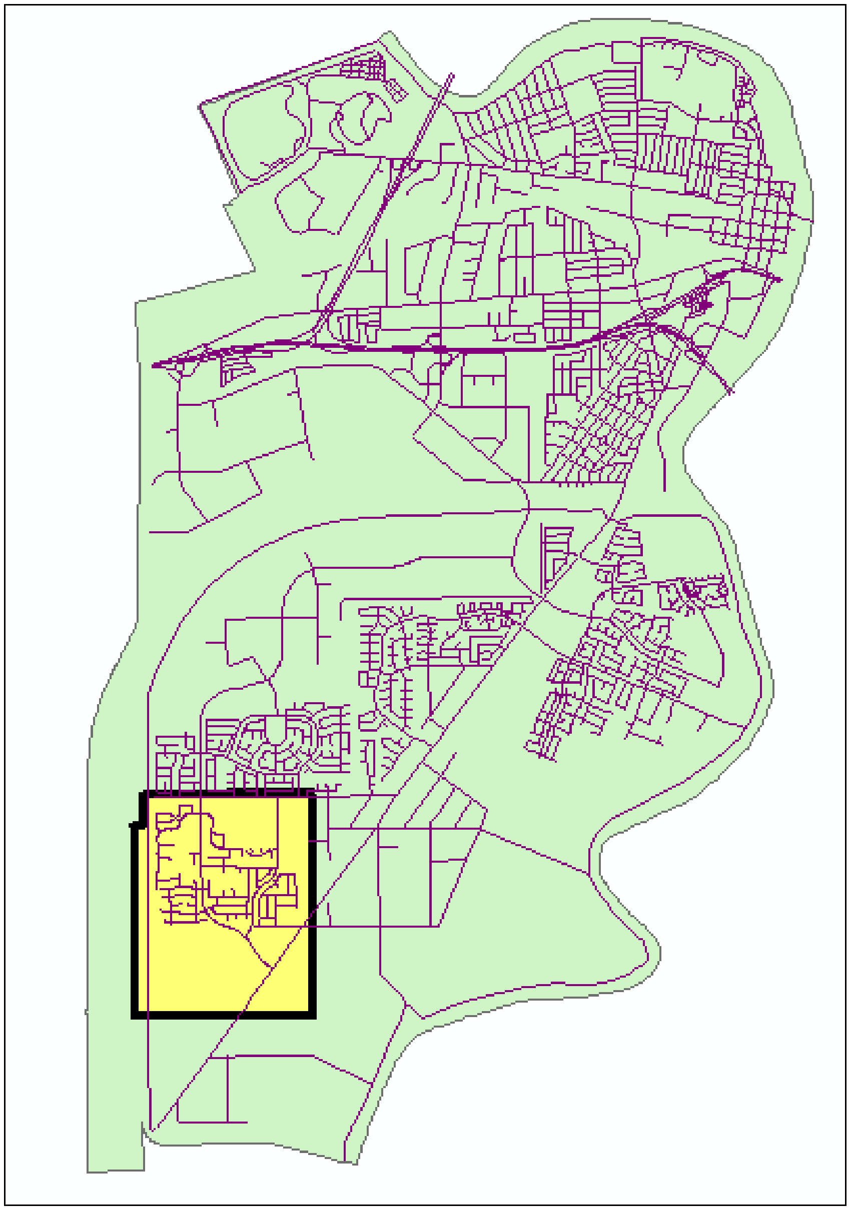
Figure 6.1 Case Study Area Illustration[41]



For this case study, a study area of approximately 1,000 acres (1.49 square miles) and 9,000 feet (1.7 miles) in diameter was selected. The size of the area was determined according to the guidance provided in the INDEX documentation (e.g., less than two miles in diameter or 2,000 acres in area). The study area (**Figure 6.2**) was selected because a portion of the area is currently vacant or designated for medium and low-density residential development, so a hypothetical mixed-use development can be placed within the study area to test the software's sensitivity to such a proposal.

[41] "INDEX PlanBuilder Release 9.1.9 User Notebook," Criterion Planners, August 2006.

Figure 6.2 The Case Study Area within the City of West Sacramento



6.2.2 Coding of Land-Uses

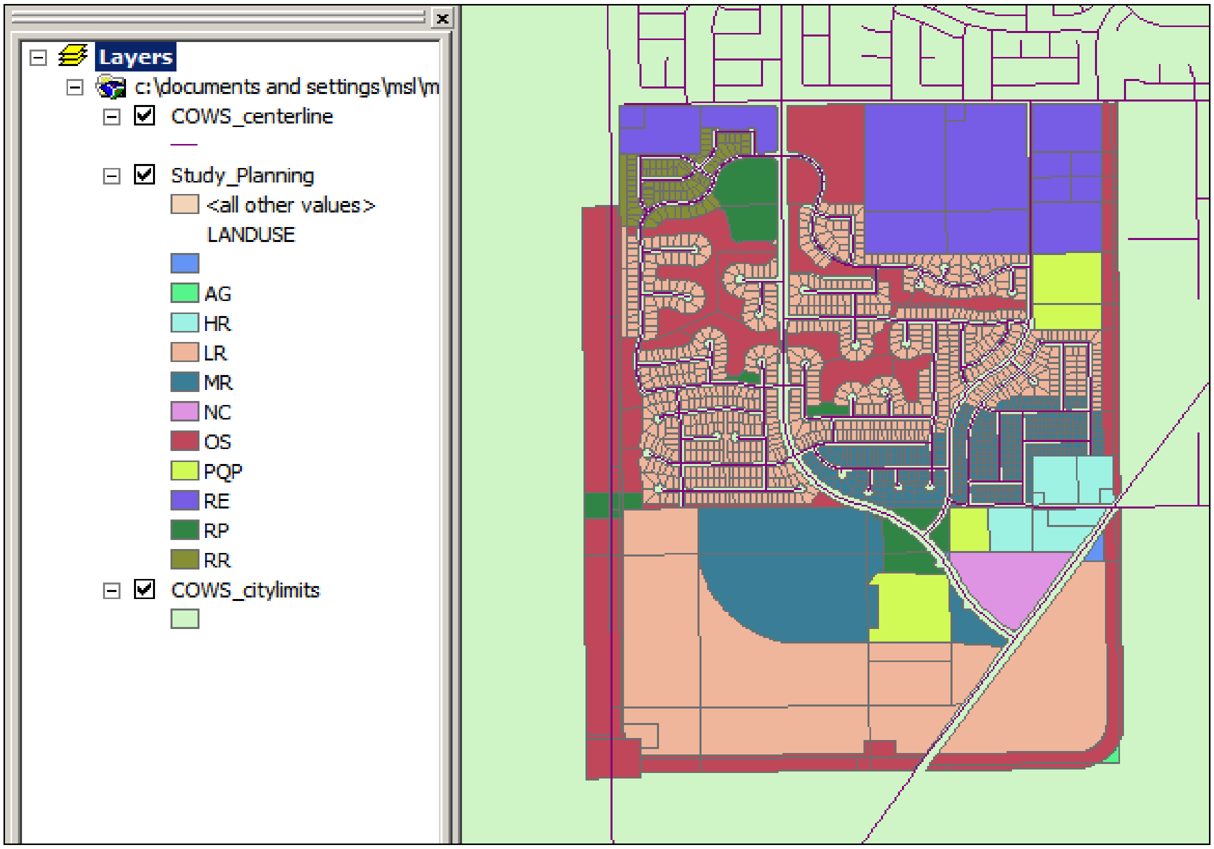
INDEX requires that land-use types be represented by a numeric value between 18 and 250 (values 1-17 are reserved for sample land-use definitions). The numeric values are matched up with land-use zoning definitions in the City's General Plan. **Table 6.1** shows the definitions of West Sacramento's land-use zones.

Table 6.1 INDEX Land-Use Type and West Sacramento Land-Use Match-Up

LAND-USE	LAND-USE DESCRIPTION	INDEX TYPE ID	INDEX TYPE DESCRIPTION
RR	RURAL RESIDENTIAL	20	RESIDENTIAL SINGLE FAMILY
RE	RURAL ESTATES	20	RESIDENTIAL SINGLE FAMILY
LR	LOW DENSITY RESIDENTIAL	20	RESIDENTIAL SINGLE FAMILY
MR	MEDIUM DENSITY RESIDENTIAL	21	RESIDENTIAL, MULTI-FAMILY, MODERATE DENSITY
HR	HIGH DENSITY RESIDENTIAL	22	RESIDENTIAL, MULTI-FAMILY, HIGH DENSITY
NC	NEIGHBORHOOD COMMERCIAL	30	COMMERCIAL RETAIL
CC	COMMUNITY COMMERCIAL	30	COMMERCIAL RETAIL
GC	GENERAL COMMERCIAL	30	COMMERCIAL RETAIL
HSC	HIGH SERVICE COMMERCIAL	30	COMMERCIAL RETAIL
WRC	WATER RELATED COMMERCIAL	30	COMMERCIAL RETAIL
O	OFFICE	31	COMMERICIAL OFFICE
BP	BUSINESS PARK	31	COMMERCIAL OFFICE
MCI	MIXED COMMERCIAL / INDUSTRIAL	41	INDUSTRIAL / WAREHOUSE
LI	LIGHT INDUSTRIAL	40	INDUSTRIAL
HI	HEAVY INDUSTRIAL	40	INDUSTRIAL
WRI	WATER RELATED INDUSTRIAL	40	INDUSTRIAL
CBD	CENTRAL BUSINESS DISTRICT	30	COMMERCIAL, RETAIL
RMU	RIVER MIXED USE	75	DEVELOPABLE
PQP	PUBLIC / QUASI PUBLIC	47	UTILITY
RP	RECREATION AND PARKS	50	PARK
OS	OPEN SPACE	55	OPEN SPACE
AG	AGRICULTURE	60	AGRICULTURE

The land-use parcels within the study area are extracted from the City's GIS database (**Figure 6.3**). These parcels are the same as those used by the City for planning purposes.

Figure 6.3 Land-use Parcels within the Case Study Area



In order to calculate indicator scores, estimates of residential population for each residential parcel need to be made by multiplying the dwelling unit counts with a conversion coefficient (**Table 6.2**). For example, for a single-family parcel, it is assumed that each dwelling unit contains 2.7 people. For a multi-family parcel, each unit contains 2.2 people. Other variables such as student count and required parking spaces are also populated with the coefficients in **Table 6.**

Table 6.2 Assumption of Residential Population

Fields	Queries - Select by Attributes	Calculations – Input Fields & Coefficients
Residential Population	[DwellingGroup] = 'Single Family' [DwellingGroup] = 'Multi Family'	= [DwellingUnitCount] * 2.7 (res/du) = [DwellingUnitCount] * 2.2 (res/du)
Student Count	[DwellingGroup] = 'Single Family' [DwellingGroup] = 'Multi Family'	= [DwellingUnitCount] * 1.2 (students/du) = [DwellingUnitCount] * 0.7 (students/du)
Required Parking Spaces	[DwellingGroup] = 'Single Family' [DwellingGroup] = 'Multi Family [BusinessGroup] = 'Retail' [BusinessGroup] = 'Service' [BusinessGroup] = 'Other'	= [DwellingUnitCount] * 2.0 (parking spaces) = [DwellingUnitCount] * 1.2 (parking spaces) = [EmploymentCount] * 2 (parking spaces) = [EmploymentCount] * 1.2 (parking spaces) = [EmploymentCount] * 1 (parking spaces)

Source: INDEX PlanBuilder Release 9.1.9 User Notebook

6.2.3 Coding of the Transportation Network and Services

Street Centerlines

The GIS layer of the street centerlines within the City of West Sacramento is shown in **Figure 6.2**. The centerline segments extend beyond the study area to capture the effect of the surrounding streets on the study area.

Pedestrian Routes

Modeling of pedestrian routes is an important part of creating walkable neighborhoods, and INDEX evaluates the pedestrian environment with several "proximity" indicators. The GIS layer is used solely for proximity calculations and requires no additional attributes. It should represent paths where people walk including: streets (excluding freeways), off-road sidewalks, and trails. The pedestrian and bicycle routes for West Sacramento, illustrated in **Figure 6.4**, are simply all the local streets in the city except for freeways and ramps.

Points of Interest

The “points-of-interest” layer contains two types of points: amenities and central nodes. Amenities are local destinations people frequent, such as grocery stores. Central nodes are heavily trafficked points in the neighborhood, such as a main intersection or community center. Key features are not currently used in the application. For this study, two grocery stores in the vicinity of the study area are identified and used as amenities in the “points-of-interest” layer. The location where Jefferson Boulevard meets the ramps of Highway 275 is used as the central node. The location is chosen for its high turning movement volumes based on traffic count data.

Transit Routes and Stops

Bus routes and stops within the City of West Sacramento are identified in relation to the bikeway and pedestrian route map (**Figure 6.4**) prepared by the City.

The entire collection of GIS layers is presented in **Figure 6.5**.

Figure 6.4 West Sacramento Transit, Pedestrian and Bikeway Map

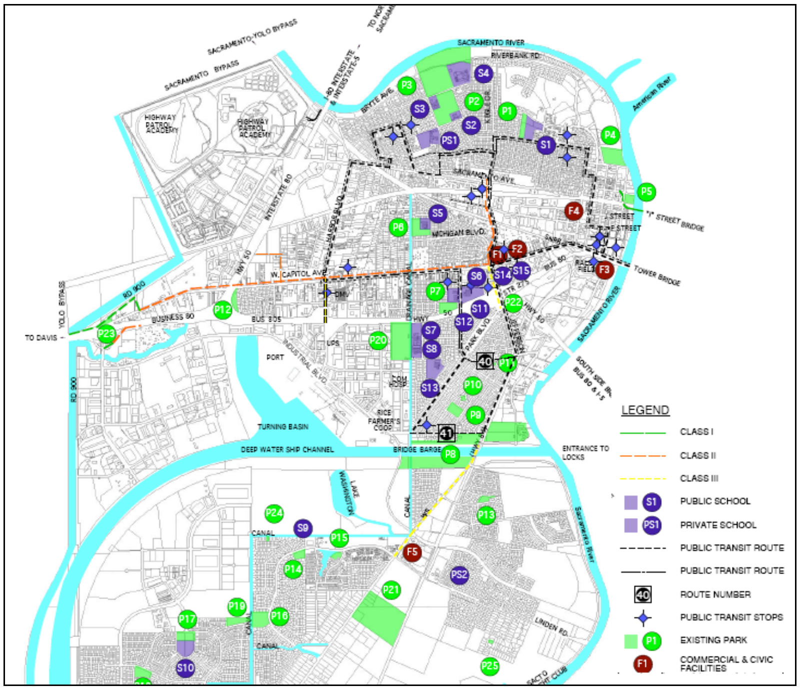
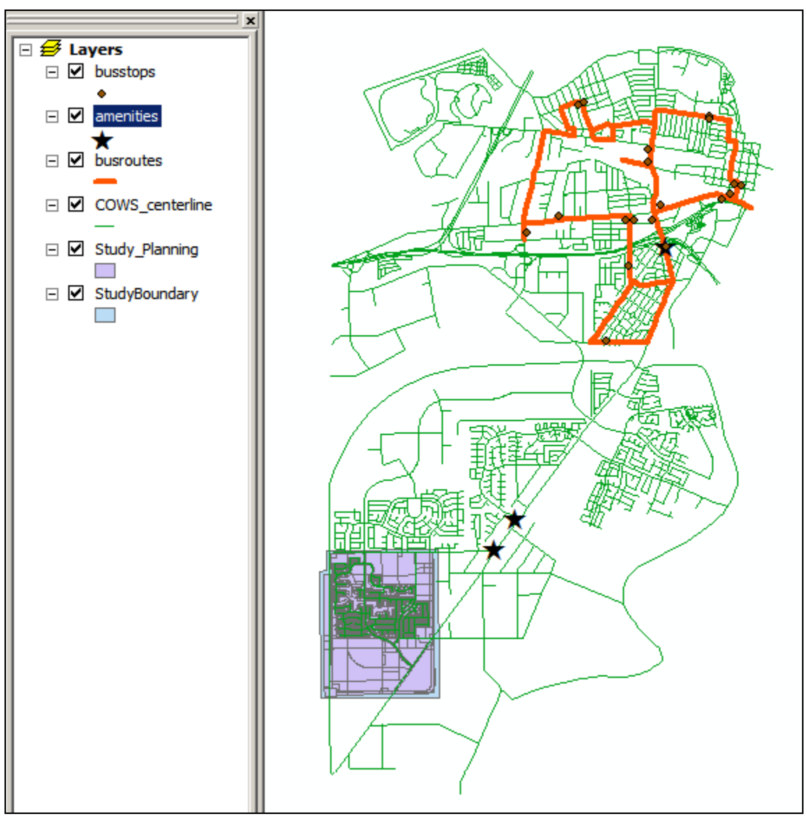


Figure 6.5 GIS Layers of West Sacramento INDEX Study



6.2.4 Benchmarking Baseline Conditions

After assembling the database, the GIS layers are loaded into the INDEX Planbuilder to benchmark the baseline conditions. Indicators are calculated and the scores are used to provide a baseline for estimating the effects of proposed developments. During plan implementation when development proposals are evaluated, each proposal's scores can be compared to benchmark measurements to estimate the amount of change that would be caused by the development.

To benchmark baseline conditions and to evaluate proposed development using INDEX, users select those indicators that are most relevant to the subject. For the purpose of this study, the indicators relevant to multi-modal travel impacts are selected (**Table 6.3**). The indicator list also includes population and employment density measures to distinguish differences between scenarios. Formulation of the indicators can be found in the INDEX Indicator Dictionary.

6.2.5 Creation of Development Scenarios

Once baseline conditions have been evaluated, INDEX can be used to create and assess various alternative scenarios. To apply INDEX as a development evaluation tool, it is necessary to describe development proposals in GIS form.

Five hypothetical development proposals were created for this sensitivity test. The five scenarios are intended to test the ability of INDEX and the 4D elasticities to reflect travel impacts under various development densities, land-use mixes, and transit route availability:

Scenario 1: Mixed-Use Development

A hypothetical mixed-used project was formulated for the vacant residential parcels within the study area. Parcels and streets representing the development proposal were provided in GIS format (**Figure 6.6**).

In addition to the parcels and streets, the development proposal contained two grocery stores. The stores are represented as amenities in the "points-of-interest" layer. The entire collection of GIS layers for the proposed development is shown in **Figure 6.7**. Four new land-use types were introduced as indicated in **Table 6.4**, which also lists the attributes of the new land-use types.

For proposed parcels with residential units, the residents to dwelling unit ratios in **Table 6.2** are used to convert dwelling-unit counts to residential population for single and multi-family units. The conversion factors for student count and required parking spaces in **Table 6.2** are also used for the proposed parcels.

Table 6.3 INDEX Indicators Selected

ID	Indicator Name	Unit
2	Population	residents
3	Employment	employees
4	Population Density	residents/gross acre
7	Use Mix	0-1 scale
8	Use Balance	0-1 scale
75	Dwelling Density	DU/gross acre
73	Dwelling Unit Count	total DU
15	Single Family Dwelling Density	DU/net acre
16	Multi Family Dwelling Density	DU/net acre
22	Transit Adjacency to Housing	% pop within user buffer
23	Transit Proximity to Housing	average walk ft to closest stop
25	Employment Density	employments/net acre
27	Transit Adjacency to Employment	% employments within user buffer
28	Transit Proximity to Employment	average walk ft to closest stop
43	Street Network Density	Centerline mi/sq mi
45	Transit Service Coverage	stops/sq mi
46	Transit Service Density	vehicle route mi/sq mi
65	Transit-Oriented Residential Density	DU/net acre within user buffer of stops
66	Transit-Oriented Employment Density	employments /net acre within user buffer of stops
47	Pedestrian Network Coverage	% of streets with sidewalks
56	Street Route Directness	Walk distance/straight-line ratio
69	Home Based Vehicle Miles Traveled Per Capita	mi/day/capita
70	Non-Home Based Vehicle Miles Traveled Per Capita	mi/day/capita
71	Home Based Vehicle Trips Per Capita	trips/day/capita
72	Non-Home Based Vehicle Trips Per Capita	trips/day/capita

Table 6.4 Proposed New Land-Use Types

LAND-USE	LAND-USE DESCRIPTION	INDEX ID
RES-ROWHOUSE	RESIDENTIAL ROWHOUSE	23
MIX-COMRES	MIXED COMMERCIAL RESIDENTIAL	35
INST-GENERAL	PUBLIC INSTITUTION	45
ROW-PARKING	MISCELLANEOUS PARKING	68

Figure 6.6 Land-Use Parcels and Streets of the Proposed Development

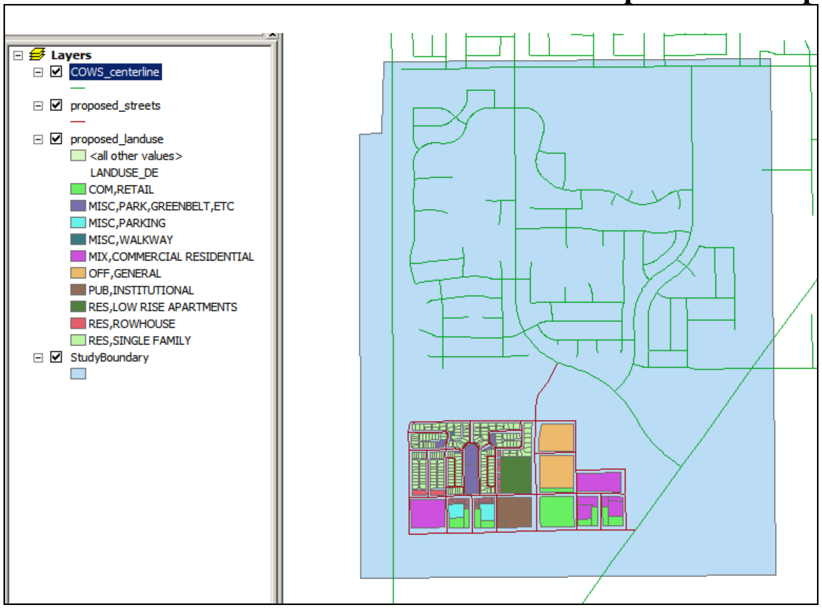
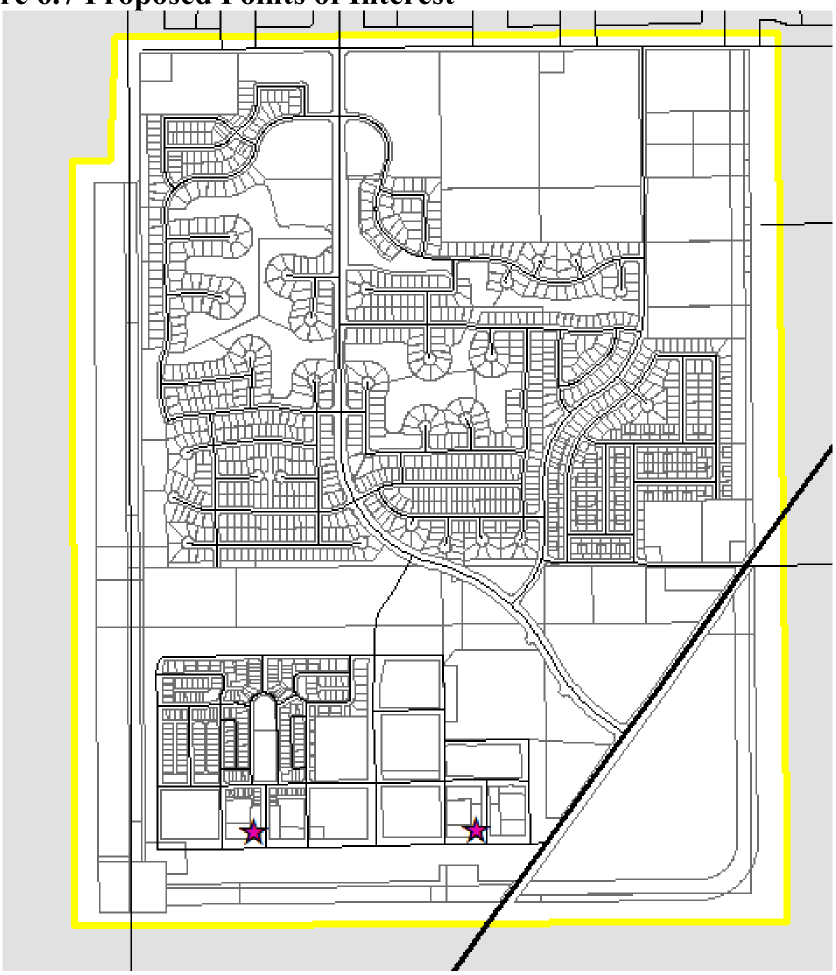


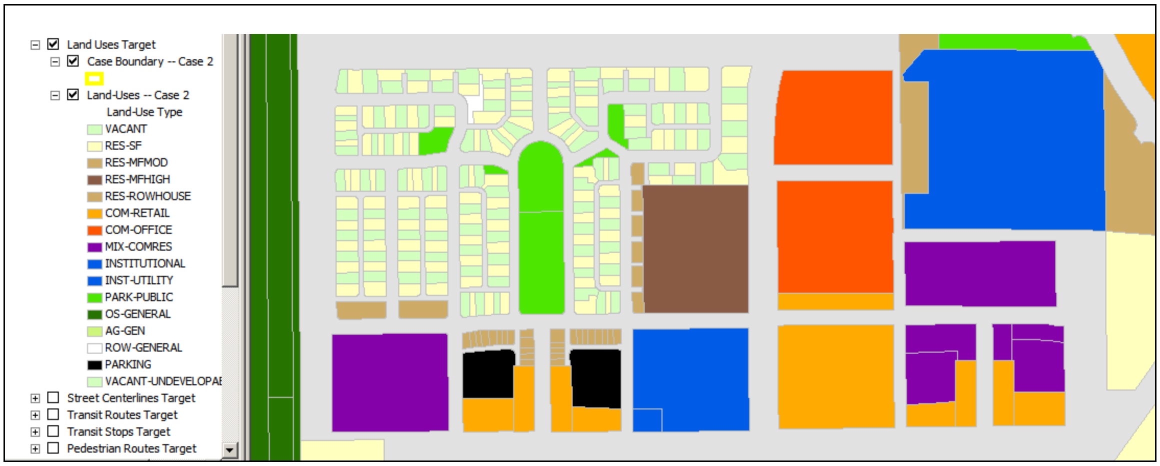
Figure 6.7 Proposed Points of Interest



Scenario 2: Reduced Residential Density

Scenario 2 is built on Scenario 1 with the same collection of layers and settings. The only difference between the two is that the density of residential units in the land-use-parcels layer is reduced. Approximately 50% of the single-family parcels are left vacant lots (to indicate larger parcels and lower densities), and the residential unit count on each medium- to high-density residential parcel is also reduced. Parcels representing the development proposal are shown in **Figure 6.8**.

Figure 6.8 Reduced Residential Parcels in Scenario 2



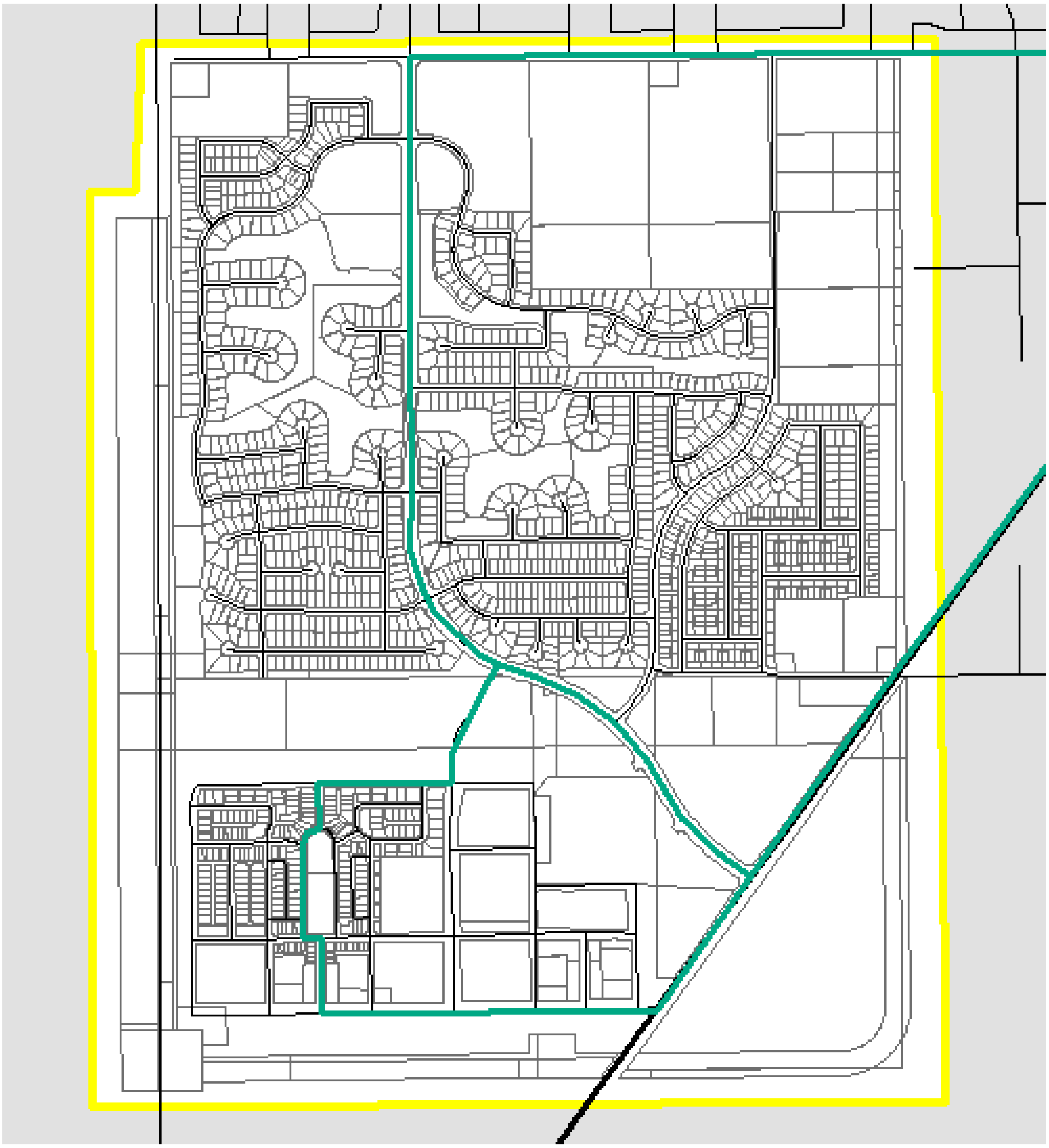
Scenario 3: Development with No Retail Uses

Scenario 3 is also built on Scenario 1 with the same collection of layers, but the numbers of retail land-uses are eliminated from the proposed development to test the software's ability to reflect different land-use mixes. In addition, the two additional points of interest are removed, because the two points were added in conjunction with the retail land-uses in Scenarios 1 and 2.

Scenario 4: Development with A Bus Route

Scenario 4 is again built on Scenario 1 with the same collection of layers. The only difference between Scenarios 1 and 4 is that a bus route is added in Scenario 4. The route runs through the development with four new bus stops. Parcels representing the development proposal in this scenario are shown in **Figure 6.9**.

Figure 6.9 Bus Transit Line in Scenario 4



<u>Scenario 5: Reduced Sidewalk Coverage</u>

Scenario 5 is created to test if INDEX will reflect the effect of reduced sidewalk coverage on VMT and VT per capita measures. This scenario is again built on Scenario 1. The only difference between Scenarios 1 and 5 is that the percentage of sidewalk coverage for the streets in the proposed development (**Figure 6.6**) is reduced by 50% in Scenario 5.

6.2.6 Comparison of Scenarios

As mentioned in the previous chapters, the 4D elasticities adjust VMT and VT per capita estimates by accounting for the trip reduction effects of the 4D factors: density, diversity, design, and destination. In this sensitivity test, scenarios were compared within a single site. Thus, the destination factor is held constant for all cases. The 4D elasticities calculate values for the following variables entered into the GIS layers of the study area: the population and employment, street network density, sidewalk completeness, street route directness, and accessibility.

Base Case vs. Scenario 1

Table 6.5 shows the results of INDEX indicator calculations comparing the baseline case with Scenario 1.

A use mix score of 0.25 – 0.4 represents a moderately diverse area and 0.65 – 0.8 a highly diverse area. A use balance of 0.7 – 0.9 represents a well-balanced area and 0.3 – 0.5 an imbalanced area. Putting a mixed-use development in the study area increases the diversity in the study area. Because there are no bus lines near the study area in this scenario, all of the transit-related scores for the Base Case and Scenario 1 are either very large (i.e., long distance to transit lines) or 0 (i.e., no transit line in the vicinity of the study area). The pedestrian network coverage score of both cases is 100 % because it is assumed that all the local streets in the study area have sidewalks.

The VMT and VT per capita scores for the Base Case are estimates based on the West Sacramento travel demand model. Because the purpose of this analysis is to evaluate the sensitivity (i.e., difference in results due to development scenarios) using INDEX with the 4D elasticities, the numerical assessment focuses on the addition or reduction from scenario to scenario. The accuracy of the Base Case VMT and VT per capita assumption does not affect the assessment.

For Scenario 1, all of the VMT and VT per capita indicators (i.e., indicator 69 to 72) show a decrease from the baseline case, indicating that the 4D elasticities in INDEX take into consideration the difference in mixed land-uses. It is important to note that the VMT and VT measures are per capita, not for study area total. The large reductions in VT and VMT per capita between the Base Case and Scenario 1 result from the significant increase in employment in the development. Because there is almost no employment in the Base Case, the change in Scenario 1 produces an increase in the Diversity variable of over 700 percent. When applied to the elasticities for Diversity, this results in a decrease of about 40 percent in VT and VMT. The elasticities are designed to test moderate changes in the variable, and this test case may exceed the range of change for which the elasticity should be used.

Scenarios 1 to 3

Because Scenarios 2 to 3 are all based on Scenario 1 and the travel environment for the three scenarios are identical (i.e., the same street network and transit lines), the indicator scores of these three are compared together. **Table 6.6** shows the results of the INDEX indicator calculations.

Table 6.5 Indicator Score Base Case vs. Scenario 1

ID	Indicator Name	Units	Base Case	Scenario 1
2	Population	residents	22,724	23,961
3	Employment	employees	170	2,311
4	Population Density	residents/gross acre	23.83	25.13
7	Use Mix	0-1 scale	0.08	0.16
8	Use Balance	0-1 scale	0.57	0.61
75	Dwelling Density	DU/gross acre	10.63	11.17
73	Dwelling Unit Count	total DU	10,134	10,650
15	Single Family Dwelling Density	DU/net acre	2.81	3.28
16	Multi Family Dwelling Density	DU/net acre	100.00	99.77
22	Transit Adjacency to Housing	% pop within user buffer	0.0	0.0
23	Transit Proximity to Housing	average walk ft to closest stop	22,536	22,716
25	Employment Density	employments/net acre	3.95	31.55
27	Transit Adjacency to Employment	% employments within user buffer	0.0	0.0
28	Transit Proximity to Employment	average walk ft to closest stop	22,026	26,197
43	Street Network Density	Centerline mi/sq mi	9.8	13.2
45	Transit Service Coverage	stops/sq mi	0.0	0.0
46	Transit Service Density	vehicle route mi/sq mi	0.0	0.0
65	Transit-Oriented Residential Density	DU/net acre within user buffer of stops	0.0	0.00
66	Transit-Oriented Employment Density	employments /net acre within user buffer of stops	0.0	0.00
47	Pedestrian Network Coverage	% of streets with sidewalks	100.0	100.0
56	Street Route Directness	Walk distance/straight line ratio	1.13	1.14
69	Home Based Vehicle Miles Traveled Per Capita	miles/day/capita	22.0	13.2
70	Non-Home Based Vehicle Miles Traveled Per Capita	miles/day/capita	5.0	3.0
71	Home Based Vehicle Trips Per Capita	trips/day/capita	4.0	2.4
72	Non-Home Based Vehicle Trips Per Capita	trips/day/capita	1.0	0.6

Table 6.6 Indicator Scores Scenario 1 to 3

ID	Indicator Name	Base Case Score	Scenario 1 Score	Scenario 2 Score	Scenario 3 Score
2	Population	22,724	23,961	23,310	23,961
3	Employment	170	2,431	2,431	1,050
4	Population Density	23.83	25.13	24.45	25.13
7	Use Mix	0.08	0.16	0.16	0.16
8	Use Balance	0.57	0.61	0.62	0.61
75	Dwelling Density	10.63	11.17	10.88	11.17
73	Dwelling Unit Count	10,134	10,650	10377	10,650
15	Single Family Dwelling Density	2.81	3.28	3.06	3.28
16	Multi Family Dwelling Density	100.00	99.77	97.97	99.77
22	Transit Adjacency to Housing	0.0	0.0	0.0	0.0
23	Transit Proximity to Housing	22,536	22,716	22,641	22,745
25	Employment Density	3.95	31.55	31.55	18.65
27	Transit Adjacency to Employment	0.0	0.0	0.0	0.0
28	Transit Proximity to Employment	22,026	26,197	26,281	25,399
43	Street Network Density	9.8	13.2	13.2	13.2
45	Transit Service Coverage	0.0	0.0	0.0	0.0
46	Transit Service Density	0.0	0.0	0.0	0.0
65	Transit-Oriented Residential Density	0.0	0.00	0.00	0.00
66	Transit-Oriented Employment Density	0.0	0.00	0.00	0.00
47	Pedestrian Network Coverage	100.0	100.0	100.0	100.0
56	Street Route Directness	1.13	1.14	1.14	1.13
69	Home Based Vehicle Miles Traveled Per Capita	22.0	13.2	13.2	16.8
70	Non-Home Based Vehicle Miles Traveled Per Capita	5.0	3.0	3.0	3.8
71	Home Based Vehicle Trips Per Capita	4.0	2.4	2.4	2.9
72	Non-Home Based Vehicle Trips Per Capita	1.0	0.6	0.6	0.7

For indicators of travel impacts (i.e., VMT and VT per capita), Scenario 2 shows identical scores as Scenario 1. This is because INDEX only displays scores with one digit after the decimal point. The population decrease from Scenario 1 to the Scenario 2 (i.e., 651 persons) is not large enough to result in a visible increase in VMT and VT per capita scores. With the design of the street network and the location of the study site held

unchanged (i.e., design and destination held constant), the VMT and VT per capita scores depend on the density and diversity (i.e., the combination of population and employment densities) in the study area. Reducing employment while holding population constant tends to reduce the values of both density and diversity. This results in higher VMT and VT per capita. **Table 6.8** shows that with a decrease in employment density, Scenario 3 results in VMT and VT per capita increases.

Scenarios 4 and 5

Scenarios 4 and 5 are both based on Scenario 1, but Scenario 4 has a bus line running through the study area, and Scenario 5 has reduced sidewalk coverage. The indicator scores of these two are compared together with the Base Case and Scenario 1. **Table 6.7** shows the result of INDEX indicator calculations comparing Scenario 1 with Scenarios 4 and 5.

Scenario 4 shows identical scores for VMT and VT per capita as Scenario 1. This is because Scenario 4 has exactly the same population, employment, and street network as Scenario 1. Although Scenario 4 has a bus line running through the study area, the INDEX methodology does not consider the bus line in the calculation of scores for VMT and VT per capita. The lack of consideration for bus lines is rooted in the formulation of the 4D methodology (**Figure 4.1**) identified in **Chapter 4**. With the formulation, it is clear that for the same study area, the Density and Diversity elasticities only vary by the amount of employment and population. The Design factor varies by the layout of the street network and its sidewalk coverage. The Destination factor is derived from the zonal accessibility measure that is estimated using the street network. Therefore, none of the 4D elasticities incorporate measures of bus transit lines into the calculation. As a result, the presence of a bus line in the study area does not change the values of the 4D elasticities, so subsequently the VMT and VT per capita will not change.

The guidelines for use of the 4Ds are clear that they should not be used to measure changes to the transportation network. That is why they are best used in conjunction with a travel demand model if major network changes are under consideration. (Research is underway that could result in an additional elasticity to better capture the effects of transit services.)

In Scenario 5, by reducing the sidewalk coverage to 50% for all streets in the proposed development, the pedestrian network coverage is reduced to 87.1% for the entire study area. The reduction results in a lower score for the design factor. However, the small amount of reduction in design does not result in an increase in the score for VMT and VT per capita. Scenario 5 has the same score for VMT and VT per capita as Scenario 1. The result is likely a combination of the relative weight (1.18) applied to sidewalk completeness in the design variable in the regression equation or the limited sensitivity of vehicle-trip making to design changes (the design variable has the smallest elasticity among the 4D variables). The results seem reasonable, because a 13 percent reduction in sidewalk coverage would not be expected to result in a change great enough to register a change in VT or VMT when they are only reported to two significant digits.

Table 6.7 Indicator Scores for Scenarios 4 and 5

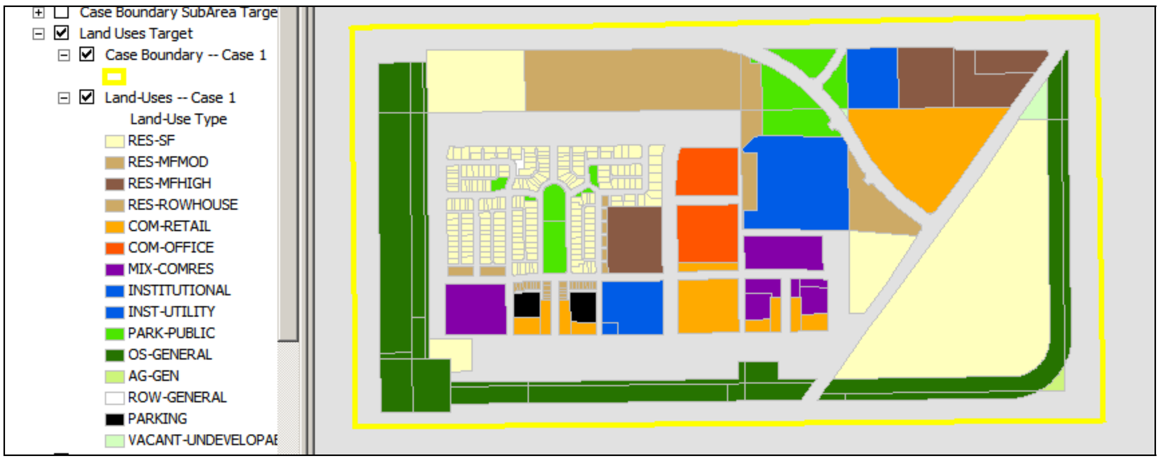
ID	Indicator Name	Scenario 1 Score	Scenario 4 Score	Scenario 5 Score
2	Population	23,961	23,961	23,961
3	Employment	2,431	2,431	2,431
4	Population Density	25.13	25.13	25.13
7	Use Mix	0.16	0.16	0.16
8	Use Balance	0.61	0.61	0.61
75	Dwelling Density	11.17	11.17	11.17
73	Dwelling Unit Count	10,650	10,650	10,650
15	Single Family Dwelling Density	3.28	3.28	3.28
16	Multi Family Dwelling Density	99.77	99.77	99.77
22	Transit Adjacency to Housing	0.0	92.2	0.0
23	Transit Proximity to Housing	22,716	5,918	22,716
25	Employment Density	31.55	31.55	31.55
27	Transit Adjacency to Employment	0.0	97.7	0.0
28	Transit Proximity to Employment	26,197	2,617	26,197
43	Street Network Density	13.2	13.2	13.2
45	Transit Service Coverage	0.0	0.7	0.0
46	Transit Service Density	0.0	177.9	0.0
65	Transit-Oriented Residential Density	0.00	12.61	0.00
66	Transit-Oriented Employment Density	0.00	39.14	0.00
47	Pedestrian Network Coverage	100.0	100.0	87.1
56	Street Route Directness	1.14	1.14	1.14
69	Home Based Vehicle Miles Traveled Per Capita	13.2	13.2	13.2
70	Non-Home Based Vehicle Miles Traveled Per Capita	3.0	3.0	3.0
71	Home Based Vehicle Trips Per Capita	2.4	2.4	2.4
72	Non-Home Based Vehicle Trips Per Capita	0.6	0.6	0.6

6.2.7 Modification of Development Scenarios

Based on the results of the initial tests of scenarios, it appears that the significant number of existing single-family units on the northern half of the study area might have diluted the proposed development's scores for mixed-use and for transit and pedestrian network coverage, leading to negligible changes in VT and VMT per capita. For example, in

Scenario 5 the 50% reduction in sidewalk coverage for all proposed streets only results in a 13% coverage reduction in the entire study area. To see if a smaller and focused study area might produce more pronounced travel impact scores, a new study area was created. The new area included only the vacant parcels on the southern end and excluded the existing single-family parcels on the northern end. **Figure 6.10** shows the new study area and the proposed development. The modified area is approximately 0.65 square miles (430 acres), which is appropriate for applications of the 4D method (i.e., less than 2,000 acres in area and greater than 200 acres).

Figure 6.10 Modified Study Area and the Proposed Development



The five scenarios tested in the previous round were applied within the modified study area. The results for the modified Scenarios 1 to 3 are shown in **Table 6.8** and those for modified Scenarios 4 and 5 are shown in **Table 6.9**.

Comparing the scores for VT and VMT per capita of the original Scenario 1 (**Table 6.7**) and the modified Scenario 1, the modified scenario has higher scores for VMT and VT per capita than the original. The difference is mainly caused by the difference in the ratio of population to employment. The original Base Case has a very high population to employment ratio, which translates to a very low diversity score. The increase in employment from the Base Case to Scenario 1 results in a significant percentage increase in the diversity score. This leads to a significant reduction in VMT and VT per capita. For the modified cases, because the percentage increase in diversity score from the Base Case to Scenario 1 is less significant than the unmodified case, the modified Scenarios 1 to 3 have smaller reductions in VMT and VT per capita than the original scenarios.

Table 6.8 INDEX Indicator Scores for Modified Scenarios 1 to 3

ID	Indicator Name	Modified Base Case	Modified Scenario 1	Modified Scenario 2	Modified Scenario 3
2	Population	561	1,798	1,147	1,798
3	Employment	110	2,371	2,371	990
4	Population Density	1.35	4.34	2.77	4.34
7	Use Mix	0.09	0.28	0.28	0.28
8	Use Balance	0.66	0.84	0.86	0.84
75	Dwelling Density	0.61	1.86	1.20	1.86
73	Dwelling Unit Count	254	770	497	770
15	Single Family Dwelling Density	0.07	2.71	1.59	2.71
16	Multi Family Dwelling Density	681	11.04	7.65	11.04
22	Transit Adjacency to Housing	0.0	0.0	0.0	0.0
23	Transit Proximity to Housing	22,115	25,010	24,456	25,187
25	Employment Density	3.61	36.74	36.74	22.61
27	Transit Adjacency to Employment	0.0	0.0	0.0	0.0
28	Transit Proximity to Employment	22,004	26,300	26,400	25,626
43	Street Network Density	4.0	11.9	11.9	11.9
45	Transit Service Coverage	0.0	0.0	0.0	0.0
46	Transit Service Density	0.0	0.0	0.0	0.0
65	Transit-Oriented Residential Density	0.0	0.0	0.0	0.0
66	Transit-Oriented Employment Density	0.0	0.0	0.0	0.0
47	Pedestrian Network Coverage	100.0	100.0	100.0	100.0
56	Street Route Directness	1.07	1.15	1.15	1.14
69	Home Based Vehicle Miles Traveled Per Capita	22.0	16.6	16.2	17.5
70	Non-Home Based Vehicle Miles Traveled Per Capita	5.0	3.8	3.7	4.0
71	Home Based Vehicle Trips Per Capita	4.0	3.1	3.1	3.3
72	Non-Home Based Vehicle Trips Per Capita	1.0	0.8	0.8	0.8

Table 6.9 Indicator Scores for Modified Scenarios 4 and 5

ID	Indicator Name	Modified Scenario 1	Modified Scenario 4	Modified Scenario 5
2	Population	1,798	1,798	1,798
3	Employment	2,371	2,371	2,371
4	Population Density	4.34	4.34	4.34
7	Use Mix	0.28	0.28	0.28
8	Use Balance	0.84	0.84	0.84
75	Dwelling Density	1.86	1.86	1.86
73	Dwelling Unit Count	770	770	770
15	Single Family Dwelling Density	2.71	2.71	2.71
16	Multi Family Dwelling Density	11.04	11.04	11.04
22	Transit Adjacency to Housing	0.0	100.0	0.0
23	Transit Proximity to Housing	25,010	2,933	25,010
25	Employment Density	36.74	36.74	36.74
27	Transit Adjacency to Employment	0.0	100.0	0.0
28	Transit Proximity to Employment	26,300	2,496	26,300
43	Street Network Density	11.9	11.9	11.9
45	Transit Service Coverage	0.0	1.5	0.0
46	Transit Service Density	0.0	240.7	0.0
65	Transit-Oriented Residential Density	0.0	12.58	0.0
66	Transit-Oriented Employment Density	0.0	39.14	0.0
47	Pedestrian Network Coverage	100.0	100.0	67.0
56	Street Route Directness	1.15	1.15	1.15
69	Home Based Vehicle Miles Traveled Per Capita	16.6	16.6	16.6
70	Non-Home Based Vehicle Miles Traveled Per Capita	3.8	3.8	3.8
71	Home Based Vehicle Trips Per Capita	3.1	3.1	3.2
72	Non-Home Based Vehicle Trips Per Capita	0.8	0.8	0.8

Comparing the modified Scenarios 1 and 2, it can be seen that the modified Scenario 2 does show a visible increase in VMT and VT per capita from the modified Scenario 1, which was not visible in the unmodified case. The effect is achieved by the smaller study area that accentuates the effect of population density on reduction in the VMT and VT per capita.

In the scores of the modified Scenario 3, it can be seen again that the amount of employment has a great effect in both the density and diversity elasticities. The reduction in employment between Scenario 3 and 1 results in increases in VMT and VT per capita.

For modified Scenario 4, the VMT and VT per capita scores are expected to remain the same as the modified Scenario 1 because the presence of a bus line is not taken into account by the 4D elasticities.

Because of the smaller study area, the pedestrian network coverage score for modified Scenario 5 is 67%, which is closer (than the unmodified case) to the 50% reduction made to the sidewalk coverage of the streets in the proposed development. The reduction results in a lower design factor. Of the four travel measures, only Home Based Vehicle Trips Per Capita shows a detectable increase. It increases from 3.1 to 3.2 trips per capita.

6.3 Lessons Learned from the Sensitivity Test

This study used INDEX to test the sensitivity of the embedded 4D elasticities to a variety of land-use and transportation planning scenarios. Through the specially designed scenarios, the following observations can be made:

General Observations

The sensitivity test of INDEX with the 4D elasticities demonstrates that additional sensitivity to smart-growth land-use strategies can be provided. The use of the supplemental tools does show reduced VT and VMT from the smart-growth concepts tested. Although the differences in VT and VMT were not particularly large for the sample scenarios tested, they did seem to be in the right direction.

While the methods tested provided greater sensitivity to smart-growth land-use strategies, the methods do not draw on all of the characterization of land-use characteristics available from the City's travel model database. Other than employment and population, common socio-demographic variables employed in the City's travel model, such as income level of a household and the number of workers in a household, are not taken into consideration by INDEX with the 4D elasticities for estimating reductions in VMT and VT per capita.

While the application of the methods tested may be appropriate for general policy development and planning, its use in assessing local traffic impacts may be limited. One important reason is that the adjustments to VMT and VT per capita are for daily trips. INDEX with the 4D elasticities does not produce adjustment factors that apply specifically to peak-hour trips and non-peak-hour trips. (Inferences can be made about time-of-day effects given the results for HBW for NHB - in general, the HBW effects are likely to affect peak-hours while NHB effects could affect off-peak or peak conditions.) There is also no distinction as to which sub-area within the study area has the most significant effects on vehicle trip reduction.

INDEX with the 4D elasticities does not take into consideration the effect of bus lines in the study area. The elasticities are developed for density, diversity, design, and destination; measures of bus line layout or services do not enter the calculation of any of the four elasticities. INDEX does offer indicators such as Transit Service Coverage and Transit Service Density that increase with the bus line coverage. However, these indicators do not enter the calculation for VMT and VT adjustment. Although there is a 5th D (distance from a heavy rail line) factor in the most recent INDEX update (i.e., the 5D method), this factor is not applicable for buses.

In addition, when heavy rail is present in the study area, the 5th D factor does not result in adjustment to VMT and VT per capita like the other four Ds. The 5th D is used to estimate the portion of trips from the study area that will shift to the heavy rail mode. Other than the indicator on mode shift to heavy rail, INDEX with the 4D elasticities contains no treatment of the effects of carpools and HOV lanes in terms of mode choice.

The sensitivity test does illustrate one limitation of the 4D elasticities. Reductions in VMT and VT per capita are predicted based on changes in density and mixed-use, including where there is virtually no transit service. Because of the way in which the 4D elasticities are estimated using cross-sectional data for different zones, lower vehicle utilization rates in the data set are almost always correlated with higher transit services. The application of the 4D elasticities will, therefore, result in vehicle trip reductions from higher density and mixed use, even if transit services are not available to accommodate the trips diverted from driving. The developers of the 4D elasticities (Fehr & Peers) indicate that "Accessibility" was added to capture some of the differences in transportation options for different locations in a region, and that part of the effect of the generalized provision of bus service is reflected in the design elasticity inasmuch as development density is commonly considered when determining the amount of transit service that will be provided in an area.

Study Area Consideration

According to the technical documentation for INDEX, the basic analysis Case Study Area to which the 4D elasticities are directly applied should be less than two miles in diameter or less than 2,000 acres. If larger areas are evaluated, the 4D elasticities should be sampled within two-mile sub-areas of the larger area, and the results averaged. With the various scenarios tested in this study, it is observed that the basic study area should include mainly the proposed development and the surrounding area that forms an integral area with the proposed development. It was observed from the test application that the effects of the 4D elasticities can be diluted or augmented by the amount and placement of employment, population, and travel facilities in the surrounding area. For example, using a study area that includes a significant existing population density will result in a pronounced reduction in VMT and VT per capita when employment is increased. (Note that total VMT and VT reductions depend on the total population of the study area). A larger study area with considerable existing development also tends to dilute the density and design elasticities when proposed development is added to the area.

Combinatorial Effects of the 4Ds

According to the results of the sensitivity testing, bringing in employment to residential areas tends to result in reduction in VMT and VT per capita. With the design of the street network and the location of the study site held unchanged (i.e., design and destination held constant), the VMT and VT per capita depend on the density and diversity (i.e., the combination of population and employment densities) in the study area. Employment is entered into calculations of both the density and diversity elasticities. Increasing employment while holding population constant increases the values of both density and diversity. This results in greater reduction in VMT and VT per capita. Increasing population while holding employment constant will increase the density score, but the diversity score may become lower once the population to employment ratio becomes unfavorable. Conversely, adding population to a predominantly employment area will improve both the density and diversity of the area and reduce the VMT and VT more dramatically.

The results of this analysis suggest that additional research is needed to improve the 4D elasticities so that certain factors which influence trip making can be better reflected in the elasticities, such as household income, availability of bus transit, and parking costs. In addition, existing 4D elasticities may also need to be updated because some of the travel behavior studies that were used to derive the elasticities were conducted a decade ago.

One potential approach to tackle this issue is to make use of recent travel surveys. As more and more smart-growth and transit-oriented developments are now completed, data from these recent travel surveys potentially contain critical information that can be used to improve the 4D elasticities. For example, NCHRP Project 08-51, "Enhancing Internal Trip Capture Estimation for Mixed-Use Developments," is assembling data on vehicle trip generation rates in mixed-use developments. Another recently approved NCHRP study will provide vehicle trip generation rates for urban infill land uses (Project 08-66). In addition, U.S. EPA is initiating a study that may provide the opportunity to update the 4D elasticities with more extensive national data from the same recent vintage as the household survey data sets used to develop and validate UTMS models.

Chapter 7

Conclusions and Recommendations

7.1 Overview of Study Findings

This study has led to a set of findings that can help guide choices of tools for analyzing smart-growth strategies by local jurisdictions (the cities and county agencies responsible for making local land-use decisions) and focus additional research and development activities to improve the tools available. The findings include conclusions in two areas:

- Local Model Sensitivity to Smart-Growth Strategies
- Supplemental Methods

Study recommendations are provided in three areas:

- Local Jurisdiction Practice Regarding Local Travel Modeling
- Local Jurisdiction Practice Regarding 4D Elasticity Tools
- Research, Development, and Training

The conclusions and recommendations were the product of a cooperative effort of the research team and several participants in the Technical Advisory Committee.

One of the primary areas of focus of this study was an assessment of how well the tools currently available to local jurisdictions in California capture the potential trip and VMT reduction benefits of smart-growth strategies. A limited review of the models used by local jurisdictions indicated that virtually all used some version of the Urban Transportation Modeling System (UTMS) or what is commonly referred to as the "four-step" travel demand model. A thorough review of the steps in the UTMS process was conducted to identify where sensitivity to smart-growth strategies may be limited by the modeling process. This review suggested that most UTMS applications by local jurisdictions had little sensitivity to smart-growth strategies. Many options for improving the sensitivity to UTMS were identified and examples were given of where some of these options had been implemented by agencies in California.

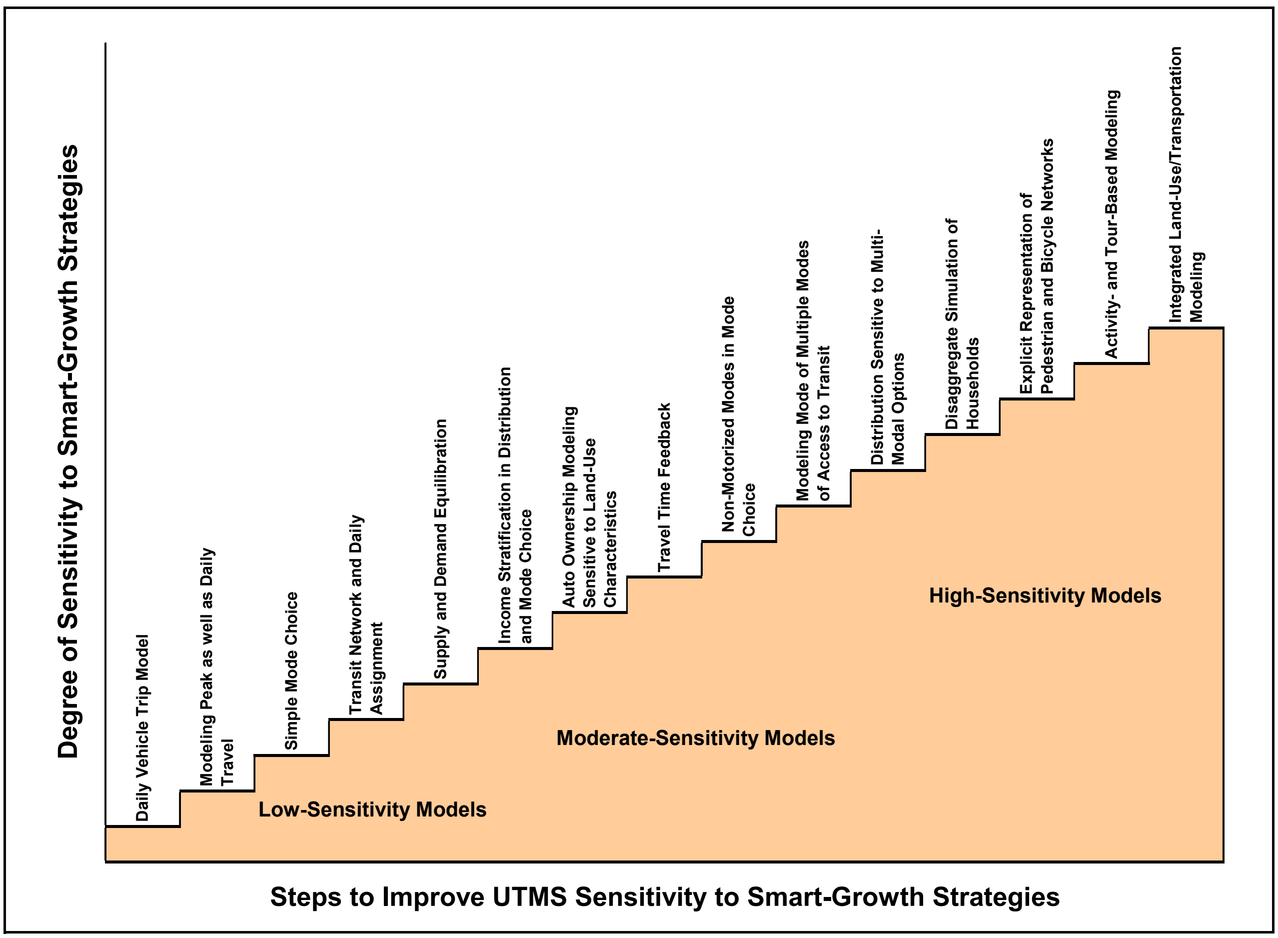
Research was also conducted on available methods to supplement local travel models for analysis of smart-growth strategies. The supplemental methods examined all relied on the "4D elasticities" that have been developed in recent years (**Chapter 4**). **Table 7.1** provides a summary of the improvements required for UTMS modeling to gain sensitivity to the intended travel effects from smart-growth strategies and how well the 4D elasticities are able to reflect the smart-growth effects. This assessment was the primary basis for many of the conclusions and recommendations presented in this chapter.

Table 7.1 Summary of 4D Elasticities and UTMS Sensitivity to Smart-Growth Strategies

		Smart Growth Effect	Potential Options to Address UTMS Deficiencies	4D Sensitivity
1	**Providing opportunities to satisfy travel needs at nearby destinations with shorter vehicle trips, trip chaining or non-motorized travel**			
	1.1	Clustering of potential non-home destinations such as daycare, cleaners, restaurants, stores, etc. near work sites	Small Zones, More Purposes, Non-motorized Modes, Tour-based Modeling	Density, Diversity
	1.2	Providing a higher level of diversity in mixed-use clusters	Small Zones, More Purposes, Non-motorized Modes	Density, Diversity
	1.3	Developing neighborhoods with more self-sufficient land uses	Small Zones, More Purposes, Non-motorized Modes	Density, Diversity
	1.4	Providing more jobs-housing balance within sub-areas of regions that allows shorter commutes	Small Zones, Feedback to Distribution	Diversity, Destination
	1.5	Providing a more complete range of housing options and pricing near employment centers	Income Stratification in Distribution	Destination
2	**Using land use to create trips with origin-destination pairs that are more easily traveled by alternative modes**			
	2.1	Providing higher density residential and work sites near transit	Small Zones, Transit Modeling, Transit Access Modeling	Destination, Distance to a heavy rail station (not applicable for buses, and light rails)
	2.2	Providing higher density residential and work sites along bike routes and trails	Small Zones, Non-motorized Modes	
	2.3	Location of schools along bicycle routes and trails	Small Zones, Non-motorized Modes	
	2.4	Clustering potential destinations such as daycare, cleaners, restaurants, stores near work sites and high density residential areas	Small Zones, More Purposes, Non-motorized Modes	
3	**Providing better and more attractive conditions for travel by alternative modes**			
	3.1	Locating business entrances as close as possible to transit stops or stations	Small Zones, Transit Modeling, Transit Access Modeling	Distance to a heavy rail station (not applicable for buses, and light rails)
	3.2	Locating entrances to higher density residential buildings as close as possible to transit stops or stations	Small Zones, Transit Modeling, Transit Access Modeling	Distance to a heavy rail station (not applicable for buses, and light rails)
	3.3	Providing good pedestrian and bicycle access to transit stops or station	Small Zones, Transit Modeling, Transit Access Modeling	Design
	3.4	Providing bicycle storage facilities at transit stops and stations		
	3.5	Providing bicycle storage facilities at high density residential developments, work places, schools, and shopping areas		
	3.6	Locating development on a grid street network	Small Zones, More Purposes, Non-motorized Modes	Design
	3.7	Providing a high level of sidewalk coverage	Small Zones, More Purposes, Non-motorized Modes	Design
4	**Provide economic incentives for use of alternative modes**			
	4.1	Providing a limited supply of parking	Auto Ownership, Parking Constraint, Multimodal, Non-motorized Modes	
	4.2	Charging separately for parking at multi-family residential, employment and shopping sites	Incorporate Price in all Steps, Auto Ownership	

The review of the conventional UTMS modeling practice in this study indicated that there is a range of smart-growth sensitivity in UTMS modeling in California and many options to improve the sensitivity. **Figure 7.1** provides a graphic representation of the most significant steps that can be taken to improve a UTMS model. Most of these steps have been taken by at least one agency in California, although most often by various Metropolitan Planning Organizations (MPO) or Congestion Management Agencies (CMA) rather than by local jurisdictions. The graphic also characterizes ranges of models for "low," "moderate" and "high" sensitivity to smart-growth based on the improvement steps incorporated in the model. The graphic is not intended to be an accurate representation of the amount of sensitivity that is gained by each step, but is instead designed to show a reasonable progression of steps that could be taken to improve the sensitivity of a model system. While the most basic level of UTMS modeling has almost no sensitivity to smart-growth strategies, models with all of the improvements listed in the figure can achieve significant sensitivity. A number of recommendations in the study are based on this categorization of models.

Figure 7.1 Logical Progression of Steps to Improve UTMS Sensitivity to Smart-Growth Strategies



7.2 Study Conclusions

7.2.1 Local Model Sensitivity to Smart-Growth Strategies

The research in the study provided evidence that there is a significant lack of sensitivity to smart-growth strategies in the travel modeling tools that local jurisdictions use in making land-use decisions. Specific conclusions include the following:

1. Few local jurisdictions in California use models that have sensitivity to smart-growth strategies because the models: lack the capability to estimate transit or carpool use; do not include representation of walk or bicycling trips; and/or do not allow for variation in vehicle trip rates on the basis of density, mix of land-use, or design.
2. Local jurisdictions using Metropolitan Planning Organization (MPO) or Congestion Management Agency (CMA) travel demand models with "moderate-to high-sensitivity" (**Figure 7.1**) can capture some of the smart-growth sensitivity listed in **Table 7.1**, but it is not clear how much is actually captured.
3. GIS systems for local jurisdiction land-use and transportation system characteristics are making it possible to bring more information into the UTMS modeling process, and that has the potential to increase smart-growth sensitivity. This includes parcel-level land-uses and GIS layers for street systems, bicycle routes, sidewalks, topography, environmentally sensitive areas, etc. GIS systems are also facilitating the application of supplemental methods such as I-PLACE3S and INDEX.

7.2.2 Supplemental Methods

The research on supplemental methods for gaining smart-growth sensitivity and a review of experience with their application in California found that the tools available can be useful in appropriate situations to support land-use and transportation planning. Specific conclusions include the following:

1. Local jurisdictions with low-sensitivity travel models (**Figure 7-1**) can benefit from applying a 4D elasticities post-processor either as a spreadsheet supplement to the local model or applied in sketch-planning software, such as INDEX or I-PLACE3S, if used appropriately. It is also possible to integrate the 4Ds within the local jurisdiction model, but this effort requires more effort and should include calibration to local conditions.
2. For the 4D elasticities to function properly, it is necessary to follow the guidelines developed for their use (**Chapter 4**), and to calibrate them to local conditions.
3. The 4D elasticities are able to capture some - but not all - smart-growth sensitivity.

4. When the 4D elasticities are applied in conjunction with a travel model that already has “moderate” or “high” sensitivity to smart-growth, there may be double-counting of the smart-growth benefits -- unless the 4D elasticities are adjusted to reflect the local model’s sensitivity. Therefore, it is recommended that the “moderate” or “high” model be tested to determine its actual degree of sensitivity, and that the 4Ds be calibrated, based on local data, to account only for the sensitivity unaccounted for in the travel model.
5. The 4D elasticities (or any “correction factors” that are based on aggregate cross-sectional data) most likely capture some unknown trip or VMT reduction effects as a result of correlation between the smart-growth variables of interest (e.g., the 4Ds) and other factors not listed in the formula but related to how an area developed. These factors may include:
   - Income
   - Race and cultural characteristics
   - Complementary land-uses
   - Quality and frequency of transit service
   - Parking costs and availability
   - Auto ownership

   However, developing locally estimated 4D elasticities can be done in a manner that controls for many of these variables. Doing so allows the 4D adjustments to predict trip reducing effects of smart-growth independent of, for example, income and race.
6. The 4D elasticities estimate reduced VT and VMT for travel that is assumed to be made via transit, walking, or biking by assuming that basic transit and bicycle facilities are available. The 4D adjustments directly account for the presence or absence of sidewalks and pedestrian route connectivity, but do not explicitly account for bicycle facilities or bus or rail transit service. [42] If the study area has less than basic bus or bicycle facilities, the elasticities may overestimate the reduction in VT and VMT and assume a level of bus ridership that could not be accommodated by the planned bus service. However, if the smart-growth study area plans to offer basic bus service (similar to the service in other areas of the region with similar densities), and basic bicycle facilities (consistent with other areas of the region with similar densities and route connectivity), the 4Ds provide a reasonable approximation of the VT and VMT reductions resulting from pedestrian, bicycle, and bus availability.
7. It is possible to calibrate the 4Ds to account for complementary destinations (e.g., land-uses that allow opportunities for individual or household activity needs away from home, such as at work, to be met by non-motorized modes rather than by automobile) and their effect on VT and VMT reduction. This may be accomplished through developing locally validated 4D elasticities for non-home-based trip purposes, as several 4D studies have done.

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[42] While the 4Ds do not account for the presence of rail transit, if the smart-growth study area is expected to offer rail service, the 5th D (Distance to Rail Transit) or Direct Transit Ridership Modeling , can be used to assess the effect of rail proximity on the amount of transit ridership generated in an area.

7.3 Study Recommendations

7.3.1 Local Jurisdiction Practice Regarding Local Travel Modeling

The recommendations for local jurisdiction practice regarding travel modeling were developed primarily on the basis of the review of the smart-growth sensitivity of the conventional (UTMS) modeling system (**Chapter 3**) and how travel modeling is practiced for land-use planning by local jurisdictions in California. The case study analyses in **Chapter 5** provide a useful illustration of the range of local jurisdiction modeling practice in California, and how the smart-growth sensitivity of the local jurisdiction modeling is affected by the availability of a more sophisticated MPO or CMA model system in the region.

1. Local jurisdictions that implement models that already have "moderate" to "high" smart-growth sensitivity (**Figure 7.1**) should strive to continue to enhance their models regarding smart-growth sensitivity rather than to supplement them with 4D elasticities or other post-processing approaches. A model should be tested for its sensitivity to smart-growth, however, because the presence of the desirable features listed in **Figure 7-1** does not guarantee sensitivity. The 4Ds research and other research on smart-growth effectiveness provide evidence of the expected range of sensitivity a model should have to smart-growth and can provide a benchmark for travel model testing. A model can be tested to determine whether it captures the expected range of sensitivity before a decision is made about how to add sensitivity. To perform this type of sensitivity testing, users need full access to travel demand models.
2. Due to the need to better understand and balance regional benefits associated with smart-growth strategies with localized traffic impacts, local jurisdictions that have access to a moderate- to high-sensitivity regional agency model should consider using it to assess proposed land-use plans and projects if such a model provides sufficient detail.
3. Local jurisdictions with low-sensitivity models should consider using a supplemental tool such as one of the 4D elasticities post-processors to evaluate smart-growth strategies in land-use planning efforts.
4. Methods used to capture smart-growth sensitivity (either improvements in the travel model or supplemental tools) should be calibrated with local data and tested for reasonableness before being used to assess land-use plans or projects.

7.3.2 Local Jurisdiction Practice Regarding 4D Elasticities Tools

The study recommendations for local jurisdiction practice regarding 4D elasticities tools were developed to provide guidance in the appropriate use of the 4D elasticities. They are based on recommendations of the developers of the 4D elasticities as well as the developers of the tools that are used to apply them: I-PLACE3S, INDEX and 4D post-processors. The recommendations also came from experiences reported by modelers who had used the elasticities in practical applications. These reported experiences came from the research for the case study cities (**Chapter 5**) and from conversations with members of the Technical Advisory Committee who had experience with the methods. The recommendations are as follows:

1. There should be testing of an existing travel model to assess whether it already has smart-growth sensitivity and whether it estimates travel activity consistent with local travel survey results in order to determine whether a post-processor (such as the 4Ds) should also be used.
2. Local jurisdictions with low-sensitivity models should consider using a 4Ds methodology to gain some sensitivity to smart-growth strategies, either applied in sketch-planning software such as I-PLACE3S, INDEX, or as a spreadsheet post-processor to a local travel model.
3. It is recommended that 4Ds processes (whether in I-PLACE3S, INDEX, or as a spreadsheet post-process to a local travel model) can appropriately be used as part of local planning, public participation, and decision-making processes, such as:
    - Developing and/or updating city and county general plans and specific area community plans
    - Creating and communicating various land-use/transportation "scenarios" to workshop participants as part of these processes, and providing feedback to them regarding various potential benefits and impacts
    - Assessing land-use projects and plans regarding air quality benefits and impacts
    - As part of regional "visioning" processes (such as, for example, the SACOG Regional Blueprint Project) to gather input from participants and provide feedback to them regarding estimated benefits and impacts of their choices

    It is <u>not</u> recommended that 4Ds processes be used for conducting corridor planning of streets or highways (e.g., regarding numbers of lanes or other specific project-level details).

4. For transportation impact studies of proposed land-use development projects, for traffic impact fee programs, or for any CEQA or NEPA documentation, the 4Ds may be used but only if the following requirements are adequately met:
    - the 4Ds elasticities are applied in conjunction with a local travel model,
    - the 4Ds elasticities have been calibrated to local conditions using a local travel survey,

- the 4Ds elasticities have been calibrated to reflect smart-growth effects and trip purposes that are captured directly by the local travel model (for models with moderate or high sensitivity), and
- the project is at least 200 acres in size.

5. For the 4D elasticities to function properly, it is necessary to apply them according to the guidelines established by the developers of the elasticities and in a way that reflects the conditions for which they were developed (**Chapter 4**). These include the following guidelines:
   - Set minimum and maximum boundaries on the size of areas to be analyzed to reflect the general size of the analysis zones used in the estimation of the elasticities
   - Limit the possible percentage change in the 4Ds to the range observed in the estimation data
   - Calibrate to local conditions
   - Use household travel surveys, if/when they are available, to determine actual elasticities appropriate for an area before conducting analyses of land-uses using a 4D elasticities post-processor
   - Follow recommendations regarding the proper use of each tool (**Chapter 4**)

7.3.3 Research, Development and Training

The review of current modeling practice by local jurisdictions in California and the review of supplemental tools revealed a need for additional development of the models and tools available to increase their sensitivity to smart-growth strategies and overall accuracy. The study revealed a need for additional research to support the enhancement of supplemental tools and to identify the sensitivity gained by UTMS model improvements. Because of the limited use of models and supplemental tools that are sensitive to smart-growth strategies by local jurisdictions, additional documentation and training regarding these tools are also needed. Specific recommendations for research, development and training are as follows:

1. The diversity of the case studies in this report shows that "best practices" are emerging and a project of training and education (in the form of technology transfer) targeting the majority of smaller MPOs is urgently needed.
2. Procedures and standards should be developed for testing a model's sensitivity to smart-growth conditions and judging whether the model is within an acceptable range, or the degree to which adjustment is needed.
3. More research, development, and training should be conducted to support the use of more sophisticated modeling tools by local jurisdictions.
4. The most advanced model systems, including activity-based and tour-based models, should be used to conduct research on elasticities for post-processing or correcting less sensitive models, especially to capture the benefits of modeling all modes of travel, short and long trips and the inter-relationship between trips.
5. Better documentation and explanation of supplemental post-processor methods such as the 4Ds methodologies (including, I-PLACE3S, INDEX and 4D post-

processors) should be provided, along with parameters and recommendations for their appropriate use. Guidelines should be provided that describe a calibration process for these tools.

6. An assessment should be undertaken of the benefits that improved regional modeling may have in assisting local governments' abilities to analyze smart-growth land use and transportation strategies at local and site-specific levels.
7. Additional research should be conducted to further support 4D elasticities and other post-processing methods to provide more direct sensitivity to smart-growth effects and to reduce correlation with other factors. There should also be research conducted on the elasticities for a broader range of area types. [43]
8. The 4Ds elasticities, outside of proprietary and copyrighted software, should evolve as "open architecture" freely available via the Internet.
9. The elasticities in proprietary and open source software should be tested periodically to verify their evolution over time and most important their transferability across California.
10. Additional research should be conducted with models from one or more case-study areas to assess how much sensitivity is added by different levels of improvement of UTMS modeling and by activity-based modeling. Comparison of results should be made with results from 4D methods to assess the effectiveness of 4D calibration to local model sensitivity. Sensitivity testing should also be used to provide guidance regarding which smart-growth strategies are most effective in different types of locations and settings.

[43] Research currently underway includes: NCHRP Project 08-51, "Enhancing Internal Trip Capture Estimation for Mixed-Use Developments," is currently assembling data on vehicle trip generation rates in mixed-use developments. NCHRP Project 08-66, "Trip-Generation Rates for Infill Land Use Developments in Metropolitan Areas" was recently approved. In addition, U.S. EPA is initiating a study that may provide the opportunity to update the 4D elasticities with more recent national data.

APPENDIX 1: Study Participants

Technical Advisory Committee

Member	Organization
Marc Birnbaum	Caltrans Local Development/Intergovernmental Relations (LD/IGR) Program
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Authors of the final report by Chapter:

CHAPTER	AUTHOR(S):
Executive Summary	William Loudon
Chapter 1 – Introduction	William Loudon
Chapter 2 – Overview of Travel Models and their Uses in Local Planning	William Loudon, Joe Story
Chapter 3 – Review of the Conventional Transportation Planning Model: Characteristics, Sensitivity to Smart-Growth Strategies, and Areas for Possible Improvement	Michael McNally, William Loudon, Joe Story, Michael Mauch, John Gibb
Chapter 4 - Overview of New Methods for Reflecting Smart-growth	Ming Lee, William Loudon
Chapter 5 - Travel Modeling Practice in California	William Loudon, Ming Lee, Miriam Leung, Kostas Goulias, Joe Story, Michael Mauch
Chapter 6 - Sensitivity Test of 4D Elasticities	Ming Lee
Chapter 7- Conclusions and Recommendations	William Loudon
Appendices	Michael McNally, William Loudon

APPENDIX 2: Definition of Acronyms

Transportation Terms

ADT – Average Daily Traffic
CBD – Central Business District
CEQA – California Environmental Quality Act
CMA – Congestion Management Agency
DU – Dwelling Units
EIR – Environmental Impact Report
FAR – Floor-Area Ratio
GIS – Geographic Information System
GPS – Global Positioning System
HB – Home-Based
HBO – Home-Based Other
HBW – Home-Based Work
HCN – Highway Capacity Manual
NHB – Non-Home-Based
HOV - High-Occupancy Vehicle
MPO – Metropolitan Planning Organization
O-D – Origin-Destination
PEF – Pedestrian Environment Factor
RTPA – Regional Transportation Planning Agency
SGI – Smart-growth INDEX
TIA – Traffic Impact Analysis
TAZ – Traffic Analysis Zone
UTMS – Urban Transportation Modeling System
VHT – Vehicle Hours of Travel
VMT – Vehicle Miles Traveled
VT – Vehicle Trips

Organizations

ACCMA – Alameda County Congestion Management Agency
AMBAG - Association of Monterey Bay Area Governments
EPA – U.S. Environmental Protection Agency
FHWA – Federal Highway Administration
FTA – Federal Transit Administration
MTC – Metropolitan Transportation Commission of the San Francisco Bay Area
OCCOG - Orange County Council of Government
OCTA – Orange County Transportation Authority
SACOG – Sacramento Area Council of Governments

SANDAG – San Diego Association of Governments
SCAG – Southern California Association of Governments
SCVTA – Santa Clara Valley Transportation Authority
SFCTA – San Francisco County Transportation Authority
SMAQD – Sacramento Metropolitan Air Quality District
USDOT – U.S. Department of Transportation
U.S. EPA – U.S. Environmental Protection Agency

Regional, County or City Model Systems

BAYCAST - Model for the San Francisco Bay Area
ITAM - Irvine Transportation Analysis Model
OCTAM – Orange County Transportation Analysis Model
SACMET – Model System for the Sacramento Metropolitan Area

APPENDIX 3: Glossary of Terms

Local Travel Models Glossary

A

Access	The right to enter and leave a location, facility, or service from a public right-of-way. Accessibility is typically defined as a measure of the ability of individuals or groups to exercise access.
Access and Egress	Access defines movement toward and egress defines movement from, as in access/egress to and from a development site or access/egress modes associated with getting to a transit stop (an access point reached, for example, via car as an access mode) and from the transit stop (an egress point) to a destination (via an egress mode, such as walking).
Accessibility	Accessibility is a measure of the ability of individuals to travel between various activity locations within a region (see also mobility).
Activity Based Approach	A modeling perspective focused on activities and reflecting the generally held belief that travel is a demand derived from activity participation. Activity-based models address individual and household travel / activity patterns, the sequence of travel and activities over the course of one or more days.
Alternative Modes	Non-automotive modes of travel including public transportation options and non-motorized modes such as bicycles and walking. Also includes evolving modes such as Segways and electric scooters that can utilize walkways and bikeways.
Alternatives Analysis	A systematic analysis of the engineering and economic feasibility of transportation system alternatives under consideration for a corridor or region, a process required before federal support can be allocated.
ArcInfo	One of the most complete and extensible GIS available today. Developed by ESRI [web].
Assignment	See Trip Assignment.

Attraction	The location or zone drawing a generated trip, and also used for the attracted trip itself: a zone is an *attraction* for N *trip attractions*. Compare with origins and destinations.
Authorization	Federal legislation that establishes the operation of a federal program or agency for a particular type of funding obligation (ISTEA, TEA-21, etc.) (see also appropriation).
Average Cost	The expected value of cost, where cost is typically taken as either travel time or generalized cost for network links or O-D pairs. In network assignment, equilibrating average costs of link performance functions leads to a user equilibrium result (see also marginal cost).

B

Baseline	A reference point in travel forecasting, representing the current state of the transportation and activity systems, on which comparisons with future alternatives are made.
Benefit	A result of an action expressed in terms of the utility gained from the action. In transportation, benefits are often expressed as cost savings
Benefit-Cost Analysis	An evaluation technique that compares the societal benefits and costs, measured in monetary terms, of proposed projects or policies. Alternative actions are incrementally compared to find the greatest net benefits.

C

Caltrans	California Department of Transportation.
Capacity	The maximum sustainable flow (typically measured in vehicles per hour) past a defined point (or over a uniform roadway segment) during a defined time period, under prevailing traffic and roadway conditions (see also LOS).
CBD	**C**entral **B**usiness **D**istrict: The traditional downtown retail, commercial, service, and institutional employment center of a metropolitan area.
Census Tract	The US decennial census aggregates household demographic data by spatially defined units called census tracts. Similar in design and spatial scale as TAZs, census tracts are mapable to TAZs but not identical.

Centroid	A defined point within a TAZ from which all trips are assumed to start or end. It should be located to reflect the center of activity in a TAZ and not necessarily the geographic center. Centroids are connected to the network via centroid connectors, abstract links that represent general access onto the formal network. Some travel models load trips directly onto network links (such as microsimulation models).
Centroid Connector	Abstract links that connect centroids to network nodes and represent general access from a TAZ to the formal transportation network.
Chain	A trip chain: a sequence of trips and activities, typically starting and ending at home (aka tour). Trip chaining is the process of linking non-home activities to reduce overall travel cost.
CMA	**C**ongestion **M**anagement **A**gency, in metropolitan counties in California, an agency responsible for the development and implementation of a Congestion Management Program (CMP) required under Prop 111 since 1990.
CMP	**C**ongestion **M**anagement **P**rogram (see CMA).
Comprehensive Plan	The long-range plan for a community's future development, a comprehensive plan (also known as a master plan or a general plan) defines goals and objectives, policies and standards, and constraints for the growth and development of the community. It provides a plan for zoning and land-use indicating planned land-uses (e.g., residential, commercial, institutional) for districts and parcels, and addresses all planning elements including transportation infrastructure and services, the natural and built environment, and demographic trends.
Conformity	The agreement of regional transportation plans with commitments designed to attain federal and state air quality standards.
Congestion	Interference between vehicles as flow densities increase, causing reduced speed and increased travel time. At low traffic volumes, limited interaction allows vehicles to proceed uninterrupted and flow is uncongested. As volume approaches capacity, vehicle interaction increases and queues begin to form.

Congestion Management Plan	Required by California's Proposition 111 (1990) in metropolitan counties to link land-use, transportation, and air quality for growth management that effectively utilizes transportation funds, alleviates traffic congestion, and improve air quality and other congestion impacts (see CMA).
Context-sensitive Design	A collaborative, interdisciplinary planning and design approach in which stakeholders are integral parts of the design team and the objectives of safety, mobility, environmental sustainability, and preservation of community values are simultaneously addressed.
Cost	Costs represent trade-offs between alternate uses of resources, and can be measured by money and time expended, or opportunities lost, to obtain a benefit. Transportation costs directly incurred include travel time costs; out-of-pocket costs (fares, tolls, and parking charges); and vehicle expenses (capital and operating costs). Transportation costs indirectly incurred include infrastructure capital, maintenance, and operations costs; accident costs; and environmental costs. Transportation benefits are equivalent to a reduction in costs (such as reduced travel time).
Cost-Benefit Analysis	See Benefit-Cost Analysis.
Cube	A software packages for travel forecasting, incorporating an integrated GIS. Developed by Citilabs [web]. Other travel forecasting packages include EMME/2, QRSII, MinUTP, Tranplan, and TransCAD.

D

Delay	The difference between the actual time spent traversing a link and the free-flow (unimpeded) time. Often represented as total or average delay (taken over all vehicles in a defined period) and serving as a measure of congestion.
Demand	The quantity of transportation desired at a given price, often defined for specific users in a specific time and place.

Demand Function

In Transportation Systems Analysis, the demand function reflects characteristics of the Activity System that, together with a performance function that reflects characteristics of the Transportation System, determines network traffic flows (volumes and travel times).

Demographic Data

Characteristics of the population, including population and household counts as well as descriptors such as age and gender, usually defined at the zonal level. While often used interchangeably with the term socio-economic data, demographic data are best viewed as fixed population characteristics that define a state (such as age and gender) whereas socio-economic data correspond to time-varying attributes that define status within a state (such as auto ownership and income). Demographic and socio-economic data, together with land-use data, are key inputs to trip generation.

Density

[1] The number of flow units (vehicles) present on a defined section of roadway at a given time (typically measured in vehicles per mile). With volume and speed, density defines the fundamental diagram of traffic flow (which provides a direct link to performance functions. [2] The number of units of some activity measure (population, employment, etc.) per unit area (e.g., population per square mile). In the 4D elasticities process, density, design, diversity, and destinations are measures to comparatively describe the built environment. In the 4Ds, an area's density is defined as the sum of population and employment divided by total land area.

Derived Demand

The demand for travel is derived from the demand to perform an activity that is located so as to require travel to access the activity.

Design

[1] Design is a systematic process to develop solutions to address a specified problem or need. Design reflects an open-ended problem-solving approach that recognizes alternate solutions and a range of constraints. [2] Design also refers to the resulting solution itself, in general or specific terms. Thus, design can be defined as a measure to describe an area's transportation network. Together with density and diversity, design forms the 4 Ds, measures to comparatively describe the built environment. In the 4D process, an area's design is a weighted combination of sidewalk completeness, route directness, and street network density.

Destination

The location or zone where a trip ends, but also used for the trip itself: a zone is a *destination* for N *trip destinations*. The origin is where a trip begins. Compare with production and attraction.

Destination Accessibility

Destination Accessibility is a measure of an area's regional accessibility. Together with density, design, and diversity, destination accessibility forms the 4 Ds, measures to comparatively describe the built environment. An extension of the 4D process, destinations is an index defined for a given area "i" as the denominator of a gravity model for a region, or $\Sigma_j A_j f(c_{ij})$, where A_j is the number of attractions in zone j and $f(c_{ij})$ is some function of the generalized cost from area i to destination j.

Distance

The basic measure of spatial separation and thus a measure of total travel. Defined alternatively as straight-line distance ("as the crow flies") or as actual travel distance from a trip origin to its destination. In policy studies, distance is often replaced by policy-sensitive equivalents such as travel cost, travel time, or generalized cost

Distance (from Heavy Rail)

An area's distance from a heavy rail transit station is a measure of an area's ability to draw trips from street networks. Together with density, design, diversity, and destination accessibility, distance forms the 5 Ds, measures to comparatively describe the built environment. An extension of the 4D process, the distance measure, defined as an exponential function of population and employment within a half mile of a rail station, rail service frequency, and feeder bus service frequency), is only applicable in zones containing a heavy rail station.

Diversity

Diversity is a measure of an area's land-use mix, or more specifically, its jobs-population balance. Together with density, design and destinations, diversity forms the 4Ds measures to comparatively describe the built environment. In the 4D process, an area's diversity is defined as {1 - [abs((E/P)p - e) / ((E/P)p + e)] }, where E and P are regional employment and population and e and p are the corresponding local values.

DRAM/EMPAL

Direct **R**esidential **A**llocation **M**odel and **EMP**loyment **AL**location are components of the Integrated Transportation Land-use Package, ITLUP.

E

Term	Definition
Elasticity	The elasticity of y with respect to x is the percent change in variable y with respect to the percent change in variable x, or $e_{y\|x} = (dy/y)/(dx/x)$ (the elasticity of transit demand D with respect to transit fare f is (dD/D)/(df/f) and is often found to be about -0.30).
EIR/EIS	**E**nvironmental **I**mpact **R**eport/**E**nvironmental **I**mpact **S**tatement: A comprehensive analysis of the environmental impacts of proposed transportation and land development projects (EIR is the California requirement to CEQA; EIS is the federal requirement to NEPA). **Draft** EIR/EIS are circulated for agency and public comment. The final EIR/EIS must address significant impacts and also provide means to mitigate adverse impacts.
EMME/2	A software package for travel forecasting and transportation network analysis. Developed by INRO. Other travel-forecasting packages include Cube, QRSII, MinUTP, T-Model, Tranplan, and TransCAD.
Equilibrium	A system state where overall demand and system performance are balanced. Any increase in demand corresponds to an increase in cost that reduces that demand. Network flow is in equilibrium when no traveler can unilaterally change route and be better off, thus there is no incentive to change.
Evaluation	As part of the Transportation Planning Process, evaluation is the process of systematically assessing the costs and benefits of competing alternatives. In addition to *a priori* applications, evaluation is also performed as an *ex post* performance assessment of existing transportation systems.
External Trip	A trip with either its origin or its destination located outside of the study area. The external trip end is assigned to an external station. Often referred to as "IE" for internal-to-external or "EI" for external-to-internal trips. Through trips have both trip ends outside the study area. Internal trips have both trip ends inside the study.

F

FAR	See Floor Area Ratio.
Feedback	Using the output from a step in a modeling sequence as revised input to a prior step to re-execute the model sequence. In the last step of the Four Step Model, trip assignment has conventionally been equilibrated given a fixed trip table as input, with no feedback to prior steps. Most recent models take output travel times and feed them back to the minimum path algorithms and then repeat trip distribution and mode choice with more consistent estimates of network travel times and costs.
Floor Area Ratio	In zoning, the **F**loor **A**rea **R**atio expresses the total floor space of a building as a fraction of the total area of a site. FAR combines horizontal (e.g., setback) and vertical (e.g., height restriction) dimensional limits into a single parameter that correlates well with site traffic impact measures (trips, parking demands, etc.).
Flows	In Transportation Systems Analysis, the output of demand performance equilibration (trip assignment in the basic Four Step Model) is a set of flows, represented by a set of link volume and level-of-service measures. Flow is often taken as only traffic volume (especially in traffic operations), typically measured in vehicles per hour (vph).
Four Step Model	The conventional model for travel forecasting, so named for the four major steps of the process: trip generation, trip distribution, mode choice, and trip assignment.

G

Generalized Cost	A weighted combination of attributes of travel cost such as monetary cost, travel time (with component parts such as access, waiting, and in-vehicle time often separated), and distance. May involve composite general costs over alternate modes. See impedance.
General Plan	See Comprehensive Plan.

Geo-coding — Geo-coding is the process of mapping activity locations reported in travel surveys to a geographical coordinate system (e.g., latitude and longitude) for use in travel forecasting. In the past, geo-coding assigned activity locations by TAZs number. GPS automatically provides precise geo-coded location data and is increasingly used in travel surveys.

GIS — A **G**eographical **I**nformation **S**ystem is an integrated spatial database, analysis, and graphic display tool (such as ArcInfo or TransCAD).

H

Home-based — A classification for trips that either begin and/or end at a trip maker's residence (home). Regardless of the origin and destination, the home location is *always* the production for home-based trips; the other end is always the attraction (see Non-home-based).

Household Travel Survey — A survey designed to measure household travel behavior and the characteristics of the household that are relevant to its travel behavior. The survey typically collects information on the household, household members, household vehicles, and a travel activity diary that records all activity and travel that occurs during the survey period. Typically conducted in metropolitan areas every 10 years.

I

Impact — Intended or unintended effects on the natural and built environments as a result of operation or implementation of transportation infrastructure and services.

Impact Fees — Fees assessed by municipal or regional government and charged to developers to mitigate for the degradation in traffic performance caused by a particular proposed development project. Fees are based on established performance standards and/or the cost of the mitigation strategy.

Impedance Impedance, a computed measure of the disincentive to travel due to spatial separation, is a composite function of travel time (often split by access, in-vehicle, and egress time), travel cost, and/or distance. Also known as deterrence. Economists use the term "generalized cost."

INDEX INDEX is a GIS-based software package that analyzes and graphically presents the impacts of alternative planning scenarios using a range of design measures (such as the 5 Ds). INDEX estimates travel impacts such as changes in vehicle-trip rates and VMT and can be applied at spatial scales ranging from neighborhoods to regions. It was developed by Criterion Planners [web].

Induced Demand Travel demand postulated to be generated by added transportation capacity. An alternate theory is that this "induced demand" represents trips that have been made to other destinations, by other modes and routes, and/or at other times, now reflected in a new travel choice in response to improved local performance due to the added capacity, rather than representing new (latent) demand on the network.

Intermodal Transportation planning or operations that involve more than one mode of transportation. Sometimes taken as the operational aspect that involved direct interactions between modes (such as in passenger or freight transfers). See also multimodal.

Internal Capture In mixed-use developments, internal capture is the proportion of trips attracted to a particular parcel that are drawn from other parcels in the development and thus reduces the traffic impact on adjacent streets. The design of sustainable communities is in part based on a land-use mix that accommodates internal trips being made by public or non-motorized modes or with shorter trip lengths.

Intrazonal Trip A trip with both origin and destination in the same zone. In trip assignment, intrazonal trips are not loaded on the network.

ISTEA **ISTEA**, The Intermodal Surface Transportation Efficiency Act of 1991, followed by TEA-21, the Transportation Efficiency Act of 1998, and SAFETEA-LU, the Safe, Accountable, Flexible, and Efficient Transportation Efficiency Act -- A Legacy for Users of 2005, are the three most recent federal transportation authorization acts.

ITLUP	**I**ntegrated **T**ransportation and **Land-use** **P**ackage is a land-use (activity system) modeling software package, incorporating components such as DRAM/EMPAL, used in many metropolitan transportation studies over the past few decades (Putman, 1983). More recent land-use software packages include MEPLAN, TRANUS, MUSSA, and UrbanSim.
ITS	The **I**nstitute of **T**ransportation **S**tudies of the University of California, and also an acronym for **I**ntelligent **T**ransportation **S**ystems, which include Advanced Transportation Management Systems (ATMS), Advanced Vehicle Control Systems (AVCS), and Advanced Traveler Information Systems (ATIS).

J, K

Jobs-Housing Balance	The spatial distribution of employment relative to the distribution of workers (by residence) within a defined area. An area with a balance of jobs and housing would imply a greater likelihood that a worker would find a job nearby, minimizing commute trip length. Variations in job and worker types require a concise definition of balance as having complementary job and housing characteristics.
Jurisdiction	A level of government (city, county, state, or federal) or regulatory authority (local, regional, state, or federal) responsible for some or all aspects of the planning, implementation, operations, and maintenance of transportation facilities and services in a defined area.

L

Land-use	The primary activity for which a parcel of land is used (residential, commercial, industrial, open space, undeveloped, etc.). Municipal zoning and general plans identify legal designations of current and planned land-use.

Land-use Data	Description of the amount of land for specified land-use designations, defined spatially by various zoning systems (e.g., parcels, TAZs). Amounts may be represented in aerial units (e.g., acres), by activity descriptors (e.g., number of housing units), or densities (e.g., population per square mile). In travel forecasting, land-use data includes these quantitative and quantitative attributes as well as demographic and socio-economic data that describe the population utilizing the land in question. Together these define the activity system.
Land-use Model	One of an extensive range of quantitative models and procedures that describe land-use patterns (the activity system) of a region. These models typically describe and predict the spatial distribution of population and employment, and the corresponding land consumed. While transportation networks are typically incorporated in the activity location sub-models, historically, land-use models were not fully integrated with travel forecasting models. However, recently developed land-use models such as MEPLAN, MUSSA, and UrbanSim are integrated land-use transportation models.
Latent Demand	Travel demand is a relationship between the price of travel and the quantity of travel demanded. Travel that corresponds to that part of a demand relationship that is not being realized due to limited capacity and/or high price is considered latent demand that may materialize as these constraints are relaxed.
Level of Service	A set of quantitative or qualitative descriptors of transportation system performance. The Highway Capacity Manual defines levels of service (LOS) for traffic operations with ratings that range from A (best) to F (worst). In Transportation Systems Analysis (TSA), link performance functions model LOS as a function of system characteristics (such as speed and capacity) and link volume.
Local Jurisdiction	A level of government or regulatory authority responsible for some or all aspects of the planning, implementation, operations, and maintenance of transportation facilities and services for a local area (e.g., city or county).

Local Model	The phrase *local models* (or *travel models used at the local level*) may be interpreted as (a) models that are developed by city or county agencies and/or are applied at the city or county level (although increasingly reflecting regional model characteristics) and/or (b) *alternate* models that are directed toward capturing traffic impacts of evolving land-use policies at the local level (contrast with regional and land-use models). Local models provide data inputs to micro-simulation analyses; to infrastructure and control system design; and to planning, investment, and operation decisions, including the review of the effects of local land-use projects, general and specific plans, and other transportation system elements.
Logit Model	A choice model based on the theory that an individual maximizes utility in choosing between available alternatives. The logit model's utility function comprises a deterministic component (a function of measurable characteristics of the individual and of the alternatives in the individual's choice set) and a stochastic component (error term).
LOS	See Level of Service.

M

Marginal Cost	The change in total cost, where cost is typically taken as either travel time, or generalized cost, for network links or O-D pairs. In network assignment, equilibrating marginal costs of link performance functions leads to a system optimal result (see also average cost).
MEPLAN	A land-use model software package developed by Echenique & Partners (1987). Similar packages include TRANUS, MUSSA, UrbanSim, and ITLUP.
Metropolitan Planning Organization	The MPO is the local or regional agency designated by the state to coordinate federal transportation planning requirements.
Microsimulation	A simulation focusing on the behavior of individual system elements (such as individual persons or vehicles).
MinUTP	A software package for travel forecasting and transportation network analysis. Other travel-forecasting packages include Cube, EMME/2, QRSII, T-Model, Tranplan, and TransCAD.

Mitigation To reduce the impact of a proposed project by developing counter-measures to restore the impacted to area to prior or otherwise acceptable conditions. Perhaps most commonly linked with traffic impact studies where the traffic impacts of a proposed development are estimated and a plan to ameliorate the impacts is proposed and funded by the developer, evaluated by the appropriate government agency, and implemented as part of the project.

Mitigation Measures Specific design commitments made as part of a Traffic Impact Study (TIS) or environmental impact assessment that serve to reduce the impacts of a proposed project. These measures may include planning and development commitments, environmental measures, and/or right-of-way improvements.

Mobility Mobility is a measure of the degree to which the demand for personal travel is achieved, measured by a variety of system performance indicators (see also accessibility).

Mode A means of conveyance between origins and destinations, modes are motorized (cars and other private vehicles, buses, rail transit) and non-motorized (walking, bicycles). About 90 percent of all travel is by private vehicles, with the remainder by other modes (this percentage varies over activity and transportation characteristics and geographic areas).

Mode Choice **M**ode **C**hoice (MC) is the third step in the conventional four-step model of travel forecasting. MC is the process by which a traveler chooses a transportation mode for a trip, given the trip's purpose, origin, and destination (the results of the first two steps of the four step model); characteristics of the traveler; and characteristics of the modes available to the traveler. Mode choice typically follows trip distribution in the four-step model sequence. Historical use of aggregate mode choice has given way to the multinomial logit as the preferred mode choice formulation.

Mode Split The market share of trips by each of the transport modes serving an area. The historical application of aggregate mode share models is often referred to as modal split.

Model An analytical, typically mathematical, abstraction of reality used by transportation analysts as a tool to forecast travel and activities, land-use and economic activity, and associated environmental impacts.

MOE — A **M**easure **o**f **E**ffectiveness is a variable that is designed to assess system performance. Also know as a Performance Measure.

MPO — **M**etropolitan **P**lanning **O**rganization (see MPO).

Multimodal — Transportation planning or operations that involve more than one mode of transportation. Sometimes taken as a coordinated planning focus on two or more modes of transportation. See also intermodal.

Multinomial Logit — A logit model for choice between more than two alternatives (referred to as "binary logit" when the choice is between two alternatives).

MUSSA — A land-use model software package developed by Francisco Martinez (1996). Similar packages include MEPLAN, TRANUS, UrbanSim, and ITLUP.

N

NCHRP 187 — TRB's NCHRP Report 187 *Quick-Response Urban Travel Estimation Techniques and Transferable Parameters* (1978) documented "transferable parameters, factors, and manual techniques for simplified travel forecasting". See NCHRP 365.

NCHRP 365 — TRB's NCHRP Report 365 *Travel Estimation Techniques for Urban Planning* (1998) updated NCHRP 187.

Neo-traditional Design — A neighborhood design philosophy derived from traditional community characteristics such as mixed land-uses in relatively close proximity. It is also known as Traditional Neighborhood Development. Neo-traditional design, although often used interchangeably with the New Urbanism and Transit-Oriented Development, is more an architectural design philosophy.

Network — A graphical and/or mathematical representation of a region's transportation infrastructure and services, comprising links and nodes.

New Urbanism — An urban design philosophy derived from traditional community characteristics such as grid street layouts, higher densities, and mixed land-uses that increase the relative accessibility of non-automotive modes of travel. By reducing automobile travel and land consumption, New Urbanism seeks to minimize impacts on the built and natural environments. Transit-oriented development and neo-traditional design are often components of New Urbanism development strategies.

No Build Alternative	In alternatives analysis, the No Build Alternative represents the option of no additional transportation improvements beyond what has already been planned and programmed prior to the current study. Serves as a baseline for comparison of various alternatives to improve or expand infrastructure and services.
Non-Home-Based	A classification for trips that neither begin nor end at a trip maker's residence (home). The origin of a NHB trip is also the production; the destination of a NHB trip is also the attraction (see HB).

O

O-D	An origin - destination pair.
Off-peak	A period of relatively low traffic volume and density (see peak).
Origin	The location or zone where a trip begins, but also used for the trip itself: a zone is an *origin* for N *trip origins*. The destination is where a trip ends. Compare with production and attraction.

P

Peak	The period of maximum traffic volume and density. The distribution of trip frequency by time-of-day typically shows morning (AM peak) and afternoon/evening peak (PM peak) periods. Travel forecasting models have conventionally focused on problems associated with peak-period flows (such as congestion). A behavioral response to increased congestion in peak-periods has been the increase in duration of the peak-period, deemed peak spreading (see off-peak).
Peak-hour	For a transportation facility or network, the hour of the day during which the maximum traffic volume occurs. Often a longer "peak-period" is the salient operational period for analysis.
Peak Spreading	The lengthening of the peak-period caused by earlier and later departure times of travelers attempting to avoid increased peak-period congestion.

PECAS	Production Exchange and Consumption Allocation System is a comprehensive land-use model developed by Hunt and Abraham at the University of Calgary based on the TRANUS model.
PEF	**P**edestrian **E**nvironment **F**actor is a qualitative index of the degree that an area is accommodating to travel by walking.
P-E Fit	**P**erson-**E**nvironment **F**it is a measure of the degree that an individual's activity requirements are met by the current physical and social environments.
Performance	A general term for the output level of service for an element of transportation infrastructure. For roadways, a performance function represents the relationship between input variables such as free speed, capacity, and volume and the output performance measure of travel time. Performance, rather than supply, is a more appropriate term for assessing level-of-service for transportation facilities and, thus, for determining system equilibrium.
Performance Function	In Transportation Systems Analysis, the performance function represents the relationship, for a given volume, between characteristics of a facility and the resulting level-of-service. The performance and demand functions are solved to determine system flows.
Performance Measures	Output measures of system effectiveness, either measured or modeled. Also known as Measures of Effectiveness (MOE) or Performance Indicators.
Person-mile	One person traveling one mile. "Total person-miles traveled" is an indicator of system performance measuring total mobility in a region based on total distance traveled (see Vehicle-mile).
Person Trip	A single trip by a single person. The output of trip generation is measured in person-trips. A vehicle-trip is a single trip by a vehicle, regardless of the number of occupants of the vehicle. A vehicle with three occupants on the same trip equals one vehicle-trip or three person trips.

I-PLACE3S	**PLA**nning for **C**ommunity **E**nergy, **E**conomic and **E**nvironmental **S**ustainability is a planning method developed to enable users to quickly forecast the energy use of a given land-use plan. Alternate land-use assumptions can be specified via a GIS interface. I-PLACE3S also can estimate the distribution of households and employment in the study area and compare land-use plans in terms of transportation impacts, such as vehicle trips and VMT. Development of PLACES3 was originally jointly supported by the state energy offices of California, Oregon, and Washington.
Planned Unit Development	Land development permitted and planned on multiple parcels with a compatible mix of land-uses. PUD permits developers with greater flexibility in meeting density and land-use goals. This variation from fixed lot size "grid" development often led to sprawling, automobile-dominated development patterns.
Production	The location or zone responsible for a trip occurring but also used for the produced trip itself: a zone is a *production* for N *trip productions*). A household generates N productions that may be split as home-based or non-home-based. Home-based trips, by definition, have their production in the zone containing the household, regardless of the origin and destination of the trip. The productions for non-home-based trips must be allocated to the NHB trip's origin zone (see reallocation model).

Q

QRSII	**Q**uick **R**esponse **S**ystem: a software package for travel forecasting, incorporating transferable models and parameters compiled from NCHRP187. Developed by AJH Associates. Other travel-forecasting packages include Cube, EMME/2, MinUTP, T-Model, Tranplan, and TransCAD.
Quick Response	A compilation of transferable parameters, factors, and manual techniques for simplified transportation planning analysis (see NCHRP 187, NCHRP 365, and QRSII).

R

Regional Model	The phrase *regional models* may be interpreted as models that are developed by regional agencies and/or are applied at the regional level. These models reflect economics and demographics that interplay at the regional level.

Route Choice	Route choice is often used synonymously for trip assignment, the fourth major step in the four-step model sequence, but is sometimes reserved for the application of actual (stochastic) route choice models (versus the typically deterministic models used in most trip assignment). RC is based on the assumption that a traveler will choose the route that will minimize expected travel time (or generalized cost) for a trip.
RTIP	The **R**egional **T**ransportation **I**mprovement **P**rogram lists the transportation projects that a region proposes for funding, compiled from priority lists submitted by local jurisdictions and agencies. RTIP projects must be consistent with the regional transportation plan (RTP). RTIPs are combined with state-level projects in the State Transportation Improvement Program (STIP).
RTP	The **R**egional **T**ransportation **P**lan (RTP), prepared by the designated Metropolitan Planning Organization (MPO), comprises policies, programs, and specific projects to meet long-range transportation needs. The RTP is updated every three years and must reflect funding constraints and air quality regulations.

S

SAFETEA-LU	ISTEA, the Intermodal Surface Transportation Efficiency Act of 1991, followed by TEA-21, the Transportation Efficiency Act of 1998, and **SAFETEA-LU**, the Safe, Accountable, Flexible, and Efficient Transportation Efficiency Act -- A Legacy for Users of 2005, are the three most recent federal transportation authorization acts.
Site Access	Access and egress points from a land development site to the adjacent transportation network. Site access design is a key component of traffic impact studies, influencing the directional distribution of traffic to and from the site and thus traffic impacts and options for mitigation.
Sketch Planning	Sketch planning is the application of simple, approximate methods of analysis to provide rough performance estimates in the initial screening of alternatives. With technological advances in computing, such simplified methods are of less benefit.

Smart-growth	Smart-growth is a planning concept focusing on increased density and diversity, circulation continuity, alternative travel modes, and a better sense of neighborhood scale. By reducing automobile travel, land consumption, and the need for new transportation infrastructure, smart-growth seeks to minimize impacts on the built and natural environments. Also known as the New Urbanism, neo-traditional design, and transit-oriented development.
Smart-growth Index	A GIS sketch planning tool for comparing alternative and use and transportation scenarios and evaluating outcomes using community and environmental performance indicators. Developed by Criterion Planners for USEPA in 2002. See also INDEX.
Socio-Economic Data	Characteristics of the population, including income, employment status, and auto ownership, usually defined at the household and individual levels. While often used interchangeably with the term demographic data, socio-economic data are perhaps best viewed as time-varying attributes that define status within a state (such as auto ownership or income) whereas demographic data correspond to fixed characteristics of population that define the state (such as age and gender). Socio-economic and demographic data, together with land-use data, are key inputs to trip generation.
Special Generator	A location or zone that exhibits trip rates or patterns that cannot be directly captured by a study area's trip generation model. Separate surveys and models are used to estimate productions and attractions for special generators. Examples include airports, college campuses, and military bases.
Specific Plan	Part of a comprehensive plan corresponding to a defined function and/or spatial area and containing development standards and criteria that supplement those of the comprehensive plan.
Sprawl	See urban sprawl.
STIP	**S**tate **T**ransportation **I**mprovement **P**rogram (see TIP).
Study Area	A defined region within which estimates of travel demand and system performance are desired. A corridor is a linear study area focused on one or more transportation facilities along the corridor.

Supply	The physical extent of transportation system infrastructure and services provided.
Sustainable Development	A land-use pattern characterized by growth and development occurring in a manner supported by infrastructure and financial resources, and proportional to the preservation of the current built and natural environments.

T

TAZ	Traffic Analysis Zone, a defined zone for travel forecasting and traffic simulation studies, represented in the network by a centroid.
TDM	**T**ravel **D**emand **M**anagement constitutes travel demand reduction programs such as flextime, ridesharing, telecommuting, alternative transit options, etc.
TEA-21	ISTEA, the Intermodal Surface Transportation Efficiency Act of 1991, followed by **TEA-21**, the Transportation Efficiency Act of 1998, and SAFETEA-LU, the Safe, Accountable, Flexible, and Efficient Transportation Efficiency Act -- A Legacy for Users of 2005, the three most recent federal transportation authorization acts.
Time-of-Day	In the conventional Four Step Model, Time-of-Day (ToD) modeling can be considered a 5th step, executed at a point prior to trip assignment to convert generated daily trips to those trips occurring during a particular period of analysis (such as the peak-hour).
TIP	**T**ransportation **I**mprovement **P**rogram (TIP).
TMIP	U.S. DOT's **T**ravel **M**odel *I*mprovement **P**rogram is designed to foster the development and application of improved transportation modeling methods and capabilities to meet local, state, and federal planning requirements
T-Model	A software package for travel forecasting and transportation network analysis. Developed by T-Model Corporation [web]. Other travel-forecasting packages include Cube, EMME/2, MinUTP, QRSII, Tranplan, and TransCAD.
Tour	A trip chain -- a sequence of trips and activities, typically starting and ending at home.
Tour-based Model	A variation of the conventional trip-based travel-forecasting model that uses tours rather than individual trips and thus can account for the linkages between individual trips and activities.

TP+ A software package for travel forecasting and transportation network analysis that evolved from TranPlan. Marketed by Citilabs [web]. Other travel-forecasting packages include Cube, EMME/2, MinUTP, QRSII, T-Model, and TransCAD.

Traffic Calming Local street design techniques that reduce traffic speeds and discourage traffic incursion in residential neighborhoods to improve local street safety and neighborhood quality of life. Techniques include physical traffic barriers (e.g., diverters, chokers, speed humps), revised street alignments (e.g., traffic circles, chicanes), and traffic speed enforcement.

Traffic Impact Study A Traffic Impact Study (TIS) is conducted to assess the effects on traffic flows of changes in land development. The analysis typically follows the general steps of the four-step model but while regional travel-forecasting models may be used with large-scale development changes (often as part of an EIR), various heuristic methods are often used for smaller scale land-use changes. A TIS focus is the quantification of traffic impact and the development of mitigation measures and impact fees.

TranPlan A software package for travel forecasting and transportation network analysis. Evolved into TP+. Marketed by Citilabs [web]. Other travel-forecasting packages include Cube, EMME/2, MinUTP, QRSII, T-Model, and TransCAD.

TransCAD A software package for travel forecasting, incorporating an integrated GIS. Developed by Caliper [web]. Other travel-forecasting packages include Cube, EMME/2, MinUTP, QRSII, T-Model, and Tranplan.

TRANSIMS A third generation travel analysis software package, incorporating microsimulation and activity-based approaches to provide more accurate assessment of travel impacts, especially regarding performance and air quality assessment. Developed by Los Alamos National Laboratories, TRANSIMS is marketed by IBM Business Consultants.

Transit-Oriented Development

Residential, commercial, and/or mixed-use developments designed to maximize access to and use of public transportation. "New Urbanist" and "Neo-Traditional" development designs are typically more amenable to transit-oriented development than are conventional urban development approaches, but these design alternatives do not require transit. Transit-Oriented Developments (TODs) are often designed jointly with transit systems. The growth in domestic rail transit systems was first accompanied with expectations for *joint development* where the accessibility benefits of TOD could be taxed to help pay for the rail project. Today, TODs may receive tax concessions and other financial incentives to encourage development that encourages transit use.

Transportation Improvement Program

The **T**ransportation **I**mprovement **P**rogram (TIP) is a plan for state and federal funds to be allocated to local and regional transportation projects. In California, the annual TIP is cooperatively prepared by local governments, local and regional transportation agencies, and Caltrans. It covers a 7-year period and is updated every 2 years. A Regional TIP lists highway and transit projects from priority lists developed by local jurisdictions. The state TIP is submitted to the California Transportation Commission and incorporates selected elements of the regional TIPs.

Transportation Planning Process

The Transportation Planning Process is the system-analytic application of continuing, comprehensive, and cooperative planning. Often represented as five broad stages of (1) problem definition, (2) solution generation, (3) solution analysis, (4) evaluation and choice, and (5) implementation and monitoring. Travel forecasting occurs during the third stage, solution analysis.

Transportation Research Board

The **T**ransportation **R**esearch **B**oard, a branch of the National Academy of Science, promotes innovation and progress in transportation through research and facilitates the sharing of information on transportation practice and policy [web].

Transportation Systems Analysis	**T**ransportation **S**ystems **A**nalysis (TSA) as formalized by Manheim and later expanded by Florian (1986) is a framework for the systematic analysis and evaluation of transportation systems. The framework is flexible to allow components to be specified exogenously or endogenously based on the scale and scope of the models and policies being studies. Basic components include demand and performance procedures, as well as activity location and supply procedures.
TRANUS	A land-use model software package developed by Sr. de la Barra (1990). Similar "integrated" modeling software includes: MEPLAN, MUSSA, UrbanSim, and PECAS.
Travel Activity Diary	A primary component of household travel surveys, the travel and activity diary records all trips and activities for all household members for one or more days. In the past, diaries recorded daily travel behavior by trips and associated characteristics (including trip purpose). Now, most diaries record activities and associated characteristics (including travel attributes). While in theory the same data is collected, results suggest that activity diaries provide a more complete recording of all travel and activity. Recent develops include the use of GPS and the application of computer-based diaries to complement or replace manual recording.
Travel Cost	Travel cost can refer to the actual monetary expenditure on a trip or to a more general measure of travel disutility. Regarding monetary expenditure, travel cost can refer to actual out-of-pocket costs on a trip or a more complete cost accounting of total cost. Regarding general measures, in travel-forecasting models, travel time is often individually used for travel cost or as a component of generalized cost.
Travel Forecasting	Often referred to as travel demand forecasting or travel demand modeling, this is the primary metropolitan modeling framework for estimating the performance and impacts of future transportation system alternatives. Although the basic modeling structure (the four step model) appears relatively unchanged over the past 40 years, model components and software sophistication have evolved significantly. Changes have included a move from aggregate to disaggregate models and data, a greater behavior basis, and more sophisticated equilibration algorithms. Still evolving are activity-based, dynamic, and microsimulation approaches.

Travel Survey

The primary mechanisms to collect data on travel behavior are travel surveys. The Household Travel Survey serves as the primary data for regional travel-forecasting model development. Other surveys include external, transit on-board, and commercial vehicle surveys. Travel survey data complements non-travel survey data from census, land-use, and employer surveys.

Travel Time

Travel time is a key determinant of travel behavior, frequently used as the sole measure of travel cost in conventional travel forecasting. In Transportation Systems Analysis, travel time is an output of performance functions and an input to demand functions, both of which are equilibrated to solve for system flows. In the four-step model, travel time is a key variable in the trip distribution, mode choice, and trip assignment steps, and is the basis for feedback in the model system. Mean travel time (overall, by time-of-day, by trip type, etc.) is a key performance measure in alternatives analysis and system evaluation.

Trip

A movement by an individual from one activity location to another activity location.

Trip Assignment

Trip **A**ssignment (TA) is the fourth step in the conventional four-step model of travel forecasting. TA is a process by which trips, defined by time-of-day and mode, are allocated to feasible paths between an origin and a destination in a network. The output of TA is the number of vehicle-trips (or passenger-trips) equilibrated over a modal network. Also known as Traffic Assignment or Network Assignment See also Route Choice).

Trip Attraction

A trip generated (typically) by a household has both a production and an attraction. The number of trip attractions in a zone is proportional to the level of activity (land-use) in that zone associated with the type of trip in question. If the trip maker's residence (home) is one end of the trip, then the other trip end is the attraction. If the trip maker's residence (home) is at neither trip end (i.e., a NHB trip), then the attraction is the same as the trip destination. Trip attractions are typically modeled as aggregate regression models using data pooled from zones into districts (since travel surveys are residential-based, there are usually not enough observed attractions in all zones to estimate zonal attractions directly. See also production or origin.

Trip Chaining
The traveler's process of linking trips into tours. A trip chain, or tour, is defined such that the destination of the first trip is the origin of the second, the destination of the second trip is the origin of the third, and so forth.

Trip Distribution
Trip **D**istribution (TD) is the second step in the conventional four-step model of travel forecasting. TD is the process of pairing generated productions and attractions (or origins and destinations) to determine the number of trips between all pairs of zones in the study area. The primary TD outputs are trip tables (typically 24-hour person trips, specified by trip purpose). TD follows trip generation in the four-step model sequence, and is followed by mode choice or time-of-day factoring. The gravity model is the most common tool applied. In disaggregate terms, it is the process by which a trip's destination is selected, given the trip's purpose, origin, and travel cost to possible destinations.

Trip Frequency
The number of trips per unit time (typically, daily trips).

Trip Generation
Trip **G**eneration (TG) is the first step in the conventional four-step model of travel forecasting. TG is the process of estimating trip productions (or origins) and attractions (or destinations) for all zones in the study area. In regional travel-forecasting studies, category or regression models are applied to estimate trip ends by trip purpose as a function of individual, household, or zonal socio-economic, land-use, or accessibility characteristics (results are typically aggregated to the zone level). In traffic impact studies, land-use-based trip rates (such as ITE) are applied at the project or parcel level in place of regional TG models. The outputs of trip generation analysis ("Os and Ds" or "Ps and As") serve as input to the second step of the four-step process, trip distribution.

Trip Production
A trip generated generally by a household as a function of household socio-economic or residential land-use characteristics. If the trip maker's residence (home) is either end of the trip, then that location or zone is the production. If the trip maker's residence (home) is at neither trip end (i.e., a NHB trip), then the production location is the same as the trip's origin (compare with attraction and destination).

Trip Purpose
The purpose of virtually any trip is the activity in which the trip maker will participate at the location of the end of the trip. The demand for the trip is derived from the demand for the activity. Conventional travel-forecasting models employ a number of aggregate trip purposes in lieu of actual trip purposes. Such purposes usually identify both ends of the trip preceding the activity, such as "home-work" (or HBW), "home-other" (or HBO), or "non-home-based" (or NHB). Many larger metropolitan areas use additional purpose categories.

Trip Rate
For a specified land-use or geographic area, a trip rate is the number of trips per unit time per unit size. For example, the number of vehicle-trips entering a 7-11 store in a peak-hour for every 1000 square feet of retail floor space. Trip rates may be expressed as mode-specific or by time-of-day. The Institute of Transportation Engineers publishes a widely used compendium of average trip rates for a variety of land-uses and land-use characteristics. Trip rates, in general, are modeled in the four-step model in trip generation analysis via techniques such as category analysis (which explicitly yields a trip rate model).

Trip Table
A trip table is a matrix of trips from each origin (or production) to each destination (or attraction) in a region (also thus referred to as O-D or P-A matrices). Trip tables may be specified for a particular trip purpose, time period, or mode, or for person- or vehicle-trips. Trip tables are output from trip distribution models (and modified in subsequent steps of the four step model). Trip tables may also be estimated or updated using traffic counts.

U

Urban Growth Boundary
A defined boundary around a metropolitan area intended to accommodate projected population and employment growth within a defined planning period. Such a smart-growth strategy is intended to control sprawl beyond the boundary.

Urban Sprawl
An often-pejorative term referring to the expansive growth of a metropolitan region. The development of most American suburban areas is considered sprawl.

UrbanSim
A land-use model software package developed by Paul Waddell (2000). Similar integrated land-use/transportation software includes: MEPLAN, PECAS, MUSSA, TRANUS, and ITLUP.

UTMS	The **U**rban **T**ransportation **M**odeling **S**ystem is a generic name for the formal application of conventional travel forecasting models. UTPS was the first computer implementation of, and became synonymous with, UTMS. A more common generic name is the four-step model.
UTPS	The **U**rban **T**ransportation **P**lanning **S**ystem, one of the first travel-forecasting modeling packages, was developed in the 1970s by the US Department of Transportation. Its widespread use in the first travel forecasting led to its name becoming synonymous with the modeling process itself. Designed for mainframe computers, UTPS has been replaced by various PC or workstation-based software packages (e.g., see TransCAD).

V

Value of Time	The opportunity cost of travel time, value of time is the monetary amount that a traveler would be willing to spend to save time. VOT is a parameter used in benefit-cost analysis to ascertain traveler time benefits of transportation infrastructure and service improvements.
Vehicle-hour	One vehicle traveling for one hour. Total vehicle-hours traveled, or VHT, is an indicator of system performance measuring the total amount of vehicular travel in a region based on total time spent traveling.
Vehicle-mile	One vehicle traveling one mile. Total vehicle-miles traveled, or VMT, is an indicator of system performance measuring the total amount of vehicular travel in a region based on distance traveled (see Person-mile).
Vehicle Trip	A single trip by a single vehicle, regardless of the number of occupants of the vehicle. A vehicle with three occupants on the same trip equals one vehicle-trip or three person-trips. The inputs to trip assignment are vehicle-trips for highway modes and person-trips for non-vehicular modes.
VHT	Vehicle-hours traveled. VHT is a common performance measure for traffic flow indicative of the total amount of travel in a region (see VMT).
VISUM	A comprehensive travel forecasting software package, integrated with VISSIM, a traffic microsimulation software package, and VISEM, an activity-based travel forecasting software package.

VMT	Vehicle-miles traveled. VMT is a common performance measure indicative of the total amount of travel in a locality or region.
Volume	The number of units of flow (e.g., vehicles) passing a defined point (or over a uniform roadway segment) during a defined time period, typically measured in flow units (vehicles) per hour (vph) (see also LOS and capacity).

W, X, Y, Z

Zone	The basic geographical unit for conventional travel forecasting. All locations in a study area are contained in one and only one analysis zone, the number and size of which depend on the scale and scope of the modeling effort. Zones should be homogenous to the extent possible with respect to the resulting travel behavior. Usually referred to as Traffic Analysis Zones (TAZs).
Zoning	The general term for land-use regulation, with authorized land-use designations defined spatially (in "zones"). Applied at the local level (city or county), zoning serves to control the compatibility of neighboring land-uses as well as the overall distribution of land-use. Zoning also regulates land-use density via requirements for setbacks, floor-area ratios, and height restrictions, as well as transportation attributes such as parking and site access.

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3D Process	The 3D process is an approach for assessing travel impacts relative to changes in measures of the built environment. The original 3D measures were density, diversity, and design (a fourth D was added as Destination accessibility). The methodology utilizes a compilation of elasticities of vehicle trip rates and VMT relative to the defined "D" measures. These impacts are typically not captured in the standard four-step model. See also 4D Process.
4D Elasticities	The 4D Elasticities process assesses potential travel impacts of changes in the built environment by applying elasticities (drawn from case studies or estimated locally) that reflect expected changed in trip rates, VMT, or other performance measures for a percent change in planning variables that measure density, diversity, design, and destination accessibility.

4D Process The 4D process is an extension of the 3D Process that reflects a fourth measure of the built environment, Destination accessibility).

4-Step Model The conventional model for travel forecasting, so named for the four major steps of the process: trip generation, trip distribution, mode choice, and trip assignment.

5D Method An extension of the DD Process as implemented in the INDEX software. The fifth measure of the built environment is distance from a rail transit station.

SOURCES

This glossary has been compiled by Dr. Michael McNally (U.C. Irvine) over many years of teaching and practice in travel forecasting. Text books and several existing glossaries served as additional sources of information, including:

• Cambridge Systematics, Inc. (1997). "*Time-of-Day Modeling Procedures: State-of-the-Practice, State-of-the-Art*", Federal Highways Administration (FHWA)

• Deakin, Harvey, Skabardonis (1993). *"Manual of Regional Transportation Modeling Practice for Air Quality Analysis"*, National Association of Regional Councils (NARC).