ABSTRACT

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ABSTRACT: The SANDAG regional travel demand model comprises a complex set of assumptions, input data, computations, and model interactions. This report presents a basic description of the components of the SANDAG travel demand model used in the 2050 Regional Transportation Plan, including a general flow of information and some of the key inputs, assumptions, and computations for each of the components.
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EXECUTIVE SUMMARY

SANDAG deals with many complex mobility issues facing the San Diego region, including the development of a long-range Regional Transportation Plan (RTP). Transportation and land use models perform a very basic yet vital set of functions. Models are the principal tools used for alternatives analysis, and they provide planners and decision makers with information to help them equitably allocate scarce resources. The SANDAG transportation model provides a systematic analytical platform so that different alternatives and inputs can be evaluated in an iterative and controlled environment.

For the 2050 RTP, SANDAG uses an enhanced four-step transportation model. Four-step models have been the standard in transportation modeling since the late 1950s, and they are used by nearly every MPO in the United States for the development of transportation plans, corridor studies, Federal Transit Administration New Starts proposals, and air quality analyses. The estimates of regional transportation related emissions analyses meet the requirements established in the Transportation Conformity Rule, 40 CFR Sections 93.122(b) and 93.122(c). These requirements relate to the procedures to determine regional transportation-related emissions, including the use of network-based travel models, methods to estimate traffic speeds and delays, and the estimation of vehicle miles of travel.

The four major steps of the transportation model include:

- trip generation;
- trip distribution;
- mode choice; and
- network assignment (highway and transit).

After a first pass through the four steps, a feedback process is used to send congested travel conditions back into trip distribution and through to assignment. After several feedback iterations, a final pass is made through the mode choice and assignment steps to reflect congested travel conditions in mode decision-making. Travel model results are then combined with additional post-process input and output functions to form the complete modeling chain. Additionally, a truck model is run parallel to the four-step model, and truck trip tables are merged with passenger vehicle trip tables for highway assignment and air quality procedures.

A trip generation analysis is the first step in the transportation modeling process. Trip generation estimates the average weekday number of trip productions and attractions, or trip ends, in the region based on land use and demographic information from the series 12 regional growth forecast. Over a 24-hour period, roughly the same number of trips will originate in a zone as are destined there. However, residential zones will generate primarily trip productions while nonresidential zones will generate primarily trip attractions.

After trip generation, trip distribution allocates and balances trip productions and attractions through a gravity approach based on trip end density and location. Trip distribution considers the
distance between a trip ends that is based on the assumed highway and public transportation networks that are input for any given future year. The model is designed to modify trip patterns in response to new land use developments and transportation facility changes. For example, the opening of a new shopping center would shift trips from other nearby shopping areas to the new development. Another example would be the introduction of mixed-use development. In this case the model would yield shorter trip lengths by recognizing the increased opportunity for interaction between residential and commercial areas in the development.

Mode choice splits total person-trip movements between zones into different forms of transportation by auto, transit, and non-motorized modes (bicycling and walking). The mode choice step selects the most likely form of transportation for each trip, based on access, traveler’s income, trip purpose, parking costs, fuel price, transit fares, travel time, and other time and pricing parameters.

During network assignment, the model places each trip on the most efficient auto, transit, or non-motorized path based on the mode of transportation that was chosen earlier. Highway assignment produces traffic-volume estimates for all roadway segments in the system. These traffic volumes are an important input to emissions modeling. Similarly, transit trips are assigned to transit routes and segments.

Once these four steps are completed for the millions of trips in the region on an average weekday, the SANDAG model iterates the trip distribution and mode choice step and runs through traffic assignment again based on levels of congestion measured in the previous iteration. The iterations continue until all trips are assigned the most efficient path for their mode. Each step is sensitive to an extensive set of inputs used to prepare a model scenario.

TransCAD 5.0 is the transportation planning computer package used by SANDAG to provide a framework for performing much of the computer processing involved with modeling, and it is used for the trip distribution and assignment steps. ArcInfo, a Geographic Information System (GIS), is used extensively in the modeling process as well to maintain, manipulate, and display transportation, land use, and demographic data. SANDAG has written numerous customized programs that provide a linkage between TransCAD and ArcInfo. Other custom programs perform some modeling functions, such as trip generation and mode choice.

The remainder of the report highlights new features of the series 12 model and comparisons to the previous series 11 model. This model documentation is designed to provide insight into the process and a basic understanding of the relationships among the models and the data requirements.
CHAPTER 1: GROWTH FORECAST BACKGROUND

1.1 OVERVIEW

SANDAG has produced economic and demographic forecasts for nearly 40 years, and transportation forecasts for nearly three decades. These forecasts are an integral part of SANDAG’s planning process as well as that of other governmental and private organizations.

Unlike the prior two forecasts, the 2050 Regional Growth Forecast includes assumptions about how local plans and policies may evolve over time in response to the region’s continuing growth. This forecast looks out forty years to the year 2050, while the horizon year of current local plans is typically ten or twenty years (i.e. out to 2020 or 2030). To bridge this gap, SANDAG began the forecast with adopted general plans and policies from the 18 incorporated cities. Then local jurisdictions were asked to provide detailed feedback on how land use plans might change in the future. Hence, the 2050 Regional Growth Forecast provides an assessment of where change may occur in the coming decades.

SANDAG uses four integrated models in its demographic, economic, and land use forecasts: (1) the Demographic and Economic Forecasting Model (DEFM), (2) the Interregional Commute Model (IRCM), (3) the Urban Development Model (UDM) and (4) the Population Age, Sex, and Ethnicity Forecast (PASEF), in conjunction with the Transportation Model. The 2050 Regional Growth Forecast is spatially linked to the transportation model via SANDAG’s Master Geographical Reference Areas (MGRAs). Employing the MGRA geography as a touchstone between models ensures data feedback between the Forecast and Transportation Model.

A noteworthy feature of the forecasting process is the feedback of information from one model to another (See Figure 1). For example, regionwide projections of jobs and housing from DEFM are used in the IRCM and then the output from the IRCM is used to adjust the output from DEFM. DEFM then provides the regionwide projections that serve as the basis for UDM and PASEF. Similarly, data from UDM and PASEF are major inputs to the transportation model, and then transportation model data are used in subsequent UDM calculations. A key feature of the modeling system is the central role that land use and transportation policies play in determining future travel patterns and the associated location of people, houses, and jobs.

These interrelated models satisfy the federal requirements specified in the Clean Air Act Amendments of 1990 and the Safe, Accountable, Flexible, Efficient, Transportation Equity Act: A Legacy for Users (SAFETEA-LU). These legislative acts mandate that transportation plans consider the long-range effects of the interaction between land uses and the transportation system.
Figure 1: 2050 Regional Growth Forecast Models
1.2 DEMOGRAPHIC AND ECONOMIC FORECASTING MODEL (DEFM)

DEFM is designed to forecast population and economic variables for the region. To forecast demographic variables, DEFM considers factors such as birth rates, survival rates, and the age, sex, and ethnic distributions of the resident population. Economic variables including employment, income, and housing supply are forecast based on assumptions about national, state, and local growth patterns and inter-industry relationships.

There are many linkages, both direct and indirect, between the demographic and economic variables that are accounted for and modeled by DEFM. For example, the population determines housing demand, demand for public facilities, and associated public finance projections. Economic activity, as measured by employment and output, depends in part on the size of the local population and income level. Income, in turn, depends in part on employment and labor market conditions. Over time, the population responds to economic conditions as is evident from net migration levels. Thus, the region’s economic activity depends on the local population, but the local population also depends on economic activity. DEFM is designed to capture the main interdependencies and interactions that exist in the region’s economy.

1.3 INTERREGIONAL COMMUTE MODEL (IRCM)

The 2050 Regional Growth Forecast is the third SANDAG forecast to include an Interregional Commute Model (IRCM). The purpose of the model is to account for individuals who work in the region but live outside its boundaries. Historically, the amount of interregional commuting into and out of the San Diego region had been relatively small. However, recent evidence indicates that interregional commuting is increasing rapidly. Between 1990 and 2000, for example, the number of workers commuting from Riverside County to job sites in the San Diego region has increased four-fold.

The IRCM predicts, using a gravity model, the future residential location of the workers holding new jobs created in the San Diego region. The residential location can be either inside the San Diego region, in Orange County, southwest Riverside County, Imperial County, or in Tijuana/Northern Baja California.

The IRCM assigns the residential location of workers based upon the accessibility of potential residential sites to job locations, the availability of residential land for development, and the relative price of homes. There are three basic tenets of the IRCM. First, as commuting time from work to possible residential locations increases, the probability of choosing those locations decreases. Second, more land available for residential development increases the potential for residential growth. Third, lower home prices also are an attraction factor in residential location. These three basic tenets also underlie the gravity model used in the Urban Development Model (UDM).

The results from the IRCM are used to modify the DEFM regional forecast. The initial regional forecast, referred to as the Baseline, is modified to reflect the fact that not all housing units, population, employment, and other elements predicted by the Baseline forecast will occur in the region. Rather, some residential and economic activity will occur in nearby areas outside the region.
1.4 URBAN DEVELOPMENT MODEL (UDM)

The Urban Development Model (UDM) allocates employment, population, housing and income from the regional forecast produced by DEFM to neighborhoods and jurisdictions within the region. The model is designed to forecast the location of residential and non-residential activity within the region for 5 year periods. Major model inputs include the current spatial distribution of jobs, housing units, income, and population. Land use data collected from local jurisdictions including general plans, policies, and current and future transportation infrastructure are also critical to the model.

UDM combines the transportation and land use factors mathematically to determine the likelihood that an employee at his or her place of work will reside in alternative residential locations around the region. In general, areas closer to employment opportunities are more attractive to employees as potential residences than areas further away from the place of employment. Therefore, as available residential capacity closer to work places is consumed, new employees are forced to travel longer distances to find suitable residential locations. Residential growth in a jurisdiction is influenced by growth within that jurisdiction as well is in surrounding areas and other parts of the region.

1.5 POPULATION BY AGE, SEX, AND ETHNICITY FORECAST (PASEF)

- The program for forecasting detailed demographic characteristics (age, sex, and ethnicity - PASEF) is a demographic model designed to forecast detailed demographic characteristics at a neighborhood level. The detailed demographic forecast comes directly from DEFM, but requires aggregating the single year of age detail into the five-year age groups used in PASEF, and an adjustment for special populations. The model projects population for 18 five-year age groups (0-4, 5-9..., 80-84, and 85+) broken down by gender and ethnicity for the region and smaller geographies.

- The final stage in PASEF distributes the demographic characteristics estimates from the census tracts to the MGRAs. The model assumes that each MGRA has the same demographic characteristic distribution as the census tract in which it lies.
## 1.6 DATA SOURCES

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<th>Data</th>
<th>Source(s)</th>
<th>Model(s)</th>
</tr>
</thead>
<tbody>
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<td>U.S. Census Bureau, San Diego County Assessor, local jurisdictions</td>
<td>DEFM, UDM</td>
</tr>
<tr>
<td>Labor market (employment, unemployment, labor force participation)</td>
<td>U.S. Bureau of Labor Statistics</td>
<td>DEFM</td>
</tr>
<tr>
<td>Population and demographic characteristics</td>
<td>U.S. Census Bureau, California Department of Finance</td>
<td>DEFM, UDM, PASEF</td>
</tr>
<tr>
<td>Price levels and inflation</td>
<td>U.S. Bureau of Labor Statistics, National Association of Realtors, DataQuick Information Systems</td>
<td>DEFM, IRCM</td>
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<tr>
<td>Public finance</td>
<td>California Department of Finance</td>
<td>DEFM</td>
</tr>
<tr>
<td>Travel times</td>
<td>SANDAG transportation model</td>
<td>IRCM, UDM</td>
</tr>
<tr>
<td>United States projections</td>
<td>U.S. Census Bureau, and economic projections purchased from private-sector vendor (varies depending on series)</td>
<td>DEFM</td>
</tr>
<tr>
<td>Vital records (births, deaths)</td>
<td>California Department of Health</td>
<td>DEFM</td>
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</table>
CHAPTER 2: TRANSPORTATION MODELS

2.1 INTRODUCTION

Transportation models are designed to compute transportation system impacts such as traffic volumes, traffic speeds, and transit ridership for transportation network and policy alternatives given land use and demographic forecasts from the IRCM, UDM, and DEFM. SANDAG makes use of an advanced four-step transportation modeling process of trip generation, trip distribution, mode choice, and assignment to forecast personal travel activity in the San Diego region. Figure 2 illustrates how the four-step process is run in iterations or stages and combined with additional input and output functions to form the complete modeling chain.

TransCAD, created by Caliper Corporation, is a transportation planning computer package used by SANDAG to provide a framework for performing much of the computer processing involved with modeling. Another software package used extensively in the modeling process is ArcInfo, distributed by Environmental Systems Research Institute, Inc. This geographic information system (GIS) maintains, manipulates, and displays transportation, land use, and demographic data. SANDAG has written numerous FORTRAN and Visual Basic programs that provide linkages between TransCAD and ArcInfo. Other programs manipulate data and perform some modeling functions such as trip generation and mode choice.

SANDAG has extensive experience with both transportation modeling software and ArcInfo. SANDAG used TRANPLAN between 1981 and 2004 for a wide range of modeling applications, and then switched to TransCAD in 2004. ArcInfo first was installed at SANDAG in 1985. TRANPLAN and ArcInfo have been used in conjunction for transportation modeling since 1987.

The SANDAG transportation modeling and database maintenance is performed on a mix of Windows servers and individual personal computers. The time necessary to execute the entire transportation modeling process on these machines is about 16 hours, which is felt to be the maximum run time in order to provide reasonable turnaround on modeling projects. Turnaround time is important since SANDAG performs hundreds of model runs each year that range in scope from quantifying traffic impacts of individual development projects to evaluating system level impacts of alternative growth scenarios and transportation facilities for the Regional Transportation Plan (RTP). All of these modeling projects make use of the same basic procedures and data sets. The complexity of modeling procedures and the number of zones, time periods, iterations, modes and other factors determine model execution time. All of these factors have been evaluated so that the model functions within the 16-hour limit.
Figure 2:
Transportation Modeling Process
Before running the models in production, a considerable amount of time is spent calibrating model parameters and validating model accuracy. The purpose of calibration is to develop model relationships that can accurately reflect existing travel behavior, so there is confidence the models can be used to forecast future travel behavior. For example, the models correctly estimate current trolley ridership so they should be able to forecast future ridership on proposed trolley extensions and on new bus rapid transit service. Most recently the models were recalibrated to year 2008 conditions before use in the 2050 RTP. This process included a separate validation exercise where modeled results were compared to a variety of observed data sources from the last two decades. A detailed report of the validation exercise was released by SANDAG in June of 2011 (San Diego Association of Governments Travel Demand Model Validation Report). Additionally, the travel model was subjected to a variety of sensitivity tests to assess the response to potential policy questions. The SANDAG Transportation Model Sensitivity Analysis and Report is available on the SANDAG Regional Models website. The next section of this chapter (Section 2.2) describes the survey data used in this calibration and validation process.

As indicated in Figure 2, the modeling process can be broken down into four steps and four phases. In the model input phase, growth forecast data files are assembled, and highway and transit networks are coded. Preparing inputs to the models is often the most time consuming part of a modeling project. Several sections of this chapter document the three major inputs for the rest of the modeling process:

- growth forecast inputs used to describe existing and planned land use patterns and demographic characteristics (Section 2.3)
- highway networks used to describe existing roadway facilities and planned improvements to the roadway system (Section 2.4)
- transit networks used to describe existing and planned public transit service (Section 2.5)

After preparing model inputs, there are four major steps of trip generation, trip distribution, mode choice, and assignment, along with a minor function of path-building and skimming. Additionally, there is a parallel process for the truck model before the results are combined in for highway assignment. There is a section describing each of the modeling steps listed in the order that they are executed as follows:

- trip generation (Section 2.6)
- path-building and skimming (Section 2.7)
- trip distribution (Section 2.8)
- mode choice (Section 2.9)
- truck model (Section 2.10)
- highway assignment (Section 2.11)
- transit assignment (Section 2.12)
One of the complexities of the modeling process is that transportation measures needed as input to a modeling step may not be produced until later in the modeling process. For this reason there are numerous iterations through the modeling process. As a starting point, the first-stage of the modeling process makes use of simplified trip distribution, mode choice, and highway assignment procedures to produce initial highway travel time forecasts for use in the subsequent feedback loop phase.

Processing may stop after the first stage for small scale modeling projects to reduce costs for outside clients without seriously compromising mode accuracy. However, regional planning studies proceed on to a feedback loop phase and a final stage of mode choice and assignment. These additional stages incorporate the effects of traffic congestion on destination choice and mode choice. For example, people in heavily congested corridors may choose shopping locations closer to home rather than contend with traffic delays. Conversely, widening a congested freeway may make fringe housing more accessible and increase average commute trip lengths. This relationship between trip length and congestion is one aspect of induced travel (Section 2.13).

The details of performing the trip distribution, mode choice, and assignment steps vary depending on which stage of the modeling process is being executed. These variations are described in the sections of the report dealing with each modeling step.

### 2.2 Survey Inputs

The transportation models make use of survey data to establish relationships between input variables and model-estimated results. For example, trip generation rates are applied to dwelling units from the growth forecasting process to determine the number of trips generated from residential areas. Data collection is costly and time consuming, so surveys are conducted relatively infrequently. This normally does not create a problem since underlying model relationships are relatively stable over time.

The following eight survey groups provide most of the calibration data for the transportation models.

- 1995 & 2006 Travel Behavior Survey
- 2001 Caltrans Statewide Survey & 2009 National Household Travel Survey
- 2001-2003 & 2009 San Diego Regional Transit Survey
- External Trip Surveys
- Traffic Generation Studies
- 1991 San Diego Visitor Survey
- Census Transportation Planning Package & American Community Survey
- 2000 Market Research Survey
Additional data sources are used to verify model estimates with observed data. Major sources of validation data are traffic counts from Caltrans and local jurisdictions, transit passenger counts from the SANDAG Transit Passenger Counting Program, and SANDAG Vehicle Occupancy and Classification Study.

2.2.1  1995 & 2006 Travel Behavior Surveys

Every ten years SANDAG conducts an extensive travel behavior survey which serves as the primary source for model calibration data. The 2006 and 1995 Travel Behavior Surveys are the basis for the existing models. The 1995 and 2006 surveys had 2,050 and 3,670 San Diego households interviewed, respectively. Survey respondents provided a complete listing of trips made on a survey data with information such as start and end location, start and end time, trip purpose, and trip mode. Information also was collected about household, household member, and household vehicle characteristics. Survey responses were expanded to regional totals and tabulated to develop the following calibration data.

- Trip generation rates for the trip generation model
- Trip length frequency distributions for the trip distribution model
- Non-transit mode use percentages for the mode choice model

2.2.2  2001 Caltrans Statewide Survey & 2009 National Household Travel Survey

In 2001 Caltrans conducted a statewide activity-based household travel survey which had a San Diego sample size of 1,200 households. Of these households, 104 also had vehicles instrumented with GPS recorders. The resulting GPS vehicle trip sample was extensively analyzed to develop underreporting correction factors. These GPS correction factors were applied to both the 1995 and 2001 Travel Survey results prior to model estimation.

In 2009 the National Household Travel Survey was conducted and included an oversample of San Diego households funded by Caltrans. Data from the survey will be used for validation purposes.

2.2.3  2001-2003 & 2009 Regional Transit Survey

Every five years SANDAG, in cooperation with transit operators, conducts an on-board transit survey to obtain transit trip and transit user characteristics. The most recent survey, conducted between 2001 and 2003 and also in 2009, provides data used to calibrate the transit portion of the mode choice model.

In the transit survey, surveyors stationed on-board buses, trolleys, and the COASTER distributed questionnaires to passengers over 12 years of age as they boarded the vehicle. Passengers filled out forms while they completed their trip and dropped off forms as they got off vehicles. About 50,000 surveys were returned with useable information, which were tabulated to obtain the following calibration and validation data:

- Transit trip shares by income level, trip purpose, and trip length for mode choice calibration
- Park-and-ride locations for coding transit network park-and-ride nodes
• Walk access distance distribution to set maximum walk access distances
• External transit trip table for external trip modeling
• Relationship of total boardings to linked trips for transit assignment validation
• Access mode percentages for transit assignment validation
• Zone-to-route trips for transit network validation
• Zone-to-zone trip tables for transit network calibration

2.2.4 External Trip Surveys

Roadside interview surveys are conducted periodically to determine the travel characteristics of trips coming into or passing through the San Diego region from outside the region. These surveys are difficult to collect since motorists must be stopped as they are entering or leaving the region and asked a series of questions about trip characteristics. Surveys conducted between 1986 and 1999 and also in 2006 are used to obtain the following parameters:

• trip purpose distributions for the trip generation model
• external trip lengths for the trip distribution model
• through trips which are added to internal and internal-external trips

2.2.5 Traffic Generator Studies

These studies are conducted periodically to collect site level traffic data. The last major study, completed in 1999, placed traffic counters and video cameras at all entrances and exits to 26 survey sites, which included shopping centers, offices, schools, and housing developments. Traffic counts were totaled and averaged over five days to obtain average weekday trip generation totals for the sites. Trips rates then were calculated based on site characteristics such as number of employees, acres, and dwelling units. Travel behavior survey trip rates for nonresidential uses were adjusted to agree with traffic generator trip rates to correct for under-reporting of trips in travel behavior surveys.

2.2.6 1991 Visitor Survey

San Diego is a major convention and vacation destination. A small-scale visitor survey was conducted during the months of July, August and September 1991 to obtain a more complete picture of visitor travel patterns. Surveyors stationed outside selected hotels and tourist attractions questioned passers-by about their trips made on the previous day. Visitor trip generation rates and visitor trip lengths for gravity model calibration were obtained from this survey.

2.2.7 Census Transportation Planning Package and American Community Survey

Since 1960, the decennial census “long form” has included a series of transportation related questions about work trips, including travel time, travel mode, and employment location. The Census 2000 Transportation Planning Package (CTPP) data had limited usefulness for model
calibration due to Census Bureau data suppression procedures for protecting confidentiality. The American Community Survey (ACS) is a continuous survey process that is replacing the long form. ACS results will be available more frequently although suppression issues are expected to continue. Early ACS information was used for interregional commute information.

2.2.8  2000 Market Research Survey

In 2000 the Metropolitan Transit Development Board conducted a stated preference survey of 858 San Diego households to identify traveler attitudes towards new forms of public transit by market segments. The resulting datasets were used to estimate mode choice model parameters for comparison with models estimated from traditional revealed preference travel surveys.

2.2.9  Traffic Counts

Traffic counts, used in model validation, are obtained from a variety of different sources. The Caltrans program called PeMS (Performance Monitoring System) which is a system that provides counts at 630 directional freeway locations. Counts at additional locations will be available as the ramp metering system is expanded. PeMS outputs more detailed counts by five minute intervals and also outputs speed estimates which can be compared with model-estimated speeds. A third Caltrans program counts freeway on and off-ramps on a three-year cycle.

The City and County of San Diego and some of the other cities conduct comprehensive traffic count programs and maintain computerized count files. SANDAG converts traffic count stations into an ArcInfo point coverage and subsequently matches counts to network links. SANDAG also collects counts to produce a biennial Traffic Flow Map. Counts from this program are used for cities without computerized count files.

2.2.10  Transit Passenger Counts

SANDAG has operated a Passenger Counting Program since 1979, within which every bus route is counted once a year. Trips are counted by stationing surveyors on-board transit vehicles. Surveyors record the number of passengers boarding and alighting at each transit stop. The number of passengers on board vehicles between stops is computed from the boarding and alighting data. Surveyors also record arrival and departure times at selected time points along a route. An up-to-date transit route and stop inventory is maintained as part of the Passenger Counting Program. Screenlines (imaginary lines that run across multiple transit paths) can be created to look at passenger flows through a corridor. Summing the number of passengers on-board each route that crosses a screenline yields the total screenline count. This helps equalize factors, such as changes in frequency or route path to look at corridor passenger flows over time.

Bus stop inventories from the Passenger Counting Program provide bus stop locations for transit network coding. The Passenger Counting Program also produces the following validation data for checking the accuracy of transit assignment estimates.

- Ons and offs at stops
- Screenline counts
• Boardings by route and mode
• Transit link passenger volumes

2.2.11 2006 Vehicle Occupancy and Classification Study

SANDAG and Caltrans station surveyors at 22 freeway locations to monitor trends in vehicle occupancy and vehicle classification. These counts are taken every five years. Vehicle occupancies from the most recent 2006 study were used to verify mode choice model estimates and vehicle classifications were input to air pollution emission modeling.

2.3 GROWTH FORECAST INPUTS

The number and location of people living and working in the San Diego region largely determine the amount of travel activity that occurs. The previous chapter described how population, employment, and land use forecasts are produced at the SANDAG smallest unit of geography, the over 800,000 parcel polygons.

Parcel polygons provide flexibility for designing zone boundaries, however, the current generation of transportation models is unable to efficiently use parcel level forecasts. Therefore, the parcel forecasts are aggregated to three different levels of a nested zone system that has been designed to maximize model accuracy while minimizing execution time. There are 21,633 non-motorized zones (MGRAs) that are the smallest unit of geography used by the transportation models. This detailed zone system enables the models to accurately compute the amount of activity within walking distance for input to the mode choice model. The highway assignment model makes use of a 4,682 traffic analysis zone system (TAZ) to obtain link level traffic volumes. Finally, a 2,000 trip distribution zone system (TDZ) is used within the feedback loop process to determine trip flows between zones. Figure 3 shows the nested relationships between MGRA (thin black line), TAZ (grey line), and TDZ (red line).
TAZs range in size from individual blocks in Centre City San Diego up to 150 square miles in sparsely developed rural areas. SANDAG uses a relatively large number of TAZs to reduce the need for developing sub-zones to address local planning needs. TAZ boundaries attempt to group areas with similar land uses and access to the transportation system.

The zone systems include 12 external zones located where major roads cross the county line. These external zones are used to represent travel between the San Diego region and other areas, such as Riverside County, Orange County, and Mexico.

Most studies use regional growth forecasts directly, however the purpose of some studies is to evaluate impacts on the transportation system of proposed land use changes. For example, Environmental Impact Reports may identify traffic volumes on roadways in the vicinity of proposed development projects with and without the proposed project. Cities may use the models to evaluate traffic impacts of proposed General Plan changes. Recently there has been increasing interest in smart growth development and SANDAG has evaluated regional land use alternatives that implement smart growth principles to varying degrees. These land use studies modify the SANDAG standard forecasts within the study area to reflect the proposed changes.

2.4 HIGHWAY NETWORK INPUTS

At many points in the modeling process a computerized representation of the highway system is needed for obtaining inputs to the models. SANDAG uses GIS software to maintain highway information in an ArcInfo master transportation coverage. Coverage is an ArcInfo term used to describe all the individual files which together represent a geographic system in digital form. This
network coverage includes existing and planned freeways, toll lanes, HOV lanes, managed lanes, ramps, surface streets classified on general plan circulation elements, and some local roads needed for network connectivity. The network coverage also includes zone connector links, which are used to schematically represent how traffic from zones accesses the street system.

The SANDAG master network files reflect facility improvements proposed in the most recent RTP and General Plan circulation elements from each jurisdiction in the region. The purpose of many planning studies is to look at the impacts of alternative highway improvements. Once these planning studies are completed, recommended facility changes are coded into the master network. At a more local level, the models are often used to evaluate traffic volume impacts of subdivision plans that fine-tune standard highway assumptions.

2.4.1 Highway Facilities

Alignments for existing roads were originally obtained from SanGIS (another agency responsible for maintaining various geographic databases) and have been updated extensively based on high resolution digital aerial photography. Alignments for planned roads are derived from a number of different sources including Caltrans route location studies, local general plan circulation elements, environmental impact reports, and corridor studies.

ArcInfo automatically creates nodes at at-grade intersections. Coders insert additional nodes where traffic signals, stop signs, and ramp meters occur in between street intersections. The ArcInfo dynamic segmentation function also is used to code routes that indicate where turns are prohibited by physical barriers or signs.

2.4.2 Highway Attributes

Once highway alignments have been determined a large number of attributes are coded about each highway segment and node. A number of attributes are informational, such as street name, node numbers, link ID numbers, and functional classification. Other attributes, used to calculate travel time, include segment length (computed by ArcInfo from highway alignments), posted speed, one/two-way operation, and type of intersection control. Another set of attributes used to calculate capacity includes number of lanes, median condition, number of freeway auxiliary lanes, type of operation (mixed flow or high occupancy vehicle only), type of intersection control, and the number of through, left turn, and right turn lanes at intersection approaches. The phasing of new roads, improvements to existing roads, and in some cases the deletion of existing roads is identified using another set of attributes. Finally, additional attributes provide cross-references to traffic count files that are used for model calibration.

Many base year physical attributes can be obtained from high resolution digital photography. These include one/two way operation, location and type of intersection controls, median condition, and the number of main lanes, auxiliary lanes and through, right turn, and left turn intersection approach lanes. Planned highway improvements are obtained from local circulation elements, Regional Transportation Improvement Programs, local Capital Improvement Programs, and long range Regional Transportation Plans.
2.4.3 Highway Capacities

Highway network coverages for specific model years and alternatives are selected from the master transportation coverage. Computer programs convert these ArclInfo coverages to TransCAD highway networks by reformatting data items and computing additional attributes needed in the modeling process, such as capacities, travel times, distances, and costs from attributes coded on coverages.

Two capacities are calculated for each direction of a highway link: (1) intersection capacity which is the amount of traffic that can be accommodated by an intersection approach at the end of a link, and (2) mid-link capacity which is the amount of traffic a link could accommodate without intersection controls. Both intersection approach and mid-link capacities are computed on an hourly basis and then factored to A.M. peak period, P.M. peak period, and off-peak period capacities using hourly to time period expansion factors of 2.25, 2.85, and 11.1, respectively. These expansion factors are overridden with location specific expansion factors on freeways where hourly traffic counts are available.

Mid-link Capacity

Mid-link capacity calculations vary for four different types of facilities: freeways, freeway HOV/managed lanes, urban streets, and rural highways. Hourly directional freeway capacities are calculated using the equation below which multiplies the number of main lanes by a per lane carrying capacity supplied by Caltrans that varies between 1,900 and 2,100 vehicles per hour per lane. Auxiliary lane capacity, assumed to be 1,200 vehicles per hour per lane, is added to main lane capacity. A capacity increase of 10 percent is phased in between 2010 and 2030 on freeway segments that are currently not metered, but are slated for ramp metering in the future.

\[ f_{wyc} = (ml \times mlc + al \times 1200) \times (1.0 \rightarrow 1.1) \]

where:
- \( f_{wyc} \) = hourly directional freeway capacity (vehicles per hour) for link
- \( ml \) = number of mixed-flow main lanes on link
- \( mlc \) = capacity per lane for link (vehicles per hour per lane)
- \( al \) = number of auxiliary lanes on link

It is assumed that single occupancy vehicle (SOV) usage of managed lanes will be controlled to keep speeds from falling below level-of-service “D” or 1,600 vehicles per lane. The number of lanes on managed lane facilities also can vary by time period, such as the existing Interstate 15 (I-15) HOV lanes which operate as two lanes southbound in the morning and two lanes northbound in the afternoon.

\[ h_{ovc}(tm) = hl(tm) \times 1600 \]

where:
- \( h_{ovc} \) = hourly directional HOV capacity (vehicles per hour) for link in time period “tm”
- \( hl \) = number of HOV lanes on link in time period “tm”

Mid-link capacities for urban street segments are calculated using the equation below. Two-lane rural highways typically can accommodate much less traffic and a lower capacity of 950 vehicles per hour per direction is assumed for these facilities.

\[ urbc = ln \times 1800 - 300 - 20Q(m < 2) \]
where:
urbc = urban street mid-link capacity for link
ln = number of mid-block lanes on link
m = median code (0 or 1 indicates no median)

**Intersection Approach Capacity**

Because the most significant traffic congestion on urban streets often occurs at traffic signals, procedures have been developed to represent individual signal approach capacity within the model using the following equation.

\[
xc = (tl \times 1800 \times gc(fc, xfc, napp) + (rl + ll) \times tlc(fc)) \times 1.0 \rightarrow 1.1
\]

where:
xc = intersection approach capacity for link
tl = number of through lanes at intersection approach
gc = green-to-cycle time ratio
fc = functional classification of street
xfc = functional classification of cross street
napp = number of intersection approaches
rl = number of right turn lanes at intersection approach
ll = number of left turn lanes at intersection approach
tlc = per lane turn lane capacity that varies by functional classification

While actual signalized operation is very complex, this equation captures the primary factors that determine capacity. A through lane capacity of 1,800 is multiplied by the number of approach lanes that have been coded. The green-to-cycle time (GC) ratio is a traffic engineering term that quantifies the fraction of total cycle time that is in the green phase for each intersection approach. Within the model, GC ratios vary between 0.09 and 0.84 depending on the functional classification of intersecting streets and number of approaches. For example, a prime arterial that intersects with another prime arterial would have a lower capacity than one with the same approach lane configuration that intersects with a local street. Similarly, two and three legged intersections have higher capacities than four legged intersections because total cycle time is apportioned to fewer phases.

A turn lane capacity that varies between 100 and 250 vehicles per lane per hour depending on the functional classification of the street is multiplied by the number of coded right and left turn lanes and added to through lane capacity. Finally, future capacity increases of up to 10 percent are phased in on regionally significant arterials as a result of improved signal coordination assumed in the 2050 RTP.

A ramp meter is a special type of signal that controls the number of vehicles that can get on a freeway during peak periods. Metering rates are determined by Caltrans and vary from ramp to ramp depending on the location of the ramp and the severity of up-stream freeway congestion. An average capacity of 1,000 vehicles per ramp meter is assumed unless location specific metering rates are available.
Stop signs also impose significant reductions in the capacity of surface streets. The model computes capacities of two-way and all-way stop-sign controlled approaches using equations similar to the signalized intersection equation shown above. In a few locations capacities are affected by toll booths and rail crossings where special capacity calculations are made.

Intersection capacity considerations are turned off for freeways and other links that have no intersection controls by setting the capacity to a maximum value.

2.4.4 Highway Travel Times

As with capacities, separate link times and intersection times are computed for each highway segment. Highway link travel times are computed using the following equation:

\[ tt(tm) = \frac{l_g}{s} \]

where:
- \( tt(tm) \) = travel time each link and time period (A.M. peak period, P.M. peak period, and off-peak)
- \( l_g \) = length on link
- \( s \) = posted or adjusted speed on link

Travel times represent the free-flow link time (ArcInfo computed link length divided by the posted speed). During the calibration process posted speeds may be varied by up to plus or minus 10 miles per hour to better match model estimated traffic volumes with traffic counts. Adjusted speeds replace posted speeds where coded.

Intersection times represent the delay time encountered at traffic signals and other intersection controls under uncongested conditions. An intersection delay time of 10 seconds per signal or stop sign accounts for idling time, acceleration/deceleration time, and the likelihood of being stopped at a signal. Baseline ramp meter times of one minute are assumed for peak period networks. Ramp meters are assumed to be turned off during off-peak hours and so no off-peak ramp meter delays are added.

These input link and intersection travel times reflect free-flow conditions without congestion. Individual link and intersection congestion delays are computed later in the highway assignment step based on forecasted, link-specific traffic volumes.

2.5 TRANSIT NETWORK INPUTS

Transit modeling requires coded transit networks that represent existing and planned conditions. Like highway networks, transit networks are maintained in the master transportation coverage using ArcInfo. However, transit network coding is more complicated than highway coding because of the need to describe how individual transit routes operate over the transit system. Also added is the concept of transit modes which group transit routes with similar operating characteristics.

Table 1 describes the seven transit modes and gives examples of existing routes in each category. Bus rapid transit (BRT) and rapid bus modes represent new types of transit service that will soon be implemented. BRT service would have stations similar to commuter rail and trolleys, and operating characteristics midway between rail and bus service. BRT service would be provided by advanced
design buses operating mostly on HOV lanes with Direct Access Ramps. Rapid Bus service would also be provided by advanced design buses operating largely on surface streets with priority transit treatments.

<table>
<thead>
<tr>
<th>Mode Number</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Commuter Rail</td>
<td>COASTER</td>
</tr>
<tr>
<td>5</td>
<td>Light Rail/Street Car</td>
<td>Trolley, Sprinter</td>
</tr>
<tr>
<td>6</td>
<td>BRT (Regional)</td>
<td>None (Proposed)</td>
</tr>
<tr>
<td>7</td>
<td>Rapid Bus (Corridor)</td>
<td>None (Proposed)</td>
</tr>
<tr>
<td>8</td>
<td>Premium Express Bus</td>
<td>MTS Routes 810,820,830</td>
</tr>
<tr>
<td>9</td>
<td>Express Bus</td>
<td>SDTC Routes 20, 50, 150</td>
</tr>
<tr>
<td>10</td>
<td>Local Bus</td>
<td>SDTC Routes 1-9</td>
</tr>
</tbody>
</table>

### 2.5.1 Transit Facilities

Most transit routes run over the same streets, freeways, HOV lanes and ramps used in the highway networks. As a result the only additional facilities that are added to the transportation coverage for transit modeling purposes are:

- Trolley, streetcar, and commuter rail lines,
- Streets used by buses that are not part of local general plan circulation elements,
- Transit exclusive right of way (transitways) that have been proposed as part of the future transportation system.

Nodes are located at each transit stop. The ArcInfo dynamic segmentation feature is used to maintain historical, existing, and planned transit routes. Existing routes and stops are modified up to several times a year as new time tables are published. A transit scheduling system (HASTUS) provides accurate existing bus transit stop information. Near term transit route changes are drawn from short-range plans produced by transit agencies. Longer range improvements are proposed as a part of the RTP and other transit corridor studies.

### 2.5.2 Transit Attributes

Transit node attributes describe stop type and park-and-ride availability at each node. Most transit network attributes are associated with routes. These attributes include transit operator, mode, and most importantly, frequency of service by time period (A.M. peak period, P.M. peak period, mid-day, and night). Initial wait time and transfer time are significant factors that affect transit use and are computed from service frequencies. Existing frequencies are calculated based on published time schedules. Planned service frequencies may be policy based, such as establishing a minimum 15-minute frequency. Alternatively, future frequencies may be computed using vehicle capacity assumptions and forecasted ridership from previous model runs. For example, passenger demand may indicate that a 10-minute frequency is needed on some routes to avoid bus overcrowding.
2.5.3 Travel Times

Transit networks for different years and alternatives are selected from the master transportation coverage. Transit travel times on links between rail stations and bus stops are computed at this time. The following equation is used to determine bus speeds.

\[ bt(tm) = ht(tm) + bs \times dt(m) \]

where:
- \( bt \) = bus travel time on link during time period “tm”
- \( ht \) = congested highway travel time
- \( bs \) = number of bus stops on link
- \( dt \) = per stop delay time by mode “m”

Bus travel times are assumed to be a function of the number of bus stops on a link and highway travel time. Since highway times include congestion effects from the highway assignment step (Section 2.10), bus travel times are recomputed at different stages of the modeling process. Highway travel times are modified for the following special conditions before computing bus times:

- Ramp meter delays at meters with HOV bypass ramps are assumed to be one-third of SOV times.
- The maximum legal speed limit is used for the free-flow bus speed on freeways, whereas highway free-flow freeway speeds are set at five MPH above the speed limit to reflect observed speeds from survey data.
- Bus speeds of 35 MPH are assumed on selected freeways that allow buses to run on shoulder lanes when speeds on adjacent general lanes fall below 35 MPH.
- Travel times on arterial streets used by BRTs are reduced by 10 percent to reflect the effects of bus priority treatments.

Stop delay times of 30 seconds for BRT, Rapid, and Express Bus service and 18 seconds for local bus routes are assumed. Express and local bus stop delays were calculated from observed data and include the effects of acceleration/deceleration, dwell time for boarding passengers, and likelihood of stopping at an individual stop. BRT and Rapid Bus stop delays were assumed to be similar to express bus based on existing systems in other regions.

Travel time procedures for rail service differ from the bus procedures described above. Where COASTER and trolley routes already exist, speeds are obtained from published time schedules. Since rail service is normally not affected by highway congestion, base year station-to-station travel times are assumed to remain unchanged over the forecast period. The travel time effects of a proposed COASTER tunnel and several additional COASTER and trolley stops are obtained from outside studies.

Travel times for proposed trolley extensions are computed based on an assumed peak operating speed, a station dwell time of 20 seconds, and acceleration/deceleration times that vary according to station spacing and peak speed.
2.5.4 Fares

In addition to transit travel times, transit fares are required as input to the mode choice model. TransCAD procedures have been augmented to replicate the San Diego region's complicated fare policies which differ among:

- buses which collect a flat fare of between $2.00 and $5.00 depending on the type of service,
- trolleys which charge a flat fare of $2.50 ($2.00 for Sprinter), and
- commuter rail which has a zone-based fare of between $4.00 and $5.50.

When transfers occur, the overall fare for the trip is set to the highest fare encountered. These fares represent cash fares and are factored later in the mode choice model to account for pass usage based on an analysis of survey data. Fares are converted to 1999 dollars for consistency with income data in the model and are assumed to remain constant over the forecast period.

2.5.5 Transit Walk Access

Accurately specifying transit access opportunities is an important part of the transit forecasting process. A series of programs generates access files based on ArclInfo transit networks, trip generation forecasts by NMZ, elevation grids, and walk barriers. First, transit stops within walking distance of each NMZ are determined using the following formula.

\[
d(nmz, s) = \sqrt{(x_{nmz} - x_s)^2 + (y_{nmz} - y_s)^2} \times wfac(nmz) + \text{abs}(z_{nmz} - z_s) \times 3
\]

where:
- \(d\) = distance between NMZ and stop “s”
- \(x_{nmz}\) = x coordinate of NMZ centroid
- \(y_{nmz}\) = y coordinate of NMZ centroid
- \(z_{nmz}\) = elevation of NMZ centroid
- \(wfac\) = walkability factor (1.1 or 1.5)
- \(x_s\) = x coordinate of transit stop
- \(y_s\) = y coordinate of transit stop
- \(z_s\) = elevation of stop

Straight line distances arc computed between each MGRA centroid and transit stop. The region has been broken down into two area types: traditional neighborhoods with grid pattern streets; and suburban neighborhoods with curvilinear street patterns. Walkability factors of 1.1 for traditional neighborhoods and 1.5 for suburban areas are applied to straight line distances so that walk distances better approximate real world conditions. Elevation differences between NMZ centroids and stops are added to horizontal distances after weighting differences by a factor of three to account for the additional difficulty of walking uphill. A maximum walk distance of three-quarter mile is assumed. MGRA-stop connections with a distance greater than the maximum walk distance are discarded as are connections that cross walk barriers. A walk barrier coverage has been developed that contains features such as ridge lines, steep slopes, water body boundaries, freeways, and fenced property lines that could block walk access.
All rail stations and BRT stops, and selected local and express bus stops are designated as transit access points (TAP) for use in transit modeling. TAPs are located approximately every one-half mile along a bus route. The mode choice model uses a walk access file of MGRA-TAP connections that are obtained by generalizing NMZ-transit stop connections found in the previous step.

Access opportunities within Centre City are too complicated to represent with these procedures. Instead, the closest TAP to each Centre City zone is identified. A Centre City walk network is coded that allows access to other TAPs in Centre City without explicitly coding each MGRA-to-TAP connection.

2.5.6 Transit Auto Access

Many transit users, who are outside walking distance of transit or have inconvenient feeder bus service, drive to park-and-ride lots or are dropped-off at transit stops. A transit auto access file is generated that represents these drive to transit opportunities.

Transit ridership survey results were analyzed to identify transit stops with significant auto access activity. The vast majority of auto access trips go to formal park-and-ride lots at rail stations and other bus transit centers. Trolley stations without parking lots also have significant auto access usage since passengers can be dropped off or possibly park on-street. The remaining auto access trips occur at shopping center and church lots adjacent to bus routes where informal park-and-ride usage can occur.

Formal park-and-ride lots, trolley stations without parking lots, and other informal lot locations are coded in an ArcInfo coverage. The parking space capacity of formal park-and-ride lots is coded, while a maximum of 25 spaces is assumed at other auto access locations. The mode choice model is able to capacity constrain auto access trips to produce more realistic ridership forecasts.

Within the modeling process, a computer program creates connections between TDZs and auto access locations, and calculates the peak period highway travel time and distance from the first stage highway assignment process. Rather than connecting all zones to all auto access locations, the following logic is used to limit the number of auto access connections to only those that are reasonable.

- For each TDZ the program first analyzes formal park-and-ride lots along each commuter rail, light rail, BRT, and express bus transit route by direction. Auto access connections are created for the closest two upstream and downstream park-and-ride lots within a maximum eight mile drive distance.

- For each TDZ the program next creates connections to the closest informal lot along each directional transit route that is within a maximum drive distance of two miles for local bus routes or four miles for commuter rail, light rail, BRT and express bus routes.

- TDZs are connected to the closest formal park-and-ride lot when no other connections have been found.
The mode choice model treats trips that drive to transit and trips that are dropped off as two different modes. However, transit survey results did not show significant differences in the locations where these two types of transit access trips occur. Therefore a single auto access file is used to represent connections for both transit auto access modes.

2.6 TRIP GENERATION

The purpose of trip generation is to estimate the number of trips entering and leaving each zone on an average weekday for each forecast year. These trip end forecasts reflect new development, redevelopment, demographic, and economic changes that occur over time, using the inputs shown in Table 2.

The model computes person trips, which account for trips by all forms of transportation including automobiles, light-duty trucks, taxicabs, motorcycles, public transit, bicycling, and walking. Trips are generated for ten trip types: home-work, home-college, home-school, home-shop, home-other, work-other, other-other, serve passenger, visitor, and regional airport. These trip types are designed to group together trips with similar travel patterns. Trips are generated for each parcel polygon from the growth forecast model and then aggregated into the three zone systems used in the transportation models: non-motorized zones (MGRA), traffic assignment zones (TAZ), and trip distribution zones (TDZ).

Table 3 illustrates the output from the trip generation model.

Each trip has two trip ends and the trip generation model calculates trip ends separately. One end is classified as a trip production and the other end as a trip attraction. The home end of home-based trips is defined as the production end and the other end is defined as the attraction end. The work end of work-other trips is defined as the production end and the other end as the attraction end. Other-other trip ends are split evenly into trip productions and trip attractions. Over a 24-hour period, roughly the same number of trips will originate in a zone as are destined there. However, residential zones will generate primarily trip productions while nonresidential zones will generate primarily trip attractions. The production/attraction distinction is important for the trip distribution model discussed in the next chapter.

### Table 2: Trip Generation Model Inputs

<table>
<thead>
<tr>
<th>Input</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling units by structure type</td>
<td>UDM</td>
</tr>
<tr>
<td>Population by age category</td>
<td>UDM</td>
</tr>
<tr>
<td>Land use acres by land use type</td>
<td>UDM</td>
</tr>
<tr>
<td>Employment by land use type</td>
<td>UDM</td>
</tr>
<tr>
<td>Unique generator trips</td>
<td>Traffic counts</td>
</tr>
<tr>
<td>External trips</td>
<td>Traffic counts, IRCM</td>
</tr>
<tr>
<td>Trip rates</td>
<td>Travel behavior surveys</td>
</tr>
<tr>
<td></td>
<td>Traffic generator studies</td>
</tr>
<tr>
<td>Regional control variables</td>
<td>DEFM, other studies</td>
</tr>
</tbody>
</table>
2.6.1 Model Structure

Trips from residential areas are calculated by applying trip rates to the number of dwelling units in each parcel polygon categorized by three structure types: single family, multifamily, and mobile home. Total trips are split into productions and attractions by trip type and then balanced to regional control totals. The residential trip generation equation for non-school purposes has the following form.

\[
\begin{align*}
\text{tp}(\text{zone,pu}) &= \text{du}(\text{zone,}st) \times \text{rate}(st) \times \text{pf}(st) \times \text{ppuf}(st, pu) \times \text{pbfac}(pu,pa) \\
\text{ta}(\text{zone,pu}) &= \text{du}(\text{zone,}st) \times \text{rate}(st) \times \text{af}(st) \times \text{apuf}(st, pu) \times \text{abfac}(pu,pa)
\end{align*}
\]

where:
- \( \text{tp}(\text{zone,pu}) \) = number of person trip productions in zone for each purpose
- \( \text{du}(\text{zone,}st) \) = number of dwelling units in zone by structure type
- \( \text{rate}(st) \) = person trip rate for structure type
- \( \text{pf}(st) \) = fraction of trip ends that are trip productions by structure type
- \( \text{ppuf}(st, pu) \) = fraction of trip productions in each purpose by structure type
- \( \text{pbfac}(pu,pa) \) = trip production balancing factor for each purpose
- \( \text{ta}(\text{zone,pu}) \) = number of person trip attractions
- \( \text{af}(st) \) = fraction of trip ends that are trip attractions by structure type
- \( \text{apuf}(st, pu) \) = fraction of trip attractions in each purpose by structure type
- \( \text{abfac}(pu,pa) \) = trip attraction balancing factor for each purpose

Special procedures have been developed to estimate home-based university and home-based school trip productions that are largely generated by school age population subgroups.

\[
\text{tp}(\text{zone,pu}) = \text{pop}(\text{zone,age}) \times \text{rate}(pu, age) \times \text{pbfac}(pu,pa)
\]

where:
- \( \text{tp}(\text{zone,pu}) \) = number of person trip productions in zone for each purpose
- \( \text{pop}(\text{zone,age}) \) = zone population by five year age category
- \( \text{rate}(age,pu) \) = person trip rate by age category and purpose
- \( \text{pbfac}(pu) \) = trip production balancing factor for each purpose
Nonresidential trip rates are usually computed as trips per acre by 80 different land use categories. The form of the nonresidential trip generation equation is similar to the residential equation.

\[ tp(\text{zone}, \text{pu}) = lu(\text{zone}, \text{lt}) \times \text{rate}(\text{lt}) \times pf(\text{lt}) \times ppuf(\text{lt}, \text{pu}) \times pbfac(\text{pu}, \text{pa}) \]

\[ ta(\text{zone}, \text{pu}) = lu(\text{zone}, \text{lt}) \times \text{rate}(\text{lt}) \times af(\text{lt}) \times apuf(\text{lt}, \text{pu}) \times abfac(\text{pu}, \text{pa}) \]

where:
\( lu = \text{land use acres} \)
\( lt = \text{land use type} \)

Employee-based nonresidential trip rates have also been calibrated for the 80 land use categories. Employee rates yield the same number of regional trips as acres rates, although they produce a different pattern of trip making across the region. Employee-based trip rates are used for homework trips to better match CTPP data. In addition, Centre City San Diego uses employee-based rates for all purposes. Centre City densities are much higher than regional averages so that acre-based rates underestimate travel. Centre City also has a greater potential for growth than is indicated by land use redesignation that determines acre-based trips.

Most model applications use the acre measure of nonresidential activity elsewhere in the region since acre-based forecasts are easier to understand, are subject to less uncertainty than employment forecasts, and produce traffic volumes that better match ground counts. Building square footage is expected to be added to future growth forecasts which should overcome problems with both the acre-based and employee-based procedures.

Trips from elementary schools, junior high schools, senior high schools, and golf courses are generated on a per site basis rather than the acre-based methodology described above. Trips from external zones are based on traffic counts on roads crossing the county boundary. These base year trips are factored to future years using output from the Interregional Commuting Model and trends in past traffic counts.

Trip ends calculated by these equations are superseded for a small number of MGRAs that contain unique generators. Unique generators are major traffic generators where traffic counts indicate that applying standard trip rates would misrepresent actual trip making. Unique generators include all military bases, major tourist attractions, major beaches, Indian casinos, the University of California San Diego (UCSD), San Diego State University (SDSU), and Lindbergh Field.

Future year person trips are reduced by a small amount to reflect increased use of tele-working and e-commerce. Reduction factors of between one and eleven percent are applied to selected trip purposes and land use categories. The assumption is that some land use types such as office uses would be more likely to take advantage of tele-working than other uses such as hospitals.

Table 4 shows the tele-work and e-commerce eligible land uses and their corresponding reduction percentages.
Table 4: Trip Generation Tele-Work Percentages

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>Series 12 Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial Park</td>
<td>7%</td>
</tr>
<tr>
<td>Planned Industrial</td>
<td>7%</td>
</tr>
<tr>
<td>Light Industry</td>
<td>7%</td>
</tr>
<tr>
<td>Regional Commercial</td>
<td>2%</td>
</tr>
<tr>
<td>Community Commercial</td>
<td>1%</td>
</tr>
<tr>
<td>Neighborhood Commercial</td>
<td>1%</td>
</tr>
<tr>
<td>Specialty Commercial</td>
<td>1%</td>
</tr>
<tr>
<td>Streetfront Commercial</td>
<td>1%</td>
</tr>
<tr>
<td>Other Commercial</td>
<td>1%</td>
</tr>
<tr>
<td>High Rise Office</td>
<td>11%</td>
</tr>
<tr>
<td>Low Rise Office</td>
<td>11%</td>
</tr>
<tr>
<td>Gov’t Office or Center</td>
<td>11%</td>
</tr>
<tr>
<td>High Rise Office</td>
<td>11%</td>
</tr>
<tr>
<td>Other Public Service</td>
<td>2%</td>
</tr>
<tr>
<td>Other Health Care</td>
<td>3%</td>
</tr>
<tr>
<td>SDSU or UCSD</td>
<td>3%</td>
</tr>
<tr>
<td>University or College</td>
<td>3%</td>
</tr>
<tr>
<td>Junior College</td>
<td>3%</td>
</tr>
<tr>
<td>School Dist. Office</td>
<td>11%</td>
</tr>
<tr>
<td>Mixed Use 67%</td>
<td>1%</td>
</tr>
<tr>
<td>Mixed Use 77%</td>
<td>1%</td>
</tr>
<tr>
<td>Mixed Use 67%</td>
<td>1%</td>
</tr>
<tr>
<td>Mixed Use 25%</td>
<td>1%</td>
</tr>
</tbody>
</table>

By definition total trip productions must equal trip attractions at the regional level. However, imbalances between the two trip ends can occur since productions are estimated independently from trip attractions. Residential trip generation equations at the zone level also are relatively straightforward and ignore demographic trends such as the aging of the population over time. To overcome these problems, zone level trip productions and attractions are totaled for the region and balancing factors are calculated to match regional control totals for each trip purpose and forecast year.

Regional control totals are obtained by factoring base year trip totals by changes in logically related demographic, economic, and trip variables produced by DEFM and other models. These variables are listed in Table 5.
Table 5:  
Regional Control Variables

<table>
<thead>
<tr>
<th>Trip Type</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home-work</td>
<td>Total employment</td>
</tr>
<tr>
<td>Home-college</td>
<td>Trip productions</td>
</tr>
<tr>
<td>Home-school</td>
<td>Trip productions</td>
</tr>
<tr>
<td>Home-shop</td>
<td>Retail sales</td>
</tr>
<tr>
<td>Home-other</td>
<td>Service sector output</td>
</tr>
<tr>
<td>Work-other</td>
<td>Total employment</td>
</tr>
<tr>
<td>Other-other</td>
<td>Total trips</td>
</tr>
<tr>
<td>Serve passenger</td>
<td>Auto passenger trips</td>
</tr>
<tr>
<td>Visitor</td>
<td>Visitor sector output</td>
</tr>
<tr>
<td>Regional airport</td>
<td>Air passenger trips</td>
</tr>
</tbody>
</table>

A TDZ income level distribution of home-based trip productions is needed as input to the mode choice model. While residential trips are being generated, dwelling unit trip rates by income level are applied and zone level trips by income level are accumulated.

Another mode choice model input is a set of production and attraction end highway terminal times which represent the time spent looking for a parking space and traveling from a parking space to a final destination. The trip generation model processes dwelling unit and land use data which enables weighted terminal times to be calculated for each zone. For example, multifamily dwelling units tend to have less convenient parking than single family houses, so the model assumes a one-minute single family terminal and a two-minute multifamily terminal time. Thus zones with larger concentrations of apartments will have longer production end terminal times.

2.6.2 Model Calibration

Trip generation rates are established from travel behavior survey data and traffic generator studies. Trip rates were initially calculated by expanding trips reported in the 1995 Travel Behavior Survey to the region, tabulating trip ends by purpose and land use, and dividing total trip ends by either the total number of acres, total number of employees, or total number of dwelling units in each land use category. A significant underreporting of trips is found with travel behavior surveys. Trip rates computed from the 1995 Travel Behavior Survey were adjusted to match trip rates found in the 2001 Caltrans GPS survey and traffic generator studies.

2.7 PATHBUILDING, SKIMMING, AND UTILITY CALCULATIONS

The purpose of this part of the modeling process is to find distances, times, costs and other impedances between zones for input to the trip distribution and mode choice models based on coded highway and transit networks described in Sections 2.4 and 2.5. As indicated in Figure 2, the skimming process is repeated numerous times during a model run in order to reflect changes in travel times due to the interaction between travel demand and highway congestion.
TransCAD makes use of a “generalized cost” measure, which combines the effects of time valued at $0.35 per minute and distance valued at $0.15 per mile. In the highway skimming process a minimum path algorithm finds the shortest generalized cost path between each zone pair and then calculates network impedances over the minimum cost path. Different network impedances are skinned at different points in the modeling process. Initially TAZ level free-flow generalized costs are output for the first stage trip distribution model. In both the feedback loop process and in the final modeling stage, TDZ level distances, times, and toll costs are output for up to eight highway modes that are described in the mode choice section. Peak and off-peak period skims are created to reflect the varying level of congestion in the two time periods. After the skimming process, intra-zonal times and costs are added where appropriate using a “nearest neighbor” technique.

Two different techniques are used to determine non-motorized skims. Since most non-motorized trips are short distance trips, SANDAG detailed 21,633 non-motorized zones (MGRA) are used where possible to reflect the increased likelihood of walking and biking offered by mixed use developments. MGRA-to-MGRA distances are calculated using the equation shown in Section 2.5.5 for nearby MGRAs within 1.5 miles. For trips longer than 1.5 miles, non-motorized distances are calculated at the more generalized TDZ level from a subset of coded highway networks without freeways and ramps. This two level approach is used to properly account for most non-motorized trips without seriously increasing model execution time.

The transit skimming process calculates minimum cost paths between transit access points (TAPs) instead of zones. TAPs, described in Section 2.5.5, are selected transit stops that are used to represent access to the transit system. The following four sets of paths are created for modes defined in Table 1

- A.M. peak period local bus (mode 10)
- A.M. peak period premium service (all modes 4-10)
- Mid-day local bus
- Mid-day premium service

By creating separate premium service and local bus paths, the model is able to split trips between the two types of service. For example, some transit riders may choose local bus routes over faster, but more expensive rail service serving the same corridor. The A.M. peak period is used to represent peak period transit service and mid-day service is used to represent off-peak conditions.

Next, TransCAD determines the following transit impedances over minimum generalized cost paths between each pair of TAPs.

- Number of transfers
- Cash fare
- First wait time
- Transfer wait time
- Transfer walk time
- Commuter rail In-vehicle time (mode 4)
- Light rail In-vehicle time (mode 5)
- BRT in-vehicle time (modes 6 and 7)
- Express bus in-vehicle time (modes 8 and 9)
- Local bus In-vehicle time (mode 10)
- Main mode indicator
First wait and transfer wait times are computed as one-half of the headway on routes serving the TAP pair. For example, a trip that gets on a bus arriving every 30 minutes and transfers to a trolley arriving every 15 minutes, would have a first wait time of 15 minutes and a transfer time of 7.5 minutes. Long first waits are factored down later in the mode choice model to reflect the inconvenience of infrequent service without over penalizing this service. A premium transit path could use a number of different modes. The main mode indicator indicates the mode that is used for the longest distance.

In the feedback loop process, trips are distributed based on a composite utility measure that combines peak and off-peak times and costs for highway, transit, and non-motorized modes. A special version of the mode choice model, described in Section 2.9, computes composite utility values by weighting utilities for individual time periods and modes by their share of total trips.

### 2.8 TRIP DISTRIBUTION

The trip distribution model links together person trip productions and attractions from the trip generation model to determine trip movements between zones. The model produces trip tables that contain a row for each production zone and a column for each attraction zone. Cells in the table contain the number of trips estimated between zone pairs. Table 6 and Table 7 list inputs to the trip distribution model and some of the major outputs.

The model is designed to modify trip patterns in response to new land use developments and transportation facility changes. For example, the opening of a new shopping center would shift trips from other nearby shopping areas to the new development. Another example would be the introduction of mixed-use development. In this case the model would yield shorter trip lengths by recognizing the increased opportunity for interaction between residential and commercial areas in the development. The model also modifies trip patterns as new roadways are added, accounting for one component of induced traffic.

The trip distribution model is also designed to account for land use characteristics that relate to transportation and behavior known as the “4Ds,” which stand for Diversity, Density, Design, and Destination Accessibility. The 4Ds measures are used to quantify urban characteristics such as compact mixed use areas associated with smart growth planning. More information on 4Ds in the SANDAG model can be found in the 4D Model Development report on the SANDAG Regional Models website.

<table>
<thead>
<tr>
<th>Input</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trip productions and attractions by zone and trip purpose</td>
<td>Trip Generation Model</td>
</tr>
<tr>
<td>Impedances between zones</td>
<td>Network Skimming</td>
</tr>
<tr>
<td>Highway terminal times and parking costs</td>
<td>Trip Generation Model</td>
</tr>
<tr>
<td>Friction factors gamma function parameters</td>
<td>Travel Behavior Surveys</td>
</tr>
</tbody>
</table>
2.8.1 Model Structure

A gravity model function distributes trips between zones. The model allocates trip productions from each zone to other zones in direct proportion to the number of attractions in other zones and in inverse proportion to the impedance between zones using the following formula.

\[
t(z_p, z_a, p_u) = t_p(z_p, p_u) \times \frac{t_a(z_a, p_u) \times f_f(t_i(z_p, z_a), p_u)}{\sum_i^n t_a(z_x, p_u) \times f_f(t_i(z_p, z_x), p_u)} \times bfac(z_a, z_p)
\]

where:
- \( t \) = Number of trips between zones “za” and “zp” for each purpose
- \( t_p(z_p, p_u) \) = Trip productions in zone “zp” for purpose “pu”
- \( t_a(z_a, p_u) \) = Trip attractions in zone “za” for purpose “pu”
- \( f_f \) = Friction factor for travel impedance “ti” and purpose “pu”
- \( t_i(z_a, z_p, p_u) \) = Travel impedance between zones “zp” and “za”
- \( bfac(za) \) = Balancing factors for zones “za” and “zp”
- \( n \) = number of zones

The term “impedance” is a measure of the difficulty of travel between two zones. The trip distribution model is run repeatedly in the overall modeling process shown in Figure 2. Different impedance measures are used at different stages of the modeling process. The previous section describes how impedance measures are calculated. First stage trip distribution uses generalized costs based on free flow times and distances as the impedance measure to distribute trips between 4,682 TAZs. The first stage model is designed to be the starting point for the feedback loop process or can be run as a standalone application for simple model applications.

The feedback loop process makes use of a more complicated measure of impedance which is the composite utility from the mode choice model based on times and costs of travel for peak and off-peak conditions. Using composite utilities instead of free flow generalized costs enables the feedback process to reflect more subtle effects of changes to the transportation system on travel patterns. For example, widening a freeway may reduce congestion and lead to longer distance trip lengths. Major transit investments could also produce transit travel times that are more competitive with the automobile and cause more trips to be made within the transit corridor. The feedback loop trip distribution model distributes trips between the more aggregated 2,000 TDZs so that reasonable model execution times are maintained.
Each trip purpose has a different average trip length that ranges from 3 miles for other-other trips to 19 miles for regional airport trips. A gamma function generates friction factors for each trip purpose using 4D factors that account for variations in density. These friction factors determine the likelihood of a trip being made in each impedance increment and are used in the trip distribution model to reflect trip length differences by trip purpose. For example shop trips, which are much shorter than commute trips, have friction factors that diminish more rapidly than work friction factors.

\[ ff = a \times ti(zp, za)^{b \cdot mf(mi, pu)} \times e^{-c \cdot ti(zp, za)} \]

where:
- \( a, b, c \) are model parameters
- \( mf = 4D \) mix (or employment) variable density factor by mixed index “mi” for purpose “pu” shown in Table 8 & Table 9

### Table 8:
**Mix Variable Density Factor**

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Low Density</th>
<th>Medium Density</th>
<th>Medium High Density</th>
<th>High Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home-Work</td>
<td>1.42</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Home-College</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>Home-Education</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Home-Shop</td>
<td>1.1</td>
<td>1.1</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Home-Other</td>
<td>0.9</td>
<td>1</td>
<td>1.05</td>
<td>1.05</td>
</tr>
<tr>
<td>Serve Passenger</td>
<td>0.98</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 9:
**Employment Variable Density Factor**

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Low Density</th>
<th>Medium Density</th>
<th>High Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work-Other</td>
<td>1</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Other-Other</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
</tr>
</tbody>
</table>

The 4D variables are defined by two category systems. One system categorizes the individual density variables by range: employment density, dwelling unit density, and total intersections. The employment ranges in Table 10 are used for identifying which factors shown in Table 9 are used for work-other and other-other trip purposes. Additionally, all 3 density variables are used for mode choice non-motorized and transit constants. The second category system uses ranges for a mixed index density variable whose formulation is based on previous work by Portland Metro. The mix index is then categorized using the breakpoints shown in Table 11.
Table 10:  
4D Variable Density Ranges

<table>
<thead>
<tr>
<th>Density Category</th>
<th>Employment (floating number of employees per acre)</th>
<th>Dwelling Unit (floating number of all dwelling units per acre)</th>
<th>Intersection (floating number of intersections per ½ mile buffer around MGRA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0-9.99</td>
<td>0-4.99</td>
<td>0-79.99</td>
</tr>
<tr>
<td>High</td>
<td>30+</td>
<td>10+</td>
<td>130+</td>
</tr>
</tbody>
</table>

\[ MI = \frac{\text{Intersections} \times \text{DwellingUnits} \times \text{Factor1} \times \text{Employment} \times \text{Factor2}}{\text{Intersections} + \text{DwellingUnits} \times \text{Factor1} + \text{Employment} \times \text{Factor2}} \]

where:
MI = Mix Index
Dwelling Units = dwelling units density within ½ mile of TDZ centroid
Employment = employment density within ½ mile of TDZ centroid
Intersections = intersections within ½ mile of TDZ centroid
Factor 1 = Mean Intersections / Mean Dwelling Unit Density
Factor 2 = Mean Intersections / Mean Employment Density

Table 11:  
Mix Index Density Bins

<table>
<thead>
<tr>
<th>Density Category</th>
<th>Mix Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0-20</td>
</tr>
<tr>
<td>Medium Low</td>
<td>21-1750</td>
</tr>
<tr>
<td>Medium High</td>
<td>1751-6500</td>
</tr>
<tr>
<td>High</td>
<td>6500+</td>
</tr>
</tbody>
</table>

The model uses a set of friction factors for each trip purpose for the two stages of the modeling process. These friction factors remain unchanged over the forecast period; however, this does not mean that the model produces the same average trip length for all areas of the region and all forecast years. Rather the model reflects trip length differences resulting from different spatial locations of activities. Thus, rural areas that are far from most employment centers would have longer home-work trips than more centrally located areas near Centre City and other major employment sites.

A number of gravity model iterations are performed to bring gravity model attraction estimates in line with trip generation estimates. The first model iteration typically overestimates trips to highly accessible areas and underestimates trips to inaccessible areas. The program computes doubly-constrained balancing factors by dividing estimated productions and attractions into input productions and attractions. The resulting factors are applied to estimated trips in the next iteration. This process continues until the model closes with a criterion of 0.01.
2.8.2 Model Calibration

Gravity model calibration involves adjusting gamma function parameters until model estimated trip length frequency distributions agree with observed trip length frequencies from the 1995 Travel Behavior Survey and 2001 Caltrans Statewide Survey. A TransCAD procedure estimates initial gamma function parameters that best fit an estimated trip length distribution to observed data. Manual adjustments to these gamma function parameters are necessary before finalizing the calibration process. After this calibration process is complete, K-factors are applied to selected zonal interchanges so that model-estimated trip patterns better match observed data for the following conditions:

- Home-college trips to San Diego State University and University of California, San Diego
- Coronado Bridge crossings
- Inter-zonal other-other and work-other trips
- High transit use corridors

2.9 MODE CHOICE

The mode choice model splits total person trips from the trip distribution model into trips by individual forms of transportation called modes. The mode choice model is designed to link mode use to demographic assumptions, highway network conditions, transit system configuration, land use alternatives, parking costs, transit fares, and auto operating costs. Table 12 and Table 13 list major mode choice model inputs and outputs.
Table 12: Mode Choice Model Inputs

<table>
<thead>
<tr>
<th>Input</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Person trips between zones by purpose</td>
<td>Trip Distribution Model</td>
</tr>
<tr>
<td>Trip distances between zones</td>
<td>Highway Network</td>
</tr>
<tr>
<td>Peak/off-peak period highway travel times</td>
<td>Highway Network</td>
</tr>
<tr>
<td>Peak/off-peak period highway distances</td>
<td>Highway Network</td>
</tr>
<tr>
<td>Peak/off-peak period highway tolls</td>
<td>Highway Network</td>
</tr>
<tr>
<td>Non-motorized distances</td>
<td>Non-motorized Network</td>
</tr>
<tr>
<td>Peak/off-peak period transit times</td>
<td>Transit Network</td>
</tr>
<tr>
<td>Peak/off-peak period transit fares</td>
<td>Transit Network</td>
</tr>
<tr>
<td>Transit walk and auto access assumptions</td>
<td>Transit Network</td>
</tr>
<tr>
<td>Automobile operating cost per mile</td>
<td>National Forecasts</td>
</tr>
<tr>
<td>Parking costs</td>
<td>Parking Surveys</td>
</tr>
<tr>
<td>Highway terminal times</td>
<td>Trip Generation Model</td>
</tr>
<tr>
<td>Trips by income level</td>
<td>Trip Generation Model</td>
</tr>
<tr>
<td>School bus percentages</td>
<td>Travel Behavior Survey</td>
</tr>
<tr>
<td>Model parameters</td>
<td>Model Calibration</td>
</tr>
<tr>
<td>Daily to time period factors</td>
<td>Travel Behavior Surveys</td>
</tr>
</tbody>
</table>

Table 13: Mode Choice Model Output

<table>
<thead>
<tr>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin-destination highway vehicle trips between zones by time period</td>
</tr>
<tr>
<td>Transit trips between TAPs by time period</td>
</tr>
<tr>
<td>Mode choice reports</td>
</tr>
</tbody>
</table>

Many applications make use of the mode choice model. Generating transit patronage forecasts for trolley extensions and other transit improvements is a common use. This model also produces performance measures used to evaluate alternative transportation network and land use scenarios.

Proposed transit improvements reduce the time of making a trip by transit and the model shifts trips to transit from other modes in response to these improvements. Conversely, new or widened highways would increase speeds for motorists and the model would increase automobile travel at the expense of transit usage. This mode shift that occurs with highway improvements is one component of induced demand.
The model reduces automobile travel and increases transit and non-motorized travel in response to smart growth land use alternatives that guide development into areas around transit stations and into mixed-use areas. These land use changes reduce trip lengths and make non-motorized travel more attractive. Increasing development around transit stations shortens station access times and increases the number of trips accessible to transit.

The model assumes that travelers make logical and systematic decisions about which form of transportation to take based on knowledge of the time and cost of completing a trip by alternative modes. The model is sensitive to a wide range of facility improvements and policies; however, the model is currently insensitive to programs designed to alter mode use without altering times or costs, such as:

- Advertising campaigns to increase the use of transit, bicycling, or ridesharing,
- Rideshare matching programs,
- Construction of bicycle lanes,
- Replacing older buses to increase the attractiveness of transit, and
- Providing safer and more comfortable transit stops.

A common misconception about the mode choice model is that it underestimates future transit use for expanded transit alternatives because model calibration is based upon current conditions. This should not be the case. The model estimates transit use for each zone-to-zone movement based upon the quality of transit service relative to other modes. Existing trolley corridors provide a basis for determining potential transit use with high quality transit service. As more light rail, BRT, and bus service is provided, the model recognizes the resulting transit service improvements and shifts travel to transit from other modes. As a result, the model forecasts a 46 percent increase of the work trip transit mode share between 2008 and 2035, when an expanded transit system is expected to be in place. This forecasted increase in transit mode share exceeds historical changes in transit mode share. For example, US Census Bureau statistics show San Diego’s work trip transit mode share increased by only 5 percent between 1980 (Census) and 2005-2009 (ACS) a time in which COASTER and Sprinter service was added and trolley service was expanded.

The mode choice model was recalibrated as part of the Mid-Coast FTA New Starts project. This included a thorough review of the mode choice code by an outside consultant and update of the code and parameters to meet FTA guidelines.

2.9.1 Model Structure

SANDAG uses a nested mode choice model that splits total person trips into 25 different submodes in a hierarchical fashion as illustrated in Figure 4. Initially, school bus trips are factored out of total trips. These trips affect a small percentage of all trips, but are a significant proportion of school trips. Next trips are split into auto, non-motorized, and transit modes. The term "auto" is used generically to include travel by automobiles, pick-ups, vans, light-duty trucks, taxicabs, and motorcycles. Auto trips are further divided into submodes based on vehicle occupancy (drive alone, two person shared-ride, and three or more person shared-ride vehicles) and type of facility.
The RTP proposes a number of different types of restricted use freeway facilities. In addition to general purpose freeway lanes the RTP includes:

- High Occupant Vehicle (HOV) Lanes. HOV lanes can only be used by buses and shared-ride vehicles with two or more occupants. Under some conditions HOV lanes may be restricted to vehicles with three or more occupants. HOV lanes now exist on I-5 north of I-805 and are planned for many other freeways.

- Managed Lanes. These multi-lane HOV facilities are sometimes called high occupancy toll (HOT) lanes. In addition to shared-ride vehicles, managed lanes are open to drive alone vehicles that are willing to pay a toll. There are currently managed lanes on I-15 between SR 163 and the Del Lago Direct Access Ramp (DAR). Managed lanes are being extended on I-15 and are planned for portions of I-5, I-805, SR 52, SR 54, SR 78, SR 94, and SR 125. In certain situations a managed lane will restrict the free HOV usage to shared-ride vehicles with three or more occupants. In this case, shared-ride vehicles with two or more occupants pay the same toll as drive alone vehicles.

- Toll Roads. The SR 125 toll road is an example of this type of facility. Toll roads require all vehicles, both drive alone and shared-ride, to pay a toll in order to use the facility. Toll Roads are planned for SR 11 and for segments north of SR 78 to the county line on I-5 and I-15.
When vehicle occupancy categories are matched with facility types, the following eight auto
submodes are possible.

- Drive Alone/Non-Toll Trips. These trips, restricted to general purpose lanes, are made up of drive
  alone trips that choose not to pay to use toll roads or managed lanes.

- Drive Alone/Toll Trips. These are toll-paying drive alone trips can use all types of facilities except
  HOV-only lanes.

- Two Person Shared-Ride Non-Toll/Non-HOV Trips. These trips, restricted to general purpose
  lanes, include shared-ride trips that choose not to pay to use tolled facilities, and trips that are
  eligible to use HOV lanes but choose not to do so.

- Two Person Shared-Ride Non-Toll/HOV Trips. These are shared-ride trips that choose to use an
  HOV lane, but are unwilling to pay a fee to use tolled facilities.

- Two Person Shared-Ride Toll/HOV Trips. These are toll-paying shared-ride trips that can use all
  types of facilities.

- Three or More Person Shared-Ride Non-Toll/Non-HOV Trips.

- Three or More Person Shared-Ride Non-Toll/HOV Trips.

- Three or More Person Shared-Ride Toll/HOV Trips.

HOV lanes in the RTP are proposed as two person HOV lanes until 2035, so the two person and
three or more person shared-ride modes are allowed to use the same facilities. In 2035 and beyond
only three or more person shared-ride modes are allowed on HOV lanes or ML/HOT lanes for free.

Non-motorized trips (pedestrian and bicycle trips) reflect the effects of land use, trip purpose, and
competing transportation modes. However, estimation procedures do not allow non-motorized
facility issues to be addressed. For example, bicycle paths are not explicitly coded and thus do not
affect non-motorized trip forecasts. A more rigorous approach is prevented by the small scale of
non-motorized facilities and the lack of before and after data showing the effects non-motorized
improvements have on non-motorized travel.

Transit trips are subdivided by transit access modes (walk, drive, and drop-off) and transit ride modes
(commuter rail, light rail, BRT, express bus, and local bus). The three transit access modes determine
how transit riders get to and from transit stops. Riders who walk at both trip ends are classified as
transit-walk trips. Drive access trips are those trips where the rider gets to or from a transit stop by
either driving or carpooling. Trips where the rider is dropped-off or picked up are classified as drop-
off trips. Access mode is important in quantifying transit level-of-service. Drive access usually shortens
overall transit trip times, but is limited to locations with park-and-ride access.

Transit ride modes represent travel behavior and non-quantifiable service differences between the
five modes. Parameters and coefficients for existing modes are estimated from survey information
and asserted for modes that do not exist in the region. During the Urban Area Transit Strategy
project it was concluded that the BRT service being proposed in the 2050 RTP would operate
midway between bus and rail service.
The model computes mode use separately for two time periods, three income levels, and six trip purposes. The two time periods split travel into peak and off-peak hours. The peak period extends from 6:00 a.m. to 9:00 a.m. and 3:00 p.m. to 6:00 p.m. The off-peak period covers the remaining 18 hours of the day. It is important to evaluate mode use separately for the two time periods because the quality of service can vary dramatically by mode. For example, transit operators often provide more frequent transit service during peak hours, reducing wait times for transit riders. Conversely, highway congestion is at its worst during peak hours making auto modes less attractive relative to transit.

Mode use also varies by income level. People in low-income households tend to own fewer automobiles and hence make more trips by transit and carpooling. People in upper-income households tend to be mode time sensitive and as a result choose modes based on time and convenience rather than cost. Households are split into three income categories:

- low income households with annual incomes less than $30,000 (constant 1999 dollars)
- high income households with incomes more than $60,000
- middle income households made up of the remaining households

There also is a strong relationship between mode use and trip purpose. For example, most students are below driving age so school trips generate almost no drive alone trips but have a very high rate of transit, school bus, and non-motorized mode use. Home-other trips tend to be made with other household members, so that two and three or more person auto modes are more heavily used than other trip types. In order to reduce computer processing time, the ten trip purposes from trip generation and distribution are collapsed into six purposes for mode choice by combining home-shop and home other trips, and combining work-other, other-other, visitor, and regional airport trips.

### 2.9.2 Utility Computations

Before determining mode shares the model computes utility measures for each mode based on a combination of a number of time and cost components that are weighted using the coefficients shown in
### Table 14: Mode Choice Time and Cost Coefficients

<table>
<thead>
<tr>
<th>Time/Cost Component</th>
<th>Purpose/Income</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Home-Work/College</td>
<td>Home-Other</td>
<td>Other-Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Auto In-Vehicle</td>
<td>-0.0280</td>
<td>-0.0160</td>
<td>-0.0220</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Auto Terminal</td>
<td>-0.0560</td>
<td>-0.0320</td>
<td>-0.0440</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Transit In-Vehicle</td>
<td>-0.0280</td>
<td>-0.0160</td>
<td>-0.0220</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Transit First Wait</td>
<td>-0.0420</td>
<td>-0.0256</td>
<td>-0.0352</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Transit Transfer Wait</td>
<td>-0.0840</td>
<td>-0.0400</td>
<td>-0.0550</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Transit Auto Access</td>
<td>-0.0560</td>
<td>-0.0320</td>
<td>-0.0440</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Bicycle</td>
<td>-0.0980</td>
<td>-0.0640</td>
<td>-0.0880</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Low</td>
<td>Mid</td>
<td>High</td>
<td>Low</td>
<td>Mid</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>All Modes</td>
<td>-0.0083</td>
<td>-0.0031</td>
<td>-0.0013</td>
<td>-0.0094</td>
<td>-0.0035</td>
<td>-0.0015</td>
<td>-0.0131</td>
</tr>
</tbody>
</table>

### Table 15: Value of Time

<table>
<thead>
<tr>
<th>Income Category</th>
<th>Home-Based Work</th>
<th>Home-Based Other</th>
<th>Non-Home Based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>$2.02</td>
<td>$1.02</td>
<td>$1.01</td>
</tr>
<tr>
<td>Mid</td>
<td>$5.42</td>
<td>$2.74</td>
<td>$2.69</td>
</tr>
<tr>
<td>High</td>
<td>$12.92</td>
<td>$6.40</td>
<td>$6.60</td>
</tr>
</tbody>
</table>

Utilities for auto modes are computed for each TDZ pair, time period, and income group and purpose using the following equation:

\[
auv(m, p, i) = (auivt(m, t, iz, jz) \times tcoef(1, p) + cermpterm(iz) + terma(jz) \times tcoef(2, p) + \text{cost}(p, jz) + toll(m, t, iz, jz) \times cpm \times ccoef(p, i)) / (clow \times ncmid \times nctop)
\]

where:
- auu = auto utility for mode “m” purpose “p” and income group “i”
- auivt = auto in-vehicle travel time between zones for mode and time period “t”
- tcoef = time coefficient for purpose from Table 14
- termpterm = terminal time at production end
- terma = terminal time at attraction end
- cost = parking cost at attraction end
- toll = toll facility cost (if any)
audist = auto distance between zones
cpm = cost per mile to operate an automobile
ccoeff= cost coefficient for purpose and income group from Table 14
nclow = nesting coefficient at lowest level of nest (0.55)
ncmid = nesting coefficient at middle level of nest (0.65)
ntop = nesting coefficient at top level of nest (0.85)

Although the form of the equation is the same for all auto modes, in-vehicle times, tolls, and distances may differ for each mode depending on the highway network being evaluated. For example in a congested corridor with a freeway HOV lane, the in-vehicle travel time for drive alone non-toll vehicles would be longer than the time for two person shared-ride HOV/non-toll vehicles which are allowed to use the less congested HOV lane.

In-vehicle highway times are calculated using procedures described in the next highway assignment section and include the effects of congestion. Terminal times represent walking time from home to parking location, walking time from parking location to final destination, and other miscellaneous time. Terminal times at the residential end are assumed to be one-quarter minute for single family units and two minutes for multifamily units since higher density developments tend to have less convenient shared parking. The trip generation step calculates average TDZ residential terminal times based on the number of units by each type. A one minute terminal time is assumed at most nonresidential locations. Higher nonresidential terminal times are assumed in Centre City, at universities, military bases, regional shopping centers, and some older outlying business districts. These terminal times vary between three and ten minutes depending on the location.

The model considers three types of auto costs: auto operating costs, parking costs, and tolls. Auto operating costs are based on the SB 375 Regional Targets Advisory Committee (RTAC) method. RTAC uses the 2009 U.S. Department of Energy annual energy outlook and forecasted fuel efficiency from the California Air Resources Board. All costs are in 1999 dollars and are shown in Table 16. Vehicle depreciation costs are not included since these costs are not usually considered when making a mode choice decision. Transit fares for future-year forecasts are assumed to remain constant. It should be noted that cost and fare assumptions can be varied for scenario testing purposes.
Table 16:
Auto Operating Costs

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>$0.138</td>
<td>20</td>
<td>$2.70</td>
</tr>
<tr>
<td>2020</td>
<td>$0.159</td>
<td>23.2</td>
<td>$3.68</td>
</tr>
<tr>
<td>2025</td>
<td>$0.152</td>
<td>24.8</td>
<td>$3.77</td>
</tr>
<tr>
<td>2030</td>
<td>$0.149</td>
<td>26.4</td>
<td>$3.93</td>
</tr>
<tr>
<td>2035</td>
<td>$0.153</td>
<td>26.7</td>
<td>$4.07</td>
</tr>
<tr>
<td>2040</td>
<td>$0.155</td>
<td>27.2</td>
<td>$4.21</td>
</tr>
<tr>
<td>2050</td>
<td>$0.159</td>
<td>28.3</td>
<td>$4.51</td>
</tr>
</tbody>
</table>

Source:
Extrapolated 2035, 2040, 2050 Prices
Fuel Efficiency from EMFAC w/ Pavley Post Processor (2020, 2030, 2035)
Fuel Efficiency extrapolated for 2040 and 2050
All fuel prices add a 2007 $0.25 California surcharge

Parking costs shown in Table 17 are applied in Centre City San Diego, universities, Lindberg Field, and business districts in Oceanside, Escondido, La Jolla, and Hillcrest. Although some individual lots charge more, the highest average parking rates of $12.50 per day are found in Centre City San Diego. These rates are made into a per trip basis by dividing by two and are applied by trip purpose. Home to work trips have a longer duration than other trip purposes leading to higher parking costs on average.

Table 17:
Parking Costs

<table>
<thead>
<tr>
<th>Area Type</th>
<th>Home-Work</th>
<th>Home-Other</th>
<th>Non-Home Based</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>2</td>
<td>$1.00</td>
<td>$0.20</td>
<td>$0.20</td>
</tr>
<tr>
<td>3</td>
<td>$3.50</td>
<td>$0.50</td>
<td>$0.50</td>
</tr>
<tr>
<td>4</td>
<td>$7.00</td>
<td>$4.50</td>
<td>$4.50</td>
</tr>
<tr>
<td>5</td>
<td>$12.50</td>
<td>$8.00</td>
<td>$8.00</td>
</tr>
</tbody>
</table>

The RTP contains two types of toll facilities: (1) managed lanes that charge a fee for use by drive alone vehicles and (2) toll roads where tolls will be charged for all vehicles using the facility.

The managed lane facilities are coded with a per mile toll cost that can vary by time period and location. Data from the existing managed lanes on I-15 were analyzed to determine default managed lane tolls of $0.26 per mile in peak periods and $0.10 per mile in the off-peak. These default toll rates can be adjusted to match model-estimated managed lane demand to available capacity. The operational goal of the managed lanes is maintain a level of service no worse than ‘D’ for any temporal period.

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One toll facility in the region already exists. On the SR-125 South Bay Expressway, the toll coding replicates the current tolling schedule that exists for autos. A separate tolling schedule is coded for truck traffic as well. The 2050 RTP has 4 additional toll facilities planned. Since no tolling schedule exists, tolls are coded on a per mile basis. These tolls vary from 10 to 27 cents per mile in during off-peak and 15 to 33 cents per mile in the peak.

Transit utility computations are more complicated than auto computations because there are more travel time components associated with transit. These utilities also need to be computed for each transit access and transit ride mode combination, and for each MGRA-MGRA pair, time period, and income group. Walk access computations use the following equation.

\[
twu(rm, p, i) = \left[ \frac{\text{trivt}(rm, t, ptap, atap) \times tcoef(3, p) + \text{sfw}(rm) \times tcoef(4, p) + \text{trxfa}(rm, t, ptap, atap) \times tcoef(5, p) + \text{fare}(rm, t, ptap, atap) \times fpct(p, i, rm) \times ccoef(p, i)}{\text{emid} \times nctop} \right]
\]

where:

- \( twu(rm, p, i) \) = transit-walk utility for ride mode “rm”, purpose “p”, and income group “i”
- \( \text{trivt} \) = in-vehicle transit time between TAPs for ride mode and time period “t”
- \( \text{tcoef} \) = time coefficient for purpose from Table 14
- \( \text{sfw} \) = short first wait time
- \( \text{lfw} \) = long first wait time
- \( \text{trxfa} \) = transfer wait time
- \( \text{wk} = \) walk time
- \( \text{etime} \) = station elevation walk time
- \( \text{wkfac} = \) walk factor of 2.5
- \( \text{fare} = \) transit cash fare
- \( \text{fpct} = \) cash fare discount factor for pass usage

As indicated in Table 14, time coefficients on wait times are higher than in-vehicle time coefficients to reflect the fact that surveys show transit riders perceive this out-of-vehicle time component to be more onerous than time spent riding in a vehicle. Transit skimming procedures calculate first-wait times based on one-half the headway of coded transit routes. In the mode choice model these wait times are split into short and long first-wait times. The first 5 minutes of first-wait times are considered short and the remainder is considered long first-wait time. Long first-wait times use a smaller time coefficient to discount their impact as people may time their station arrival better to coordinate with the transit schedule.

The transit skimming process also calculates transfer wait times, where applicable, based on one-half the headway of coded transit routes. Adjustments to these standard transfer time calculations are made for a small number of stations assumed to have bus and rail service that will be sufficiently coordinated to replace the standard transfer times with lower timed-transfer times.

Walk time to transit is another important factor in mode choice. Section 2.5.5 described how walk distances between MGRA and TAPs are calculated. The following equation is used in the mode choice model to add walk time at the start of a trip, walk time at the end of a trip, and any time spend walking between transit routes when making a transfer.
\[ \text{wktime}(rm) = \text{wkdist}(pmgra, ptap) + \text{wkdist}(atap, amgra) + \text{wkspd} + \text{xfertime}(rm, t, ptap, atap) \]

where:
\( \text{wktime} \) = overall walk time between production and attraction zones
\( \text{wkdist} \) = walk distances between MGRAs and TAPs
\( \text{wkspd} \) = average walking speed of three MPH
\( \text{xfertime} \) = walk time when transferring between routes.

Additional times are added to account for transit station access. Lot time is added to walk from the center of a park and ride lot to the station platform. Drop-off access at park and ride lots is discounted to 25% of the lot time. For transit stations that are above or below grade, additional time is added to account for elevator or stair access.

The final component of the transit walk utility equation is the transit fare. TransCAD transit skimming procedures find the cash fare between each TAP pair based on existing fare schedules. In the mode choice model these cash fares are discounted to account for pass usage. Transit surveys show pass usage varies by a number of different factors. For example, commuter rail users are more likely to use passes than are local bus riders, incidental non-work trips are less likely to use passes than work trips, and pass usage declines with higher incomes. Thus cash fare discount factors are computed and applied by ride mode, trip purpose, and income level.

Transit drive access (park-and-ride) and drop-off access (kiss-and-ride) utilities are computed in a similar manner as the previous transit walk utilities. Times and fares will differ from those for walk access because drive access connections are restricted only to transit stops with formal or informal parking available, and because drive access connections are usually faster than access by feeder bus or long distance walks. Drive access only is allowed at the production end of home-based trips since users generally do not have access to a car at the nonresidential end of a trip.

The transit auto utility equation shown below replaces walk time at the production end with drive time, and adds the cost of driving and a terminal time the end of the auto access leg of the trip.

\[
\text{tau}(rm, am, p, i) = \left[ \begin{array}{c}
\text{trivt}(rm, am, t, ptap, atap) \times ccoef(3, p) + \\
\text{sfw} \times ccoef(4, p) + \text{lfw} \times ccoef(3, p) + \\
\text{trxfer}(rm, am, t, ptap, atap) \times ccoef(5, p) + \\
(\text{wk} + \text{etime}) \times ccoef(3, p) \times \text{wkfac} + \\
\left( \frac{\text{fare}(rm, am, t, ptap, atap) \times fpc(t, p, i, rm) +}{\text{dd}(rm, am, t, pz, ptap) \times cpm} \right) \times ccoef(p, i) + \\
\text{dt}(rm, am, t, pz, ptap) \times ccoef(6, p) + \\
\text{term}(am, ptap) \times ccoef(2, p)
\end{array} \right] / (\text{ncmid} \times \text{ntop})
\]

where:
\( \text{tau}(rm, am, p, i) \) = transit-walk utility for ride mode “rm”, access mode “am” (drive or drop-off), purpose “p”, and income group “i”
\( \text{dd} \) = drive access distance
\( \text{cpm} \) = drive cost per mile
\( \text{dt} \) = drive access time
\( \text{term} \) = terminal time at the end of the drive access trip
Non-motorized utilities for bike and walk modes are computed by applying a time coefficient to non-motorized travel time. These times are derived from non-motorized distance skims described in Section 2.7 by using an average three MPH speed for walk trips and 12 MPH for bike trips. Walk trip times are categorized into short-walk time (less than 5 minutes), mid-walk time (5 to 20 minutes), and long-walk time (greater than 20 minutes). The model does not consider non-motorized operating costs.

\[
\begin{align*}
  bku(p) &= \frac{\text{mdist}}{bks} \times \text{tcoef}(10, p) \times \text{nctop} \\
  wku(p) &= \left( wk \times \text{wkfac}(1) + mwk \times \text{wkfac}(2) + lwk \times \text{wkfac}(3) \right) \times \text{tcoef}(3, p) / \text{nctop}
\end{align*}
\]

where:

- \( bku \) = bicycle utility
- \( \text{dist} \) = distance between zones
- \( bks \) = bicycle speed (12 MPH)
- \( wku \) = walk utility

After computing utilities for each mode, the program then cycles through the six trip purposes and three income levels used in the mode choice model. Exponentiated utilities for each of the 26 lower level modes are calculated using the following equation.

\[
eu(m, i, p) = \exp \left( (m, p, i) + \text{cnst}(c1, p, i) + \text{cnst}(c2, p, i) + 4\text{cnst}(p, \text{den}, \text{inter}, \text{empl}, m) \right)
\]

where:

- \( \text{eu}(m, i, p) \) = exponentiated utility for mode “m”, income group “i”, and purpose “p”
- \( \exp \) = exponential function
- \( \text{u}(m, p, i) \) = utility for mode, purpose, and income group
- \( \text{cnst} \) = modal constant for income group, and purpose
- \( 4\text{cnst} = 4D \) density modal constant for purpose, mode, density, intersection density, and employment
- \( \text{den} \) = land use density group
- \( \text{inter} \) = intersection density group
- \( \text{empl} \) = employment density group

Modal constants (Table 18), calculated during the calibration process, are used to bring model-estimated mode shares into agreement with observed mode shares for each market segment. Market segments for most modes are defined using income group and trip purpose. Federal guidelines prevent income stratification for transit ride modes. Table 19 shows how the 13 modal constants are applied to the 25 submodes. 4D constants were derived for transit and non-motorized modes. The constants were developed using the same 4D variable formulations described in the trip distribution steps. The addition of 4D constants allows the model to better reflect the propensity of using non-motorized and transit modes in mixed use and dense land use.
<table>
<thead>
<tr>
<th>Modal Constant</th>
<th>Income</th>
<th>Purpose</th>
<th>Home-Work</th>
<th>Home-College</th>
<th>Home-School</th>
<th>Home-Other</th>
<th>Other-Other</th>
<th>Serve Passenger</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Non-motorized</td>
<td>Low</td>
<td>1.4</td>
<td>-1.46</td>
<td>1.66</td>
<td>-2.51</td>
<td>-6.68</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>-1.01</td>
<td>-1.46</td>
<td>0.53</td>
<td>-4.03</td>
<td>-7.95</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>-2.78</td>
<td>-1.46</td>
<td>0.88</td>
<td>-4.76</td>
<td>-6.72</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>2.87</td>
<td>-1.43</td>
<td>-1.55</td>
<td>-5.5</td>
<td>-12.51</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>2. Transit</td>
<td>Middle</td>
<td>-2.76</td>
<td>-7.51</td>
<td>-7.25</td>
<td>-12.59</td>
<td>-18.37</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>-9.15</td>
<td>-12.81</td>
<td>-11.8</td>
<td>-19.08</td>
<td>-21.58</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>3. Shared-Ride</td>
<td>Low</td>
<td>-5.96</td>
<td>-4.33</td>
<td>0.4</td>
<td>-0.78</td>
<td>-1.05</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>-7.49</td>
<td>-2.6</td>
<td>1.06</td>
<td>-0.68</td>
<td>-1.97</td>
<td>2.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
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<td>-4.95</td>
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<td>-1.32</td>
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<tr>
<td>4. Bicycle</td>
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<td>-1.43</td>
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<td>-3.31</td>
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<td>Middle</td>
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<tr>
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<td>-1.43</td>
<td>-4.98</td>
<td>-2.78</td>
<td>-4.45</td>
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</tr>
<tr>
<td>5. 3+ Shared-ride</td>
<td>Low</td>
<td>-1.5</td>
<td>-4.17</td>
<td>1.5</td>
<td>-1.36</td>
<td>-0.91</td>
<td>-0.04</td>
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</tr>
<tr>
<td></td>
<td>Middle</td>
<td>-3.17</td>
<td>-3.38</td>
<td>1.75</td>
<td>-1.56</td>
<td>-0.85</td>
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<td>-2.43</td>
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<td>-0.98</td>
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</tr>
<tr>
<td>6. Toll</td>
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<td>-1.04</td>
<td>0.05</td>
<td>n/a</td>
<td>-6.79</td>
<td>-4.94</td>
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<td>0.05</td>
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<td>-7.71</td>
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<tr>
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</tr>
<tr>
<td>7. Shared-ride HOV</td>
<td>Low</td>
<td>0.58</td>
<td>-1.26</td>
<td>-4.4</td>
<td>0.21</td>
<td>0.58</td>
<td>-1.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>-0.2</td>
<td>-1.43</td>
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<td>0.04</td>
<td>-0.85</td>
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<tr>
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<td>0.68</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>8. Transit Auto</td>
<td>Low</td>
<td>-6.85</td>
<td>-6.81</td>
<td>-9.72</td>
<td>-6.16</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>-5.1</td>
<td>-5.12</td>
<td>-11.23</td>
<td>-4.33</td>
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<td>n/a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>-2.4</td>
<td>-5.49</td>
<td>-7.4</td>
<td>-3.97</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>9. Transit Drop-off</td>
<td>Low</td>
<td>-1.89</td>
<td>-2.36</td>
<td>1.4</td>
<td>-1.38</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle</td>
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<td>-0.22</td>
<td>3.39</td>
<td>-2.77</td>
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<td>n/a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>-3.94</td>
<td>-0.1</td>
<td>0.56</td>
<td>-1.28</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>10. Transit BRT</td>
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<td>1.12</td>
<td>0.64</td>
<td>0.64</td>
<td>0.64</td>
<td>0.88</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>11. Transit Light Rail</td>
<td>All</td>
<td>1.96</td>
<td>1.12</td>
<td>1.12</td>
<td>1.12</td>
<td>1.54</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>12. Transit Auto BRT</td>
<td>All</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>13. Transit Auto Light Rail</td>
<td>All</td>
<td>0.97</td>
<td>0</td>
<td>0</td>
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<td>n/a</td>
<td></td>
</tr>
<tr>
<td>14. Transit Commuter Rail</td>
<td>All</td>
<td>2.52</td>
<td>1.44</td>
<td>1.44</td>
<td>1.44</td>
<td>1.98</td>
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<td></td>
</tr>
<tr>
<td>15. Transit Express</td>
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<td>0.17</td>
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<td>-1.79</td>
<td>-1.79</td>
<td>-2.46</td>
<td>n/a</td>
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</tr>
</tbody>
</table>

Note: n/a indicates mode not available for purpose.
<table>
<thead>
<tr>
<th>Mode</th>
<th>Number of Modal Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Alone Non-Toll</td>
<td></td>
</tr>
<tr>
<td>Drive Alone Toll</td>
<td>+</td>
</tr>
<tr>
<td>2 Person Shared-ride Non-Toll/ Non-HOV</td>
<td>+</td>
</tr>
<tr>
<td>2 Person Shared-ride Non-Toll/ HOV</td>
<td>+ +</td>
</tr>
<tr>
<td>2 Person Shared-ride Toll/ HOV</td>
<td>+ + +</td>
</tr>
<tr>
<td>3+ Person Shared-ride Non-Toll/ Non-HOV</td>
<td>+ +</td>
</tr>
<tr>
<td>3+ Person Shared-ride Non-Toll/ HOV</td>
<td>+ + + +</td>
</tr>
<tr>
<td>3+ Person Shared-ride Toll/ HOV</td>
<td>+ + + + +</td>
</tr>
<tr>
<td>Walk</td>
<td>+</td>
</tr>
<tr>
<td>Bicycle</td>
<td>+ +</td>
</tr>
<tr>
<td>Commuter Rail/Walk Access</td>
<td>+ + + +</td>
</tr>
<tr>
<td>Commuter Rail/Drive Access</td>
<td>+ + + + +</td>
</tr>
<tr>
<td>Commuter Rail/Drop-Off Access</td>
<td>+ + + + + +</td>
</tr>
<tr>
<td>Light Rail/Walk Access</td>
<td>+ +</td>
</tr>
<tr>
<td>Light Rail/Drive Access</td>
<td>+ + + + + +</td>
</tr>
<tr>
<td>Light Rail/Drop-Off Access</td>
<td>+ + + + + +</td>
</tr>
<tr>
<td>BRT/Walk Access</td>
<td>+ +</td>
</tr>
<tr>
<td>BRT/Drive Access</td>
<td>+ + + + + +</td>
</tr>
<tr>
<td>BRT/Drop-Off Access</td>
<td>+ + + + + +</td>
</tr>
<tr>
<td>Express Bus/Walk Access</td>
<td>+ + + + + +</td>
</tr>
<tr>
<td>Express Bus/Drive Access</td>
<td>+ + + + + +</td>
</tr>
<tr>
<td>Express Bus/Drop-Off Access</td>
<td>+ + + + + +</td>
</tr>
<tr>
<td>Local Bus/Walk Access</td>
<td>+ + + + + +</td>
</tr>
<tr>
<td>Local Bus/Drive Access</td>
<td>+ + + + + +</td>
</tr>
<tr>
<td>Local Bus/Drop-Off Access</td>
<td>+ + + + + +</td>
</tr>
</tbody>
</table>

Note: + indicates constant is applied to exponentiated utility for mode.
Once exponentiated utilities have been calculated for all submodes upper level modes are obtained by combining utilities from lower level modes as follows.

\[
daeu = \exp(\ln \text{laneu} + \text{dateu} \times nclow)
\]
\[
sr2eu = \exp(\ln (r2nn + sr2nh + sr2th) \times nclow)
\]
\[
sr3eu = \exp(\ln (r3nn + sr3nh + sr3th) \times nclow)
\]
\[
dreu = \exp(\ln daeu \times nc\text{mid})
\]
\[
sreu = \exp(\ln (r2eu + sr3eu) \times nc\text{mid})
\]
\[
aueu = \exp(\ln (teu + sreu) \times nctop)
\]
\[
nmeu = \exp(\ln (vkeu + bkeu) \times nctop)
\]
\[
twkeu = \exp(\ln (rwkeu + lrkeu + brtwkeu + ebwkeu + lbwkeu) \times nc\text{mid})
\]
\[
taueu = \exp\left(\ln \left(\frac{cr\text{preu} + lr\text{preu} + br\text{preu} + eb\text{preu} + lb\text{preu} + \text{cr\text{preu} + lr\text{preu} + br\text{preu} + eb\text{preu} + lb\text{preu}}{\text{cr\text{preu} + lr\text{preu} + br\text{preu} + eb\text{preu} + lb\text{preu}}\right) \times nc\text{mid}\right)\)
\]
\[
treu = \exp(\ln (wkeu + taueu) \times nctop)
\]

where:
\[
\ln = \text{natural log function}
\]
\[
eu = \text{exponentiated utility}
\]
\[
da = \text{drive alone}
\]
\[
dan = \text{non-toll}
\]
\[
dat = \text{toll}
\]
\[
sr2 = 2\text{ person shared-ride}
\]
\[
sr2nn = \text{non-toll/non-hov}
\]
\[
sr2nh = \text{non-toll/hov}
\]
\[
sr2th = \text{toll/hov}
\]
\[
sr3 = 3+\text{ person shared-ride toll/hov}
\]
\[
dr = \text{drive}
\]
\[
au = \text{auto}
\]
\[
sr = \text{shared-ride}
\]
\[
\text{nm} = \text{non-motorized}
\]
\[
wk = \text{walk}
\]
\[
bk = \text{bicycle}
\]
\[
twk = \text{transit-walk}
\]
\[
cr = \text{commuter rail}
\]
\[
lr = \text{light rail}
\]
\[
brt = \text{bus rapid transit}
\]
\[
\text{eb} = \text{express bus}
\]
\[
\text{lb} = \text{local bus}
\]
\[
tau = \text{transit auto access}
\]
\[
pr = \text{park-ride access (drive)}
\]
\[
kr = \text{kiss-ride access (drop-off)}
\]
\[
tr = \text{transit}
\]
\[
nclow = \text{nested logit coefficient for low nest}
\]
\[
n\text{mid} = \text{nested logit coefficient for middle nest}
\]
\[
n\text{top} = \text{nested logit coefficient for top nest}
\]
The ratio of exponentiated utilities, shown in the equation below, computes mode shares. Trips by mode then are obtained by applying mode shares to total person trips in each market segment. The resulting trips are accumulated and output in summary reports and as trip tables for the highway and transit assignment process

\[ ms(ma) = \frac{eu(ma)}{eu(ma) + eu(mb)} \]

where:
- \( ms(ma) \) = mode share for mode “a”
- \( eu(ma) \) = utility for mode “a”
- \( eu(mb) \) = utility for mode “b”

### 2.9.3 Model Calibration

A major project to recalibrate the mode choice model was completed in 2006 and is documented in a report *Mode Choice Model Improvements*, November 2006. Results from the 1995 Travel Behavior Survey, 2000 Market Research Survey, and 2001 Caltrans Statewide Survey, and 2001-2003 Transit Ridership Survey were analyzed to estimate time and cost coefficients and determine a nesting structure. The mode choice model was updated in 2009 for use in the Mid-Coast FTA New Starts project.

After model estimation, observed base year mode shares were tabulated from the Travel Behavior Survey and Transit Ridership Survey which were used to calibrate modal constants so that model-estimated mode shares agree with observed mode shares by market segment.

Transit ridership forecasts from the transit assignment model were extensively evaluated to determine the accuracy of mode choice estimates and adjust model parameters to correct problem areas. Regional level Census 2000 work-trip mode shares also were used to fine-tune mode share estimates.

### 2.9.4 Mode choice variations

A number of different applications are derived from the mode choice procedures described above including:

- Creating input files to the Federal Transit Administration’s (FTA) Summit program
- Computing composite utilities for the feedback loop trip distribution model
- Calculating and applying person trip to vehicle trip conversion factors

**Summit Input Files.** FTA requires a rigorous cost effectiveness analysis when applying for federal funding for major transit investments under the New Starts program. A special version of the mode choice program creates an output file for each time period and purpose, which contains trips and exponentiated utilities for each TAZ pair and income group. These files then are used by the FTA Summit program to calculate and summarize user benefits that are used in a subsequent measure of cost effectiveness.
**Composite Utilities.** The utility calculations described above can be used to provide a trip distribution impedance measure that factors in times and costs by all modes of transportation. A special version of the mode choice model cycles through each time period, zone pair, purpose, and income group and calculates average utilities for three major modes: automobile, transit, and non-motorized. The lowest utility value then is used to compute a daily composite utility for each TDZ pair by three generalized purposes: home-work/college, home-other, and non-home based.

**Person Trip to Vehicle Trip Factoring.** First stage and feedback loop model applications use a person trip to vehicle trip conversion program to obtain vehicle trip tables for input to the highway assignment process. This conversion process is intended to reflect the effects of smart growth, transit improvements, and other conditions that are forecasted by the mode choice model, while avoiding the time and complexity of transit network modeling and applying the standard mode choice model.

Vehicle factors are obtained from a previous final stage mode choice model which computes vehicle fractions for four highway modes (non-toll/non-HOV, drive alone toll, person shared-ride non-toll/HOV, and shared-ride toll/HOV) by time period (peak period and off-peak period), mode choice purpose (home-work, home-college, home-school, home-other, serve passenger, and non-home based), TDZ pair, and forecast year (for example 2008, 2020, or 2035).

**2.10 TRUCK MODEL**

In order to address a growing number of freight related policy questions, the San Diego Association of Governments (SANDAG) in association with Parsons Brinkerhoff developed a truck model for the San Diego region. While the main intention of the model is to focus on how transportation network decisions impact regional truck flows, a secondary but critical outcome is the ability to provide more inclusive impacts to regional air quality.

The truck model was designed as a first step to address freight issues in San Diego. A model design was conceived to address both the external and internal influences on truck movements in and thru San Diego. Truck trips in San Diego are greatly influenced by shipping through the US-Mexico border and the Port of San Diego. Separating truck travel out from the passenger travel model allows for increased analysis of benefits for freight related projects. Port accessibility or border related infrastructure projects can be assessed for the relative benefit to goods movement in the region and the air quality from heavy duty trucks.

More truck model documentation (Development of a truck model for the San Diego Region) can be found on the SANDAG Regional Models website.

**2.10.1 Model Design**

The SANDAG Truck Model consists of two truck models. A local truck model simulates truck trips within San Diego County (Internal-Internal or II trips), and a regional truck model simulates truck trips that have an origin and/or destination outside San Diego County (Internal-External or IE/EI/EE trips) (see Figure 5). This two-layer

*Figure 5: Local and regional truck trips*
approach allows differentiating the level of detail for simulating trucks. For a truck trip from, for example, Encinitas to Escondido within San Diego County, the detailed location of both the origin and the destination is of interest to assign truck trips to the right highway link. For a truck trips from San Diego to the Bay Area, however, only the detailed location of the origin is of interest. Whether this long-distance truck trip has San José, Oakland or Berkeley as its final destination is irrelevant to assign the trip to the right network link within San Diego County. Thus, a two-layer approach allows simulating truck trips at the necessary level of detail without carrying a large overhead of unnecessary detail.

2.10.2 Local Truck Model

The model simulating local truck trips within San Diego County is based on the SCAG Truck Model developed by Cambridge Systematics (2008) for the Southern California Association of Governments (SCAG). This trip-based model generates truck trips based on employment and household trip rates. Given the close proximity to the SCAG region and San Diego County, the truck generation factors are expected to be transferable to the SANDAG region.

In addition to SCAG factors, trucks generated by special generators are added explicitly. Special generators are facilities that generate a significant number of trucks that cannot be explained by the employment at that facility. A cruise ship terminal, for instance, attracts a large number of trucks even though it has a comparatively small number of employees. In addition, military sites and express mail sent through the airport are treated as special generators.

Three truck types are distinguished: Light-Heavy Duty Trucks (8,500 to 14,000 lbs), Medium-Heavy Duty Trucks (14,000 to 33,000 lbs) and Heavy-Heavy Duty Trucks (more than 33,000 lbs). After generating truck trip productions and attractions, a gravity model is used to distribute truck trips. Off-peak travel times are used as impedance in the trip distribution function, since a larger number of truck trips happen in the off-peak hours.

2.10.3 Regional Truck Model

Truck trips having their origin and/or destination outside of San Diego County are simulated by the regional truck model. These truck trips are generated based on goods flows reported by the Freight Analysis Framework 2 (FAF2), which is published by the Federal Highway Administration (2002). Freight flows are reported by STCC commodity between 130 domestic FAF regions as well as international flows from and to the U.S. To increase spatial resolution, flows between 130 FAF zones are disaggregated to flows between 3,241 counties. Employment is used as a weight for this disaggregation: counties with more employment are assumed to produce and attract more trucks than counties with less employment. Using commodity-specific Payload Factors (Battelle 2002: 29) goods flows in tons are converted into number of truck trips. An average vacancy rate of 19.4 percent (U.S. Census Bureau 2008) was added to all flows.

FAF2 covers the base year 2002 and the future years 2010 to 2035 in five-year increments. This forecast as published in 2002 is quite optimistic in terms of growth of goods flows. Flows into and out of San Diego County are forecast to grow exponentially from 4.9 Mio. trucks per year in 2002 to 15.7 Mio. trucks in 2035. The current economic downturn as well as the future gas price development may result in a smaller growth. For the San Diego Truck Model, the FAF2 flows were scaled down to grow only linearly from 2020. A further adjustment was made to flows crossing the border with Mexico. Many truck trips across the border serve Maquiladoras in Mexico, which
produce goods mostly for the U.S. markets at lower labor rates. Truck trips serving the Maquiladoras tend to be short-distance trips, for which on-time delivery is more important than low vacancy rates. Accordingly, the number of truck trips across the Mexican border was inflated to match truck counts in the base year.

2.10.4 Truck Trip Reconciliation

The regional truck trips are temporarily assigned to a U.S. highway network to generate truck trip production and attraction at the external stations of San Diego County. The local truck model generates the IL truck trips, while the regional truck model provides EI, IE and EE trips. A temporal allocation splits trips into three time-of-day periods, namely AM Peak, PM Peak and Off-Peak. Hourly counts at Weigh-In-Motion (WIM) stations provide factors to split truck flows into the three time-periods. Since border crossings with Mexico are closed for trucks from 8 pm to 5 am, trucks trips to and from the Mexican border crossings are reduced in the Off-Peak period.

The truck model is validated against truck counts at WIM stations. The challenge of validating the model is that trucks are defined differently at the WIM stations than in the truck model. While the WIM stations count trucks by FHWA truck classification based on axles, the model simulates truck by weight class. The WIM counts include FHWA classes 4 through 14 and exclude the large number of pick-up trucks/vans (FHWA class 3). The simulated volumes, however, include trucks and those pick-up trucks with a weight of more than 8,500 lbs. Consequently, it is expected that simulated volumes are slightly higher than observed truck counts.

2.10.5 Air Quality

SANDAG uses the California Air Resources Board EMFAC2007 for regional air quality analysis. EMFAC2007 (California Air Resources Board 2006) has 4 vehicle classes for heavy duty trucks: Light-Heavy Duty 1 (8501-10000), Light-Heavy Duty 2 (10001-14000), Medium-Heavy Duty (14001-33000), and Heavy-Heavy Duty (33001-60000). These four vehicle classes correspond to the vehicle classes from the heavy duty truck model except for light-heavy duty which is combined into one category. The addition of the truck model enables direct modifications of VMT, vehicle trips, and speed breakdowns to the four EMFAC heavy-duty truck vehicle classes. Proposed infrastructure improvements or policies that improve mobility for heavy-duty trucks can then be assessed for air quality benefits.

2.11 HIGHWAY ASSIGNMENT

Highway assignment is the process of loading vehicle trips between zones onto specific segments of highway. Trips are apportioned to links based on the generalized cost and capacity associated with each link from the highway network coding process described earlier. Major inputs and outputs are listed below in Table 20 and Table 21.

As congestion builds over time, the highway assignment model shifts traffic to adjacent facilities having excess capacity. Similarly, corridors where new roadways or roadway improvements are planned will see traffic diversions to the new facilities from parallel facilities having slower speeds or higher congestion. These shifts in traffic between facilities are a major component of what can be characterized as induced demand.
### Table 20: Highway Assignment Model Inputs

<table>
<thead>
<tr>
<th>Input</th>
<th>Source</th>
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<tbody>
<tr>
<td>Vehicle trips between zones</td>
<td>Mode choice model</td>
</tr>
<tr>
<td>Truck trips between zones</td>
<td>Truck Model</td>
</tr>
<tr>
<td>Highway network</td>
<td>Network coding</td>
</tr>
<tr>
<td>Volume-delay functions</td>
<td>Highway Capacity Manual</td>
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<tr>
<td>Traffic counts</td>
<td>Caltrans and local jurisdictions</td>
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</table>

### Table 21: Highway Assignment Model Outputs

<table>
<thead>
<tr>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily and peak hour traffic volumes by highway segment</td>
</tr>
<tr>
<td>Congested highway times and speeds by segment and time period</td>
</tr>
<tr>
<td>Level-of-service by segment and time period</td>
</tr>
<tr>
<td>Air pollution emission model inputs</td>
</tr>
<tr>
<td>Summary reports and plots</td>
</tr>
</tbody>
</table>

#### 2.11.1 Model Structure

SANDAG loads traffic using the TransCAD “Multi-Modal Multi-Class Assignment“ function with the bi-conjugate load method. This is an iterative technique for balancing estimated link volumes with available capacity by minimizing an overall congestion index. The model first finds minimum paths between zones based on input generalized cost assumptions, including tolls, for each roadway segment and the associated value of time for that mode (Auto and Light Heavy-Duty Trucks 50 cents/min, Medium Heavy-Duty Trucks 51 cents/min, and Heavy Heavy-Duty Trucks 72 cents/min). Trips between zones are accumulated on links making up the minimum time path between each zone pair. Once all trips have been assigned, congestion levels are determined by computing mid-link and intersection volume-to-capacity (V/C) ratios. Input link times are revised using a logit-based volume delay function (VDF) that adjusts speeds based on the mid-link V/C ratio and an intersection delay function that adjusts intersection delays based on the intersection V/C. Additional assignment iterations are performed making use of revised link speeds from the previous iteration until equilibrium is reached. Equilibrium is considered reached when the convergence criterion reaches 0.001.

The logit-based VDF is available in TransCAD and was developed and calibrated by the Israel Institute of Transportation Planning and Research. Since intersection impacts are implicit in the VDF function, the function is used for both highway and arterial facility types.
Table 22: Volume Delay Function Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
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<th>P2</th>
<th>P3</th>
<th>P4</th>
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<tbody>
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<td></td>
<td>0.9526</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>0.09</td>
<td>350</td>
<td>3.5</td>
<td>2.3</td>
</tr>
</tbody>
</table>

A.M. peak period, P.M. peak period, and off-peak trip tables are loaded separately since motorists may choose different travel paths during different time periods. For example, heavily-congested facilities and metered ramps would tend to be avoided during peak periods, but not during off-peak hours. Daily volumes are obtained by adding together assignments for the three time periods.

TransCAD's ability to perform simultaneous assignments for multiple assignment modes also is used. As indicated above, the mode choice model outputs up to eight separate vehicle trip tables plus an additional six truck trip tables. Highway networks include existing and proposed HOV lanes as separate facilities. During the assignment process trips by the fourteen modes are matched with facilities that are available for use by each mode. Truck modes are loaded using passenger car equivalents to replicate the increased impact they have due to size, acceleration, and deceleration.

Table 23: Truck Passenger Car Equivalents

<table>
<thead>
<tr>
<th>Truck Mode</th>
<th>PCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Heavy-Duty</td>
<td>1.3</td>
</tr>
<tr>
<td>Medium Heavy-Duty</td>
<td>1.5</td>
</tr>
<tr>
<td>Heavy Heavy-Duty</td>
<td>2.5</td>
</tr>
</tbody>
</table>

2.11.2 Post-assignment Processing

After completing the highway assignments, additional processing is needed to produce reports, data files, and plots tailored to SANDAG needs. Some of the major functions of this post-assignment processing are described below.

Calibration Error Volume Adjustment. Base year model-estimated link volumes for individual links differ from ground counts, even after model calibration is complete. An automated adjustment procedure has been developed to adjust future year traffic volumes to compensate for calibration errors.

Managed Lane Volume Adjustments. The 2050 RTP proposes managed lanes on many freeways. Managed lanes allow solo drivers who pay a toll to make use of HOV lanes. However, traffic on managed lanes would be controlled so that level-of-service “D” is maintained. Post-assignment procedures simulate optimal managed lane operation by: (1) shifting traffic from over-capacity main freeway lanes to adjacent managed lanes that have excess capacity; and (2) shifting traffic from over-capacity managed lanes to adjacent freeway main lanes.
**Bus Volume Adjustment.** Public transit bus volumes are determined in the transit network
coding process. These volumes are added to private vehicle traffic volumes from the highway
assignment model.

**Hourly Distribution Factors.** The TransCAD assignment process outputs A.M. peak period, P.M.
peak period, and off-peak period traffic volumes, while many applications need hourly traffic
volumes. Caltrans collects hourly traffic counts at its permanent count stations. These counts are used
to compute the fraction of traffic in each hour of a time period for each direction and count station.
Resulting hourly distribution factors are applied to freeway segments after assigning freeway
segments to the closest count station.

**Level-of-Service Computations.** Highway Capacity Manual procedures are used to compute the
level-of-service (LOS) for each highway segment based on a V/C ratio using coded capacities and
volumes from the adjustment process described above. LOS computations differ by type of facility.
On freeways, an LOS rating “A” through “F” is assigned based on the hour with the highest V/C
ratio within each time period. When a V/C ratio exceeds 1.0, the hours at LOS “F” are accumulated.
While sophisticated traffic queuing procedures do not now exist as a part of long range
transportation models, an attempt is made to account for some queuing impacts in the post-
assignment process by assigning freeway links up to one mile in back of chokepoints the chokepoint
LOS. This results in somewhat higher levels of freeway congestion and lower freeway speeds which
should better reflect reality.

LOS computations on surface streets also are based on volume to capacity ratios. Street segments
between major intersections are grouped into sections. The highest V/C on any segment within a
section determines LOS for the entire section.

**Travel Time Computations.** Link travel times are re-computed based on adjusted link volumes using
Highway Capacity Manual procedures. The same V/C calculations used to assign LOS also are used to
look up speeds and intersection delay times associated with VC ratios.

Freeway speeds vary between three MPH and 75 MPH depending on the V/C ratio. Link travel times
are recomputed for each hour and an average travel time for each time period is calculated by
weighting the hourly travel time by the hourly volume. Again, freeway HOV lane LOS is assumed to
be no worse than LOS “D,” so HOV speeds vary between 62 MPH and 75 MPH.

Travel times on surface streets consider both mid-block congestion and delays at signals and stop
signs. Mid-block speeds vary between three MPH and the posted speed, depending on the V/C ratio.
Intersection delays vary between ten seconds and two minutes and are added to the link travel time
computed from mid-block speed. Delays at ramp meters ramp meters range between one minute and
15 minutes. HOV times on ramp meters with HOV bypass ramps are assumed to be one-third of SOV
delays.

**Emission Model Inputs.** The California Air Resources Board’s EMFAC2007 model is used to
estimate on-road motor vehicle emissions and fuel consumption. This model requires as input the
vehicle miles of travel in each hour by 13 vehicle types (light-duty automobiles, light-duty trucks,
heavy-duty trucks, etc.) by 18 speed ranges. Link level traffic volumes are split into vehicle types by
applying vehicle type percentages that vary by facility type and hour of the day. These percentages
were obtained from the 2000 Vehicle Classification and Occupancy Study. Resulting vehicle type
volumes are multiplied by link distances and accumulated by speed range to produce Burden inputs.
**Reporting and Plotting.** Summary statistics such as vehicle miles of travel (VMT), vehicle hours of travel (VHT), and average speeds are computed which are key performance indicators for transportation and land use alternatives. Model outputs also are linked with GIS coverages to produced computer plots and data sets used to display traffic volumes on the Internet.

### 2.11.3 Model Calibration

Comparisons of base year traffic volumes from the highway assignment model with observed traffic counts provide key measures of the model accuracy. Differences between model-estimated and observed VMT at the regional level indicate whether the overall amount of travel in the region is correct. VMT comparisons by facility type may indicate problems with speed assumptions between facility types. Traffic estimates on individual links also are compared with traffic counts. Large discrepancies may indicate network coding errors, miscoding of access opportunities, land use coding errors, or inappropriate trip generation rates.

### 2.12 TRANSIT ASSIGNMENT

The transit assignment step determines route, link, and stop level ridership using inputs listed in Table 24. These transit assignment results, as shown in Table 25, are important when evaluating model accuracy and the effectiveness of proposed transit improvements.

<table>
<thead>
<tr>
<th>Table 24: Transit Assignment Model Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input</strong></td>
</tr>
<tr>
<td>Transit trips between TAPs by time period</td>
</tr>
<tr>
<td>External transit trips</td>
</tr>
<tr>
<td>Transit network</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 25: Transit Assignment Model Output</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Output</strong></td>
</tr>
<tr>
<td>Daily and peak period boardings by route, link, and stop</td>
</tr>
<tr>
<td>Summary reports and plots</td>
</tr>
</tbody>
</table>

### 2.12.1 Model Structure

TransCAD software assigns TAP-to-TAP transit trips to the network. Eight separate transit assignments are produced for peak and off-peak periods; walk and auto access; and local bus and premium service. These individual assignments are summed to obtain total transit ridership forecasts.

Before assigning transit trips, external transit trips coming into San Diego from outside the region need to be added to the internal transit trips estimated by the mode choice model. Currently few transit trips enter from the north or east, however, over 20,000 transit trips cross the Mexican border each day. An external transit trip table for the base year is developed from on-board transit ridership surveys and factored to future years based on border crossing trends to account for these trips.
2.12.2 Model Calibration

Transit ridership forecasts from the transit assignment model are compared with transit counts from the SANDAG transit passenger counting program to determine whether transit modeling parameters need to be adjusted. The transit assignment model itself has few parameters so the calibration process is primarily a check on transit network coding and mode choice procedures.

Some of these comparisons of model-estimated boardings with actual boardings include

- system level boardings, which may reveal transfer rate problems and lead to changes to the transfer wait time factor in the mode choice model
- boardings by mode, which may reveal modal biases and lead to changes in mode choice modal constants
- boardings by frequency of service, which may show biases that lead to changes in the first wait factor in the mode choice model
- Centre City screenline crossings, which may lead to changes in parking costs
- boardings by stop location, which may indicate problems which specific generators such as a university

2.13 INDUCED DEMAND

The SANDAG regional travel demand model attempts to simplify the chaotic travel decision making process people go through in their daily lives. The regional model employs a number of behavior-based equations to replicate this process. New infrastructure investment can influence travel decision making by a multitude of factors. Induced demand (also known as induced travel) occurs when changes in travel demand are a direct or indirect result of the new infrastructure investment. The term is commonly used to describe a situation where highway expansion results in additional vehicle trips and VMT. The SANDAG regional travel demand model accounts for many of the potential ways travel could be induced. Categories of induced demand are listed below.

2.13.1 Land Use

New infrastructure development can change the near term and future distribution of housing and employment by increasing the accessibility to undeveloped or redevelopable land. This could be through new freeway access to greenfield development or transit oriented redevelopment (TOD) around a new trolley stop. The extent of induced demand depends on the geographic reference area. A change in development from one area of a city to another would cause local travel impacts, but would cause no impact at the regional level since the development does not occur in another area. Transit infrastructure may shift development from greenfields to TODs, or vice-versa for new freeway development. Any infrastructure project that shifts development from outside the county or state to internal would be regional induced demand.

SANDAG uses an iterative approach to account for this impact. The transportation model is run with the base year land use, and accessibilities are fed back to the land use model for the first forecast increment. The new travel time accessibilities influence the land use forecast increment, which is
then fed back to the transportation model and run against the draft transportation plans. The feedback process is repeated for each increment until the end of the forecast cycle.

2.13.2 Trip Generation/Activities

People engage in activities throughout the day and use the transport system to move from activity to activity. There are several activity pattern impacts that could result from increased accessibility. First, if trip travel times reduce it could create additional time windows for new activities to occur. For example, if the travel time from home to work is reduced by 15 minutes each way, a person may have more time for a new activity such as going to the gym. Second, additional activity time may shift activities made on other days of the week, such as moving a grocery trip from the weekend to a weekday. Third, increased accessibility may shift an in-home activity such as eating, movie watching, exercise, etc. to an out of home activity resulting in a new trip on the transport system. Finally, additional accessibility may reduce the need for trips to be chained together leading to additional trips and person miles traveled.

The SANDAG model does not currently reflect these travel inducements however they are being considered during the development of SANDAG’s Activity Based Model (ABM).

2.13.3 Trip Distribution

Changes in accessibility will affect the locations that people choose to travel to. Congested corridors may lead to people choosing locations close to home. If new infrastructure is built people may choose a more desirable but farther destination that is now within the same travel time window. Destination changes could result in changes to person miles traveled.

This impact if reflected in the trip distribution model. Modal accessibility that includes roadway congestion and transit availability is used during feedback loops to re-determine choice in trip destinations.

2.13.4 Trip Mode Choice

Infrastructure development will change modal choices available for each trip. A new trolley line will give more travel options to those nearby a station and would influence their choice of what mode to take for a given trip. Likewise, an expanded roadway may give reduced travel time and shift travelers from transit or non-motorized modes to an auto mode.

The SANDAG mode choice model accounts for the available travel choices for each trip and resultant shifts in mode.

2.13.5 Trip Time of Day

Increases or decreases in congestion could change the time of departure for a trip. Additional congestion will lead a condition termed as “peak spreading.” People alter their departure time to attempt to travel outside peak congested conditions and thus spread the travel impacts out into the shoulder of the peak period. Conversely, expanding capacity on a roadway could lead to peak sharpening or a remerging of the travel on the shoulders of the peak to the personally desired travel departure time. This second condition is often considered an induced travel impact of new infrastructure.
The SANDAG model does not currently account for shifts in trip departure time of day however it is being considered during the development of SANDAG’s Activity Based Model (ABM).

2.13.6 Trip Assignment

Congestion can cause vehicle trips to take less desirable paths to a destination than would occur during uncongested conditions. An expanded facility could cause travelers to change their path to the new facility to save travel time. Diverted trips from one facility to another are often considered induced demand. The changed path, while saving overall travel cost (combined time, distance, and toll costs), does not guarantee the reduction of the length of the trip leading to the potential of additional vehicle miles traveled.

The SANDAG highway assignment model accounts for diverted trips due to changes in congestion and infrastructure.
CHAPTER 3: MODEL CHANGES FOR THE 2050 RTP

This section contrasts the travel demand model used for the 2050 RTP, using the 2050 Regional Growth Forecast, and the 2030 RTP, using the 2030 Regional Growth Forecast Update.

The time period between RTPs is used to update the travel demand model to help answer emerging policy questions in the next RTP. The amount of effort to add new components or recalibrate existing models forces development work into a short time window before the next RTP cycle gets kicked off. Some of the major changes in the travel model used in the 2050 RTP are detailed below. These include:

- updating the model base year from 2004 to 2008
- updating the underlying zone system for MGRAs, TAZs, and TDZs
- thoroughly reviewing the roadway network with member jurisdictions
- adding 4D components to the trip distribution and mode choice models
- recalibrating the mode choice model to meet FTA guidelines
- adding a heavy-duty truck trip model and truck toll diversion model

3.1 SOFTWARE

TransCAD, created by Caliper Corporation, is a transportation planning computer package used by SANDAG to provide a framework for performing much of the computer processing involved with modeling. TransCAD routinely releases software updates. The SANDAG travel demand model software was updated to use and be compatible with TransCAD 5.0 build 1985 for use in the 2050 RTP.

3.2 ZONE SYSTEM

Section 2.3, Growth Forecast Inputs, describes the geographies used throughout the model system. As part of the 2050 growth forecast geographic zone systems were updated. The updated zones followed the same convention of smaller geographies nesting within the larger zone systems. MGRAs nest within TAZs, and likewise TAZs nest within TDZs.

MGRAs were realigned to follow parcel boundaries and those with little or no activity were merged with adjacent zones. MGRAs were reduced from 33,353 zones to 21,633. TAZs were realigned to follow the new MGRA boundaries. Additionally, TAZs with further disaggregated from 4605 to 4682 zones. Most new zones were in areas with new land use growth or areas identified for zone splits during community plan updates and other studies. Finally, TDZs were also realigned to follow the new TAZ boundaries. TDZs remained constant in number at 2000 zones.
3.3 GROWTH FORECAST

As part of integrating the 2050 Regional Growth Forecast, the regional transportation model was updated to a base year of 2008. New traffic and crossing count information was integrated to update cordon and port of entry forecasts. Airport demand was also revised to match the latest aviation demand from the San Diego International Airport.

3.4 HIGHWAY NETWORK INPUTS

The Series 12 baseline highway network is maintained by SANDAG for use in the transportation model. SANDAG solicited the assistance of local jurisdictions to review the 2008 transportation network data and provide feedback on its ground truth accuracy. In the past, a series of hardcopy maps would be generated and sent out to the local jurisdictions. Typically, only a handful of agencies had the resources to review and markup the hardcopy maps and submit them back to SANDAG within an adequate timeframe. For series 12, staff implemented a Web-based GIS application that allowed local transportation engineers to review and comment on the accuracy of the 2008 baseline network. As a result, the review process promoted greater participation from local jurisdictions and led to improved accuracy of the baseline network.

3.5 TRANSIT NETWORK INPUTS

The 2050 RTP introduces the streetcar as a new transit option for the region. The operating characteristics of streetcar would be similar to local buses in regards to stop spacing but would have slightly better travel times due to priority transit treatments like traffic signal prioritization. Streetcars have been given the same mode as LRT but operate an assumed operating speed of 12 MPH.

In addition, emphasis has been placed on precise network coding to capture each aspect of person travel time through the network. Such aspects as the time to walk from one’s car to the trolley platform at a park and ride lot, the added effort of climbing stairs to an elevated station, and the use of aerial photography and GPS data to accurately locate transit stops has been included.

Finally, the fares for each transit route were updated, including the recent conversion of the Trolley to a flat fare structure and the reduction of Coaster fare zones from 4 to 3.

3.6 TRIP GENERATION

New trip rates were added for public storage and service stations using a combination of ITE Trip Generation, 8th Edition, trip generation rates and SANDAG trip generation production and attraction trip purpose percentages. Trip generation rates were modified for mixed use land use. Often general plans identify large amounts of acreage for future mixed use development. Without detailed planning of the actual mix and intensity of land uses too many person trips get generated from the sites. Three levels of mixed use trip generation rates were created to accommodate the future plans.
3.7 Trip Distribution

In an effort to make the transportation model more sensitive to land use diversity, density, and urban form, 4D segmentation was added to the trip distribution model. For home based trip purposes, the model uses a mixed index to alter the friction factors. For non-home based trips, the model uses an employment density index to alter the friction factors. The resultant model shows average trip length declines as the mixed index or employment density increases (higher values of mixed index are more diverse and dense). While adding the 4D segmentation the trip distribution model was also re-estimated with the 2006 travel behavior survey.

3.8 Mode Choice Model

The mode choice model was recalibrated as part of the Mid-Coast FTA New Starts project. This included a thorough review of the mode choice code and update of code and parameters to meet FTA guidelines. During the recalibration, 4D related constants were added to transit and non-motorized utility equations to enhance their sensitivity to land use changes.

Typically SANDAG takes a conservative approach and assumes no increase in auto operating costs (AOC) throughout the forecast horizon. For the 2050 RTP the RTAC approved process for determining AOC was adopted. The RTAC process results in gas prices that outpace fuel efficiency leading to an increase of $0.02 per mile between 2008 and 2050. This will lead the model to consider non-auto modes as more attractive in the later years of the forecast.

Parking costs were also updated by area type based on a parking inventory survey completed in 2010. Parking was not assumed to expand beyond the current pay locations and was conservatively assumed to remain constant over time.

3.9 Highway Assignment

TransCAD highway assignment procedures were updated to use a newer load method that helps the highway assignment converge faster. The user equilibrium Frank-Wolfe algorithm was changed to the bi-conjugate assignment method using the n-conjugate algorithm. This has little impact on the result of the highway assignment other than allowing the model to go through more iterations and reach a tougher convergence criterion in the same amount of time. The convergence criterion was reduced to 0.001.

Additionally the script was updated to integrate assignment of 6 additional mode classes for light-heavy duty non-toll/toll, medium-heavy duty non-toll/toll, and heavy-heavy duty non-toll/toll. The assignment value of times were updated to include trucks and to calibrate to toll road count information.