Appendix S:

Travel Demand Modeling Tools

Part 1:

SANDAG Travel Model Documentation

Part 2:

Off-Model Strategies

Final

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Table of Contents

Table of Figures

Table of Tables

Appendix S, Part 1: SANDAG Travel Model Documentation

Executive Summary

The San Diego Association of Governments (SANDAG) plans for complex mobility issues facing the San Diego region through the development of a long-range Regional Transportation Plan (RTP). Transportation and land use models are used to forecast potential future scenarios of where people will live and how they will travel. 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 travel model, an activity-based model (ABM), provides a systematic analytical platform so that different alternatives and inputs can be evaluated in an iterative and controlled environment. An ABM simulates individual and household transportation decisions that compose their daily travel itinerary. People travel outside their home for activities such as work, school, shopping, healthcare, and recreation, and the ABM attempts to predict whether, where, when, and how this travel occurs.

The SANDAG ABM includes a number of methodological strengths. It predicts the travel decisions of San Diego residents at a detailed level, taking into account the way people schedule their day, their behavioral patterns, and the need to cooperate with other household members. When simulating a person's travel patterns, the ABM takes into consideration a multitude of personal and household attributes like age, income, gender, and employment status. The model's fine temporal and spatial resolution ensures that it is able to capture subtle aspects of travel behavior.

The SANDAG ABM strives to be as behaviorally realistic as possible and is based on empirical data collected by SANDAG, Caltrans, and the federal government. The model development has been regularly peer-reviewed by the ABM Technical Advisory Committee, a panel of national experts in the travel demand forecasting field.

This Regional Plan documentation is a synthesis of the detailed model code, design, and documentation publicly available at SANDAG's GitHub repository and wiki site: github.com/SANDAG/ABM/wiki.

SANDAG Travel Demand Model Documentation and Methodology

This document describes the SANDAG updated second-generation activity-based model system (ABM2+) used in San Diego Forward: The 2021 Regional Plan (2021 Regional Plan). SANDAG ABM development started in 2009, and the first SANDAG ABM was applied in San Diego Forward: The 2015 Regional Plan (2015 Regional Plan). Subsequently, SANDAG applied the ABM2 for the 2019 Federal RTP in 2019. SANDAG has been continuously updating the ABM system to ensure that the regional transportation planning process can rely on forecasting tools that are adequate for new socioeconomic environments and emerging transportation planning challenges. To support the 2021 Regional Plan, SANDAG enhanced the ABM2+ functionality for application to the 5 Big Moves planning effort. These enhancements included functions to address new trends in teleworking, use of micromobility modes and transportation network companies (TNCs), and new mobility options for Flexible Fleets and microtransit within Mobility Hubs.

The ABM2+ accounts for a variety of different weekday travel markets in the region, including San Diego region resident travel, travel by Mexico residents and other travelers crossing San Diego County's borders, visitor travel, airport passengers at both the San Diego International Airport (SDIA) and the Cross Border Xpress (CBX) bridge to the Tijuana International Airport, and commercial travel. Many of the models used to represent demand are simulation-based models, such as activity-based or tour-based approaches, while others use aggregate three- or four-step representations of travel. Table S.1 lists the SANDAG travel markets along several key dimensions.

There are two broad types of models and three specific types of models identified in Table S.1. Disaggregate models refer to models whose demand is generated via a stochastic simulation paradigm. Both activity-based and tour-based models are simulation-based. They rely upon a synthetic population to generate travel and stochastic processes to choose alternatives. The models output disaggregate demand in the form of tour and trip lists.

The resident travel model is an ABM, in which all tours and activities are scheduled into available time windows across the entire day. The approach recognizes that a person can be in only one place at one time, and their entire day is accounted for in the model. A tour-based treatment is used for other special travel markets, such as Mexico resident crossborder travel, visitor travel, airport passenger travel, and commercial vehicle travel. Tour-based models do not attempt to model all travel throughout the day for each person; rather, once tours are generated, they are modeled independently of each other. A tour-based model does not attempt to schedule all travel into available time windows.

Aggregate models rely upon probability accumulation processes to produce travel demand and output trip tables. The external heavy-duty truck model and certain external travel models are aggregate.

Table S.1: SANDAG ABM2+ Travel Markets

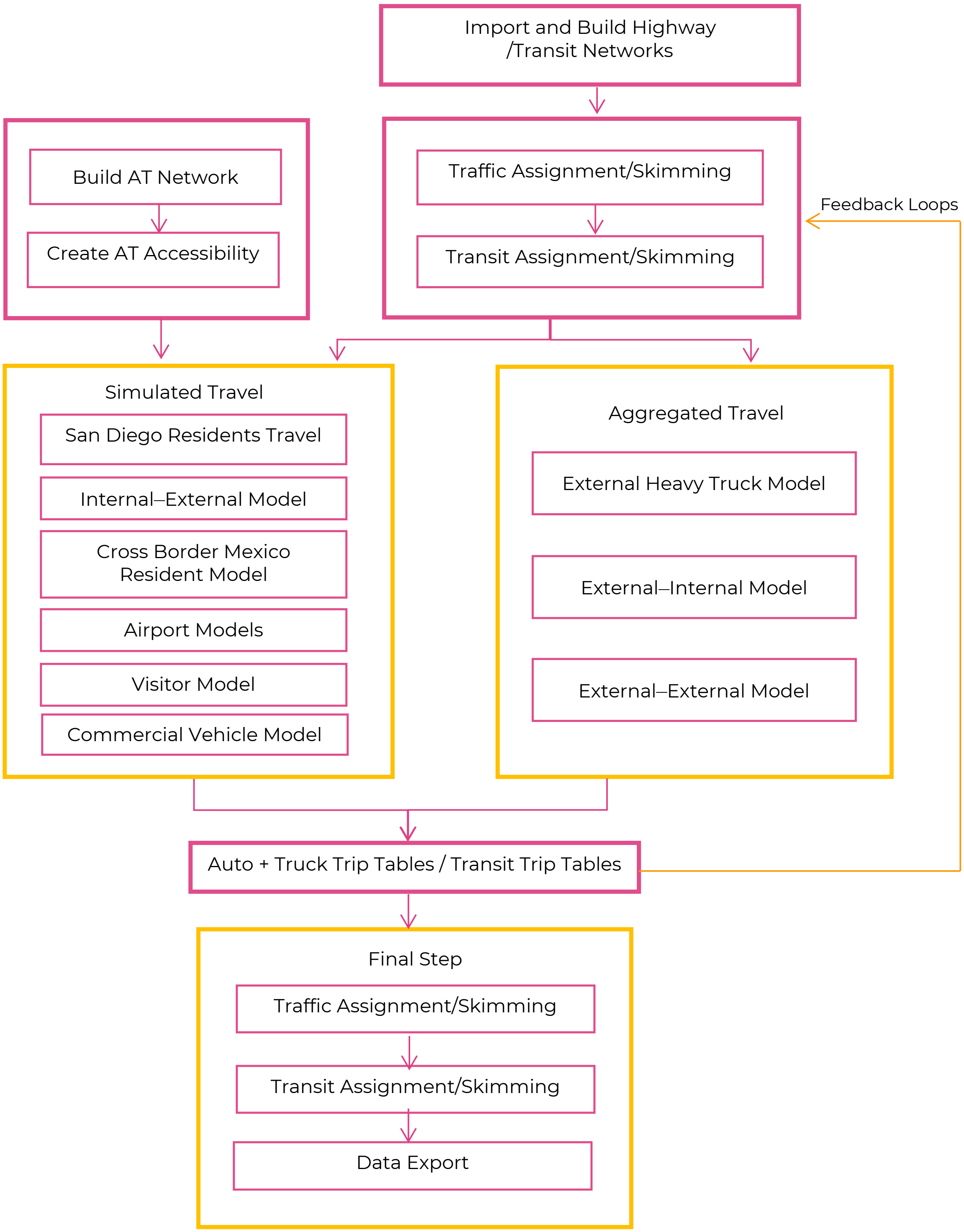
SANDAG ABM2+ Travel Markets				
Travel Market	**Description**	**Model Type**	**Temporal Resolution**	**Spatial Resolution**
San Diego resident travel (internal)	Average weekday travel made by San Diego residents within San Diego County	Disaggregate activity-based	30-minute	MGRA[1]
San Diego resident travel (internal–external)	Average weekday travel by San Diego residents between San Diego County and another county/Mexico	Disaggregate tour-based	30-minute	Internal MGRA – External cordon TAZ[2]
Mexico resident crossborder travel (external–internal and internal–internal)	Average weekday travel by Mexico residents into, out of, and within San Diego County	Disaggregate tour-based	30-minute	Internal MGRA – External cordon TAZ
Overnight visitor	Average weekday travel made by overnight visitors in San Diego County	Disaggregate tour-based	30-minute	MGRA
Airport passenger (SDIA and CBX terminal)	Average weekday travel made by air passengers and related trips such as taxis to/from airport	Disaggregate trip-based	30-minute	MGRA
External–External	Average weekday travel with neither origin nor destination in San Diego County	Aggregate trip-based	5 time periods	External cordon TAZ
Other U.S.–Internal travel	Average weekday external–internal trips made by non-San Diego and non-Mexico residents	Aggregate trip-based	5 time periods	External cordon TAZ – Internal TAZ

[1] MGRA = Master Geographic Reference Area; there are 23,002 MGRAs in the region.
[2] TAZ = Traffic Analysis Zone; there are 4,996 TAZs in the region.

SANDAG ABM2+ Travel Markets				
Travel Market	**Description**	**Model Type**	**Temporal Resolution**	**Spatial Resolution**
Commercial vehicle model	Average weekday vehicle trips made for commercial purposes (in addition to heavy trucks includes light truck goods movements and service vehicles)	Disaggregate tour-based	5 time periods	TAZ
External heavy-duty truck model	Average weekday vehicle trips for 3 weight classes for external truck travel	Aggregate trip-based	5 time periods	External cordon TAZ – External cordon TAZ; External cordon TAZ – Internal TAZ

The flow of these models is represented in Figure S.1. The SANDAG ABM2+ starts with building an all-street-based active transportation (AT) network and creating Master Geographic Reference Area (MGRA) to MGRA and MGRA to transit access point (TAP) walk, micromobility, or microtransit equivalent access files; highway and transit network building and importing into Emme (traffic modeling software licensed from INRO), then traffic and transit assignment with warm start trip tables to get the congested highway and transit skims. After the network skims and walk access files are created, the resident travel model is executed, followed by the other disaggregate models (visitor, SDIA, CBX terminal, crossborder, and commercial vehicle) and aggregate models (external heavy truck, external–external and external–internal). The trip tables from all the models are summed up by vehicle classes, time of day (TOD), and value of time (VOT) and are used by traffic assignment. The skims after the traffic assignment are used for the subsequent iteration in a three-feedback-loop model run. The final traffic and transit assignment and data export concludes the ABM2+ modeling procedure. The outputs from the final step are used to generate input for Emission Factors emissions modeling.

Figure S.1: SANDAG ABM2+ Flow Chart



Spatial and Temporal Resolutions

As indicated in Table S.1, different travel markets are operated in different model types with different spatial and temporal resolutions. The following section describes the treatment of space and time in the SANDAG ABM2+.

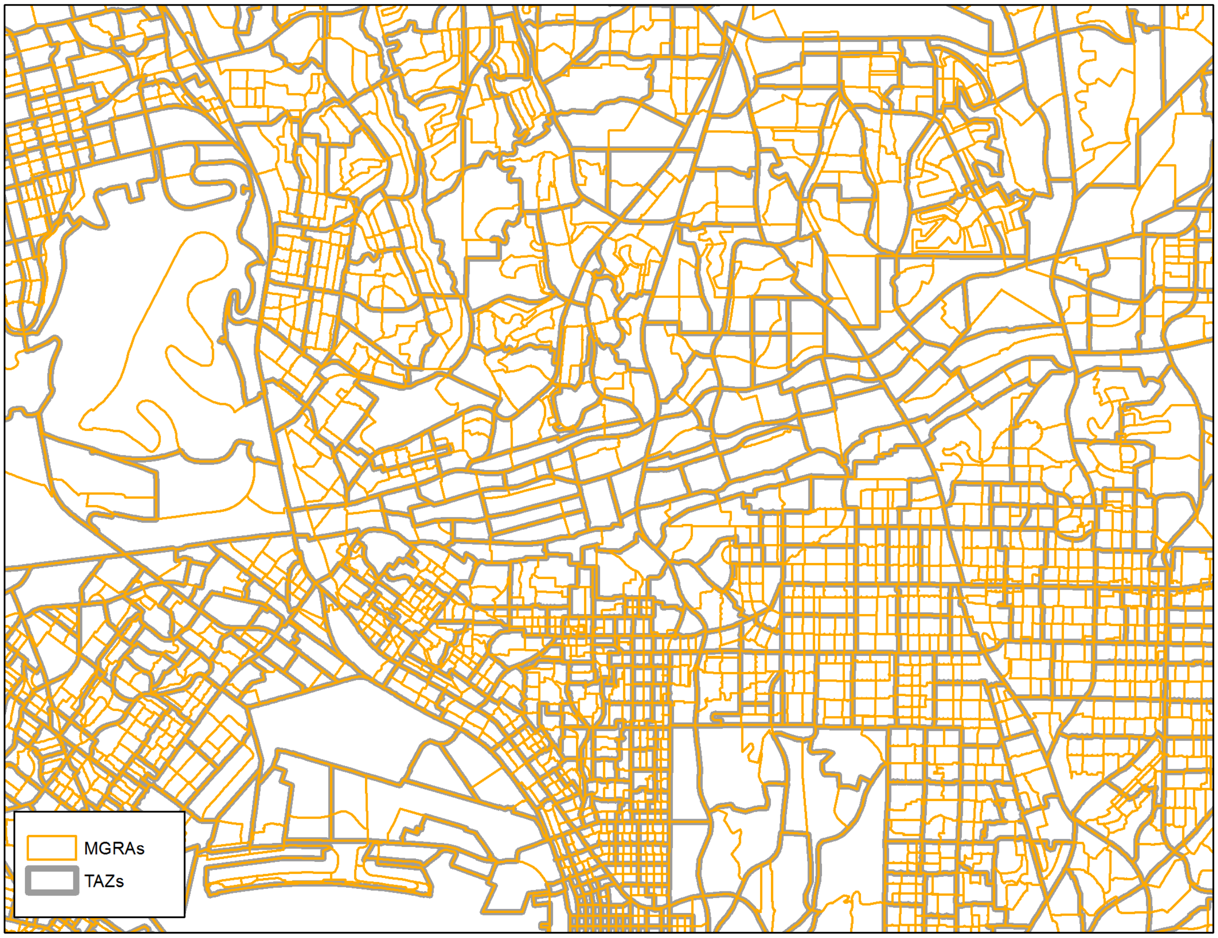
Treatment of Space

Activity-based and tour-based models can exploit fine-scale spatial data, but the advantages of additional spatial detail must be balanced against the additional efforts required to develop zone and associated network information at this level of detail. The increase in model runtime and memory footprint associated primarily with path-building and assignment to more zones must also be considered.

The use of a spatially disaggregate zone system helps ensure model sensitivity to phenomena that occur at a fine spatial scale. Use of large zones may produce aggregation biases, especially in destination choice, where the use of aggregate data can lead to illogical parameter estimates due to reduced variation in estimation data, and in mode choice, where modal access may be distorted.

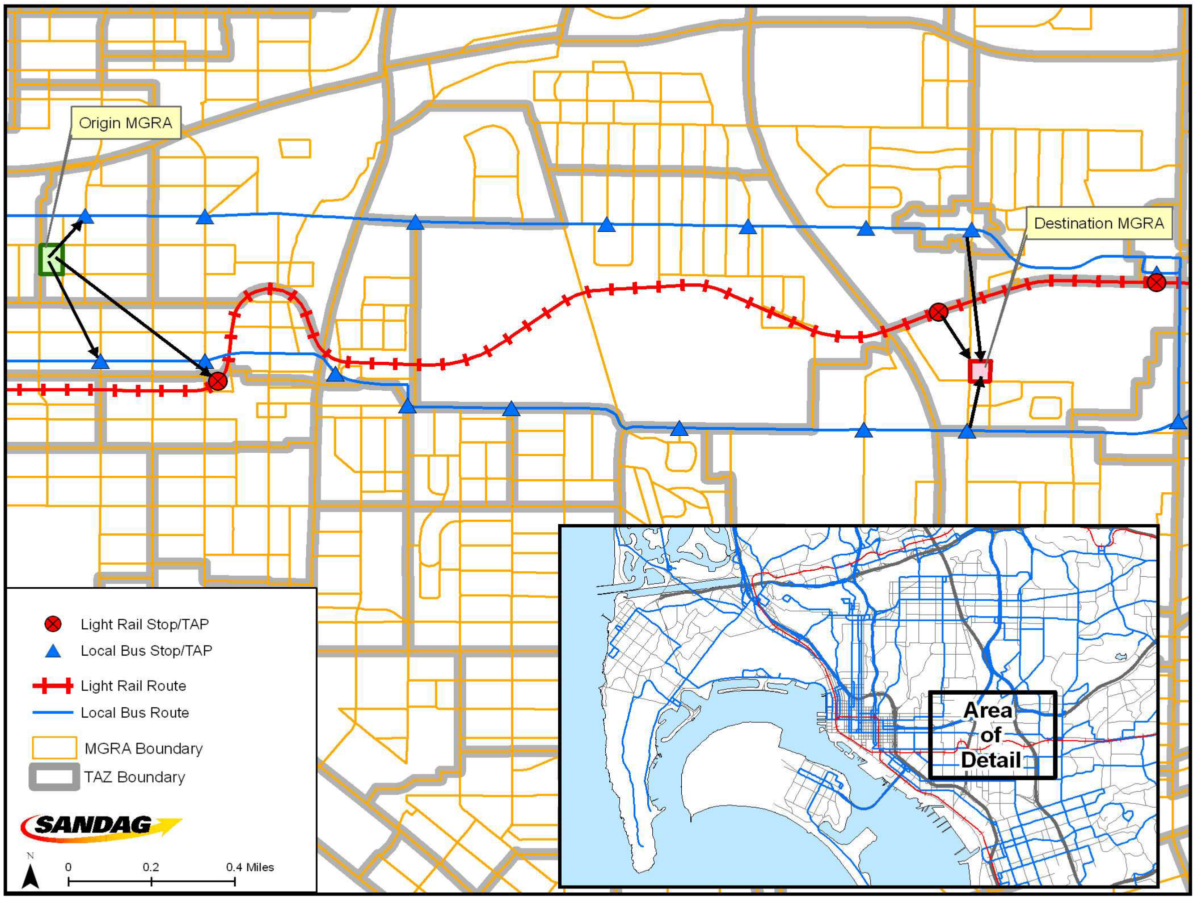
SANDAG ABM2+ uses the SANDAG MGRA zone system, which is one of the most disaggregate zonal systems used in travel demand models in the United States. The SANDAG MGRA system used in ABM2+ consists of 23,002 zones, which are roughly equivalent to Census blocks (see Figure S.2). To avoid computational burden, SANDAG relies on a 4,996 Transportation Analysis Zone (TAZ) system for roadway skims and assignment but performs transit calculations at the more detailed MGRA level. This is accomplished by generalizing transit stops into pseudo-TAZs called Transit Access Points (TAPs) and using Emme modeling software to generate TAP–TAP level-of-service matrices (also known as “skims”) such as in-vehicle time, first wait, transfer wait, and fare. All access and egress calculations, as well as paths following the Origin MGRA–Boarding TAP–Alighting TAP–Destination MGRA patterns, are computed within custom-built software. These calculations rely upon detailed geographic information regarding MGRA–TAP distances and accessibilities. A graphical depiction of the MGRA–TAP transit calculations is given in Figure S.3. It shows potential walk paths from an origin MGRA, through three potential boarding TAPs (two of which are local bus and one of which is rail), with three potential alighting TAPs at the destination end.

Figure S.2 : Treatment of Space – TAZs and MGRAs



All activity locations are tracked at the MGRA level. The MGRA geography offers the advantage of fine spatial resolution along with consistency with network levels-of-service, making it ideal for tracking activity locations.

Figure S.3 : Example MGRA – TAP Transit Accessibility



Treatment of Time

The disaggregated models function at a temporal resolution of one-half hour. These one-half hour increments begin with 3 a.m. and end with 3 a.m. the next day, though the hours between 1 a.m. and 5 a.m. are aggregated to reduce computational burden. Temporal integrity is ensured so that no activities are scheduled with conflicting time windows, except for short activities/tours that are completed within a one-half hour increment. For example, a person may have a very short tour that begins and ends within the 8 a.m. to 8:30 a.m. period, as well as a second longer tour that begins within this time period but ends later in the day.

Time periods are typically defined by their midpoint in the scheduling software.
For example, in a model system using one-half hour temporal resolution, the 9 a.m. time period would capture activities of travel between 8:45 a.m. and 9:15 a.m. If there is a desire to break time periods at "round" half-hourly intervals, either the estimation data must be processed to reflect the aggregation of activity and travel data into these discrete half-hourly bins or a more detailed temporal resolution must be used, such as half-hours (which could then potentially be aggregated to "round" half-hours).

A critical aspect of the model system is the relationship between the temporal resolution used for scheduling activities, and the temporal resolution of the network simulation periods. Although each activity generated by the model system is identified with a start time and end time in one-half hour increments, level-of-service matrices are only created for five aggregate time periods: (1) early a.m.; (2) a.m.; (3) midday; (4) p.m.; and (5) evening. The trips occurring in each time period reference the appropriate transport network depending on their trip mode and the midpoint trip time. All aggregated models operate on the five aggregated time periods. The definition of time periods for level-of-service matrices is given in Table S.2.

Table S.2: Time Periods for Level-of-Service Skims and Assignment

Time Periods for Level-of-Service Skims and Assignment			
Number	**Description**	**Begin Time**	**End Time**
1	Early	3 a.m.	5:59 a.m.
2	a.m. Peak	6 a.m.	8:59 a.m.
3	Midday	9 a.m.	3:29 p.m.
4	p.m. Peak	3:30 p.m.	6:59 p.m.
5	Evening	7 p.m.	2:59 a.m.

Network Inputs

There are three major network inputs: (1) highway networks used to describe existing and planned roadway facilities, (2) transit networks used to describe existing and planned public transit service, and (3) an AT network used to describe non-motorized bicycle and pedestrian facilities.

Highway Networks

The regional highway networks in the 2021 Regional Plan include all roads classified by local jurisdictions in their general plan circulation elements and Caltrans state facilities. SANDAG uses geographic information system (GIS) software to maintain highway information in an ArcInfo master transportation coverage. Coverage is an ArcInfo term used to describe all the individual files that together represent a geographic system in digital form. This network coverage includes existing and planned freeways, toll lanes, high-occupancy vehicle (HOV) lanes, Managed Lanes, ramps, surface streets classified on general plan circulation elements, and some local roads needed for network connectivity. Traffic control devices are included on roadway segments for traffic signals, stop signs, ramp meters, and rail crossings. The network coverage also includes zone connector links, which are used to schematically represent how traffic from zones accesses the street system.

Highway Facilities

SANDAG uses several sources to maintain the GIS roadway networks, such as high-resolution digital aerial photography, signal data from the Regional Arterial Management System, and ramp meter data from Caltrans. Alignments for planned roads are derived from several different sources, including Caltrans route location studies, local general plan circulation elements, environmental impact reports, and corridor studies.

Highway Attributes

Each highway segment and node contain attribute information that describes that feature. 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, 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 HOV 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 are identified using another set of attributes.

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 roadway improvements are obtained from local circulation elements, Regional Transportation Improvement Programs, and local Capital Improvement Programs.

Highway Capacities

Roadway network coverages for specific model years and alternatives are selected from the master transportation coverage. Computer programs convert these ArcInfo coverages to Emme 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) mid-link capacity, which is the amount of traffic a link could accommodate without intersection controls; and (2) intersection capacity, which is the amount of traffic that can be accommodated by an intersection approach at the end of a link.

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.

Mid-link capacities for arterial streets and 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.

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. While actual signalized operation is very complex, this approach 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.

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 upstream 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 techniques similar to the signalized intersection method shown above.

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

Highway Travel Times

As with capacities, separate link times and intersection times are computed for each highway segment. Travel times represent the free-flow link time (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 ten 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, 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.

Transit Network Inputs

Transit modeling requires coded transit networks that represent existing and planned conditions. Like roadway 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. Transit routes with similar operating characteristics are grouped into transit mode categories.

Transit Modes and Facilities

Table S.3 describes the seven transit modes and gives examples of existing routes in each category. Tier 1 Heavy Rail and streetcar modes represent new types of transit service that will soon be implemented. Tier 1 Heavy Rail services represent a new mode added for the 2021 Regional Plan that would operate separated from at-grade conflicts within exclusive right-of-way. *Rapid* Bus service would be provided by advanced design buses operating largely on Managed Lanes or arterials with priority transit treatments. This table is only representative of fixed-route transit services. Other nascent services, such as microtransit and other on-demand transportation concepts, are addressed in other components of ABM and are not explicitly coded in the transit network.

Table S.3: Transit Mode Definitions

Transit Mode Definitions		
Mode Number	**Description**	**Examples**
5	Tier 1 Heavy Rail	Proposed New Service
4	Commuter Rail	COASTER
5	Light Rail	Trolley, SPRINTER
5	Streetcar	Proposed New Service
6/7	*Rapid* Bus	Metropolitan Transit System Routes 215 and 235
9	Express Bus	San Diego Transit Corporation (SDTC) Routes 20, 50, 150
10	Local Bus	SDTC Routes 1–9

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:

- Transit 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 timetables are published. A transit scheduling system (HASTUS) and General Transit Feed Specification data provide 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 Regional Plan and Sustainable Communities Strategy (SCS) and other transit corridor studies.

Transit Attributes

Transit stops and routes both have specific attribute data. Transit node attributes describe stop type and Park & Ride availability at each node. Transit route attributes include transit operator, mode, and most importantly, frequency of service by time period (a.m. peak period, p.m. peak period, midday, 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.

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. Bus travel times are assumed to be a function of the number of bus stops on a link and roadway travel time. Since roadway times include congestion effects from the highway assignment step, bus travel times are recomputed at different stages of the modeling process. Roadway 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 single-occupancy vehicle (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 5 mph above the speed limit to reflect observed speeds from survey data.

Stop delay times of 30 seconds for *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. *Rapid* Bus stop delays were assumed to be similar to those of express buses 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 with the exception of the COASTER, where rail straightening, complete double-tracking, and new technologies are thought to increase travel speeds up to a top speed of 110 mph by 2035 and 125 mph by 2050. Tier 1 Heavy Rail is also assumed to have a top speed of 125 mph when implemented. Average speeds are then calculated that attempt to factor in acceleration, deceleration, and dwell times for these high-speed rail services. Streetcar routes are assumed to operate at an average speed of 12 mph.

Fares

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

- Buses collect a flat fare of between $2.50 and $5 depending on the type of service
- Trolleys and SPRINTER charge a flat fare of $2.50
- Commuter rail has a zone-based fare of between $5 and $6.50

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 2010 dollars for consistency with income data in the model and are assumed to remain constant over the forecast period unless fare policies are implemented that reduce the fares charged to transit riders.

Active Transportation Network Input

SANDAG maintains an all-street AT network including existing and planned bike projects to support bike project evaluation and impact analysis. Based on the proposed bike projects in the regional bikeway system developed through Riding to 2050 – San Diego Regional Bike Plan, SANDAG generates year-specific AT networks and uses these networks to create accessibility measures from MGRA to MGRA for walking and short-distance biking and from TAZ to TAZ for longer-distance biking modes, including e-bikes. These accessibility measures are also used for micromobility. AT accessibility measures are inputs to the SANDAG ABM2+ to simulate people's choice of travel mode and choice of bike routes.

The street geometry for the final Bike Network was developed from the SanGIS "Roads_all" shapefile, which is an All-Streets centerline network. In addition to the Roads_all shapefile, the spatial dispersal of San Diego's bike-exclusive infrastructure was captured from the SanGIS maintained "Bike" shapefile. Because these geographies exist outside the master transportation coverage, the AT network has more features and a higher fidelity due to AT trips being shorter in distance. Similar to the roadway network, evaluation of planned AT projects is possible. Future projects are manually added to the AT network.

The AT network has unique characteristics that account for facility type, bike treatments, and elevation change. The AT networks include five classification types for bike facilities in the regional bikeway system: class I: bike paths, class II: bike lanes, class III: bike routes, class IV: cycle tracks, and "class V": bike boulevards. "Class V" is an internal designation and not a California vehicle code facility type.

Resident Travel Model

The resident travel model is based on the Coordinated Travel Regional Activity-Based Modeling Platform (CT-RAMP) family of ABMs. This model system is an advanced but operational AB model that fits the needs and planning processes of SANDAG. The CT-RAMP model adheres to the following basic principles:

- Corresponds to the most advanced principles of modeling individual travel choices with maximum behavioral realism. Addresses both household-level and person-level travel choices, including intrahousehold interactions (interactions between household members).
- Operates at a detailed temporal (half-hourly) level and considers congestion and pricing effects on travel time-of-day and peak spreading of traffic volume.
- Reflects and responds to detailed demographic information, including household structure, aging, changes in wealth, and other key attributes.[3]
- Offers sensitivity to demographic and socioeconomic changes observed or expected in the dynamic San Diego metropolitan region. This is ensured by the synthetic population as well as by the fine level of model segmentation. In particular, the resident travel model incorporates different household, family, and housing types, including a detailed analysis of different household compositions in their relation to activity-travel patterns.

The resident travel model has its roots in a wide array of analytical developments. They include discrete choice forms (multinomial and nested logit), activity duration models, time-use models, models of individual microsimulation with constraints, entropy-maximization models, etc. These advanced modeling tools are combined to ensure maximum behavioral realism, replication of the observed activity-travel patterns, and

[3] Please refer to the SANDAG Regional Models website for additional documentation, including key updates from ABM1 to ABM2: sandag.org/index.asp?classid=32&fuseaction=home.classhome.

model sensitivity to key projects and policies. The model is implemented in a microsimulation framework. Microsimulation methods capture aggregate behavior through the representation of the behavior of individual decision makers. In travel demand modeling, these decision makers are typically households and persons. The following section describes the basic conceptual framework at which the model operates.

Decision-Making Units

Decision makers in the model system include both persons and households. These decision makers are created (synthesized) for each simulation year based on tables of households and persons from Census data and forecasted TAZ-level distributions of households and persons by key socioeconomic categories. These decision makers are used in the subsequent discrete choice models to select a single alternative from a list of available alternatives according to a probability distribution. The probability distribution is generated from a logit model, which takes into account the attributes of the decision maker and the attributes of the various alternatives. The decision-making unit is an important element of model estimation and implementation and is explicitly identified for each model specified in the following sections.

Person-Type Segmentation

A key advantage of using the microsimulation approach is that there are essentially no computational constraints on the number of explanatory variables that can be included in a model specification. However, even with this flexibility, the model system includes some segmentation of decision makers. Segmentation is a useful tool to both structure models such that each person type segment could have their own model for certain choices, and to characterize person roles within a household. Segments can be created for persons as well as households.

A total of eight segments of person types (shown in Table S.4) are used for the resident travel model. The person types are mutually exclusive with respect to age, work status, and school status.

Table S.4: Person Types

Person Types				
Number	**Person Type**	**Age**	**Work Status**	**School Status**
1	Full-time worker[4]	18+	Full-time	None
2	Part-time worker	18+	Part-time	None
3	College student	18+	Any	College +
4	Non-working adult	18–64	Unemployed	None
5	Non-working senior	65+	Unemployed	None
6	Driving age student	16–17	Any	Pre-college
7	Non-driving student	6–15	None	Pre-college
8	Pre-school	0–5	None	None

Further, workers are stratified by their occupation shown in Table S.5. These are used to segment destination choice size terms for work location choice based on the occupation of the worker.

Table S.5: Occupation Types

Occupation Types	
Number	**Description**
1	Management Business Science and Arts
2	Services
3	Sales and Office
4	Natural Resources Construction and Maintenance
5	Production Transportation and Material Moving
6	Military

[4] Full-time employment is defined in the SANDAG 2006 household survey as at least 30 hours/week. Part-time is less than 30 hours/week but on a regular basis.

Activity Type Segmentation

The activity types are used in most sub-model components of resident travel model, from developing daily activity patterns (DAPs) to predicting tour and trip destinations and modes by purpose.

The activity types are as shown in Table S.6. The activity types are grouped according to whether the activity is mandatory, maintenance, or discretionary. Eligibility requirements are assigned to determine which person types can be used for generating each activity type. The classification scheme of each activity type reflects the relative importance or natural hierarchy of the activity, where work and school activities are typically the most inflexible in terms of generation, scheduling, and location and discretionary activities are typically the most flexible on each of these dimensions. When generating and scheduling activities, this hierarchy is not rigid and is informed by both activity type and duration.

Each out-of-home location that a person travels to in the simulation is assigned one of these activity types.

Table S.6: Activity Types

Activity Types				
Type	**Purpose**	**Description**	**Classification**	**Eligibility**
1	Work	Working at regular workplace or work-related activities outside the home	Mandatory	Workers and students
2	University	College +	Mandatory	Age 18+
3	High School	Grades 9–12	Mandatory	Age 14–17
4	Grade School	Grades K–8	Mandatory	Age 5–13
5	Escorting	Pick-up/drop-off children at school by parents Pick-up/drop-off passengers (auto trips only)	Maintenance	Age 16+
6	Shopping	Shopping away from home	Maintenance	5+ (if joint travel, all persons)
7	Other Maintenance	Personal business/ services and medical appointments	Maintenance	5+ (if joint travel, all persons)
8	Social/Recreational	Recreation, visiting friends/family	Discretionary	5+ (if joint travel, all persons)
9	Eat Out	Eating outside of home	Discretionary	5+ (if joint travel, all persons)
10	Other Discretionary	Volunteer work, religious activities	Discretionary	5+ (if joint travel, all persons)

Trip Modes

Table S.7 lists the trip modes defined in the resident travel model. There are 22 modes available to residents, including auto by occupancy by value of time, walk, micromobility and bike non-motorized modes, and walk and drive access to local and premium transit modes. All auto modes are included in traffic assignment with Kiss & Ride to transit and TNC and taxi as shared-ride modes and Park & Ride to transit as drive-alone mode. All transit modes are included in transit assignment with TNC to transit as Kiss & Ride to transit.

Table S.7: Trip Modes for Mode Choice

Trip Modes for Mode Choice	
Number	**Mode**
1	Drive-Alone Non-Transponder
2	Drive-Alone Transponder
3	Share Ride 2 Person
4	Share Ride 3+ Person
5	Walk to Transit – Local Bus Only
6	Walk to Transit – Premium Transit Only
7	Walk to Transit – Local and Premium Transit
8	Park & Ride to Transit – Local Bus Only
9	Park & Ride to Transit – Premium Transit Only
10	Park & Ride to Transit – Local and Premium Transit
11	Kiss & Ride to Transit – Local Bus Only
12	Kiss & Ride to Transit – Premium Transit Only
13	Kiss & Ride to Transit – Local and Premium Transit
14	TNC to Transit – Local Bus Only
15	TNC to Transit – Premium Transit Only
16	TNC to Transit – Local and Premium Transit
17	Walk (walk, micromobility, and microtransit modes)
18	Bike
19	Taxi
20	TNC Single
21	TNC Pooled
22	School Bus (only available for school purpose) not in the assignment

Travel Time Reliability and Pricing Enhancements

Travel time and reliability enhancements are based upon recent federal research conducted under the Strategic Highway Research Program 2 C04 track to improve understanding of how highway congestion and pricing affect travel demand. The implemented travel time reliability and pricing features include:

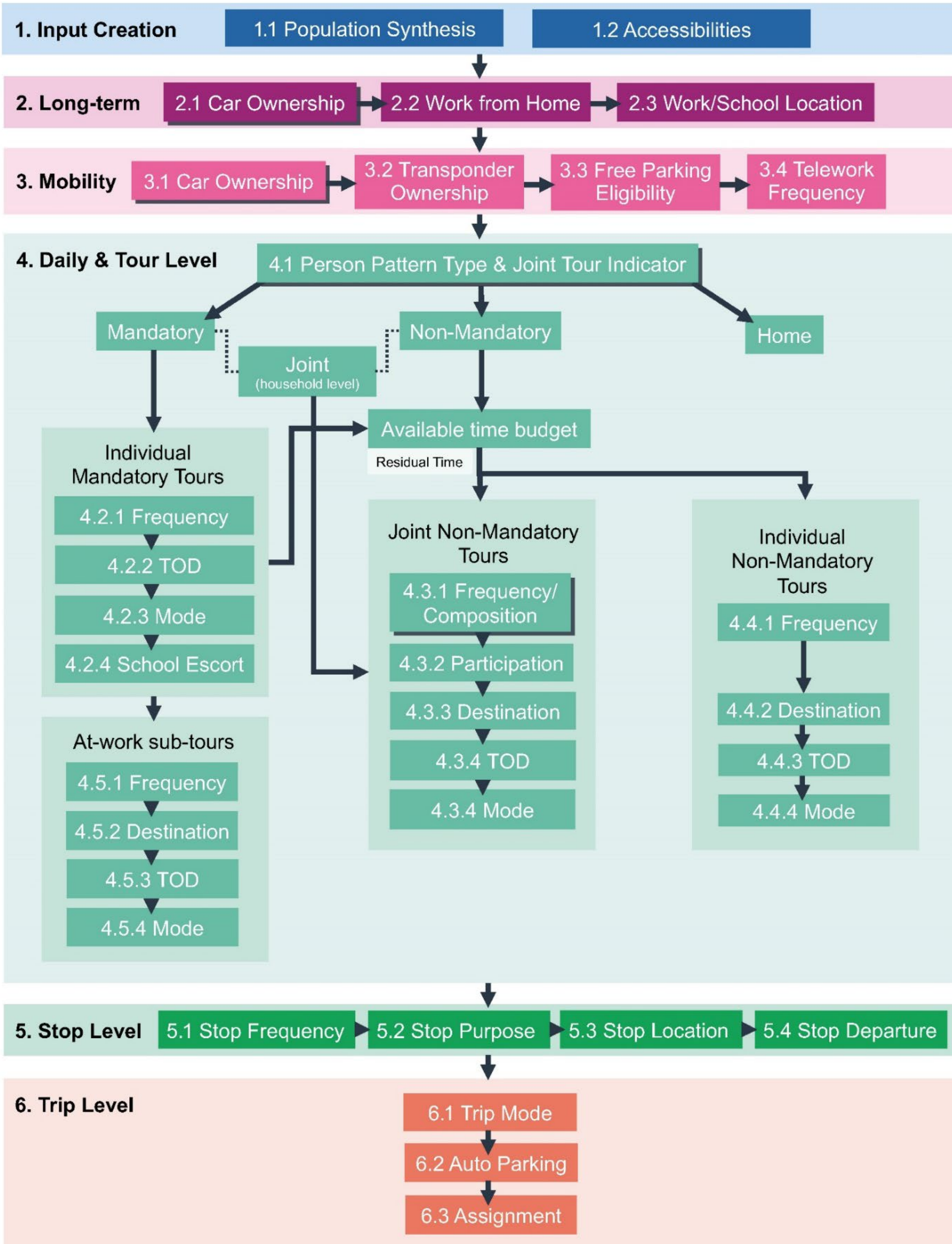
- **Implementation of travel time heterogeneity** in CT-RAMP in which traveler's sensitivity to time is drawn from a log-normal distribution with a mean equal to the previously estimated travel time coefficient and a standard deviation that generally matches stated preference estimates of travel time distributions in a number of studies across the United States.
- **Continuous cost coefficients** that are based on household income, auto occupancy, and tour/trip purpose. They replace the previous version cost coefficients that were based on household income group (not continuous).
- **VOT bins** used in assignment in which trips written by CT-RAMP are grouped into three VOT bins and assigned using a relevant cost coefficient for each bin to reflect different cost sensitivities in skimming and assignment.
- **Implementation of a link-level measure of travel time reliability** based on an analysis of INRIX data. The reliability measure is based on link characteristics including volume/capacity ratio, link speed, and proximity of the link to major interchanges (to account for unreliability due to weaving conflicts), among other variables. The reliability measure is incorporated into the CT-RAMP mode choice model utilities and therefore also affects upstream model components such as time-of-day choice and destination choice.
- **Implementation of a previously estimated toll transponder ownership model** in ABM2+. The model was not implemented in ABM1, but it was found to significantly improve model goodness-of-fit for forecasting demand on I-15 Managed Lanes.

The enhanced models have been shown to match observed demand on existing toll roads in San Diego better than the previous model and demonstrate reasonable elasticities to changes in toll cost. As part of the travel time reliability enhancement, accurate representations of toll entry/exit points and costs and the inclusion of a transponder model that constrains demand also contribute to the improvements in the revised system.

Basic Structure and Flow

The resident travel model consists of a series of interdependent sub-models to simulate person and household travel. Figure S.4 illustrates the basic structure and flow.

Figure S.4: Resident Travel Model Design and Linkage Between Sub-Models



Shadowed boxes in Figure S.4 indicate choices that relate to the entire household or a group of household members and assume explicit modeling of intrahousehold interactions (sub-models 2.1, 3.1, 4.1, and 4.3.1). The other models are applied to individuals, though they may consider household-level influences on choices.

The resident travel model uses synthetic household population as a base input (sub-model 1.1). Certain models also use destination-choice logsums, which are represented as MGRA variables (sub-model 1.2). Once these inputs are created, the travel model simulation begins.

A car ownership model (sub-model 2.1) is run before workplace/university/school location choice in order to select a preliminary car ownership level for calculation of accessibilities for location choice. The model uses the same variables as the full car-ownership model (sub-model 3.1), except for the work/university/school-specific accessibilities that are used in the full model. It is followed by long-term choices that relate to the workplace /university/school for each worker and student (sub-models 2.2 and 2.3). Mobility choices relate to household car ownership (sub-model 3.1), transponder ownership (sub-model 3.2), free parking eligibility for workers in the central business district (CBD) (sub-model 3.3), and telework frequency (sub-model 3.4) for occasional telework.

ABM2+ includes two types of telework: permanent and occasional telework. Permanent telework is modeled in the work-from-home model, while the impact of occasional telework is reflected in DAP, non-mandatory tour frequency, and non-mandatory tour stop frequency models. A multinomial logit model was estimated to predict telework frequency based on household and person variables. Occupation, household size and structure, income, work and student status, number of vehicles, and distance to work are significant. Workers who telework one or more day per week are less likely to go to work, more likely to stay home or engage in non-mandatory travel (roughly equally), somewhat less likely to engage in multiple individual non-mandatory tours, and less likely to make intermediate stops on non-mandatory tours.

The DAP type of each household member (model 4.1) is the first travel-related sub-model in the modeling hierarchy. This model classifies daily patterns by three types: (1) mandatory (that includes at least one out-of-home mandatory activity), (2) non-mandatory (that includes at least one out-of-home non-mandatory activity but does not include out-of-home mandatory activities), and (3) home (that does not include any out-of-home activity and travel). The pattern-type model also predicts whether any joint tours will be undertaken by two or more household members on the simulated day. However, the exact number of tours, their composition, and other details are left to subsequent models. The pattern choice set contains a non-travel option in which the person can be engaged in in-home activity only (purposely or because of being sick) or can be out of town. In the resident travel model, a person who chooses a non-travel pattern is not considered further in the modeling stream, except that they can make an internal–external trip. Daily pattern-type choices of the household members are linked in such a way that decisions made by some members are reflected in the decisions made by the other members.

The next set of sub-models (4.2.1–4.2.3) defines the frequency, time-of-day, and mode for each mandatory tour. The scheduling of mandatory activities is generally considered a higher-priority decision than any decision regarding non-mandatory activities for either the same person or for the other household members. “Residual time windows,” or periods of time with no person-level activity, are calculated as the time remaining after tours have been scheduled. The temporal overlap of residual time windows among household members are estimated after mandatory tours have been generated and scheduled. Time window overlaps, which are left in the daily schedule after the mandatory commitment of the household members has been made, affect the frequency of joint and individual non-mandatory tours, and the probability of participation in joint tours. At-work sub-tours are modeled next, taking into account the time-window constraints imposed by their parent work tours (sub-models 4.5.1–4.5.4).

The next major model component relates to joint household travel. Joint tours are tours taken together by two or more members of the same household. This component predicts the exact number of joint tours by travel purpose and party composition (adults only, children only, or mixed) for the entire household (4.3.1), and then defines the participation of each household member in each joint household tour (4.3.2). It is followed by choice of destination (4.3.3) time-of-day (4.3.4), and mode (4.3.5).

The next stage relates to individual maintenance (escort, shopping, and other household-related errands) and discretionary (eating out, social/recreation, and other discretionary) tours. All of these tours are generated by person in model 4.4.1. Their destination, time of day, and mode are chosen next (4.4.2, 4.4.3, and 4.4.4).

The next set of sub-models relate to the stop-level details for each tour. They include the frequency of stops in each direction (5.2), the purpose of each stop (5.2), the location of each stop (5.3) and the stop departure time (5.4). This is followed by the last set of sub-models that add details for each trip, including trip mode (6.1) and parking location for auto trips (6.2). The trips are then assigned to roadway and transit networks depending on trip mode and time period (6.3).

Main Sub-Models and Procedures

This section describes each model component in greater detail, including the general algorithm for each model, the decision-making unit, the choices considered, the market segmentation used (if any), and the explanatory variables used.

Sub-Model (SM) 1.1: Population Synthesizer

The synthetic population is derived from a process that combines a microsimulation of personal and household demographic evolution with elements of probabilistic imputation of socioeconomic attributes. The process can be divided into several phases:

- **Phase 1:** Assembling microdata (synthetic persons and households) with basic demographic attributes based on the 2010 Decennial Census data.

- **Phase 2:** Evolving synthetic persons and households (from phase 1) from April 1, 2010 (the Census day), first to January 1, 2011, and then in annual increments through January 1, 2017 (for version 17 of Series 14, this is the latest effective date for the SANDAG land use inventory).
- **Phase 3:** Evolving synthetic persons and households (from phase 2) from January 1, 2017, through January 1, 2051, in annual increments.
- **Phase 4:** Imputing income for households.
- **Phase 5:** Imputing socioeconomic attributes for persons and households.

The detailed description of data methods used at each phase is in the following section:

Phase 1: First, using a set of tables from the Summary File-1 (SF1) tabulation of the 2010 Decennial Census data, microdata for individuals are created. Each individual has the following attributes: location identifier (Census tract), sex, single-year age, race (one of seven categories), Hispanic origin (binary), and role (household head, household member, member of Military Group Quarters [GQ], College GQ, Institutional GQ, or Other GQ).

Second, controlling for the household size distribution and using probabilities from the 2010 Decennial Census Public Use Microdata Sample (PUMS) data that describe the demographic attributes of household members, individuals are allocated into households by matching household members with household heads. Lastly, households are assigned to housing units using data developed from the SANDAG land use inventory.

Phase 2: In the microsimulation, demographic events (aging, death, birth) occur to individuals. Death and birth counts are based on vital statistics data from the National Center for Health Statistics. These events may add or remove people from a household as well as alter the size of or dissolve a household. Migration is not explicitly represented in this version of the model; instead, cohort-specific (age, race, Hispanic origin, and sex) annual population targets are used from the latest population projections from the California Department of Finance (DOF).

After implementing the demographic events, the remaining population is compared with the cohort-specific targets. If the remaining cohort-specific population exceeds the target, the excess population is removed, thereby altering the households. Using the probability distributions derived from 2010 SF1 and American Community Survey (ACS) PUMS data, the target population is translated into a cohort-specific estimate of householders (individuals who are the head of a household) by household size. That estimate is compared with the count of remaining householders. If the remaining cohort- and size-specific count of householders exceeds the target, the excess households (and associated population) is removed, further altering the households.

Lastly, the final target for additional householders (cohort- and size-specific) is then developed. That target conforms to multiple constraints (e.g., the number of households and household population by jurisdiction based on the DOF's published population estimates). The remaining cohort-specific population is compared with the population target, the additional population is generated and added to a special pool (of individuals without households). In the next step, householders are matched up with the household members from the special pool. Finally, these new households are assigned to the currently unoccupied housing units, the supply of which comes from new construction and housing units that became available due to the removal of households earlier in this step.

Although this version of the model does not explicitly include migration (to or from the region) and relocation (within the region), the annual number of "new" households in the model is very close to the estimates produced by the Census ACS (tabulations that show how many households lived in the same house a year ago).

Phase 3: Conceptually, this phase is the same as Phase 2, except there are no jurisdiction-level controls. This is because there are no actual data for the future years. Deaths and births come from the DOF's projections instead of the vital statistics. New housing units come from a separate model called the Integrated Land Use, Demographic, and Economic Model, which creates a parcel-specific supply of future housing units based on local jurisdiction's land use plans and historical trends in development.

Phase 4: For the observed period (2010–2017), the overall census tract-level income distributions are borrowed from the ACS and applied to the households. The result is the percentage of households in a given Census tract in each income category from the ACS will match that same group in the synthetic household file. Further assignment to specific households uses probability distributions developed from the ACS PUMS data. These distributions show the probability that a household has a specific income, given the household size and sex and age of the householder. For the forecast period, the latest available ACS data are used. However, the distribution of households by income group is adjusted for every forecast year so that the regionwide distribution of households by income group matches the expected distribution of regionwide median income. Regionwide median household income is assumed to grow at the rate of 0.3% per year.

Phase 5: The rest of the socioeconomic personal and household attributes are imputed using a distribution from the ACS Summary File data and a set of conditional probability tables derived from the ACS PUMS data. Below is a description of the imputation steps:

- School enrollment is predicted probabilistically as conditional on age.
- Employment status is predicted probabilistically based on an individual's sex, age, and income distribution.
- Weeks worked, hours worked, educational attainment, and occupation status are predicted based on an individual's sex, age, income, and employment status.

The synthetic population includes household attributes such as household location at MGRA level, household income, number of workers, household size, household type, and poverty status (based on income and the federal poverty limit definition based on household size and the age of the household head). It also includes a list of population with characteristics as such age, sex, race, Hispanic origin, military status, employment status, weeks worked, hours worked, student type, person type, educational attainment, grade level, and occupation by industry code.

SM 1.2: Accessibilities

All accessibility measures for the resident travel model are calculated at the MGRA level. The auto travel times and cost are TAZ-based, and the size variables such as total weighted employment for all purposes are MGRA-based. This necessitates that auto accessibilities be calculated at the MGRA level. The resident travel model requires accessibility indices only for non-mandatory travel purposes since the usual location of work/school activity for each worker/student is modeled prior to the DAP, tour frequency, and tour destination choice for non-mandatory tours. In addition, school proximity to the residential MGRA and travel time by transit for each student can be used as an explanatory variable for escorting frequency. The set of accessibility measures is summarized in Table S.8.

Table S.8: Accessibility Measures

Accessibility Measures				
No.	**Description**	**Model Utilization**	**Attraction Size Variable (S_j)**	**Travel Cost (c_{ij})**
1	Access to non-mandatory attractions by SOV in off-peak	Car ownership	Total weighted employment for all purposes	Generalized SOV time including tolls
2	Access to non-mandatory attractions by transit in off-peak	Car ownership	Total weighted employment for all purposes	Generalized best path walk-to-transit time including fares
3	Access to non-mandatory attractions by walk	Car ownership	Total weighted employment for all purposes	SOV off-peak distance (set to 999 if >3)
4–6	Access to non-mandatory attractions by all modes except HOV	Coordinated daily activity pattern (CDAP)	Total weighted employment for all purposes	Off-peak mode choice logsums (SOV skims for persons) segmented by three car-availability groups
7–9	Access to non-mandatory attractions by all modes except SOV	CDAP	Total weighted employment for all purposes	Off-peak mode choice logsums (HOV skims for interaction) segmented by three car-availability groups

Accessibility Measures				
No.	**Description**	**Model Utilization**	**Attraction Size Variable (S_j)**	**Travel Cost (c_{ij})**
10–12	Access to shopping attractions by all modes except SOV	Joint tour frequency	Weighted employment for shopping	Off-peak mode choice logsum (HOV skims) segmented by three HH adult car-availability groups
13–15	Access to maintenance attractions by all modes except SOV	Joint tour frequency	Weighted employment for maintenance	Off-peak mode choice logsum (HOV skims) segmented by three adult car-availability groups
16–18	Access to eating-out attractions by all modes except SOV	Joint tour frequency	Weighted employment for eating out	Off-peak mode choice logsum (HOV skims) segmented by three adult HH car-availability groups
19–21	Access to visiting attractions by all modes except SOV	Joint tour frequency	Total households	Off-peak mode choice logsum (HOV skims) segmented by three adult car-availability groups
22–24	Access to discretionary attractions by all modes except SOV	Joint tour frequency	Weighted employment for discretionary	Off-peak mode choice logsum (HOV skims) segmented by three adult car-availability groups
25–27	Access to escorting attractions by all modes except SOV	Allocated tour frequency	Total households	AM mode choice logsum (HOV skims) segmented by three adult car-availability groups
28–30	Access to shopping attractions by all modes except HOV	Allocated tour frequency	Weighted employment for shopping	Off-peak mode choice logsum (SOV skims) segmented by three adult car-availability groups
31–33	Access to maintenance attractions by all modes except HOV	Allocated tour frequency	Weighted employment for maintenance	Off-peak mode choice logsum (SOV skims) segmented by three adult car-availability groups
34–36	Access to eating-out attractions by all modes except HOV	Individual tour frequency	Weighted employment for eating out	Off-peak mode choice logsum (SOV skims) segmented by three car-availability groups

Accessibility Measures				
No.	**Description**	**Model Utilization**	**Attraction Size Variable (S_j)**	**Travel Cost (c_{ij})**
36–39	Access to visiting attractions by all modes except HOV	Individual tour frequency	Total households	Off-peak mode choice logsum (SOV skims) segmented by three car-availability groups
40–41	Access to discretionary attractions by all modes except HOV	Individual tour frequency	Weighted employment for discretionary	Off-peak mode choice logsum (SOV skims) segmented by three car-availability groups
43–44	Access to at-work attractions by all modes except HOV	Individual sub-tour frequency	Weighted employment for at work	Off-peak mode choice logsum (SOV skims) segmented by adult two car-availability groups (zero cars and cars equal or greater than workers)
45	Access to all attractions by all modes of transport in the peak	Work location, CDAP	Total weighted employment for all purposes	Peak mode choice logsums
46	Access to at-work attractions by walk	Individual sub-tour frequency	Weighted employment for at work	SOV off-peak distance (set to 999 if >3)
47	Access to all households by all modes of transport in the peak		Total weighted households for all purposes	Generalized best path walk-to-transit time including fares

The size variable is calculated as a linear combination of the MGRA LU variables with the specified coefficients. The values of coefficients in the table have been estimated by means of an auxiliary regression model that used the LU variables as independent variables and expanded trip ends by travel purpose as dependent variables. The intercept was set to zero. The regressions were applied at the MGRA level.

These travel cost functions are used in the accessibility calculations: generalized SOV time, generalized best path walk-to-transit time, SOV off-peak distance, and off-peak mode choice logsum.

SM 2.1: Pre-Mandatory Car-Ownership Model

Number of Models:	1
Decision-Making Unit:	Household
Model Form:	Nested Logit
Alternatives:	Five (0, 1, 2, 3, 4++ autos)

The car-ownership models predict the number of vehicles owned by each household. It is formulated as a nested logit choice model with five alternatives, including “no car,” “one car,” “two cars,” “three cars,” and “four or more cars.” The nesting structure is shown in Figure S.5.

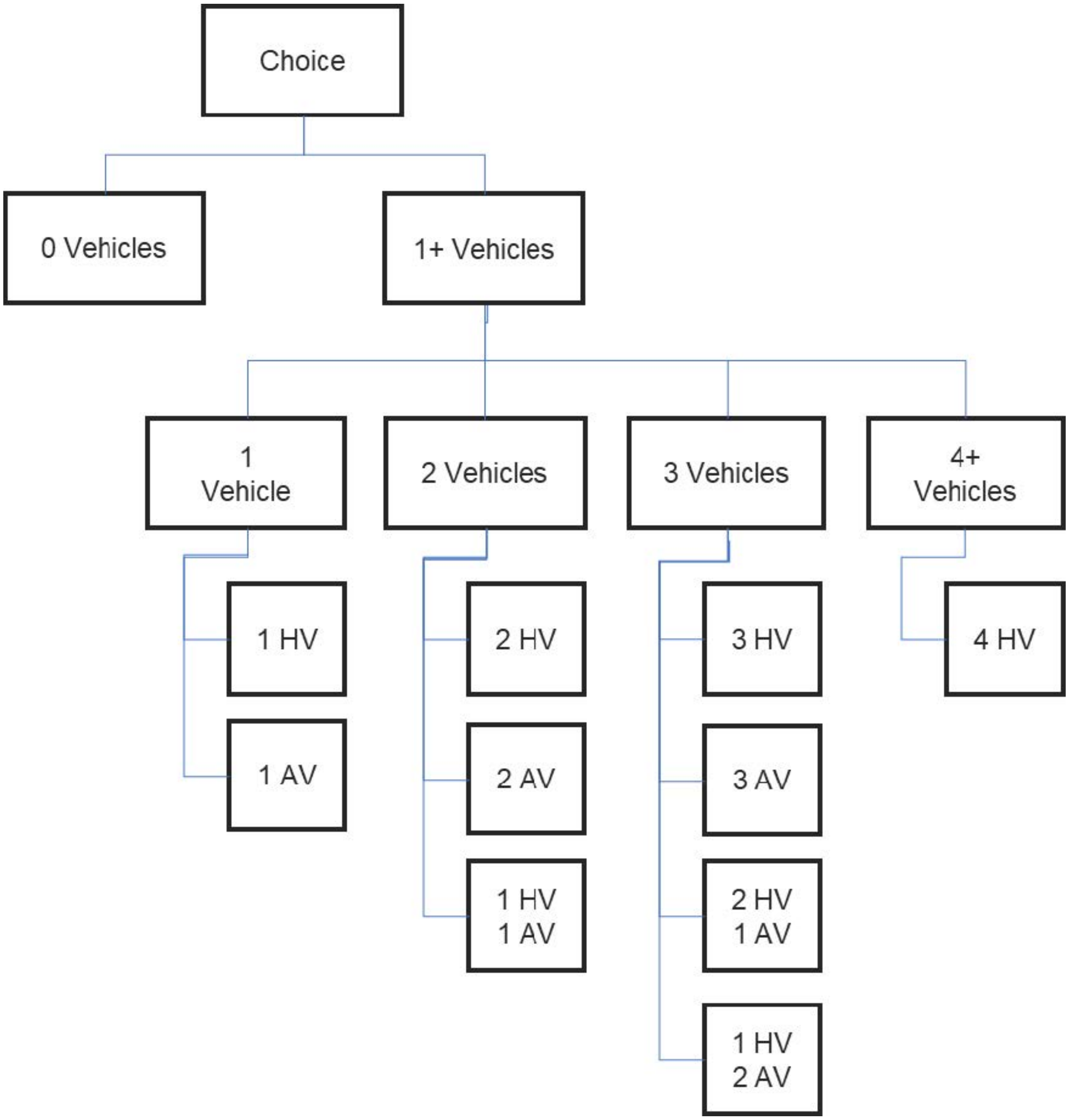
There are two instances of the car ownership model. The first instance, model 2.1, is used to select a preliminary car-ownership level for the household, based upon household demographic variables, household “4D” variables, and destination-choice accessibility terms created in sub-model 1.2 (see above). This car-ownership level is used to create mode choice logsums for workers and students in the household, which are then used to select work and school locations in model 2.2. The car ownership model is rerun (sub-model 3.2) in order to select the actual car ownership for the household, but this subsequent version is informed by the work and school locations chosen by model 2.2. All other variables and coefficients are held constant between the two models, except for alternative-specific constants.

The model includes the following explanatory variables:

- Number of driving-age adults in household
- Number of persons in household by age range
- Number of workers in household
- Number of high school graduates in household
- Dwelling type of household
- Household income
- Intersection density (per acre) within one-half mile radius of household MGRA
- Population density (per acre) within one-half mile radius of household MGRA
- Retail employment density (per acre) within one-half mile radius of household MGRA
- Non-motorized accessibility from household MGRA to non-mandatory attractions (accessibility term #3)
- Off-peak auto accessibility from household MGRA to non-mandatory attractions (accessibility term #1)
- Off-peak transit accessibility from household MGRA to non-mandatory attractions (accessibility term #2)

Note that the model includes both household and person-level characteristics, “4D” density measures, and accessibilities. The accessibility terms are destination choice (DC) logsums, which represent the accessibility of non-mandatory activities from the home location by various modes (auto, non-motorized, and transit). They are fully described under SM 1.2 above.

Figure S.5: Car-Ownership Nesting Structure



SM 2.2: Work-from-Home Choice

Number of Models:	1
Decision-Making Unit:	Workers
Model Form:	Binary Logit
Alternatives:	Two (regular workplace is home; regular workplace is not home)

The work-from-home choice model determines whether each worker works from home. It is a binary logit model, which takes into account the following explanatory variables:

- Household income
- Person age
- Gender
- Worker education level
- Whether the worker is full time or part time
- Whether there are non-working adults in the household
- Peak accessibility across all modes of transport from household MGRA to employment (accessibility term #45, see section SM 1.2)

SM 2.3: Mandatory (Workplace/University/School) Activity Location Choice

Number of Models:	5 (Work, Preschool, K-8, High School, University)
Decision-Making Unit:	Workers for Work Location Choice; Persons Age 0–5 for Preschool, 6–13 for K–8; Persons Age 14–17 for High School; University Students for University Model
Model Form:	Multinomial Logit
Alternatives:	MGRAs

A workplace location choice model assigns a workplace MGRA for every employed person in the synthetic population who does not choose "works at home" from Model 2.2. Every worker is assigned a regular work location zone (TAZ) and MGRA according to a multinomial logit destination choice model. Size terms in the model vary according to worker occupation to reflect the different types of jobs that are likely to attract different (white-collar versus blue-collar) workers. There are six occupation categories used in the segmentation of size terms, as shown in Table S.5. Each occupation category uses different coefficients for categories of employment by industry, to reflect the different likelihood of workers by occupation to work in each industry. Accessibility from the workers home to the alternative workplace is measured by a mode choice logsum taken directly from the tour mode choice model, based on peak-period travel (a.m. departure and p.m. return). Various distance terms are also used.

The explanatory variables in work location choice include:

- Household income
- Work status (full time versus part time)
- Worker occupation
- Gender
- Distance
- The tour mode choice logsum for the worker from the residence MGRA to each sampled workplace MGRA using peak level-of-service
- The size of each sampled MGRA

Since mode choice logsums are required for each destination, a two-stage procedure is used for all destination choice models in order to reduce computational time (it would be computationally prohibitive to compute a mode choice logsum for over 20,000 MGRAs and every tour). In the first stage, a simplified destination choice model is applied in which all TAZs are alternatives. The only variables in this model are the size term (accumulated from all MGRAs in the TAZ) and distance. This model creates a probability distribution for all possible alternative TAZs (TAZs with no employment are not sampled). A set of alternatives are sampled from the probability distribution and, for each TAZ, an MGRA is chosen according to its size relative to the sum of all MGRAs within the TAZ. These sampled alternatives constitute the choice set in the full destination choice model. Mode choice logsums are computed for these alternatives and the destination choice model is applied. A discrete choice of MGRA is made for each worker from this more limited set of alternatives. In the case of the work location choice model, a set of 40 alternatives is sampled.

The applied procedure uses an iterative shadow pricing mechanism in order to match workers to input employment totals. The shadow pricing process compares the share of workers who choose each MGRA by occupation to the relative size of the MGRA compared to all MGRAs. A shadow price is computed which scales the size of the MGRA based on the ratio of the observed share to the estimated share. The model is rerun until the estimated and observed shares are within a reasonable tolerance. The shadow prices are written to a file and can be used in subsequent model runs to cut down computational time.

There are four school location choice models: a preschool model, a grade school model, a high school model, and a university model.

The preschool location choice model assigns a school location for preschool children (person type 8) who are enrolled in preschool and daycare. The size term for this model includes a number of employment types and population, since daycare and preschool enrollment and employment are not explicitly tracked in the input land use data. Explanatory variables include:

- Income
- Age
- Distance
- The tour mode choice logsum for the student from the residential MGRA to each sampled preschool MGRA using peak levels-of-service
- Size of each sampled preschool MGRA

The grade school location choice model assigns a school location for every K–8 student in the synthetic population; the size term for this model is K–8 enrollment. School district boundaries are used to restrict the choice set of potential school location zones based on residential location. The explanatory variables used in the grade school model include:

- School district boundaries
- Distance
- The tour mode choice logsum for the student from the residence MGRA to the sampled school MGRA using peak levels-of-service
- The size of the school MGRA

The high school location choice model assigns a school location for every high school student in the synthetic population; the size term for this model is high school enrollment. District boundaries are also used in the high school model to restrict the choice set. The explanatory variables in the high school model include:

- School district boundaries
- Distance
- The tour mode choice logsum for the student from the residence MGRA to the sampled school MGRA using peak levels-of-service
- The size of the school MGRA

A university location choice model assigns a university location for every university student in the synthetic population. There are three types of college/university enrollment in the input land use data file: college enrollment, which measures enrollment at major colleges and universities; other college enrollment, which measures enrollment at community colleges; and adult education enrollment, which includes trade schools and other vocational training. The size terms for this model are segmented by student age, where students aged less than 30 use a “typical” university size term, which gives a lower weight to adult education enrollment, while students aged 30 or greater have a higher weight for adult education.

Explanatory variables in the university location choice model include:

- Student worker status
- Student age
- Distance
- Tour mode choice logsum for student from residence MGRA to sampled school MGRA using peak levels-of-service

SM 3.1: Car-Ownership Model

Number of Models:	1
Decision-Making Unit:	Households
Model Form:	Nested Logit
Alternatives:	Five (0, 1, 2, 3, 4+ autos)

The car-ownership model is described under SM 2.1 above. The model is rerun after work/school location choice so that car ownership can be influenced by the actual work and school locations predicted by sub-model 3.1.

The explanatory variables in model 3.2 include the ones listed under SM 2.1 above, with the addition of the following:

- A variable measuring auto dependency for workers in the household based upon their home to work tour mode choice logsum
- A variable measuring auto dependency for students in the household based upon their home to school tour mode choice logsum
- A variable measuring the time on rail transit (light rail or commuter rail) as a proportion of total transit time to work for workers in the household
- A variable measuring the time on rail transit (light rail or commuter rail) as a proportion of total transit time to school for students in the household

The household mandatory activity auto dependency variable is calculated using the difference between the SOV and the walk-to-transit mode choice logsum, stratified by person type (worker versus student). The logsums are computed based on the household MGRA and the work MGRA (for workers) or school MGRA (for students). The household auto dependency is obtained by aggregating individual auto dependencies of each person type (worker versus student) in the household.

SM 3.2: Toll Transponder–Ownership Model

Number of Models:	1
Decision-Making Unit:	Households
Model Form:	Binomial Logit
Alternatives:	Two (Yes or No)

This model predicts whether a household owns a toll transponder unit. It was estimated based on aggregate transponder ownership data using a quasi-binomial logit model to account for over-dispersion. It predicts the probability of owning a transponder unit for each household based on aggregate characteristics of the zone.

The explanatory variables in the model include:

- Percentage of households in the zone with more than one auto
- The number of autos owned by the household
- The straight-line distance from the MGRA to the nearest toll facility in miles
- The average transit accessibility to non-mandatory attractions using off-peak levels-of-service (accessibility measure #2)
- The average expected travel time savings provided by toll facilities to work
- The percent increase in time to Downtown San Diego incurred if toll facilities were avoided entirely

The accessibility terms are DC logsums, which represent the accessibility of non-mandatory activities from the home location by various modes (auto, non-motorized, and transit).

SM 3.3: Employer Parking Provision Model

Number of Models:	1
Decision-Making Unit:	Workers whose workplace is in CBD or another priced-parking area (park area 1)
Model Form:	Multinomial Logit
Alternatives:	Three (free on-site parking, parking reimbursement, and no parking provision)

The Employer Parking Provision Model predicts which persons have on-site parking provided to them at their workplaces and which persons receive reimbursement for off-site parking costs. The provision model takes the form of a multinomial logit discrete choice between free on-site parking, parking reimbursement (including partial or full reimbursement of off-site parking and partial reimbursement of on-site parking) and no parking provision.

It should be noted that free on-site parking is not the same as full reimbursement. Many of those with full reimbursement in the survey data could have chosen to park closer to their destinations and accepted partial reimbursement. Whether parking is fully reimbursed will be determined both by the reimbursement model and the location choice model.

Persons with workplaces outside of park area 1 are assumed to receive free parking at their workplaces.

Explanatory variables in the provision model include:

- Household income
- Occupation
- Average daily equivalent of monthly parking costs in nearby MGRAs

SM 3.4: Telework Frequency Model

Number of Models:	1
Decision-Making Unit:	Workers
Model Form:	Multinomial Logit
Alternatives:	Four (never or less than four days per month, one day per week, two to three days per week, and four or more days per week)

This model predicts telework frequency based on household and person variables for workers who telework occasionally. It was estimated from the 2017 Household Travel Survey data and implemented in the resident travel demand models. The outcome of the telework model are reflected in adjustments made to the coordinated daily activity pattern (CDAP) model; the mandatory tour generation model; and the non-mandatory tour frequency model, tour, and trip mode choice models.

The explanatory variables in the model include:

- Occupation
- Household size
- Household with kids
- Household income
- Work and student status
- Number of vehicles
- Distance to work

The number of significant explanatory variables decreases as telework frequency increases. This may be due in part to the limited number of observations for which more frequent teleworking is observed but may also be caused by limits in available explanatory variables. For example, some workers in the technology sector may be more able to telework than others, due to their job responsibilities. This unobserved variation in the factors that lead to teleworking suggest that future model predictions should be treated with care.

SM 4.1: Coordinated Daily Activity Pattern Model

Number of Models:	1
Decision-Making Unit:	Households
Model Form:	Multinomial Logit
Alternatives:	691 total alternatives, but depends on household size

This model predicts the main DAP type for each household member. The activity types that the model considers are:

- **Mandatory pattern (M)**, which includes at least one of the three mandatory activities—work, university, or school. This constitutes either a workday or a university/school day and may include additional non-mandatory activities such as separate home-based tours or intermediate stops on the mandatory tours.
- **Non-mandatory pattern (N)**, which includes only maintenance and discretionary tours. Note that the way tours are defined means that maintenance and discretionary tours cannot include travel for mandatory activities.
- **At-home pattern (H)**, which includes only in-home activities. At-home patterns are not distinguished by any specific activity (e.g., working at home, taking care of a child, being sick, etc.). Cases where someone is not in town (e.g., business travel) are also combined with this category.

Statistical analysis performed in a number of different regions has shown that there is an extremely strong correlation between DAP types of different household members, especially for joint N and H types. For this reason, the DAP for different household members should not be modeled independently, as doing so would introduce significant error in the types of activity patterns generated at the household level. This error has implications for several policy sensitivities, including greenhouse gas (GHG) policies. Therefore, the model is applied across all household members simultaneously; the interactions or influences of different types of household members (e.g., the effect of a child who stays at home on the simulation day on the probability of a part-time worker also staying at home) are taken into account through a specific set of interaction variables.

The model also simultaneously predicts the presence of fully joint tours for the household. Fully joint tours are tours in which two or more household members travel together for all stops on the tour. Joint tours are only a possible alternative at the household level when two or more household members have an active (M or N) travel day. The joint tour indicator predicted by this model is then considered when generating and scheduling mandatory tours in order to reflect the likelihood of returning home from work earlier in order to participate in a joint tour with other household members.

The choice structure includes 363 alternatives with no joint travel and 328 alternatives with joint travel, totaling to 691 alternatives as shown in Table S.9. Note that the choices are available based on household size. There are also two facets of the model that reduce the complexity. First, mandatory DAP types are only available for appropriate person types (workers and students). Second, and more importantly, intrahousehold coordination of DAP types is relevant only for the N and H patterns. Thus, simultaneous modeling of DAP types for all household members is essential only for the trinary choice (M, N, H), while the sub-choice of the mandatory pattern can be modeled for each person separately.

Table S.9: Number of Choices in CDAP Model

Number of Choices in CDAP Model			
Household Size	**Alternatives – No Joint Travel**	**Alternatives with Joint Travel**	**All Alternatives**
1	3	0	3
2	3×3=9	3×3−(3×2−1)=4	13
3	3×3×3=27	3×3×3−(3×3−2)=20	47
4	3×3×3×3=81	3×3×3×3−(3×4−3)=72	153
5 or more	3×3×3×3×3=243	3×3×3×3×3−(3×5−4)=232	475
Total	**363**	**328**	**691**

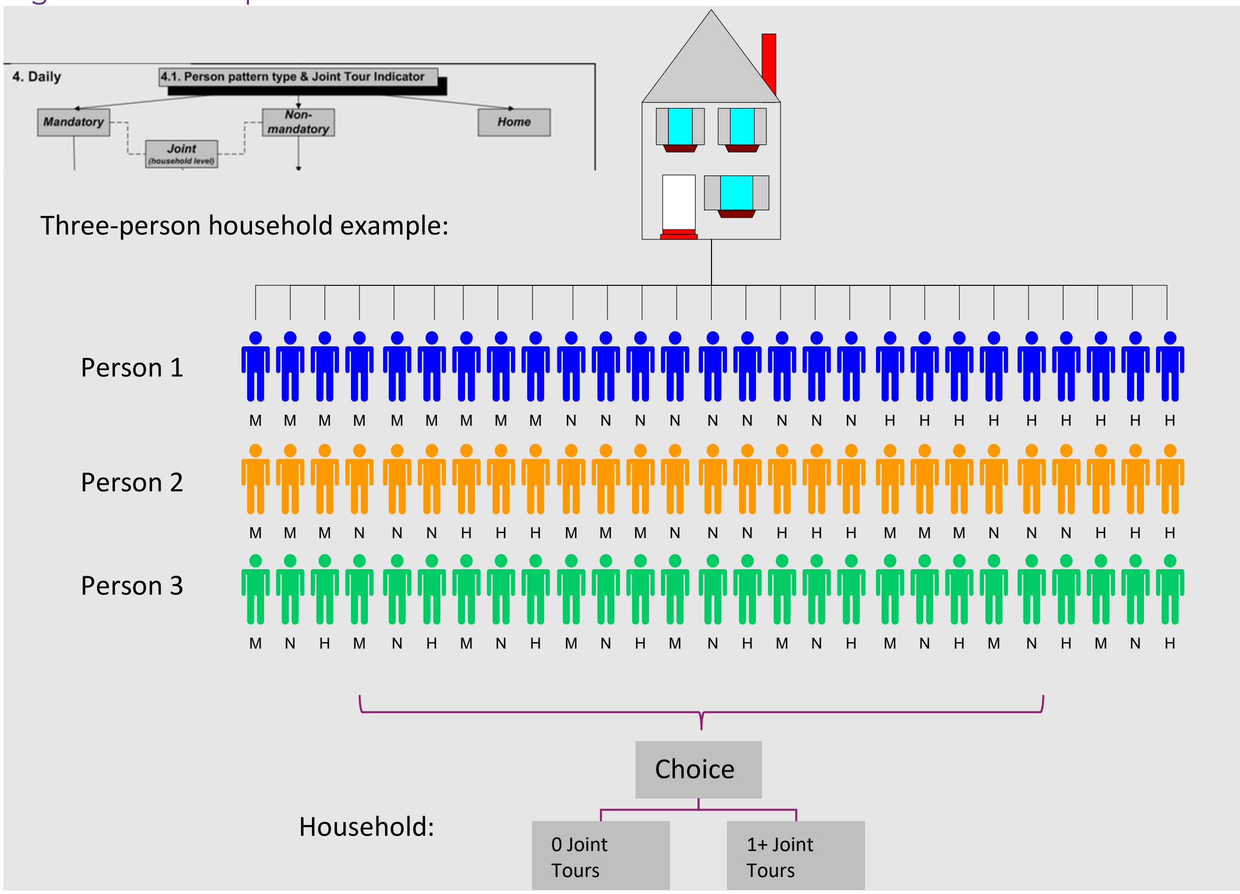
The structure is shown graphically in Figure S.6 for a three-person household. Each of the 27 DAP choices is made at the household level and describes an explicit pattern-type for each household member. For example, the fourth choice from the left is person 1 mandatory (M), person 2 non-mandatory (N), and person 3 mandatory (M). The exact tour frequency choice is a separate choice model conditional upon the choice of alternatives in the trinary choice. This structure is much more powerful for capturing intrahousehold interactions than sequential processing. The choice of 0 or 1+ joint tours is shown below the DAP choice for each household member. The choice of 0 or 1+ joint tours is active for this DAP choice because at least two members of the household would be assigned active travel patterns in this alternative.

For a limited number of households with a size of greater than five, the model is applied for the first five household members by priority while the rest of the household members are processed sequentially, conditional upon the choices made by the first five members. The rules by which members are selected for inclusion in the main model are that first priority is given to any full-time workers (up to two), then to any part-time workers (up to two), then to children, youngest to oldest (up to three).

The CDAP model explanatory variables include:

- Household size
- Number of adults in household
- Number of children in household
- Auto sufficiency (see car-ownership model for details)
- Household income
- Dwelling type
- Person type
- Age
- Gender
- Usual work location
- The tour mode choice logsum for the worker from the residential MGRA to each sampled workplace MGRA using peak levels-of-service
- The tour mode choice logsum for the student from the residential MGRA to each sampled school MGRA using peak levels-of-service
- Accessibility across all modes of transport from household MGRA to retail employment or non-mandatory locations (accessibility term #45, see section SM 1.2 above)

Figure S.6: Example of DAP Model Alternatives for a Three-Person Household



SM 4.2.1: Individual Mandatory Tour Frequency

Number of Models:	1
Decision-Making Unit:	Persons
Model Form:	Multinomial Logit
Alternatives:	5 (1 Work Tour, 2+ Work Tours, 1 School Tour, 2+ School Tours, 1 Work/1 School Tour)

Based on the DAP chosen for each person, individual mandatory tours, such as work, school, and university tours are generated at the person level. The model is designed to predict the exact number and purpose of mandatory tours (e.g., work and school/university) for each person who chose the mandatory DAP type at the previous decision-making stage. Since the DAP-type model at the household level determines which household members engage in mandatory tours, all persons subjected to the individual mandatory tour model implement at least one mandatory tour. The model has the following five alternatives: 1 Work Tour, 2 or more Work Tours, 1 School Tour, 2 or more School Tours, and 1 Work/1 School Tour.

DAPs and subsequent behavioral models of travel generation include these explanatory variables:

- Auto sufficiency
- Household income
- Non-family household (for example Group Quarters) indicator
- Number of preschool children in household
- Number of school aged children 6–18 years old in household not going to school
- Person type
- Gender
- Age
- Distance to work location
- Distance to school location
- Best travel time to work location
- HOV accessibility from household MGRA to employment (accessibility terms #25, #26, #27 [by auto sufficiency], see section SM 1.2 above)

SM 4.2.2: Individual Mandatory Tour Time of Day Choice

Number of Models:	3 (Work, University, and School)
Decision-Making Unit:	Persons
Model Form:	Multinomial Logit
Alternatives:	820 (combinations of tour departure half-hour and arrival half-hour back at home, with aggregation between 1 a.m. and 5 a.m.)

After individual mandatory tours have been generated, the tour departure time from home and arrival time back at home is chosen simultaneously. Note that it is not necessary to select the destination of the tour, as this has already been determined in sub-model 2.3. The model is a discrete choice construct that operates with tour departure from home and arrival back home time combinations as alternatives. The proposed utility structure is based on "continuous shift" variables and represents an analytical hybrid that combines the advantages of a discrete choice structure (flexible in specification and easy to estimate and apply) with the advantages of a duration model (a simple structure with few parameters, and which supports continuous time). The model has a temporal resolution of one-half hour that is expressed in 820 half-hour departure/arrival time alternatives. The model uses direct availability rules for each subsequently scheduled tour, to be placed in the residual time window left after scheduling tours of higher priority. This conditionality ensures a full consistency for the individual entire-day activity and travel schedule as an outcome of the model.

In the CT-RAMP model structure, the tour-scheduling model is placed after destination choice and before mode choice. Thus, the destination of the tour and all related destination and origin-destination attributes are known and can be used as variables in the model estimation.

The following practical rules are used to set the alternative departure/arrival time combinations:

- Each reported/modeled departure/arrival time is rounded to the nearest half-hour. For example, the half-hour "17" includes all times from 10:45 a.m. to 11:14 a.m.
- Any times before 5 a.m. are shifted to 5 a.m., and any times after 1 a.m. are shifted to 1 a.m. This typically results in a shift for relatively few cases and limits the number of half-hours in the model to 41.
- Every possible combination of the 41 departure half-hours with the 41 arrival half-hours (where the arrival half-hour is the same or later than the departure hour) is an alternative. This gives 41×42/2=861 choice alternatives.

The network simulations to obtain travel time and cost skims are implemented for five broad periods: early a.m., a.m. peak, midday, p.m. peak, and night (evening and late night) for the three mandatory tour purposes (work, university, and school).

The model includes the following explanatory variables:

- Household income
- Person type
- Gender
- Age
- Mandatory tour frequency
- Auto travel distance
- Destination employment density
- Tour departure time
- Tour arrival time
- Tour duration
- The tour mode choice logsum by tour purpose from the residence MGRA to each sampled MGRA location

SM 4.2.3: Individual Mandatory Tour Mode Choice Model

Number of Models:	3 (Work, University, and K–12)
Decision-Making Unit:	Person
Model Form:	Nested Logit
Alternatives:	22 (see Figure S.7)

This model determines how the "main tour mode" (used to get from the origin to the primary destination and back) is determined. The tour-based modeling approach requires a certain reconsideration of the conventional mode choice structure. Instead of a single mode choice model pertinent to a four-step structure, there are two different levels where the mode choice decision is modeled:

- The tour mode level (upper-level choice)
- The trip mode level (lower-level choice conditional upon the upper-level choice)

The tour mode choice model considers the following alternatives:

- Drive-Alone
- Shared-Ride 2
- Shared-Ride 3+
- Walk
- Bike
- Walk–Transit

- Park & Ride Transit (drive to transit station and ride transit)
- Kiss & Ride Transit (drop-off at transit station and ride transit)
- School Bus (only available for grade school and high school tour purposes)

The mode of each tour is identified based on the combination of modes used for all trips on the tour, according to the following rules:

- If any trip on the tour is TNC Transit, then the tour mode is TNC Transit.
- If any trip on the tour is Park & Ride Transit, then the tour mode is Park & Ride Transit.
- If any trip on the tour is Kiss & Ride Transit, then the tour mode is Kiss & Ride Transit.
- If any trip on the tour is School Bus, then the tour mode is School Bus.
- If any trip on the tour is Walk–Transit, then the tour mode is Walk–Transit.
- If any trip on the tour is Bike, then the tour mode is Bike.
- If any trip on the tour is Shared-Ride 3+, then the tour mode is Shared-Ride 3+.
- If any trip on the tour is Shared-Ride 2, then the tour mode is Shared-Ride 2.
- If any trip on the tour is Drive-Alone, then the tour mode is Drive-Alone.
- All remaining tours are Walk.

These tour modes create a hierarchy of importance that ensures that transit is available for trips on tours with transit as the preferred mode and that HOV lanes are available for trips on tours where shared-ride is the preferred mode. It also ensures that if drive–transit is used for the outbound trip on the tour, that mode is also available for the return journey (such that the traveler can pick up their car at the parking lot on the way home).

Modes for the tour mode choice model are shown in Figure S.7. The model is distinguished by the following characteristics:

- Segmentation of the HOV mode by occupancy categories, which is essential for modeling specific HOV/high-occupancy toll (HOT) lanes and policies
- An explicit modeling of toll versus non-toll choices as highway sub-modes, which is essential for modeling highway pricing projects and policies
- Distinguishing between certain transit sub-modes that are characterized by their attractiveness, reliability, comfort, convenience, and other characteristics beyond travel time and cost (such as Express Bus, Bus *Rapid* Transit, light rail transit, and commuter rail)
- Distinguishing between walk and bike modes if the share of bike trips is significant

Note that non-toll and toll-eligible alternatives for each auto mode provide an opportunity for toll choice as a path choice within the nesting structure. This requires separate non-toll and toll eligible skims to be provided as inputs to the model (where non-toll paths basically “turn off” all toll and HOT lanes). Three transit skims are built for each TAP pair to ensure that a maximum variety of transit choices are represented for each trip. They include a local-only skim, a premium-only skim (premium modes include Express Bus, Bus *Rapid* Transit, light rail transit, and/or commuter rail), and a local plus premium skim (with a required transfer). A post-processing script ensures that the path between each TAP pair is unique across all three skims. For example, if the local plus premium skim does not include a transfer between local bus and one of the premium modes, the skim values are set to zero, since the path would already be represented in either the local skim or the premium skim.

The tour mode choice model is based on the round-trip (outbound and return) level-of-service between the tour anchor location (home for home-based tours and work for at-work sub-tours) and the tour primary destination. The tour mode choice model assumes that the mode of the outbound journey is the same as the mode for the return journey in the consideration of level-of-service information. This is a simplification that results in a model with a relatively modest number of alternatives and allows the estimation process to use data from an on-board survey in which the mode for only one direction is known. Only these aggregate tour modes are used in lower-level model components such as stop frequency, stop location, and as constraints in trip mode choice.

However, the model calculates utilities for a more disaggregate set of modes in lower-level alternatives that are consistent with the more detailed modes in trip mode choice. This allows the tour mode choice model to consider the availability of multiple transit modes and/or Managed Lane route choices in the choice of tour mode, with their specific levels-of-service and modal constants. The more aggregate tour modes act as constraints in trip mode choice; for example, if walk–transit is chosen in tour mode choice, only shared-ride, walk, and walk–transit modes are available in trip mode choice. Ultimately, trips are assigned to networks using the more disaggregate trip modes.

The lower-level nest mode choices (which are the same as the trip mode choice model alternatives) are:

- Drive-Alone Non-Transponder
- Drive-Alone Transponder
- Shared-Ride 2
- Shared-Ride 3+
- Walk
- Bike
- Walk–Transit

- Park & Ride to Transit
- Kiss & Ride to Transit
- TNC to Transit
- Taxi
- TNC Single
- TNC Pooled
- School Bus

The appropriate skim values for the tour mode choice are a function of the MGRA of the tour origin and MGRA of the tour primary destination. As described in the section on Treatment of Space, all transit level-of-service and certain non-motorized level-of-service (for MGRAs within three miles of each other) are computed "on-the-fly" in mode choice. Transit access and egress times are specifically determined via detailed MGRA-to-TAP distances computed within GIS software. Actual TAP–TAP pairs used for the MGRA pair, and therefore actual transit levels-of-service, rank and retain the best four (a user-defined variable) TAP pairs regardless of line haul mode.

Figure S.7: Tour Mode Choice Model Structure

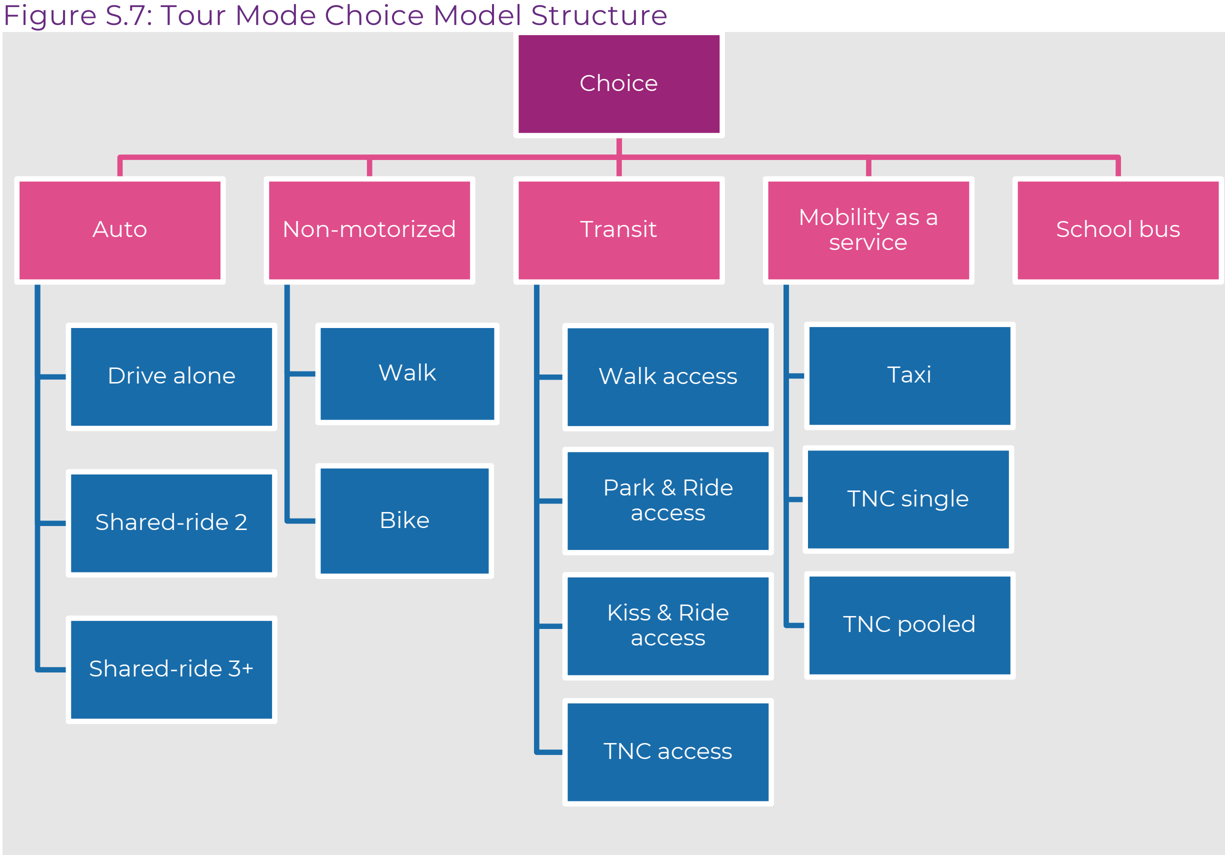


Table S.10: Skims Used in Tour Mode Choice (Auto Skims by Value of Time)

Skims Used in Tour Mode Choice (Auto Skims by Value of Time)	
Mode	**Skims**
Drive-Alone Non-Transponder	All general-purpose lanes available. HOV, HOT, and toll lanes unavailable. Toll bridges are available.
Drive-Alone Transponder	All general-purpose and toll lanes are available. HOV lanes are unavailable. HOT lanes are available for the SOV toll rate. Toll bridges are available.
Shared-Ride 2	All general-purpose, HOV, and HOT lanes are available up to 2024 (as set by policy in the 2021 Regional Plan), and toll lanes are available. Toll bridges are available.
Shared-Ride 3+	All general-purpose, HOV, and HOT lanes available for free, and toll lanes are available. Toll bridges are available.
Walk	Roadway distance, excluding freeways, but allowing select bridges with sidewalks. This is used for any MGRA pair whose distance is greater than three miles. The walk time for MGRA pairs whose distance is less than three miles relies on the GIS-based walk distances.
Bike	Roadway distance, excluding freeways, but allowing select bridges with bike lanes. This is used for any MGRA pair whose distance is greater than two miles. The bike time for MGRA pairs whose distance is less than two miles relies on the GIS-based bike distances.
Transit: Local Bus Only	Local Bus TAP-to-TAP skims, including in-vehicle time, first wait time, transfer wait time, and fare.
Transit: Premium Only	Premium TAP-to-TAP skims, including in-vehicle time, first wait time, transfer wait time, and fare. Premium mode includes Express Bus, Bus *Rapid* Transit, light rail, Tier 1 transit, and commuter rail.
Transit: Local and Premium	Local plus premium TAP-to-TAP skims (with a required transfer), including in-vehicle time, first wait time, transfer wait time, and fare.

The individual mandatory tour mode choice model contains the following explanatory variables:

- Auto sufficiency
- Household size
- Age
- Gender
- In-vehicle time (auto and transit)
- Walk and bike time
- Auto operating cost
- Auto parking cost
- Auto terminal time
- Auto toll value
- Transit first wait time
- Transit transfer time
- Number of transit transfers
- Transit walk access time
- Transit walk egress time
- Transit walk auxiliary time
- Transit fare
- Transit drive access time
- Transit drive access cost
- Intersection density
- Employment density
- Dwelling unit density

SM 4.2.4: School Escort Model

Multi-occupant vehicles account for a significant portion of overall transportation demand, and most of multi-occupant vehicles are made up of members of the same household. Some of this joint travel occurs by household members picking up and dropping off (i.e., "escorting") other household members, including for mandatory activity purposes such as school. A school escort model was added in ABM2+ to explicitly handle intrahousehold coordinated activity for escorting children to and from school.

The model is run after work and school locations have been chosen for all household members and after work and school tours have been generated and scheduled. The model labels household members of driving age as potential “chauffeurs” and children with school tours as potential “escortees.” The model then attempts to match potential chauffeurs with potential escortees in a choice model whose alternatives consist of “bundles” of escortees with chauffeurs for each half tour. A half tour is a sequence of trips between the tour origin (home) and the tour primary destination. For the chauffeur, the primary destination is the furthest drop-off or pick-up activity from home. For the child being escorted, the primary destination is school.

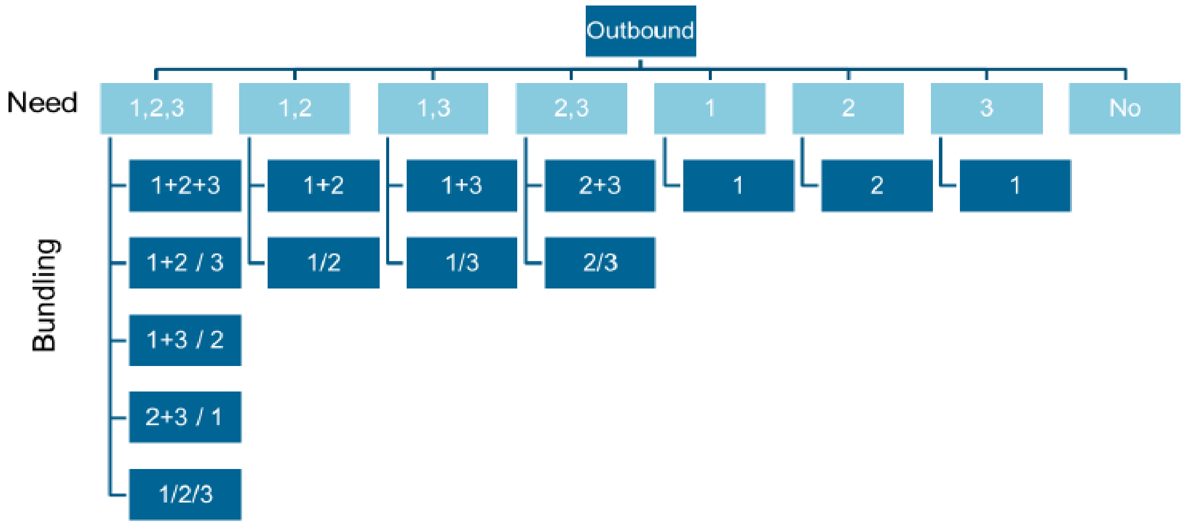
The model classifies each child’s school tour into three types:

- **No escorting:** the child walks, bikes, takes transit, drives, or takes a school bus to/from school.
- **Pure escort:** the child gets a ride to/from school, where the purpose of the chauffeur’s tour is solely for the purposes of picking up or dropping off the child.
- **Rideshare:** the child gets a ride to/from school, where the child is dropped off or picked up on the way to or from the driver’s work or school primary destination.

The model considers up to three children with school tours and up to two potential chauffeurs in each household. If there are more children in the household with school tours, the model selects the youngest three who are most likely to require escorting. A rule-based algorithm is used to select the most likely chauffeurs in households with more than two potential drivers. The potential choice set is also truncated based on scheduled work and school times for Rideshare tours, where only drivers whose departure time from home (or arrival time back at home) is within 30 minutes of the child requiring escorting are considered as potential combinations of chauffeurs/escortees. Only drivers with open time windows are allowed as potential chauffeurs for Pure Escort.

In summary, the model bundles which children are escorted by which drivers and by what type of school escort type. Figure S.8 shows an example of bundling children by chauffeur for a household with three children attending school and two eligible drivers. The first row of the alternatives shows different combinations of children being escorted. For example, in the left-most alternative, all three children are escorted, whereas in the right-most alternative, no children are escorted. The dark blue boxes under each of the first-row alternatives show different combinations of bundling children by tour; in the first box underneath the left-most alternative, both children are escorted on one half tour (one task). In the next alternative, child 1 and 2 are escorted on one tour, whereas child 3 is escorted on another tour (two tasks). Each task is matched with a chauffeur by tour type (Pure Escort versus Rideshare). In this example, there are 15 alternatives and 22 potential tasks, and each task has a potential of four different options for chauffeur type and tour, yielding 189 alternatives.

Figure S.8: School Escort Model Example of Bundling Children by Half Tour



The explanatory variables in the model include the following:

- Chauffeur disutility for ridesharing—out-of-direction distance and time
- Escortee utility for ridesharing, which considers age
- Escortee utility for non-rideshare (non-motorized time to school)
- Bundling utilities (the utility of driving each child separately versus taking children together)

The model is run for each direction separately. Since a strong symmetry effect is observed in the data, the model is run iteratively: first for the outbound direction, then for the inbound direction, and again for the outbound direction, considering the outcomes of the inbound direction. Tours are formed directly from the model results. In the case of multiple pick-ups or drop-offs on a half tour, the children are arranged by proximity to home; the nearest child is dropped off first or picked up last. The occupancy is calculated based on the number of children in the car for each trip. The software explicitly links the drivers to the children and writes all relevant information to the tour and trip file.

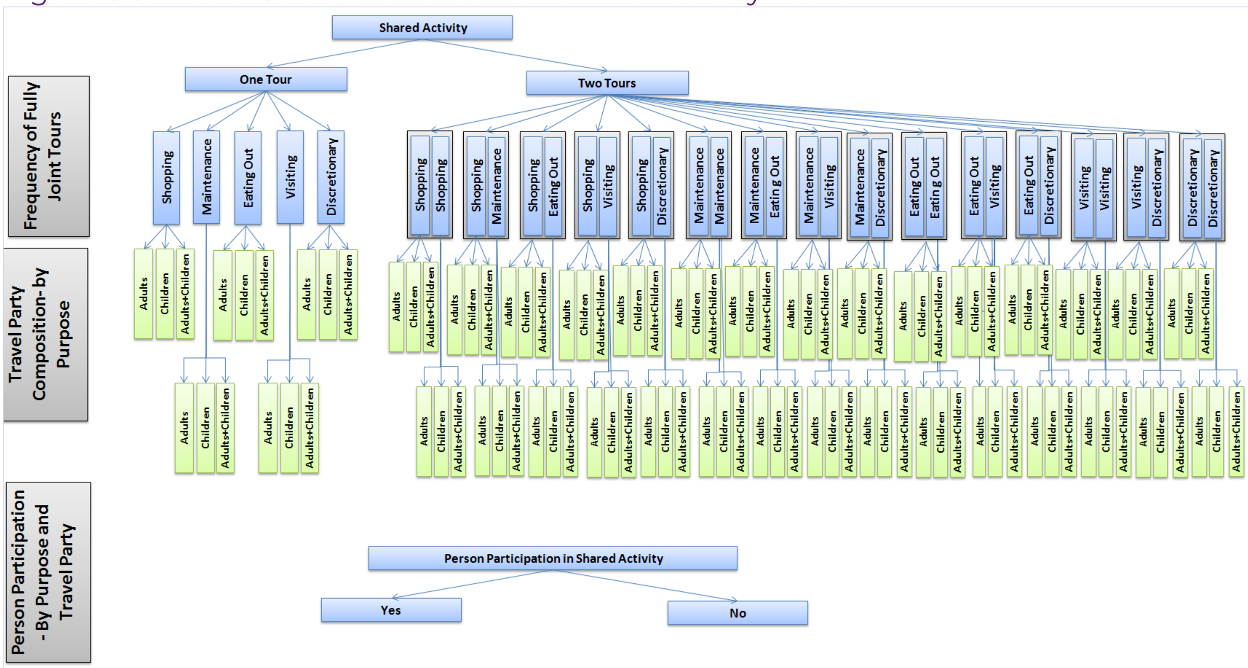
SM 4.3: Generation of Joint Household Tours

In the CT-RAMP structure, joint travel for non-mandatory activities is modeled explicitly in the form of fully joint tours (where all members of the travel party travel together from the beginning to the end and participate in the same activities). This accounts for more than 50% of joint travel.

Each fully joint tour is considered a modeling unit with a group-wise decision-making process for the primary destination, mode, frequency, and location of stops. Modeling joint activities involves two linked stages (see Figure S.9).

- A tour generation and composition stage that generates the number of joint tours by purpose/activity type made by the entire household. This is the joint tour frequency model.
- A tour participation stage at which the decision whether to participate or not in each joint tour is made for each household member and tour.

Figure S.9: Model Structure for Joint Non-Mandatory Tours



Joint tour party composition is modeled for each tour. Travel party composition is defined in terms of person categories (e.g., adults and children) participating in each tour. Person participation choice is then modeled for each person sequentially. In this approach, a binary choice model is calibrated for each activity, party composition, and person type. The model iterates through household members and applies a binary choice to each to determine if the member participates. The model is constrained to only consider members with available time windows overlapping with the generated joint tour.
The approach offers simplicity but at the cost of overlooking potential non-independent participation probabilities across household members. The joint tour frequency, composition, and participation models are described below.

SM 4.3.1: Joint Tour Frequency and Composition

Number of Models:	1
Decision-Making Unit:	Households with a Joint Tour Indicator Predicted by the CDAP Model
Model Form:	Multinomial Logit
Alternatives:	105 (1 tour segmented by 5 purposes and 3 composition classes, 2 tours segmented by 5 purposes and 3 composition classes)

Joint tour frequencies (1 or 2+) are generated by households, purpose, and tour composition (adults only, children only, or adults and children). Later models determine who in the household participates in the joint tour. The model is only applied to households with a joint tour indicator at the household level as predicted by the CDAP model.

The explanatory variables in the joint tour frequency model include:

- Auto sufficiency
- Household income
- Number of full-time workers in household
- Number of part-time workers in household
- Number of university students in household
- Number of non-workers in household
- Number of retirees in household
- Number of driving-age school children in household
- Number pre-driving-age school children in household
- Number of preschool children in household
- Number of adults in household not staying home
- Number of children in household not staying home
- Shopping HOV accessibility from household MGRA to employment (accessibility terms #10, #11, and #12 [by auto sufficiency], see section SM 1.2 above)
- Maintenance HOV accessibility from household MGRA to employment (accessibility terms #13, #14, and #15 [by auto sufficiency], see section SM 1.2 above)
- Discretionary HOV accessibility from household MGRA to employment (accessibility terms #22, #23, and #24 [by auto sufficiency], see section SM 1.2 above)
- Presence and size of overlapping time windows, which represent the availability of household members to travel together after mandatory tours have been generated and scheduled

SM 4.3.2: Joint Tour Participation

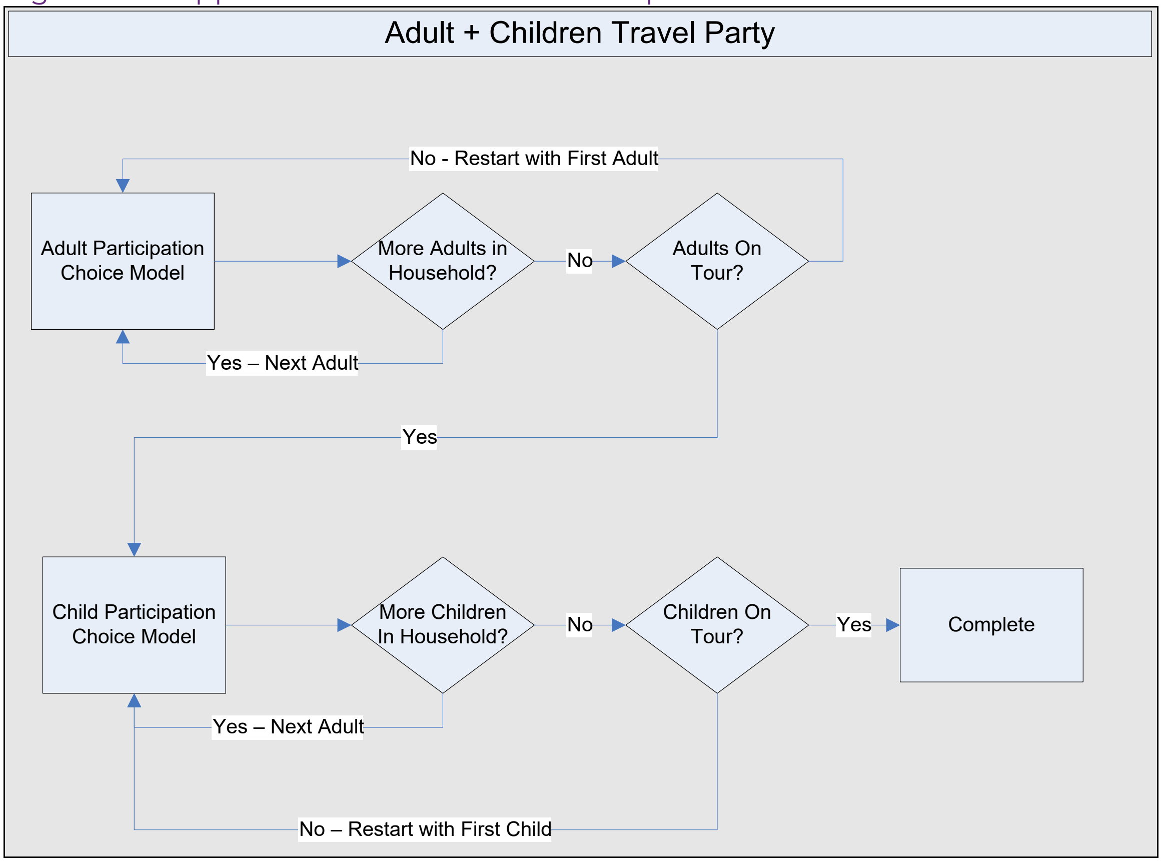
Number of Models:	1
Decision-Making Unit:	Persons
Model Form:	Multinomial Logit
Alternatives:	2 (Yes or No)

Joint tour participation is modeled for each person and each joint tour. If the person does not correspond to the composition of the tour determined in the joint tour composition model, they are ineligible to participate in the tour. Similarly, persons whose DAP type is home are excluded from participating. The model relies on heuristic process to assure that the appropriate persons participate in the tour as per the composition model.
The model follows the logic depicted in Figure S.10.

The explanatory variables in the participation model include:

- Auto sufficiency
- Household income
- Frequency of joint tours in the household
- Number of adults (not including decision maker) in household
- Number of children (not including decision maker) in household
- Person type
- Maximum pair-wise overlaps between the decision maker and other household members of the same person type (adults or children)

Figure S.10: Application of the Person Participation Model



SM 4.3.3: Joint Tour Primary Destination Choice

Number of Models:	1
Decision-Making Unit:	Tour
Model Form:	Multinomial Logit
Alternatives:	MGRAs

The joint tour primary destination choice model determines the location of the tour primary destination. The destination is chosen for the tour and assigned to all tour participants. The model works at an MGRA level, and sampling of destination alternatives is implemented to reduce computation time.

The explanatory variables for the joint tour primary destination choice model include:

- Household income
- Gender
- Age
- Maximum pair-wise overlaps between the decision maker and other household members of the same person type (adults or children)
- Number of tours left over (including the current tour) to be scheduled
- Off-peak MGRA-to-MGRA distance
- The tour mode choice logsum for the person from the residence MGRA to each sampled MGRA location
- Non-mandatory HOV accessibility from household MGRA to employment (accessibility terms #7, #8, and #9 [by auto sufficiency], see section SM 1.2 above)
- The size of each sampled MGRA by tour purpose (see section SM 1.2 above)

SM 4.3.4: Joint Tour Time of Day Choice

Number of Models:	1
Decision-Making Unit:	Persons
Model Form:	Multinomial Logit
Alternatives:	861 (combinations of tour departure half-hour and arrival half-hour back at home)

After joint tours have been generated and assigned a primary location, the tour departure time from home and arrival time back at home is chosen simultaneously. The model is fully described under sub-model 4.2.2 above. However, a unique condition applies when applying the time-of-day choice model to joint tours. That is, the tour departure and arrival period combinations are restricted to only those available for each participant on the tour after scheduling mandatory activities. Once the tour departure/arrival time combination is chosen, it is applied to all participants on the tour.

The model includes the following explanatory variables:

- Household income
- Person type
- Gender
- Age
- Mandatory tour frequency
- Auto travel distance
- Destination employment density
- Tour departure time
- Tour arrival time
- Tour duration
- The tour mode choice logsum by tour purpose from the residence MGRA to each sampled MGRA location

SM 4.3.5: Joint Tour Mode Choice Model

Number of Models:	2 (Maintenance and Discretionary)
Decision-Making Unit:	Person
Model Form:	Nested Logit
Alternatives:	23 (see Figure S.7 under the Individual Mandatory Tour Mode Choice section)

Like the individual mandatory tour mode choice model, the joint tour model determines how the "main tour mode" (used to get from the origin to the primary destination and back) is determined.

The joint tour mode choices are (drive alone, and school bus is eliminated for this model):

- Shared-Ride 2
- Shared-Ride 3+
- Walk
- Bike
- Walk–Transit
- Park & Ride to Transit
- Kiss & Ride to Transit
- TNC to Transit

The joint tour mode choice model contains the following explanatory variables:

- Auto sufficiency
- Household size
- Age
- Gender
- In-vehicle time (auto and transit)
- Walk and bike time
- Auto operating cost
- Auto parking cost
- Auto terminal time
- Auto toll value
- Transit first wait time
- Transit transfer time
- Number of transit transfers
- Transit walk access time
- Transit walk egress time
- Transit walk auxiliary time
- Transit fare
- Transit drive access time
- Transit drive access cost
- Intersection density
- Employment density
- Dwelling unit density

SM 4.4.1: Individual Non-Mandatory Tour Frequency

Number of Models:	1
Decision-Making Unit:	Households (at least one household member must have a DAP type of M or N)
Model Form:	Multinomial Logit
Alternatives:	Approximately 197 alternatives, composed of 0–1+ or 2+ tours of each type of maintenance activity (Escort, Shop, Other Maintenance, Eat Out, Visit, and Other Discretionary)

Allocated tours cover non-mandatory activities taken on by an individual on behalf of the household and include escort, shopping, other maintenance, eat out, visit, and other discretionary tours. They are generated by the household and later assigned to an individual in the household based on their residual time window. The choices include the number (0–2) and type of tours generated by each of the non-mandatory tour purposes. The explanatory variables include:

- Auto sufficiency
- Household income
- Dwelling type
- Number of full-time workers in household
- Number of part-time workers in household
- Number of university students in household
- Number of non-workers in household
- Number of retirees in household
- Number of driving-age school children in household
- Number pre-driving-age school children in household
- Number of preschool children in household
- Number of adults in household not staying home
- Number of children in household not staying home
- Gender
- Age
- Education level
- Indicator variable for whether person works at home regularly
- Number of individual/joint tours per person by tour purpose
- Population density at the origin
- Work accessibility from household MGRA to employment (accessibility terms #45, see section SM 1.2 above)
- School accessibility from household MGRA to employment (accessibility terms #45, see section SM 1.2 above)
- Escorting HOV accessibility from household MGRA to employment (accessibility terms #25, #26, and #27 [by auto sufficiency], see section SM 1.2 above)
- Shopping SOV/HOV accessibility from household MGRA to employment (accessibility terms #10, #11, #12, #28, #29, and #30 [by auto sufficiency], see section SM 1.2 above)

- Maintenance SOV/HOV accessibility from household MGRA to employment (accessibility terms #13, #14, #15, #31, #32, and #33 [by auto sufficiency], see section SM 1.2 above)
- Eating out SOV/HOV accessibility from household MGRA to employment (accessibility terms #16, #17, #18, #34, #35, and #36 [by auto sufficiency], see section SM 1.2 above)
- Walk accessibility from household MGRA to non-mandatory activities (accessibility terms #3, see section SM 1.2 above)

SM 4.4.2: Individual Non-Mandatory Tour Primary Destination Choice

Number of Models:	6 (Escort, Shop, Other Maintenance, Eat Out, Visit, and Other Discretionary)
Decision-Making Unit:	Person
Model Form:	Multinomial Logit
Alternatives:	MGRAs

The six non-mandatory tour purposes are: escorting, shopping, other maintenance, eating out, visiting, and other discretionary. The non-mandatory tour primary destination choice model determines the location of the tour primary destination for each of the six non-mandatory tour purposes. The model works at an MGRA level, and sampling of destination alternatives is implemented to reduce computation time. Note that the mode choice logsum used is based on a “representative” time period for individual non-mandatory tours, which is currently off-peak, since the actual time period is not chosen until sub-model 4.4.3.

The explanatory variables in non-mandatory tour location choice models include:

- Household income
- Age of the traveler
- Gender
- Distance
- The tour mode choice logsum for the traveler from the residence MGRA to each sampled destination MGRA using off-peak level-of-service
- Time pressure calculated as the log of the maximum time divided by number of tours left to be scheduled
- The size of each sampled MGRA

SM 4.4.3: Individual Non-Mandatory Tour Time of Day Choice

Number of Models:	6 (Escort, Shop, Other Maintenance, Eat Out, Visit, and Other Discretionary)
Decision-Making Unit:	Person
Model Form:	Multinomial Logit
Alternatives:	861 (combinations of tour departure half-hour and arrival half-hour back at home)

After individual non-mandatory tours have been generated, allocated, and assigned a primary location, the tour departure time from home and arrival time back at home is chosen simultaneously. The tour departure and arrival period combinations are restricted to only those available for each participant on the tour after scheduling individual mandatory tours and joint tours.

The model includes the following explanatory variables:

- Household income
- Person type
- Gender
- Age
- Mandatory tour frequency
- Joint tour indicator
- Auto travel distance
- Tour departure time
- Tour arrival time
- Tour duration
- Time pressure calculated as the log of the maximum time divided by number of tours left to be scheduled
- The tour mode choice logsum by tour purpose from the residence MGRA to each sampled MGRA location

SM 4.4.4: Individual Non-Mandatory Tour Mode Choice Model

Number of Models:	2 (Maintenance and Discretionary)
Decision-Making Unit:	Person
Model Form:	Nested Logit
Alternatives:	25 (see Figure S.7 under the Individual Mandatory Tour Mode Choice section)

Like the individual mandatory tour mode choice model, the individual non-mandatory tour model determines how the "main tour mode" (used to get from the origin to the primary destination and back) is determined.

The individual non-mandatory tour mode choices are (school bus is eliminated):

- Drive-Alone Non-Transponder
- Drive-Alone Transponder
- Shared-Ride 2
- Shared-Ride 3+
- Walk
- Bike
- Walk–Transit
- Park & Ride to Transit
- Kiss & Ride to Transit
- TNC to Transit
- Taxi
- TNC Single
- TNC Pooled

The individual non-mandatory tour mode choice model contains the following explanatory variables:

- Auto sufficiency
- Household size
- Age
- Gender
- In-vehicle time (auto and transit)
- Walk and bike time
- Auto operating cost

- Auto parking cost
- Auto terminal time
- Auto toll value
- Transit first wait time
- Transit transfer time
- Number of transit transfers
- Transit walk access time
- Transit walk egress time
- Transit walk auxiliary time
- Transit fare
- Transit drive access time
- Transit drive access cost
- Intersection density
- Employment density
- Dwelling unit density

SM 4.5.1: At-Work Sub-Tour Frequency

Number of Models:	1
Decision-Making Unit:	Persons
Model Form:	Multinomial Logit
Alternatives:	7 (none; 1 eating out tour; 1 work tour; 1 other tour; 2 work tours; 2 other tours; and a combination of eating out, work, and other tours)

At-work-based sub-tours are modeled last and are relevant only for those persons who implement at least one work tour. These underlying activities are mostly individual (e.g., business-related and dining-out purposes) but may include some household-maintenance functions as well as person- and household-maintenance tasks. There are seven alternatives in the model, corresponding to the most frequently observed patterns of at-work sub-tours. The alternatives define both the number of at-work sub-tours and their purpose.

The at-work sub-tour frequency model includes the following explanatory variables:

- Household income
- Number of driving age adults
- Number of preschool children
- Person type

- Gender
- Number of individual and joint mandatory and non-mandatory tours generated in the day
- Employment density at the workplace
- Mixed-use category at the workplace
- Non-motorized eating out accessibility from work MGRA to destination MGRA (accessibility terms #46, see section SM 1.2 above)

SM 4.5.2: At-Work Sub-Tour Primary Destination Choice

Number of Models:	1
Decision-Making Unit:	Person
Model Form:	Multinomial Logit
Alternatives:	MGRAs

The at-work sub-tour primary destination choice model determines the location of the tour primary destination. The model works at an MGRA level, and sampling of destination alternatives is implemented in order to reduce computation time. Note that the mode choice logsum used is based on a "representative" time period for individual non-mandatory tours, which is currently off-peak, since the actual time period is not chosen until model SM 4.5.3. The model is constrained such that only destinations within a reasonable time horizon from the workplace are chosen, such that the tour can be completed within the total available time window for the sub-tour.

The explanatory variables in the at-work sub-tour choice models include:

- Person type
- Distance
- The tour mode choice logsum for the traveler from the residence MGRA to each sampled destination MGRA using off-peak level-of-service
- The size of each sampled MGRA

SM 4.5.3: At-Work Sub-Tour Time of Day Choice

Number of Models:	1
Decision-Making Unit:	Person
Model Form:	Multinomial Logit
Alternatives:	861 (combinations of tour departure half-hour and arrival half-hour back at home, with aggregation of time between 1 a.m. and 5 a.m.)

After at-work sub-tours have been generated and assigned a primary location, the tour departure time from workplace and arrival time back at the workplace is chosen simultaneously. The model is fully described under SM 4.5.2, above. The tour departure and arrival period combinations are restricted to only those available based on the time window of the parent work tour.

The model includes the following explanatory variables:

- Household income
- Sub-tour purpose
- Auto travel distance
- Tour departure time
- Tour arrival time
- Tour duration
- Maximum available continuous time window (in hours) between 5 a.m. to 11 p.m. before this tour is scheduled
- The tour mode choice logsum from the work MGRA to each sampled MGRA location

SM 4.5.4: At-Work Sub-Tour Mode Choice Model

Number of Models:	1
Decision-Making Unit:	Person
Model Form:	Nested Logit
Alternatives:	25 (see Figure S.7 under the Individual Mandatory Tour Mode Choice section)

Like the individual mandatory tour mode choice model, the at-work sub-tour model determines the main sub-tour mode used to get from the workplace to the primary destination and back.

The at-work sub-tour mode choices are (school bus is eliminated):

- Drive-Alone Non-Transponder
- Drive-Alone Transponder
- Shared-Ride 2
- Shared-Ride 3+
- Walk
- Bike
- Walk–Local Bus
- Walk–Premium Transit
- Park & Ride–Local Bus

- Park & Ride–Premium Transit
- Kiss & Ride–Local Bus
- Kiss & Ride–Premium Transit
- TNC–Local Bus
- TNC–Premium Transit
- Taxi
- TNC Single
- TNC Pooled

The at work sub-tour mode choice model contains the following explanatory variables:

- Auto sufficiency
- Household size
- Age
- Gender
- In-vehicle time (auto and transit)
- Walk and bike time
- Auto operating cost
- Auto parking cost
- Auto terminal time
- Auto toll value
- Transit first wait time
- Transit transfer time
- Number of transit transfers
- Transit walk access time
- Transit walk egress time
- Transit walk auxiliary time
- Transit fare
- Transit drive access time
- Transit drive access cost
- Intersection density
- Employment density
- Dwelling unit density

SM 5.1: Intermediate Stop Frequency Model

Number of Models:	9 (by purpose, plus one model for at-work sub-tours)
Decision-Making Unit:	Person
Model Form:	Multinomial Logit
Alternatives:	16, with a maximum of 3 stops per tour direction—6 total stops on tour

The stop frequency choice model determines the number of intermediate stops on the way to and from the primary destination. The SANDAG model allowed more than one stop in each direction (up to a maximum of three) for a total of six trips per tour (three on each tour leg). An additional constraint placed on this model was that no stops were allowed on drive–transit tours. This was enforced to ensure that drivers who drove to transit picked up their cars at the end of the tour.

The stop frequency model was based on the following explanatory variables:

- Household income
- Number of full-time workers in the household
- Number of part-time workers in the household
- Number of non-workers in the household
- Number of children in the household
- Number of individual/joint mandatory and non-mandatory tours made by household
- Person type
- Age
- Tour mode
- Tour distance from anchor location (home) to primary destination
- Maintenance accessibility (#31, #32, and #33)
- Discretionary accessibility (#40, #41, and #42)

SM 5.2: Intermediate Stop Purpose Choice Model

Number of Models:	1
Decision-Making Unit:	Stop
Model Form:	Lookup Table
Alternatives:	9 Stop Purposes (Work, University, School, Escort, Shop, Maintenance, Eating Out, Visiting, or Discretionary)

The stop purpose choice model is a lookup table of probabilities based upon tour purpose, stop direction, departure time, and person type.

SM 5.3: Intermediate Stop Location Choice Model

Number of Models:	1
Decision-Making Unit:	Person
Model Form:	Multinomial Logit
Alternatives:	MGRA

The stop location choice model predicts the location (MGRA) of each intermediate stop (each location other than the origin and primary destination) on the tour. In this model, a maximum of three stops in outbound and three stops in inbound direction are modeled for each tour. Since a large number (over 23,000) of alternative destinations exist, it is not possible to include all alternatives in the estimation data set. A sampling-by-importance approach was used to choose a set of alternatives. Each record was duplicated 20 times, then different choice sets with 30 alternatives each were selected based on the size term and distance of the alternative destination. This approach is statistically equivalent to selecting 600 alternatives for the choice set. It is not straightforward to segment the model by purpose, because size (or attraction) variables are related to purpose of the stop activity, while impedance variables are strongly related to the tour characteristics—primary tour purpose, primary mode used for the tour, etc. Therefore, a single model is estimated with size variables based on stop purpose and utility variables based on both stop and tour characteristics.

The stop location choice model includes the following explanatory variables:

- Household income
- Gender
- Age
- Mode choice logsum
- Distance deviation or “out-of-the-way” distance for stop location when compared to the half tour distance without detour for any stop
- Distance of stop location from tour origin and destination is used to define closeness to tour origin or destination.
- Stop purpose
- Tour purpose
- Tour mode
- Stop number
- Direction of the half tour

Size variables:

- Employment by categories

- Number of households
- School enrollments: preschool, grades K–6, and grades 7–12, based on type of school child in the household
- University and other college enrollments

SM 5.4: Intermediate Stop Departure Model

Number of Models:	1
Decision-Making Unit:	Trips other than first trip and last trip on tour
Model Form:	Lookup Table
Alternatives:	40 (stop departure half-hour time periods, with aggregation between 1 a.m. and 5 a.m.)

The stop departure model is a lookup table of probabilities based upon tour purpose, stop direction, tour departure time, and stop number.

SM 6.1: Trip Mode Choice Model

Number of Models:	6 (Work, University, K–12, Maintenance, Discretionary, and At-Work Sub-Tours)
Decision-Making Unit:	Person
Model Form:	Multinomial Logit
Alternatives:	22 (see Figure S.7 under the Individual Mandatory Tour Mode Choice section)

The trip mode choice model determines the mode for each trip along the tour. Trip modes are constrained by the main tour mode. The linkage between tour and trip levels is implemented through correspondence rules (which trip modes are allowed for which tour modes). The model can incorporate asymmetric mode combinations, but in reality, there is a great deal of symmetry between outbound and inbound modes used for the same tour. Symmetry is enforced for drive–transit tours by excluding intermediate stops from drive–transit tours.

The tour and trip mode correspondence rules are shown in Table S.11. Note that in the trip mode choice model, the trip modes are the same as the modes in the tour mode choice model. However, every trip mode is not necessarily available for every tour mode. The correspondence rules depend on a hierarchy with the following rules:

- The highest occupancy across all trips is used to code the occupancy of the tour.
- There is no mode switching on walk and bike tour modes.
- Shared-ride trips are allowed on walk–transit tours.
- Drive-alone is disallowed for walk–transit and Kiss & Ride–transit tours, since driving on a trip leg in combination with walk–transit would imply Park & Ride–transit as a tour mode.

- Walk trips are allowed on all tour modes except for driving alone and biking, since these modes imply that the traveler is attached to the mode of transport (the auto or bike) for the entire tour.
- Note that cases in which a traveler parks at a lot and then walks to their destination are treated as a single trip in the context of trip mode choice. A subsequent parking location choice model breaks out these trips into the auto leg and the walk leg for trips to parking-constrained locations.
- An additional restriction on availability is imposed on work-based sub-tours, where drive-alone is disallowed if the mode to work is not one of the three auto modes (drive-alone, shared-ride 2, or shared-ride 3+).

The school bus tour mode, which is only available for the School tour purpose, implies symmetry—all trips on school bus tours must be made by school bus.

The trip mode choice model's explanatory variables include:

- Household size
- Auto sufficiency
- Age
- Gender
- Tour mode
- Individual or joint tour indicator
- Number of outbound and return stops
- First and last stop indicators
- In-vehicle time (auto and transit)
- Walk and bike time
- Auto operating cost
- Auto parking cost
- Auto terminal time
- Auto toll value
- Transit first wait time
- Transit transfer time
- Number of transit transfers
- Transit walk access time
- Transit walk egress time
- Transit walk auxiliary time

- Transit fare
- Transit drive access time
- Transit drive access cost
- Intersection density
- Employment density
- Dwelling unit density

Table S.11: Tour and Trip Mode Correspondence Rules

Tour and Trip Mode Correspondence Rules												
Trip Mode	Tour Mode											
	Drive-Alone	Shared-Ride 2	Shared-Ride 3+	Walk	Bike	Walk–Transit	Park & Ride–Transit	Kiss & Ride–Transit	TNC–Transit	Taxi	TNC Single	TNC Pooled
Drive-Alone Non-Transponder	A	A	A				A					
Drive-Alone Transponder	A	A	A				A					
Shared-Ride 2		A	A			A	A	A	A	A	A	A
Shared-Ride 3+			A			A	A	A	A	A	A	A
Walk	A	A	A	A		A	A	A	A	A	A	A
Bike					A							
Walk–Local Bus						A	A	A	A			
Walk–Premium						A	A	A	A			
Walk–Local Bus & Premium						A	A	A	A			
Park & Ride–Local Bus							A					
Park & Ride–Premium							A					
Park & Ride–Local Bus & Premium							A					
Kiss & Ride–Local Bus								A				
Kiss & Ride–Premium								A				
Kiss & Ride–Local Bus & Premium								A				
TNC–Local Bus									A			
TNC–Premium									A			
TNC–Local Bus & Premium									A			
Taxi										A		
TNC Single											A	
TNC Pooled												A
School Bus	Available for school bus tour mode only, on school tours.											

A = Trip mode is available by that particular tour mode.

SM 6.2: Parking Location Choice

Number of Models:	2 (Work and Other)
Decision-Making Unit:	Trips with Non-Home Destinations in Areas with Paid Parking
Model Form:	Multinomial Logit
Alternatives:	In estimation, lots sampled in the parking behavior survey; in application, MGRAs within three-quarters of a mile of the destination MGRA

The parking location choice model determines where vehicles are parked at the terminal end of each trip with a destination in park area 1 (Downtown San Diego area). For work trips, the model subtracts the output from the employer parking reimbursement model from the daily price of parking at each alternative destination to determine the effective price borne by the individual. The output of the model is used to obtain traffic assignments that are more accurate at small scales in the downtown area during the morning and afternoon peaks. The coefficients from the parking location choice model estimation are also used in defining the logsum-weighted average parking cost used in mode choice.

The parking location model explanatory variables include:

- Number of stalls available to the driver (size variable)
- Parking cost
- Walking distance to destination

Resident Travel Model Outputs

The outputs of resident travel model are:

- Household car ownership
- Household member work or school locations at MGRA level
- Employer-paid parking
- Individual tour and trip list
- Joint tour and trip list at MGRA level
- Auto trips by TAZ origin to TAZ destination by five TOD and by three VOT bins
- Transit trips by tap by three access modes and by five TOD

The auto trip tables are combined with special market model output and used in traffic assignment.

Special Market Models

Crossborder Model

The model measures the impact of Mexico resident travel on the San Diego transport network. The model accounts for Mexico resident demand (such as auto volume, transit boarding, and toll usage) for transportation infrastructure in San Diego County. It also forecasts border crossings at each current and potential future border-crossing station. The model is based on the 2010 SANDAG Cross Border Survey, Mexico resident border crossings into the United States, and their travel patterns within the United States. Data were collected at the three border crossing stations: San Ysidro, Otay Mesa, and Tecate. The model flow and inputs are shown in Figure S.11.

Crossborder Tour Purposes

There are six tour purposes for the Mexico resident model. They were coded based on the activity purposes engaged in by the traveler in the United States according to a hierarchy of activity purposes as follows:

- **Work:** At least one trip on the tour is for working in the United States.
- **School:** At least one trip on the tour is made for attending school in the United States, and no work trips were made on the tour.
- **Cargo:** At least one trip on the tour was made for picking up or dropping off cargo in the United States, and no work or school trips were made on the tour.
- **Shop:** No trips on the tour were made for work, school, or cargo, and the activity with the longest duration on the tour was shopping in the United States.
- **Visit:** No trips on the tour were made for work, school, or cargo, and the activity with the longest duration on the tour was visiting friends/relatives in the United States.
- **Other:** No trips on the tour were made for work, school, or cargo, and the activity with the longest duration on the tour was other (collapsed escort, eat, personal, medical, recreation, sport, and other activity purposes).

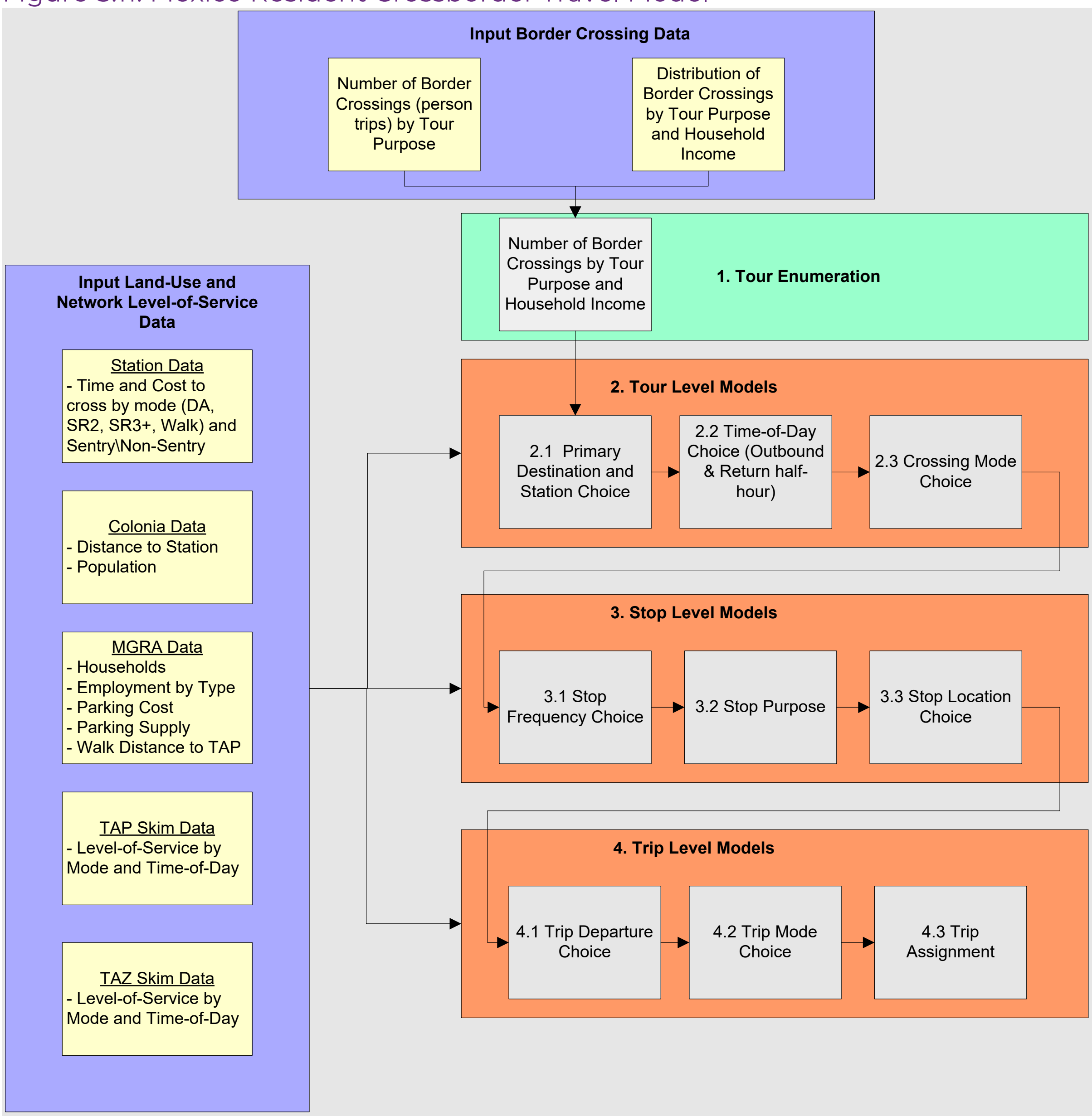
Tour Mode

The tour mode is the mode used to cross the border, which conditions the mode used for all trips on the tour, including the trip from the border crossing to the first destination in the United States. The tour modes are defined by whether the border was crossed via auto or by foot, the occupancy if by auto, and whether the SENTRI lane was used or not. SENTRI lanes offer expedited border crossings to prequalified citizens of the United States and Mexico. One must apply for a SENTRI pass, which requires extensive background checks. Mexico residents must have a valid U.S. visa, Mexico passport, and contact number in the United States. This typically means that in order to obtain a pass, Mexico residents must be lawfully employed in the United States.

Trip Mode

The trip modes used in the Mexico resident travel model are the same modes available in the resident travel model. Note that toll and HOV usage was not asked as part of the survey. Usage of these facilities in the model is based upon the characteristics of the trips/vehicle occupancies and income (VOT) of travelers and validated along with resident demand models.

Figure S.11: Mexico Resident Crossborder Travel Model



Treatment of Space

Every trip ending in San Diego County is allocated to an MGRA. Within Tijuana, each border crossing origin is assigned to a *colonia*, or neighborhood, with which survey respondents identify. Population estimates are collected by the Instituto Nacional de Estadística y Geografía at the level of a basic geostatistical area (Área Geoestadística Básica [AGEB] roughly equivalent to U.S. Census Tracts). AGEBs and *colonias* largely overlap within Tijuana city boundaries (though there is no coherent spatial nesting scheme), and AGEB population estimates were redistributed to *colonia* based on a proportional area operation to operationalize *colonia* trip origins in the model. Outside of Tijuana, the origins are distributed to a *localidad*, or locality. These units are similar to the Census Designated Place in the United States.

San Diego International Airport Ground Access Model

The model captures the demand of airport travel on transport facilities in San Diego County, a model of travel to and from the airport for arriving and departing passengers. It allows SANDAG to test the impacts of various parking price and supply scenarios at the airport. The model is based on the 2008 SDIA survey of airport passengers in which data was collected on their travel to the airport prior to their departure.

The SDIA ground access model has the following features:

- A disaggregate microsimulation treatment of air passengers with explicit representation of duration of stay or trip in order to accurately represent costs associated with various parking and modal options.
- The full set of modes within San Diego County, including auto trips by occupancy, transit trips by line-haul mode (bus versus Trolley), and toll/HOT/HOV lanes modes.
- Forecasts of airport ground access travel based upon the official SDIA enplanement projections.

The model flow and inputs are shown in Figure S.12 and described in detail in the following sections.

San Diego International Airport Model Trip Purposes

Four trip purposes were coded based on the resident status of air passengers and the purpose of air travel, as follows:

- **Resident Business:** Business travel made by San Diego County residents (or residents of neighboring counties who depart from SDIA).
- **Resident Personal:** Personal travel made by San Diego County residents (or residents of neighboring counties who depart from SDIA).
- **Visitor Business:** Business travel made by visitors to San Diego County (or a neighboring county).

- **Visitor Personal:** Personal travel made by visitors to San Diego County (or a neighboring county).

San Diego International Airport Model Trip Mode

The model of airport ground access is trip-based because the survey did not collect the full tour from origin to airport. In addition, the survey only collected information on the trip to the airport before the passenger boarded their plane; information was not collected on the trip in which passengers arrived at the airport and traveled to a destination in San Diego County. Therefore, symmetry is assumed for the non-reported trip. Finally, the survey did not collect data on whether an HOV lane or toll lane was used for the trip, so path-level mode cannot be determined. If private auto is used to access the airport, the choice of parking versus curbside pick-up/drop-off is explicitly represented. For travelers who park, the chosen lot (terminal, airport remote lot, private remote lot) is explicit as well. Note that auto occupancy is not a choice for airport ground access trips. Auto occupancy is based upon travel party size, which is simulated as part of the attribution of ground access trips.

San Diego International Airport Model Inputs

The model system requires the following exogenously specified inputs (note that three additional data sets are required in addition to the data currently input to the resident ABMs):

- **SDIA enplanement forecast:** The total number of yearly enplanements, without counting transferring passengers, at SDIA, and an annualization factor to convert the yearly enplanements to a daily estimate. This is input for each simulation year. The data is available in the Aviation Activity Forecast Report. [5]
- **Traveler characteristics distributions:** There are a number of distributions of traveler characteristics that are assumed to be fixed but can be changed by the analyst to determine their effect on the results. These include the following:
  - The distribution of travelers by purpose.
  - The distribution of travelers by purpose and household income.
  - The distribution of travelers by purpose and travel party size.
  - The distribution of travelers by purpose and trip duration (number of nights).
  - The distribution of travelers by purpose, direction (arriving versus departing), and time period departing for airport.
- **MGRA data:** The population and employment (by type) in each MGRA, parking cost and supply, etc. This data provides sensitivity to land use forecasts in San Diego County. These are the same data sets as are used in the resident ABM.

[5] Airport Development Plan: San Diego International Airport, Leigh|Fisher, March 2013, page 47–68 (Table 22).

- **TAP skim data:** Transit network level-of-service between each TAP (transit stop). This provides sensitivity to transit network supply and cost. These are the same data sets as are used in the resident ABM.
- **TAZ skim data:** Auto network level-of-services between each TAZ. This provides sensitivity to auto network supply and cost. These are the same data sets as are used in the resident ABM.

San Diego International Airport Model Description

This section describes the model system briefly, followed by a more in-depth discussion of each model component.

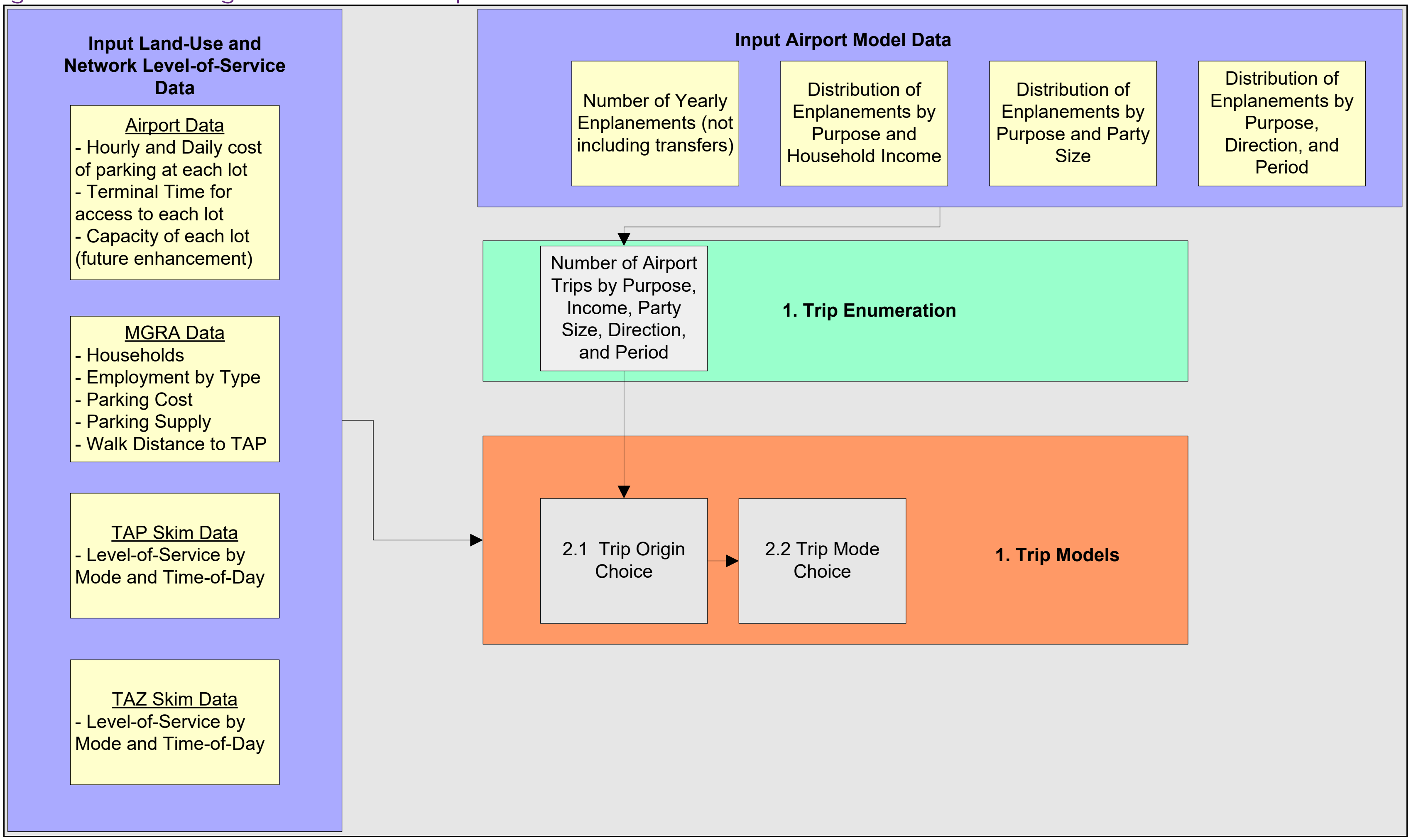
Trip enumeration and attribution: A total number of airport trips is created by dividing the input total enplanements (minus transferring passengers) by an annualization factor. The result is divided by an average travel party size to convert passengers to travel parties. This is converted into a list format that then is exposed to the set of traveler characteristic distributions, as identified above, to attribute each travel party with the following characteristics:

- Travel purpose
- Party size
- Duration of trip
- Household income
- Trip direction (it is assumed that 50% of the daily enplanements are arriving passengers and 50% are departing passengers)
- Departure time for airport

Trip Models:

- **Trip origin:** each travel party is assigned an origin MGRA.
- **Trip mode:** each travel party is assigned a trip mode.

Figure S.12: San Diego International Airport Ground Access Travel Model



Cross Border Xpress Terminal Model

The CBX terminal is a unique facility that provides access to Tijuana International Airport from the United States via a pedestrian bridge. The terminal provides a much faster border crossing than is available at either San Ysidro or Otay Mesa, especially for returning passengers. In order to use the facility, each traveler must have a Tijuana International Airport boarding pass and pay a fee to cross each direction. The terminal offers parking, rental car services, airline check-in services, duty-free shopping, and dining. It opened in December 2015.

The model structure is borrowed from the SDIA ground access model. The model is calibrated based on a passenger survey conducted beginning of April 2016 at Tijuana International Airport. The survey collected information from departing passengers who either used the CBX facility or could have used the facility but chose to cross at one of the other border crossings instead.

The model segments travelers according to travel purpose, which is a combination of residence status (resident/visitor), the reported purpose of travel (business/personal) and whether the traveler's origin before departing the airport was in San Diego County or not (internal/external).

Visitor Model

The visitor model captures the demand of visitor travel on transport facilities in San Diego County. The model is estimated based on the 2011 SANDAG Visitor Survey of airport passengers and hotel guests in which data was collected on their travel while visiting San Diego.

The visitor model has the following features:

- A disaggregate microsimulation treatment of visitors by person type, with explicit representation of party attributes
- Special consideration of unique visitor travel patterns, including rental car usage and visits to San Diego attractions like Sea World
- The full set of modes within San Diego County, including auto trips by occupancy, transit trips, non-motorized trips, and toll/HOT/HOV lanes modes

The model flow and inputs are shown in Figure S.13 and described in detail in the following sections.

Visitor Model Inputs

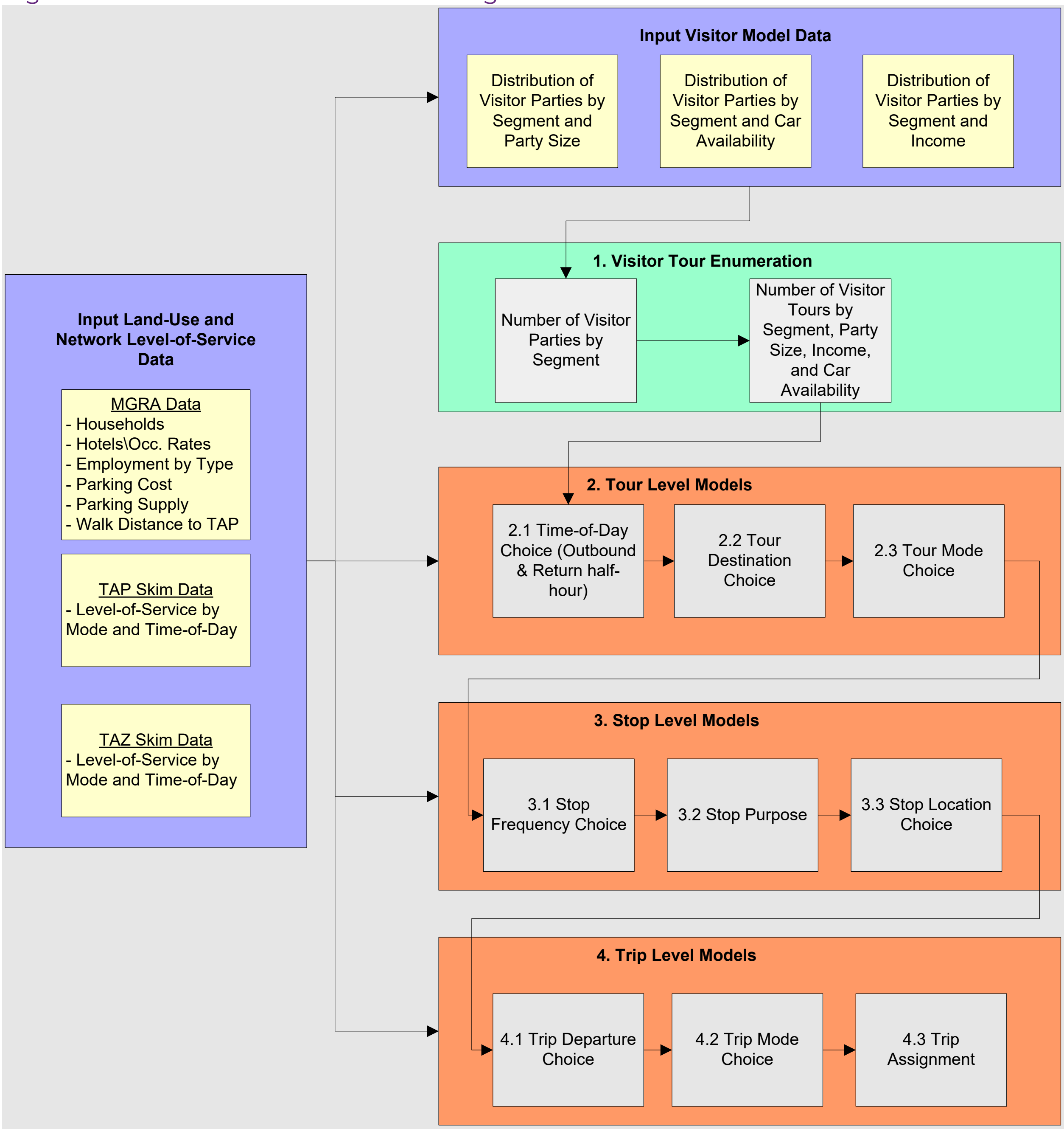
The model system requires the following exogenously specified inputs (note that three additional data sets are required in addition to the data currently input to the resident ABMs):

- **Traveler characteristics distributions:** There are a number of distributions of traveler characteristics that are assumed to be fixed but can be changed by the analyst to determine their effect on the results. These include the following:
    - Rates of visitor occupancy for hotels and separately for households
    - Shares of visitor parties by visitor segment for hotels and separately for households
    - The distribution of visitor parties by household income
    - The distribution of business segment travel parties by number of tours by purpose
    - The distribution of personal segment travel parties by number of tours by purpose
    - The distribution of visitor tours by tour purpose and party size
    - The distribution of visitor tours by tour purpose and auto availability
    - The distribution of visitor tours by outbound and return time-of-day and tour purpose
    - The distribution of visitor tours by frequency of stops per tour-by-tour purpose, duration, and direction
    - The distribution of stops by stop purpose and tour purpose
    - The distribution of stops on outbound tour legs by half-hour offset period from tour departure period and time remaining on tour
    - The distribution of stops on inbound tour legs by half-hour offset period from tour arrival period and time remaining on tour
- **MGRA data:** The population, employment (by type), and number of hotel rooms in each MGRA, parking cost and supply, etc. This data provides sensitivity to land use forecasts in San Diego County. These are the same data sets as are used in the resident ABM.
- **TAP skim data:** Transit network level-of-service between each TAP (transit stop). This provides sensitivity to transit network supply and cost. These are the same data sets as are used in the resident ABM.
- **TAZ skim data:** Auto network level-of-service between each TAZ. This provides sensitivity to auto network supply and cost. These are the same data sets as are used in the resident ABM.

Visitor Model Description

This section describes the model system briefly.

Figure S.13: SANDAG Visitor Model Design



Visitor Tour Enumeration: Visitor travel parties are created by visitor segment based upon input hotels and households. Travel parties are attributed with household income. Tours by purpose are generated for each party. Each tour is attributed with auto availability and party size. The tour origin MGRA is set to the MGRA where the tour was generated.

Tour-Level Models

- **Tour Time of Day:** Each tour is assigned a time of day, based on probability distribution.
- **Tour Destination Choice:** Each tour is assigned a primary destination, based on the coefficients estimated through a multinomial logit model.
- **Tour Mode Choice:** Each tour selects a preferred primary tour mode, based on an asserted nested logit model (the resident tour mode choice model).

Stop Models

- **Stop Frequency Choice:** Each tour is attributed with a number of stops in the outbound direction and in the inbound direction based upon sampling from a distribution.
- **Stop Purpose:** Each stop is attributed with a purpose based upon sampling from a distribution.
- **Stop Location Choice:** Each stop is assigned a location based upon a multinomial logit model (asserted based upon resident stop location choice models).

Trip-Level Models

- **Trip Departure Choice:** Each trip is assigned a departure time period based upon sampling from distributions.
- **Trip Mode Choice:** Each trip within the tours selects a preferred trip mode based on an asserted nested logit model.
- **Trip Assignment:** Each trip is assigned to the network.

External Models

The external travel models predict characteristics of all vehicle trips and selected transit trips crossing the San Diego County border. This includes both trips that travel through the region without stopping and trips that are destined for locations within the region. See Figure S.14 for current crossing locations, also known as cordons. Future crossing locations that can also be modeled depending on scenarios include Otay Mesa East, and Jacumba.

External Model Trip Type Definition

The external–external, external–internal, and internal–external trips in San Diego County were segmented into the following trip types:

- **US–US:** External–external trips whose production and attraction are both in the United States, but not in San Diego County.
- **US–MX:** External–external trips with one trip end in the United States and the other in Mexico.
- **US–SD:** External–internal trips with a production elsewhere in the United States and an attraction in San Diego County.
- **MX–SD:** External–internal trips with a production in Mexico and an attraction in San Diego County (covered by the Mexico resident crossborder model).
- **SD–US:** Internal–external trips with a production in San Diego and an attraction elsewhere in the United States.
- **SD–MX:** Internal–external trips with a production in San Diego County and an attraction in Mexico.

External Model Estimation of Trip Counts by Type

The total count of trips by production and attraction location was estimated in a series of steps:

The number of trips made by Mexico residents to attractions in San Diego was previously determined during development of the Mexico resident travel microsimulation model.

- The trips in the resident travel survey were expanded to estimate the total number of trips made by San Diego residents to attractions in Mexico.
- The number of MX–SD (1) and SD–MX (2) trips was subtracted from the total number of border crossings to derive an estimate of the number of US–MX trips. The distribution of US–MX trips among external stations on the U.S. side of San Diego County is assumed to be proportional to the total volume at each external station, regardless of the point of entry at the Mexico border.
- The number of US–MX trips was then subtracted from the total number of trips in the Southern California Association of Governments (SCAG) cordon survey to arrive at an estimate of the combined total of US–US, US–SD, and SD–US trips with routes through San Diego County.
- Finally, the actual amounts of US–US, US–SD, and SD–US trips at each external station were estimated from the remaining trips (4) according to their proportions in the successfully geocoded responses in the SCAG cordon survey.

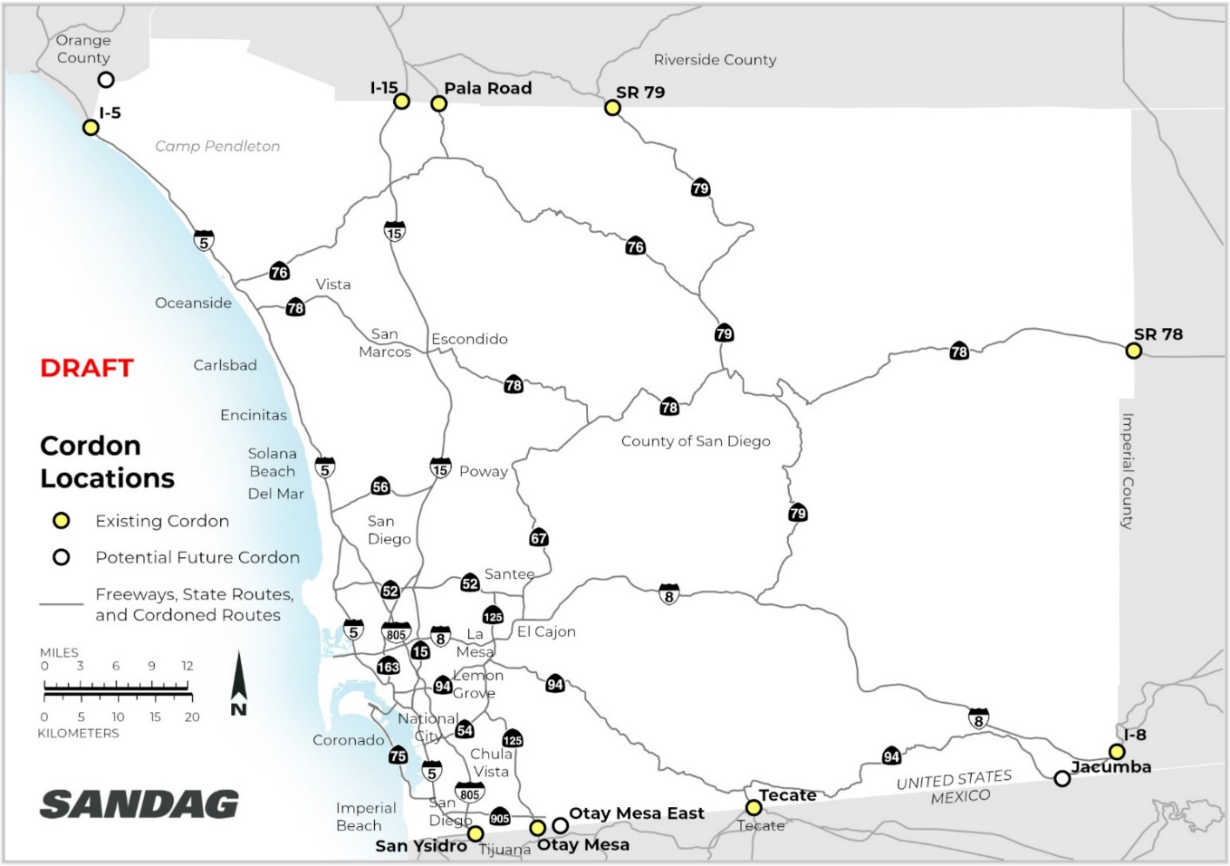
External Model Design Overview

The behavioral characteristics of the different types of external trips were derived from the various data sources available as follows:

- **US–US trips:** A fixed external station OD trip matrix was estimated from the SCAG cordon survey.

- **US–MX trips:** A fixed external station OD trip matrix was estimated from the SCAG cordon survey, Customs and Border Protection vehicle counts, and Mexico resident border-crossing survey as described in the previous section.
- **US–SD trips:** Rates of vehicle trips per household for each external county were developed from the SCAG cordon survey, and the trips were distributed to locations in San Diego County. according to a destination choice model estimated from the interregional survey.
- **MX–SD trips:** A microsimulation model of Mexico resident crossborder travel.
- **SD–US trips:** A binary logit model for a person's making a trip as a function of accessibility to external stations and demographic characteristics was developed from the San Diego County resident survey, and the trips were distributed to external stations according to their market shares in the base year, which were estimated as described in the previous section.
- **SD–MX trips:** A binary logit model simulating an individual's decision to make a trip as a function of accessibility to external stations and demographic characteristics was developed from the San Diego County resident survey, and the trips were distributed to external stations according to their market shares in the base year, which were estimated as described in the previous section.

Figure S.14: San Diego County Cordons



US–SD External–Internal Trips

The US–SD External–Internal (EI) trip model covers vehicle trips with destinations in San Diego made by persons residing in other areas of the United States. Intermediate stops and transit trips are not modeled in this segment due to the small contribution of these events to the total demand in the segment.

The US–SD model accepts as an input the total number of work and non-work vehicle trips from the SCAG cordon survey at each external station.

External–Internal Destination Choice Model

Number of Models:	2 (Work and Non-Work)
Decision-Making Unit:	Tour
Model Form:	Multinomial Logit
Alternatives:	MGRAs

The external–internal destination choice model distributes the EI trips to destinations within San Diego County.

The EI destination choice model explanatory variables are:

- Distance
- The size of each sampled MGRA

Vehicle occupancy and diurnal factors (Table S.12 and Table S.13) are then applied to the total daily trip tables to distribute the trips among shared-ride modes and different times of day.

Table S.12: US–SD Vehicle Occupancy Factors

US–SD Vehicle Occupancy Factors	
Vehicle Occupancy	**Percentage**
One	58%
Two	31%
Three or more	11%
Total	**100%**

Table S.13: US–SD Diurnal Factors

US–SD Diurnal Factors				
	Work Percentage		**Non-Work Percentage**	
Time Period	**Production to Attraction**	**Attraction to Production**	**Production to Attraction**	**Attraction to Production**
Early a.m.	26%	8%	25%	12%
a.m. Peak	26%	7%	39%	11%
Midday	41%	41%	30%	37%
p.m. Peak	6%	42%	4%	38%
Evening	2%	2%	2%	2%
Total	**100%**	**100%**	**100%**	**100%**

External–Internal Toll Choice Model

Number of Models:	2 (Work and Non-Work)
Decision-Making Unit:	Tour
Model Form:	Multinomial Logit
Alternatives:	MGRAs

The trips are then split among toll and non-toll paths according to a simplified toll choice model. The toll choice model included the following explanatory variables:

- In-vehicle-time
- Toll cost

Internal–External Trips

Internal–External Trip Generation Model

Number of Models:	2 (Work and Non-Work)
Decision-Making Unit:	Person
Model Form:	Binary Logit
Alternatives:	2 (made an internal–external trip or not)

The internal–external (IE) trip generation model covers the SD–US and SD–MX trips.

The IE trip generation model explanatory variables are:

- Household income
- Vehicle ownership
- Age
- Accessibility to external stations

Internal–External Destination Choice Model

Number of Models:	1
Decision-Making Unit:	Trip
Model Form:	Multinomial Logit
Alternatives:	MGRAs

The IE trips are distributed to external stations with a destination choice model. The explanatory variables of the IE destination choice model are:

- Distance
- Size variable equal to the percentage of IE trips using the external zone in the base year

Internal–External Mode Choice Model

Number of Models:	1
Decision-Making Unit:	Trip
Model Form:	Multinomial Logit
Alternatives:	Trip Modes

After choosing an external station, the IE trip maker chooses a mode according to an asserted nested logit mode choice model. The explanatory variables in the trip mode choice model are:

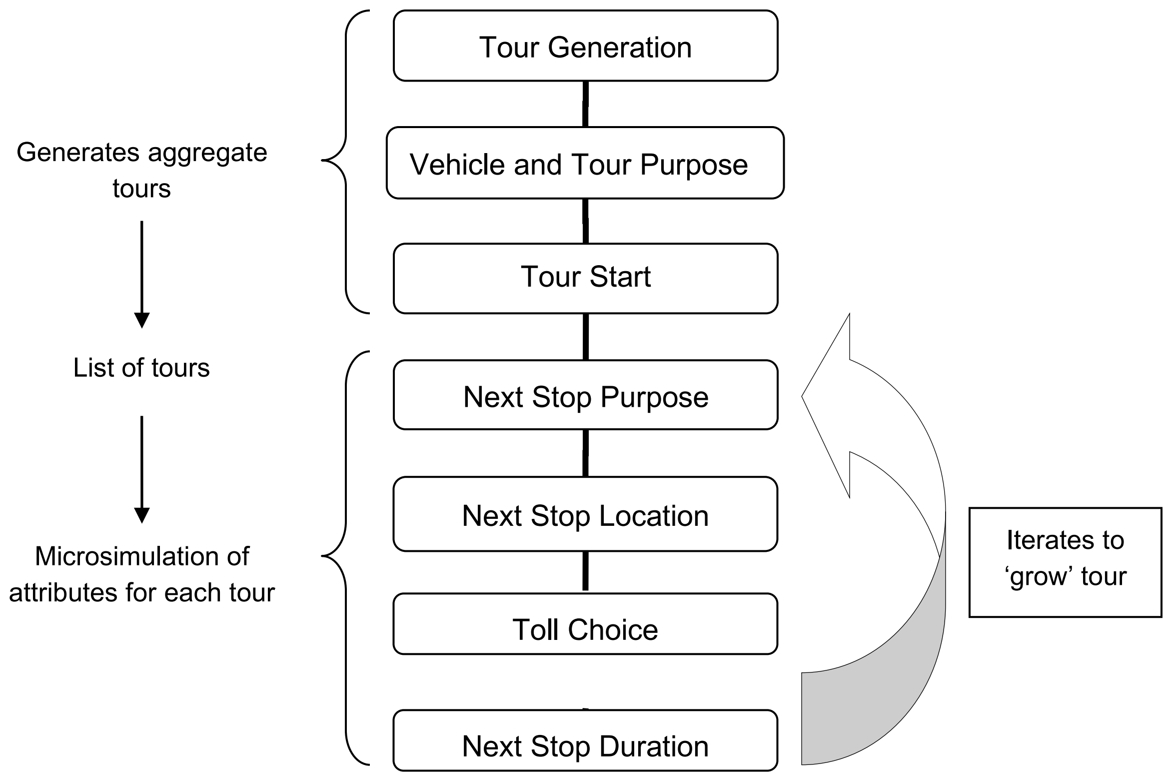
- Household income
- Gender
- In-vehicle time (auto and transit)
- Walk time
- Bike time
- Auto operating cost
- Auto parking cost
- Auto toll value
- Transit first wait time
- Transit transfer time
- Number of transit transfers
- Transit walk access time
- Transit walk egress time
- Transit walk auxiliary time
- Transit fare
- Drive access to transit in-vehicle time
- Drive access to transit cost

Commercial Vehicle Model

Commercial vehicle model (CVM) is a disaggregated tour-based model developed in 2014. This model was based upon a local commercial vehicle survey and replaces the aggregate intraregional heavy-duty truck model (HDTM) and nonfreight commercial vehicle components of the original aggregate CVM. The internal/external component of the HDTM was retained in the new model system but was updated to Freight Analysis Framework (FAF) 4 data. The ABM2+ runs the CVM with a scale factor of 1 and the generated demand for light trucks in the midday period is scaled to 2.8 times to compensate for the lack of commercial vehicle travel in the disaggregate CVM.

CVM was developed based on establishment work-related person and vehicle movement travel data, collected as part of the SANDAG Work-Related Travel Survey conducted between November 2012 to September 2013, together with 2013 GPS SANDAG area commercial vehicle movement data purchased by SANDAG from the American Transportation Research Institute. The tour-based CVM is a group of models that work in series. A basic schematic of the models is shown in Figure S.15.

Figure S.15: Commercial Vehicle Model Tour-Based Model Structure



Tour generation of quantities by vehicle type, tour purpose, and time of day are generated for each TAZ, using logit and regression equations applied with aggregate TAZ inputs and travel accessibilities, to create a list of tours.

Individual tours generated from each TAZ are then assigned a next stop purpose, next stop location, and next stop duration using a microsimulation process.

In this process, Monte Carlo techniques are used to incrementally "grow" a tour by having a "return-to-establishment" alternative within the next stop purpose allocation. If the next stop purpose is not "return-to-establishment," then the tour extends by one more stop. The location and duration of the next stop are then estimated. For each trip, it is also determined whether a toll facility is used as part of the route choice process.

These steps are repeated until the "return-to-establishment" next stop purpose is chosen.

Seven establishment types are considered, based on aggregations of North American Industry Classification System (NAICS) categories:

- **Industrial** (IN): NAICS 11, 21, 23, 31–33
- **Wholesale** (WH): NAICS 42
- **Service** (SE): NAICS 61, 62, 71, 72, 81
- **Government/Office** (GO): NAICS 51, 52, 53, 54, 55, 56, 92
- **Retail** (RE): NAICS 44–45
- **Transport and Handling** (TH): NAICS 22, 48–49
- **Fleet Allocator** (FA): (All but Military.) A specific type of establishment that uses a large, coordinated fleet that tends to service an area rather than specific demands—examples include mail and courier, garbage hauling, newspaper delivery, and utilities and public works.

Four commercial vehicle types are used:

- **Light Vehicle:** Federal Highway Administration (FHWA) classes 1–3
- **Medium Truck < 8.8 short tons (17,640 pounds):** FHWA classes 5–6
- **Medium Truck > 8.8 short tons (17,640 pounds):** FHWA classes 5–6
- **Heavy Truck:** FHWA classes 7–13

Five TAZ level land use types are used in the model:

- **Low Density**
- **Residential**
- **Commercial**
- **Industrial**
- **Employment Node**

The outputs of the CVM are trips by establishment type by TOD and by vehicle classes. These trips are added to all other trips prior to traffic assignment.

External Heavy Truck Model

The external heavy truck model predicts truck flows into, out of, and through San Diego County. The model is based upon a data set created by Bureau of Transportation Statistics and the FHWA known as the Freight Analysis Framework (FAF). The FAF integrates data from a variety of sources to create a comprehensive picture of freight movement among states and major metropolitan areas by all modes of transportation. The model uses FAF 4 data, which is based on the 2012 Commodify Flow Survey, and provides forecasts through 2045.

There are several steps to the heavy truck model. In the first step, FAF commodity flows are used to generate a truck trip table, which is assigned to a national network. A sub-area matrix is generated from this assignment using select link analysis with nodes at the external stations to capture movements into, out of, and through San Diego County. The outputs of this step are external–external (EE) trip tables and estimates of internal–external (IE) and external–internal (EI) volume totals at each external station. In the next step, the MGRA land use data is used to calculated heavy truck attractions for IE and EI heavy truck trips by MGRA, which are then aggregated to a TAZ level. Then trip ends from the external stations and internal TAZs are fed into a gravity model to create IE and EI trip tables. Finally, these trip tables are added to all other trips prior to traffic assignment.

Trip Assignment

The final steps of the SANDAG ABM2+ are to assign the trip demand onto the roadway and transit networks. Assignments are run for the five time periods identified in Table S.2.

Traffic Assignment

The traffic assignment for the ABM2+ is a 15-class assignment with generalized cost by five time periods. Auto vehicle classes are broken out by VOT bins for $8.81, $18, and $85 per hour representing the 33rd, 66th, and 99th percentiles for the low-income, medium-income, and high-income groups, respectively. The 15 classes are drive-alone non-transponder, drive-alone transponder, shared-ride 2, and shared-ride 3+ by three VOT bins and heavy truck by three weight classes: light-heavy, medium-heavy, and heavy-heavy.

The SANDAG volume-delay function (VDF) is a link-based function that consists of both a mid-block and an intersection component. The intersection component is only active when the B-node of the link is controlled by a traffic signal, stop sign, roundabout, or ramp meter. Otherwise, the intersection component adds no delay. The VDF results in travel times that increase monotonically with respect to volume. Capacities are based on link and intersection characteristics but do not consider volumes on upstream links or opposing volumes. New VDF coefficients were estimated based on INRIX travel time and SANDAG transport network data. Data was based on INRIX travel time data for 2015 and SANDAG auto networks and estimated volumes. The estimated alpha parameter is 0.8, and the estimated beta parameter is 4 for mid-block of all link types except freeway in the a.m. and p.m. period with alpha of 0.6 and beta of 4 and off-peak with alpha of 0.24 and beta of 5.5. These parameters are not very different from the widely used Bureau of Public Roads (BPR) formula parameters of 0.15 and 4, respectively. Non-freeway links use BPR factors of 4.5 (or 6.0 for metered ramp) and 2.0 for intersection components.

The traffic assignment is run using Second-Order Linear Approximation method in Emme modeling software to a relative gap of $5\times10{-}4$. The per-link fixed costs include toll values and operating costs which vary by class of demand. Assignment matrices and resulting network flows are in passenger car equivalent. For more details, please see github.com/SANDAG/ABM/wiki/files/traffic_assignment.pdf.

Transit Assignment

The transit assignment uses a headway-based approach, where the average headway between vehicle arrivals for each transit line is known, but exact schedules are not. Passengers and vehicles arrive at stops randomly and passengers choose their travel itineraries considering the expected average waiting time.

The Emme Extended transit assignment is based on the concept of optimal strategy but extended to support a number of behavioral variants. The optimal strategy is a set of rules that define sequence(s) of walking links, boarding, and alighting stops, which produces the minimum expected travel time (generalized cost) to a destination. At each boarding point, the strategy may include multiple possible attractive transit lines with different itineraries. A transit strategy will often be a tree of options, not just a single path. A line is considered attractive if it reduces the total expected travel time by its inclusion. The demand is assigned to the attractive lines in proportion to their relative frequencies.

The shortest "travel time" is a generalized cost formulation, including perception factors (or weights) on the different travel time components, along with fares, and other costs/perception biases such as transfer penalties, which vary over the network and transit journey.

The ABM2+ has three access modes to transit (walk, Park & Ride, and Kiss & Ride, including TNC to transit) and three transit sets (local bus only, premium transit only, and local bus and premium transit sets), for nine total demand classes by five times of day. These classes are assigned by slices, one at a time, to produce the total transit passenger flows on the network.

While there are nine slices of demand, there are only three classes of skims: local bus only, premium only, and all modes. The access mode does not change the assignment parameters or skims.

Data Sources

The SANDAG ABM2+ uses a variety of data as inputs. The most important data source is household travel survey data. The latest household travel survey conducted for SANDAG was the 2016–2017 Household Travel Behavior Survey (HTS2016) with smartphone-based travel diaries as the primary means of travel data collection. Since 1966, consistent with the state of the practice for the California Household Travel Survey and National Household Travel Survey, SANDAG and Caltrans conduct a comprehensive travel survey of San Diego County every ten years. HTS2016 surveyed 6,139 households in San Diego County. The survey asked all households with smartphones to participate using the smartphone-based GPS travel diary and survey app (rMove) for one week and accommodated participating households without smartphones by allowing them to complete their one-day travel diary online or by calling the study call center.

As part of a joint survey effort with the Metropolitan Transportation Commission and SCAG funded by California Senate Bill 1 (Beall, 2017) (SB 1), SANDAG conducted a TNC survey in 2019 to better understand the TNC usage in San Diego region. The TNC survey includes 2800 complete persons,[6] 17,340 completed person-days, and 1,578 TNC trips. SANDAG used the 2019 TNC survey data to estimate TNC single and pooled use in the mode choice model.

Additional data needed for the mode choice components of the resident travel model comes from a transit on-board survey. The most recent SANDAG survey of this kind is the 2015 Transit On-Board Survey (OBS2015). OBS2015 collected data on transit trip purpose, origin and destination address, access and egress mode to and from transit stops, the on/off stop for surveyed transit routes, number of transit routes used, and demographic information.

Table S.14 lists data sources mentioned above, along with other necessary sources of data not collected directly by SANDAG listed in Table S.15. Modeling parking location choice and employer reimbursement of parking cost depends on parking survey data collected from 2010 into early 2011 as well as a parking supply inventory. The transponder ownership sub-model requires data on transponder users. Data needed for model validation and calibration include traffic counts, transit-boarding data, and Caltrans Performance Measurement System (PeMS) and Highway Performance Monitoring System data.

[6] A complete person-day is when a person completes all trip surveys and the daily survey for a given travel day. A person is considered complete if they have at least one complete person-day.

Table S.14: SANDAG Surveys and Data

SANDAG Surveys and Data	
Survey Name	**Year**
Household Travel Behavior Survey	2016–2017
Transit On-Board Survey	2015
SB 1 TNC Survey	2019
Commute Behavior Survey	2018
Taxi Passenger Survey	2009
Parking Inventory Survey	2010
Parking Behavior Survey	2010
Border Crossing Survey	2011
Visitor Survey	2011
Establishment Survey	2012
Tijuana Airport Passenger Survey	2017
Commercial Vehicles Survey	2011
Beach Intercept Survey	2017
Passenger Count Program	2016
Vehicle Classification & Occupancy Survey	2006

Table S.15: Outside Data Sources

Outside Data Sources	
Source	**Year**
SDIA Air Passenger Survey	2009
SDIA Passenger Forecasts – Airport Development Plan: San Diego International Airport[7]	2013
Decennial Census SF1 tabulation	2010
ACS	2015, 2016, 2017
Transponder ownership data	2012
FAF 4	2012
Bicycle counts	2011
Jurisdiction annual traffic counts	2016
Caltrans PeMS	2016
Caltrans Highway Performance Monitoring System – California Public Road Data	2016
Caltrans Traffic Census Program – Annual Average Daily Traffic	2016
INRIX Speed Data	2015, 2016
Streetlight Origin–Destination Location-Based Services Data	2017

[7] The SDIA Aviation Activity Forecast updated in April 2019 and released in September 2019 as part of the recirculated Draft Environmental Impact Report occurred after the ABM2+ airport model was updated. As part of the next ABM2+ release scheduled in 2022, SANDAG will update the airport model with this forecast.

Travel Model Validation

Model validation compares base year 2016 model outputs to independent data, not used to estimate or calibrate model parameters, to ensure that the model is ready to be used for forecasting. Estimated traffic volumes from the model are compared with traffic counts and estimated transit ridership is compared with observed transit boardings. SANDAG maintains a traffic count database that is assembled from various sources: PeMS counts, Caltrans District 11 State Highway Traffic Census Counts, arterial counts from local jurisdictions, and some special counts collected by SANDAG. Average weekday traffic was derived from PeMS daily counts collected over the year 2016—the most reliable count data source for model validation. SANDAG modeling staff went through an extensive effort to create a new PeMS inventory with 498 counts in 2019, which is 172 more than the previous 326-count PeMS inventory. The new count inventory was built based on observed five-minute data rather than the one-hour data used in the previous count inventory. This improvement provides more accurate observed count inventory for validating traffic flow of each ABM TOD. Combined with other count inventories, the final count inventory has 797 counts available for validating traffic flow of main lane freeway. Local jurisdiction traffic counts typically do not cover the entire year, and therefore are subject to larger error than the PeMS counts. Estimated transit boardings from the model are validated against 2016 daily transit ridership from the SANDAG Passenger Count Program.

SANDAG performed roadway validations at regional, subregional (Major Statistical Areas), and highway corridor levels, segmented by time of day and roadway facility types and by road type and volume group. Overall validation results are satisfactory with no systematic deviation from the 45-degree line in validation scatter plots. Estimated regional vehicle miles traveled (VMT) matched 2016 California Public Road Data well, with a slight underestimation (less than 0.1%).

Validation by road type shows freeway results fare better than those of other road types. The model tends to underestimate volumes on arterials, ramps, and collectors. The lack of a systematic approach of collecting traffic counts on arterials and collectors could be a contributing factor to the less-than-ideal performances on arterials and collectors. Validation by volume group shows that the larger estimated link volumes are the better they match the counts; percent root mean square errors decrease as the estimated volumes increase. Validation was performed on major highway corridors, including I-5, I-15, I-805, SR 67, SR 125, SR 163, I-8, SR 52, SR 54, SR 56, SR 78, and SR 94. Overall, the model performs well at corridor level. Transit validations were performed by transit line haul mode, including commuter rail, light rail, Express Bus, *Rapid* Bus, and local bus. Overall, the model-estimated transit ridership matched observed 2016 transit passenger counts well, with a 6.7% overestimation of total regional transit ridership.

Input Assumptions

Telework

Working from home, or teleworking, may contribute to reductions in driving since employees do not have to travel to a workplace. The SANDAG ABM explicitly accounts for this reduction by identifying the work location of some workers as "home." In the SANDAG ABM, persons who work from home do not make work trips, but they can make other trips during the simulation day that may offset the reduced home–work VMT. Based on information from the National Household Travel Survey, California Household Travel Survey, SANDAG Regional Transportation Study, and the ACS, SANDAG developed a telework trend to project future teleworking amounts as shown in Table S.16. As part of the effort to review and update Off-Model Calculators, researchers from the Institute of Transportation Studies at UC Irvine reviewed and confirmed the telework assumptions.

Table S.16: Telework Future Assumptions

Telework Future Assumptions			
Year	Telework Always or Primarily	Telework Occasionally	Telework Total
2016	7.1%	8%	15.1%
2020	9.2%	8.8%	18%
2025	9.7%	9.8%	19.5%
2035	10.9%	11.8%	22.7%
2050	12.7%	13.8%	26.5%

Auto Operating Costs

Common travel-modeling practice assumes that as a person considers whether to drive or take another mode of transportation, two driving cost components are considered: fuel cost per mile of travel and non-fuel operating costs. Fuel cost per mile is calculated based on forecasts for how much gas will cost as well as the fuel efficiency of a vehicle. Non-fuel operating costs comprise vehicle maintenance, repair, and tires. Auto operating cost (AOC) does not typically include the costs associated with the purchase of a vehicle (purchase/lease costs, insurance, depreciation, registration, and license fees) as these are part of a long-term car ownership decision-making process.

For the 2015 SCS and California Senate Bill 375 (Steinberg, 2008) GHG target setting, SANDAG and the other large metropolitan planning organizations (MPOs) in the state developed a consistent approach to define, estimate, and forecast AOC. After the second SCS cycle, the California Air Resources Board (CARB) produced an AOC draft calculator that provides a framework for producing an average AOC for all fuel types.

In addition to the CARB AOC draft calculator, SANDAG uses the Oil Price Information Service (OPIS) by IHS Markit for current and historical gasoline prices and the U.S. Energy Information Administration (EIA) for future gasoline prices. The OPIS data was purchased for San Diego County specifically.

The EIA publishes an Annual Energy Outlook (AEO) forecast with several variations of forecasts for economic growth, oil prices, and resources and technology based on different assumptions (effectively resulting in a range of forecasts). The Big 4 MPO group for the second SCS used the U.S. EIA AEO low forecast plus 75% of the difference between the high and low oil price forecast with an adjustment from U.S. costs to California costs. U.S. to San Diego cost differences have been escalating in recent years, with the 2019 San Diego average costs reaching $1 per gallon higher than the U.S. average.

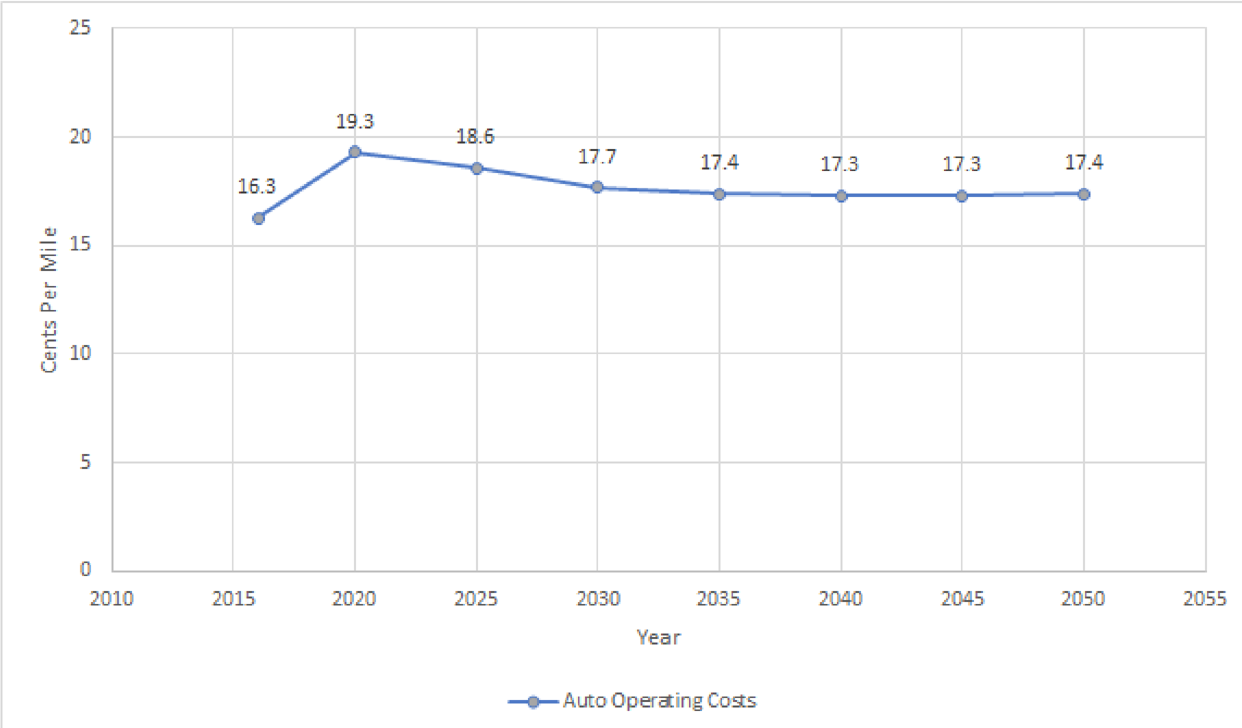
For the 2021 Regional Plan and third SCS, SANDAG used the CARB draft AOC calculator assumptions for alternative fuel prices, maintenance, fuel consumed, and fuel efficiency. The only exception to the CARB draft AOC calculator is for gasoline fuel costs. Gasoline fuel costs were based on the 2020 U.S. EIA AEO low forecast plus 75% of the difference between the high and low oil price forecast with adjustment from U.S. costs to San Diego costs. The gasoline fuel cost calculation is consistent with the methodology applied in the second SCS and 2018 target setting. Additionally, the U.S. EIA fuel forecasts are historically volatile, with forecasts being heavily factored based on the current year starting price. Using a forecast that is higher than reference case brings the fuel costs somewhat closer to the assumptions used over the past decade and more in line with historic average fuel costs. SANDAG will hold the 2019 U.S. to San Diego cost difference of $1 constant through the forecasted years. Maintenance costs use American Automobile Association costs, which are based on national current-year costs of automobiles.

Figure S.16 shows the calculated AOC values for current and future years used in the ABM2+. From 2016 to 2020, EIA projected fuel costs increase faster than fuel efficiency and alternative fuel/vehicle use. From 2020 to 2050, fuel efficiency increases offset increases in fuel costs, resulting in a more stabilized auto operating cost.

Impacts of gas prices on vehicle use can be found in research sponsored by CARB.[8] The CARB draft AOC calculator can be found at arb.ca.gov/cc/sb375/aoc_calculator_posting.xlsm.

8 See arb.ca.gov/sites/default/files/2020-06/Impacts_of_Gas_Price_on_Passenger_Vehicle_Use_and_Greenhouse_Gas_Emissions_Technical_Background_Document.pdf.

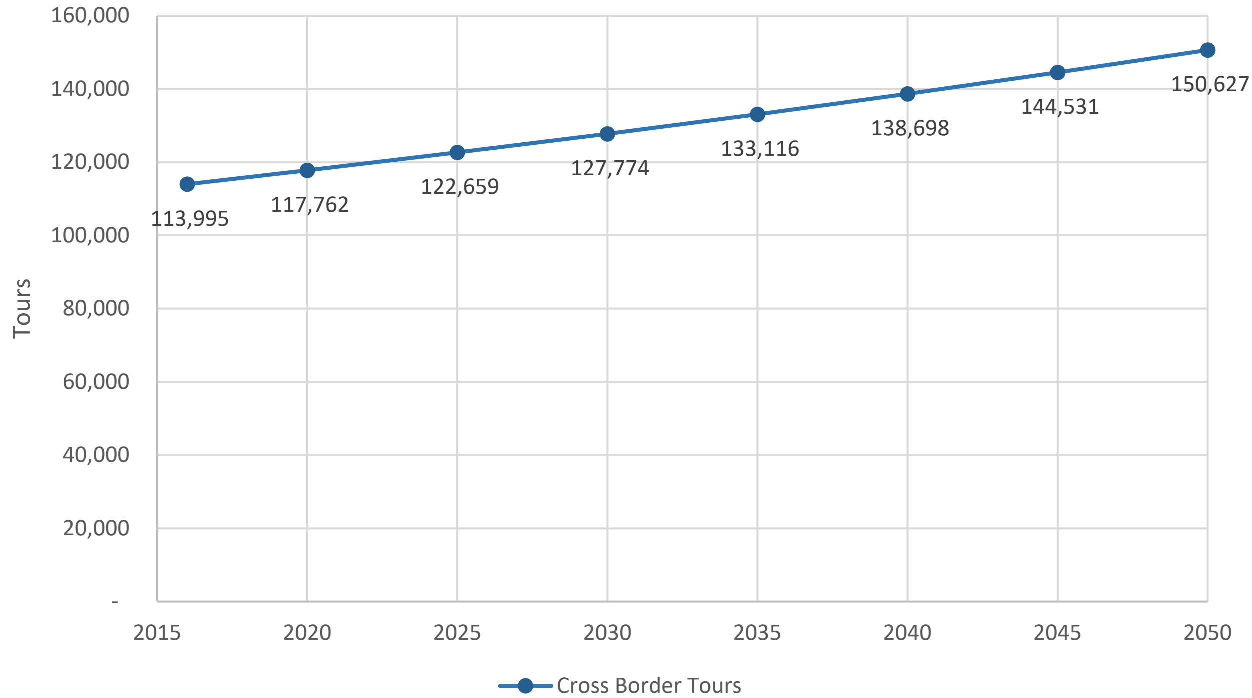
Figure S.16 : ABM2+ Auto Operating Costs



Crossborder Tours

The future projected increase of border tours uses 2016 crossing volumes for vehicle passengers and pedestrians as a starting point. Vehicle passengers are then grown at an annual growth of 0.7% based on information from the SR 11 Otay Mesa East Traffic and Revenue Report. Pedestrians are grown at an annual growth of 1.2% based on an analysis of historical growth trends.

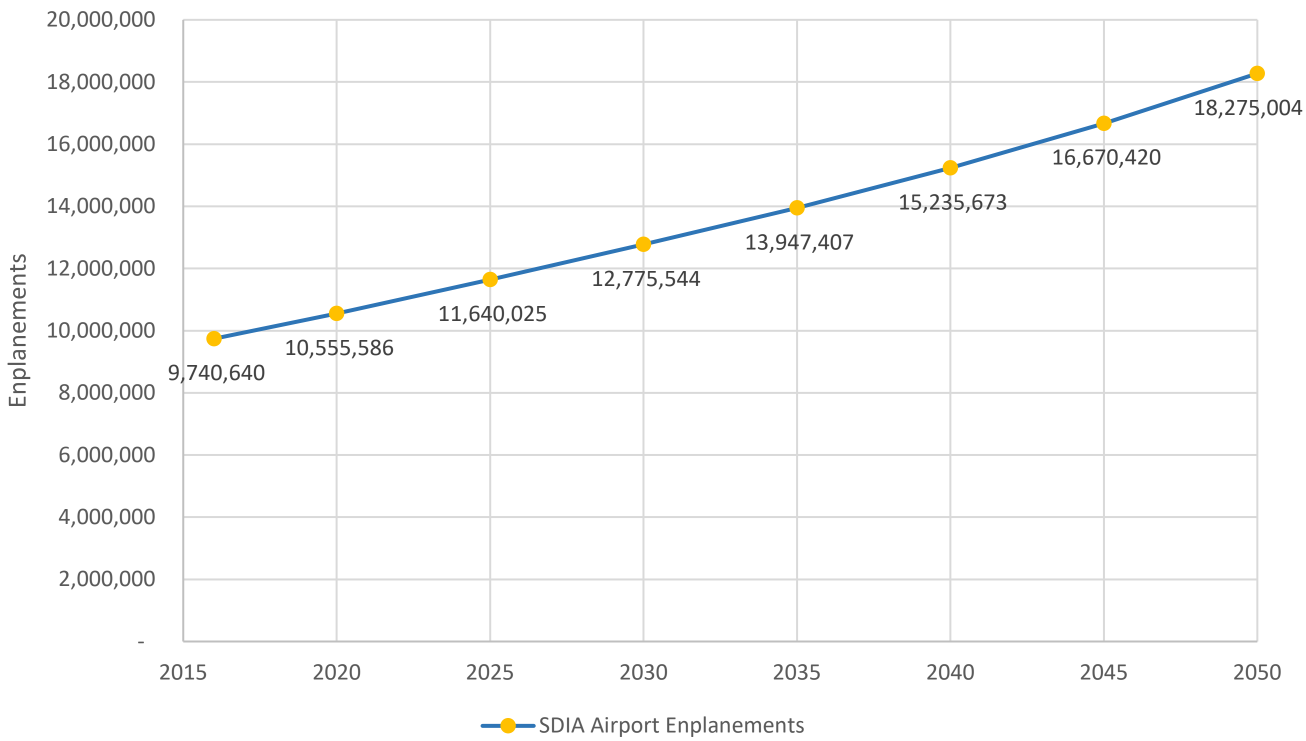
Figure S.17: Crossborder Tours



Airport Enplanements

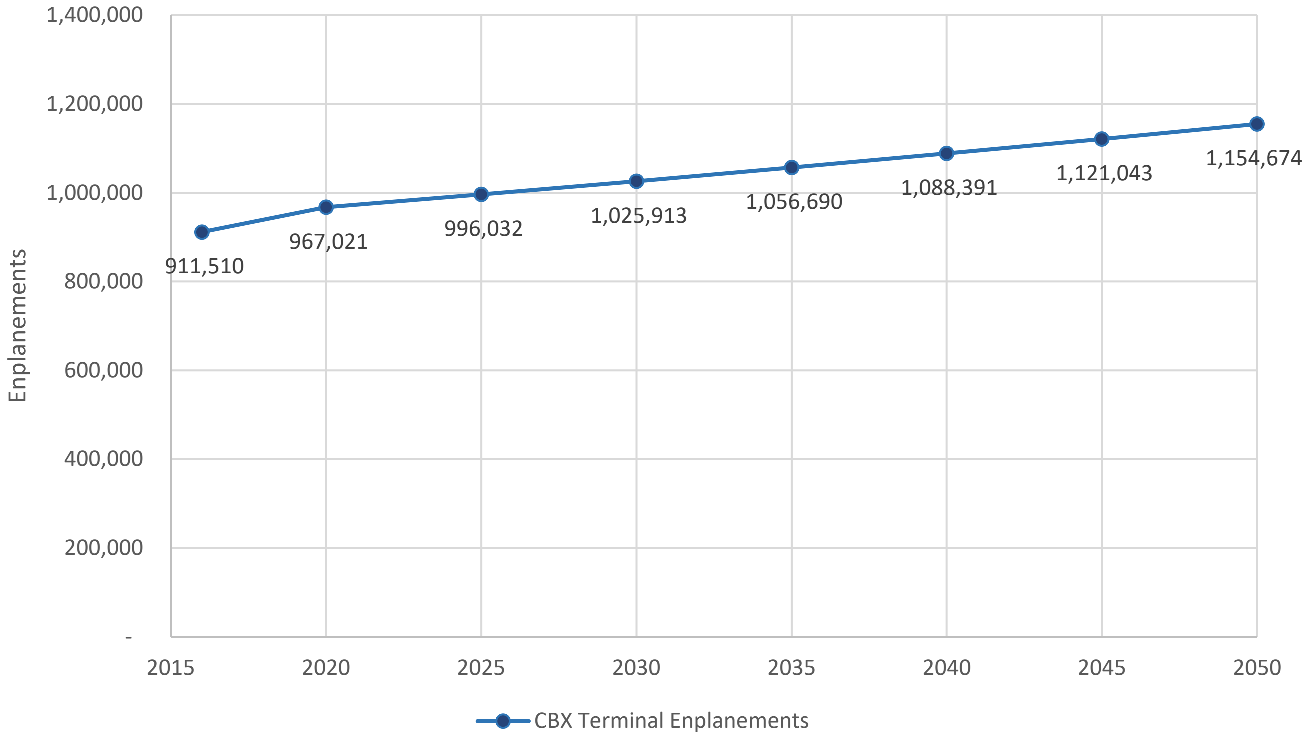
As discussed earlier, enplanements are a key input to the ground access model for SDIA. The total number of yearly enplanements at SDIA (without counting transferring passengers) is input for each simulation year (see Figure S.18). The data are available in the Aviation Activity Forecast Report.[9]

Figure S.18: San Diego International Airport Enplanements



[9] Airport Development Plan: San Diego International Airport, Leigh|Fisher, March 2013, page 47–68 (Table 22).

Figure S.19: Tijuana International Airport Enplanements Through the Cross Border Xpress Terminal



External Cordon Trips

External cordon trips are those trips originating external to the San Diego region and destined for either within the region or to another external area. External-to-internal trips are based on traffic counts at the cordons and projections in population growth from the California DOF.

Figure S.20: External Trips

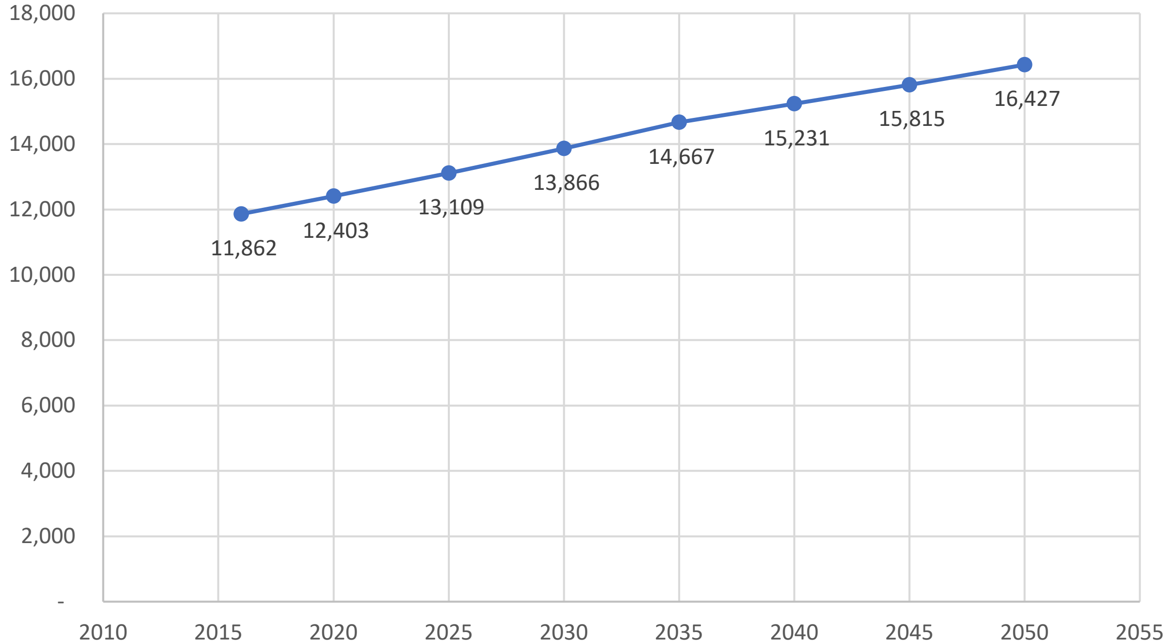
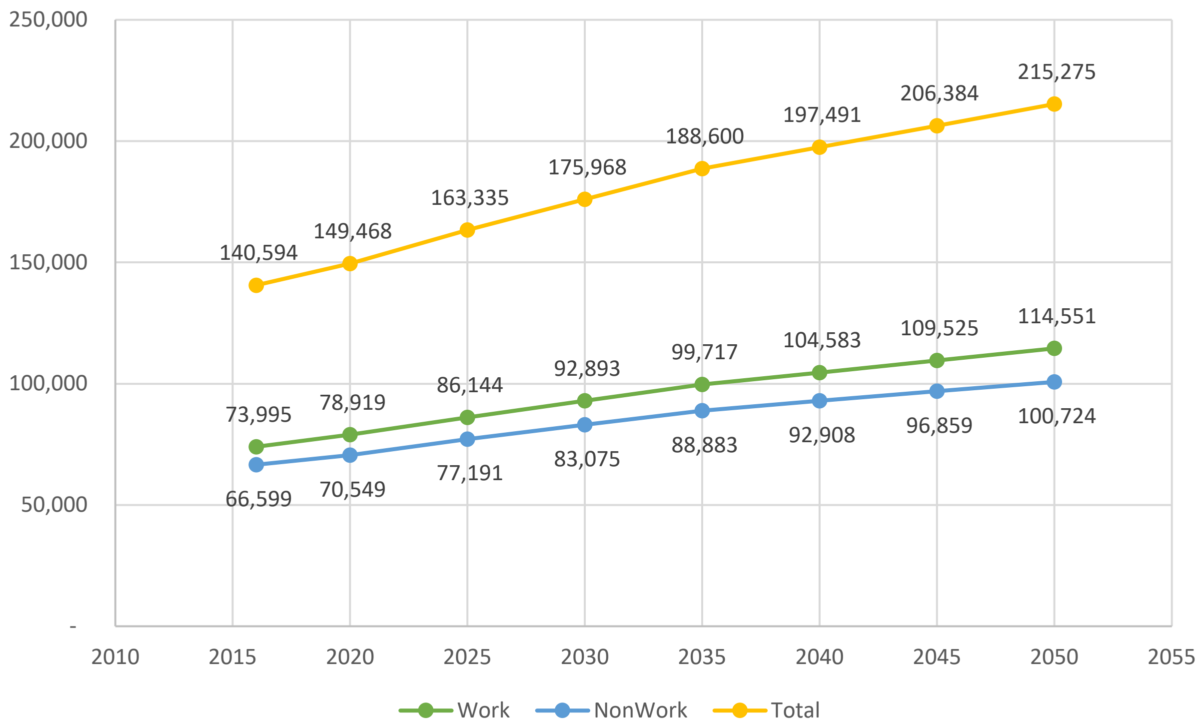


Figure S.21: Non-Crossborder External Trips into the San Diego Region



ABM2+ Technical Advisory Committee Expert Review

To guide ABM2+ development, SANDAG formed an ABM Technical Advisory Committee (TAC). The 11-member TAC is comprised of nationally recognized leaders in the travel demand modeling field who come from a vast array of organizations, including FHWA, CARB, major MPOs, academia, and independent consultancies.

SANDAG hosted two rounds of TAC review and evaluation. The first TAC meeting was held in May 2019 to evaluate modeling strategies to address emerging technologies, such as TNCs, connected and autonomous vehicles (AVs), transformative modes (e.g., high-speed rail), micromobility (e.g., e-scooters, dockless bicycles), and pricing options. The second TAC meeting was held in March 2020 to follow up on implementing the TAC's short-term model recommendations from the first meeting and to evaluate ABM2+ and its usage for the 2021 Regional Plan. The TAC gave very high remarks on ABM2+, concluding that it not only remained well above the state of the practice, but that some components were state-of-the-art for travel demand models. The new mobility features in ABM2+ go beyond the state of the practice, especially for TNC and AV components.

Due to the future uncertainty in AVs (penetration rates, level of AV, public policies, and regulations) and based on the recommendations from the TAC, the 2021 Regional Plan did not use the AV functionality of ABM2+.

ABM2+ Sensitivity Testing

In response to the Final Sustainable Communities Strategy Program and Evaluation Guidelines issued by CARB, to examine the responsiveness of ABM2+ to potential SANDAG 2021 Regional Plan strategies and prepare for the ABM2+ TAC peer review held in March 2020, SANDAG modeling staff conducted a series of sensitivity tests to demonstrate the effects of various inputs on VMT, mode share, trip length, and transit boardings using ABM2+ in February 2020. TAC gave high remarks on the extensive sensitivity tests.

Following CARB's sensitivity test guidelines, SANDAG modeling staff conducted land use, transit infrastructure, AT, local/regional pricing, new mobility, and exogenous variable sensitivity tests. Some tests were adjusted either to conform to the ABM2+ structure or to set with testing values that are more in line with RTP strategies. Tests in the new mobility category, including AV, TNC, and micromobility, were beyond CARB's recommendations. Most sensitivity tests were based on 2035 model runs using 2035 revenue-constrained networks from the 2019 Federal RTP. The population forecast was prepared by SANDAG Economic and Demographic Analysis staff in August 2019. The 2035 revenue-constrained scenario was used as the baseline scenario to derive elasticity. Land use–related tests used the 2050 forecast to account for the full potential impact of population growth on VMT and mode share. For a detailed sensitivity testing report, please refer to github.com/SANDAG/ABM/wiki/files/SensitivityReportV3.pdf.

ABM2+ Model Changes Between Draft and Final

Software changes were made between the release of the draft 2021 Regional Plan and final 2021 Regional Plan. These changes could have influence on the reported performance of the 2021 Regional Plan between draft and final. Those changes are documented in SANDAG's GitHub wiki site located here: github.com/SANDAG/ABM/wiki/Version_14_2_2_updates.

Model Runs Used in the Final 2021 Regional Plan

Table S.17: Model Runs Used in the Final 2021 Regional Plan

Model Runs Used in the Final 2021 Regional Plan				
Scenario No.	**Name**	**Forecast Year**	**ABM Version**	**Land Use Version**
458	2016	2016	version_14_2_2	DS-ID 38
463	2020 (non-COVID)	2020	version_14_2_2	DS-ID 38
464	2023 Build	2023	version_14_2_2	DS-ID 38
461	2025 No Build	2025	version_14_2_2	DS-ID 39
462	2025 Build	2025	version_14_2_2	DS-ID 38
467	2026 Build	2026	version_14_2_2	DS-ID 38
473	2029 Build	2029	version_14_2_2	DS-ID 38
470	2030 No Build	2030	version_14_2_2	DS-ID 39
465	2030 Build	2030	version_14_2_2	DS-ID 38
468	2032 Build	2032	version_14_2_2	DS-ID 38
469	2035 No Build	2035	version_14_2_2	DS-ID 39
475	2035 Build	2035	version_14_2_2	DS-ID 38
471	2040 Build	2040	version_14_2_2	DS-ID 38
472	2040 No Build	2040	version_14_2_2	DS-ID 39
459	2050 Build	2050	version_14_2_2	DS-ID 38
460	2050 No Build	2050	version_14_2_2	DS-ID 39

Abbreviations List

Abbreviations List	
Acronym	**Description**
ABM	Activity-based model
ACS	American Community Survey
AEO	Annual Energy Outlook
AGEB	Área Geoestadística Básica
AOC	Auto operating costs
AT	Active transportation
Caltrans	California Department of Transportation
CARB	California Air Resources Board
CBD	Central business district
CBX	Cross Border Xpress
CDAP	Coordinated daily activity pattern
CVM	Commercial vehicle model
DAP	Daily activity pattern
DC	Destination choice
DOF	California Department of Finance
EE	External to external
EI	External to internal
EIA	U.S. Energy Information Administration
Emme	Modeling software made by INRO: inrosoftware.com/en/products/emme
FAF	Freight Analysis Framework
GIS	Geographic information system
HDTM	Heavy-duty truck model
HOT	High-occupancy toll
HOV	High-occupancy vehicle
HTS	Household Travel Behavior Survey
IE	Internal to external
MGRA	Master Geographic Reference Area
MPO	Metropolitan planning organization
OBS	Transit On-Board Survey
OPIS	Oil Price Information Service
PeMS	Caltrans Performance Measurement System
RTP	Regional Transportation Plan

Abbreviations List	
Acronym	**Description**
SANDAG	San Diego Association of Governments
SCAG	Southern California Association of Governments
SCS	Sustainable Communities Strategy
SDIA	San Diego International Airport
SOV	Single-occupancy vehicle
TAC	Technical Advisory Committee
TAP	Transit access points
TAZ	Transportation analysis zone
TNC	Transportation network company
TOD	Time of day
VDF	Volume-delay function
VOT	Value of time

Travel Modeling Glossary

its.uci.edu/~mmcnally/tdf-glos.html

Appendix S, Part 2: Off-Model Strategies

Off-Model Overview

Travel models are the principal tools used to evaluate transportation and land use scenarios and alternatives. They provide planners and policymakers alike with information needed to help make informed decisions. The SANDAG travel model, an activity-based model (ABM), provides a systematic analytical platform so that different alternatives and inputs can be evaluated in an iterative and controlled environment. Travel models can be updated over time to reflect changes in updated travel data, travel behavior, and new travel options. The travel model version used to evaluate San Diego Forward: The 2021 Regional Plan (2021 Regional Plan)/Sustainable Communities Strategy (SCS) is referred to as ABM2+. Though travel models are comprehensive and complex tools, there may be instances where the impacts of certain 2021 Regional Plan/SCS policies under consideration cannot be measured in ABM2+. In these instances, SANDAG relies on off-model techniques to evaluate the impacts of these strategies. Off-model methodologies are based on evidence from empirical data and research and were developed in collaboration with other metropolitan planning organizations (MPOs), research institutions, and consultation with the California Air Resource Board (CARB) Policies and Practices Guidelines.

For the 2021 Regional Plan, the off-model analysis includes an evaluation of a suite of regional strategies and programs that help further the goals identified in the 2021 Regional Plan and are not captured in ABM2+. Strategies proposed in this methodology include programs facilitated and administered by SANDAG as well as services operated by third parties, as detailed below.

- **Vanpool:** The SANDAG Vanpool Program encourages the formation of vanpools in the San Diego region by providing a monthly subsidy for eligible commuters
- **Carshare:** The Flexible Fleets strategy supports the deployment of carshare services that provide vehicles as short-term rentals and help reduce the reliance on owning a personal vehicle
- **Pooled rides:** The Carpool Incentive Program encourages the formation of pooled rides (or carpools) throughout the San Diego region by providing trip incentives to commuters who pool to and from work
- **Regional Transportation Demand Management Ordinance (TDMO):** Support the implementation of a regional TDMO that would require large employers to offer commuter benefit programs to employees
- **Electric vehicles (EVs):** Develop and implement regional EV charger and vehicle incentive programs to support electrification of vehicles

To support this evaluation, SANDAG partnered with the Institute of Transportation Studies at UC Irvine (ITS-Irvine) to review and validate SANDAG travel behavior modeling and off-model methodologies. Additionally, SANDAG, as one of the four largest MPOs in California, has partnered with the Metropolitan Transportation Commission, the Sacramento Area Council of Governments, and the Southern California Association of Governments (SCAG) to establish the Future Mobility Research Program and jointly fund research on the potential impacts of transportation technologies. This cooperative effort developed a consistent approach to evaluating the range of potential changes to travel behavior associated with emerging technologies and provided recommendations on how to model travel behavior and incorporate technology into each MPO's Regional Transportation Plan/SCS.

The methods employed for the off-model methodologies are based on the Transportation Demand Management (TDM) Calculators developed by WSP USA and the EV Calculators developed by Ascent Environmental. ITS-Irvine was contracted in March 2020 to conduct a methodological review of these calculators for use in evaluating the 2021 Regional Plan. The methodological review generally affirmed the approaches adopted by WSP USA and Ascent Environmental, with some suggestions adopted to improve the methodological validity of the calculators.

Summary of Transportation Demand Management and Electric Vehicle Off-Model Calculators

Table S.18 summarizes the daily carbon dioxide (CO_2) and percent per capita reduction impacts of the various TDM and EV off-model methodologies.

Table S.18: Carbon Dioxide Reduction Impacts of Off-Model Methodologies

Carbon Dioxide Reduction Impacts of Off-Model Methodologies				
Off-Model Strategy	**Daily Total CO_2 Reductions (short tons)**		**Percent per Capita CO_2 Reduction as Compared to 2005**	
	2035	**2050**	**2035**	**2050**
Vanpool	143.7	156.2	0.31%	0.32%
Carshare	82.0	—	0.17%	—
Pooled rides	5.6	5.5	0.01%	0.01%
Regional TDMO	173.9	274.5	0.37%	0.56%
EV program incentives	1,010.0	836.0	2.15%	1.72%
Total	**1,415.2**	**1,272.2**	**3.01%**	**2.61%**

Transportation Demand Management Off-Model Calculators

The off-model methodology for estimation of vehicle miles traveled (VMT) and greenhouse gas (GHG) emission reductions from TDM strategies share a common overall methodology that is implemented in a series of Excel spreadsheet calculators. These strategies are part of the SANDAG regional TDM program, iCommute. iCommute works with employers throughout the region to design and implement commuter benefit programs and provides residents with information about vanpool and carpool services, shared mobility, support for biking, teleworking, and transit solutions.

The VMT reductions are based on historical data, applicable research, and case study findings for each strategy. Where possible and if available, local data were used to inform the assumptions used in the methodology. To minimize double counting, the methodology intentionally employs a conservative approach to estimate reasonable program impacts. While the off-model calculators use mode-based inputs from ABM2+ to estimate program impacts, calculator outputs remain off-model and do not interact or feed back into ABM2+.

In general, the research is used to estimate the following methodological parameters:

1. **Population that has access to the mobility service, or market:** The market may be defined in terms of persons or households.
2. **Level of supply/geographic extent:** The level of supply may be defined as a function of cities, neighborhoods, or employers in which the program or service is available.
3. **Regional infrastructure and policy:** Regional investments in transportation infrastructure, policies, or programs that may help facilitate or incentivize use of the strategy and impact travel behavior.
4. **Baseline VMT:** An estimate of the average VMT per person or per household among persons/households that do not participate in the program or mobility service.
5. **Project VMT:** An estimate of the average VMT per person or per household expected among persons per households that participate in the program or mobility service. This is estimated directly from average trip lengths and indirectly from mode shifts, changes in car occupancy, and/or reductions in average number of trips.
6. **GHG emission factors:** Based on total trip forecasts produced by the SANDAG ABM and CO_2 estimates developed with Emission Factors (EMFAC) 2014.

The following sections detail specific program characteristics along with the methodologies and assumptions for each TDM off-model calculator.

Vanpool

Strategy Overview

The SANDAG Vanpool Program is offered by iCommute. This program provides a subsidy of up to $400 per month for eligible vanpool groups. Vanpools can also leverage Managed Lanes and high-occupancy vehicles (HOVs) for travel and can take advantage of priority parking for rideshare at employment sites and within mobility hubs. The program requires that vanpools have either an origin or destination in San Diego County, maintain 80% vehicle occupancy, and travel at least 20 miles within the county. Vanpools have been shown to reduce GHG emissions since only one (albeit larger) vehicle is required to transport the same number of people that would normally take 7 to 15 single-occupant vehicles to transport. In FY 2019, the VMT reduction attributed to the SANDAG Vanpool Program was approximately 93 million miles.

The iCommute team works closely with major employers and conducts targeted marketing campaigns to encourage the formation of vanpools in the region. More than half of the vanpools are military or federal employees who also benefit from the Transportation Incentive Program stipend, making vanpooling a cost-effective alternative to driving alone. Participation in the SANDAG Vanpool Program is expected to grow through iCommute outreach and incentives. In 2019, the program even grew to offer more diverse and affordable vehicles from three vanpool vendors, including an all-electric vanpool service. More than 85% of vanpools in the SANDAG program use vehicles with a maximum occupancy of seven to eight passengers, and almost half of vanpools originate from Riverside County. The influx of vanpools traveling into the region from Riverside County can leverage Managed Lanes on the I-15 that allow vanpoolers to use the HOV lanes free of charge and offer travel time reliability.

Off-Model Calculator Assumptions and Methodology

The calculation of VMT reductions is based on the SANDAG Vanpool Program data, including vanpool fleet and trip information. These data include the total number of active vanpools, vehicle type, vanpooler industries, commute trip origin and destination, distance traveled within San Diego County, and vehicle occupancy. Historical program data indicate that the SANDAG Vanpool Program caters to a workforce that commutes long distances to work (50 miles one way on average) and works for large employers that have fixed schedules.

Based on existing Vanpool Program trends, the vanpool off-model calculator estimates that vanpooling in the region will continue to grow relative to the total workers employed in San Diego County. Therefore, as the region adds jobs within industries that have historically had higher rates of vanpooling (i.e., military, biotech, federal employers), it is assumed that enrollment in the SANDAG Vanpool Program will also grow. While employers in the region are currently implementing telework policies due to the COVID-19 pandemic, the industries in which vanpooling thrives are those that in large part are considered “non-teleworkable,” such as manufacturing and military, which require employees to perform their job duties on site.

Vanpools in the San Diego region can also leverage the exclusive use of Managed Lanes (HOV and I-15 Express Lanes) to shorten their commute time during peak travel periods. The reliability of the Managed Lanes makes vanpooling an attractive option. Consistent with this assumption, the vanpool off-model calculator assumes that as the region's Managed Lane network expands, commuters who choose to vanpool are likely to experience shorter travel times than commuters driving alone. This travel time savings will encourage a shift from driving alone to vanpooling.

Based on historical program participation data, three vanpool markets were defined based on the vanpoolers' employer industry: military vanpools, federal non-military vanpools, and non-federal vanpools. This segmentation was used to calculate employment growth factors that are specific to each of these industries. The travel time savings methodology also varies depending on industry type, because the destinations of the future military vanpools are defined. Other inputs used to derive the impact of vanpooling on GHG and VMT, such as average distance traveled and average vehicle occupancy, also vary by type of industry and are based on historical Vanpool Program data.

The Vanpool Program off-model GHG-reduction methodology estimates that vanpools in the region will grow to 676by 2035 and 739 in 2050. Vanpool growth estimates and VMT reductions in were determined using the following approach:

1. Segment active vanpools in program and summarize their associated travel characteristics (average round-trip mileage, occupancy) into three targeted markets: federal, military, and non-federal.
2. Estimate vanpool growth due to employment for each vanpool market. New vanpools = base year vanpools × percent change in employment markets (federal, military, and non-federal). Employment growth is based on Series 14 Regional Growth Forecast.
3. Estimate vanpool growth due to induced demand from travel time savings on regional Managed Lane investments for each vanpool market. Travel time savings are calculated via ABM2+ and defined as the difference between the travel time experienced when using all available highways, and the travel time experienced using general-purpose lanes only (excluding HOV and Express Lanes). The elasticity of vanpooling with respect to travel time = (marginal disutility wrt travel time) × (travel time) ⁄ (1 − probability of vanpooling). Compute the demand induced by travel time savings by applying the demand elasticity formula to the estimated number of vanpools for each scenario year, after accounting for employment growth.
   New vanpools = (elasticity wrt travel time) × (% change in travel time).
4. Estimate VMT reduction for each vanpool market based on vanpool trip characteristics. Daily VMT reduction = total vanpools [2 + 3] × average occupancy (excluding the driver) × round-trip mileage within San Diego County only.

Table S.19: Vanpool Off-Model Results

Vanpool Off-Model Results		
	2035	**2050**
Total Vanpools	676	739
Daily VMT Reduction	308,790	,337,458
Daily Total CO_2 Reduction (short tons)	143.7	156.2
Daily Per Capita CO_2 Reduction	0.31%	0.32%

Carshare

Strategy Overview

Carshare services offer access to vehicles as short-term rentals 24 hours a day, 7 days a week. Carshare can provide first- and last-mile connections to transit or fill gaps in the region's transit services by providing an efficient transportation alternative for commute and non-commute trips. In recent years, the carshare market in the region has changed with the exit of the one-way carshare service provider car2go from the region. To date, only round-trip and peer-to-peer services offered by ZipCar, Turo, and Getaround exist in the San Diego region.

As part of the Vision for the 2021 Regional Plan, Flexible Fleets are envisioned to operate throughout the region. Flexible Fleets provide more travel options that reduce the reliance on owning a personal vehicle and offer reliable connections to and from transit. To help encourage deployment of Flexible Fleets like carshare in the region, SANDAG will support carsharing through iCommute outreach and incentives as well as the provision of infrastructure (e.g., EV chargers, designated/priority parking, or curb space) needed to support carsharing in Mobility Hubs.

Research indicates that households that participate in carsharing tend to own fewer motor vehicles than non-member households.[10] With fewer cars, carshare households shift some trips to transit and non-motorized modes, which helps to contribute to overall trip-making reductions. Estimates of the VMT reductions attributed to carshare participation have been reported to be 7 miles per day[11] and up to 1,200 miles per year[12] for round-trip carshare. A survey of car2go users in five North American cities, including San Diego, found that carshare households reported decreases in VMT ranging from 6% to 16%, with San Diego users reporting an average 10% VMT reduction, or

10 E. Martin and S. Shaheen (2016). Impacts of car2go on Vehicle Ownership, Modal Shift, Vehicle Miles Traveled, and Greenhouse Gas Emissions. An Analysis of Five North American Cities.

11 Cervero, R. A. Golub, and Nee (2007) "City CarShare: Longer-Term Travel-Demand and Car Ownership Impacts", Presented at the 87th Transportation Research Board Annual Meeting, Washington, D.C.

12 E. Martin and S. Shaheen (2010), "Greenhouse Gas Emission Impacts of Carsharing in North America," Mineta Transportation Institute. MTI Report 09-11.

approximately 1.4 miles per day.[13] Similar behavior has been reported for participants in London's free-floating carshare service, with carshare members exhibiting a net decrease in VMT of approximately 1.5 miles per day.[14]

Off-Model Calculator Assumptions and Methodology

The carsharing methodology only accounts for VMT and GHG emission benefits associated with round-trip carshare service. While the off-model calculator is able to account for the VMT reduction impacts of free-floating carshare service, it is assumed that this type of service will not return to the San Diego region due to the rise and popularity of on-demand ridehailing service providers like Uber, Lyft, and Waze Carpool.

Based on market trends in the San Diego region, it is expected that carshare will remain a viable transportation option in neighborhoods that exhibit similar supporting land uses as those where carsharing is provided today. In support of regional Mobility Hub planning efforts, the SANDAG TDM program seeks to promote and encourage the provision of carshare within the region's employment centers, colleges, military bases, and within the proposed Mobility Hub network (Figure S.22). Given the future trend toward mobility-as-a-service, it is assumed that carsharing will evolve to be part of a fleet of shared, electric, and on-demand vehicles by the year 2050; therefore, carshare coverage areas are only defined until 2035. Within these defined carshare service areas, it is assumed that participation in the carshare program may vary depending on the supporting density.[15] The population density thresholds that support carshare participation in the region are based on the car2go service area prior to its exit from the San Diego market. Based on the 2016–2017 San Diego Regional Transportation Study and available research on carshare participation rates, it is assumed that areas with a population greater than 17 people/acre will have a 2% participation rate. Areas with a population density lower than 17 people/acre will have a 0.5% participation rate. These density thresholds are specific to carshare trends exhibited in the San Diego region. VMT reduction impacts from round-trip carshare also assume a daily average reduction of seven miles per day per round-trip carshare member based on the latest available research.[16]

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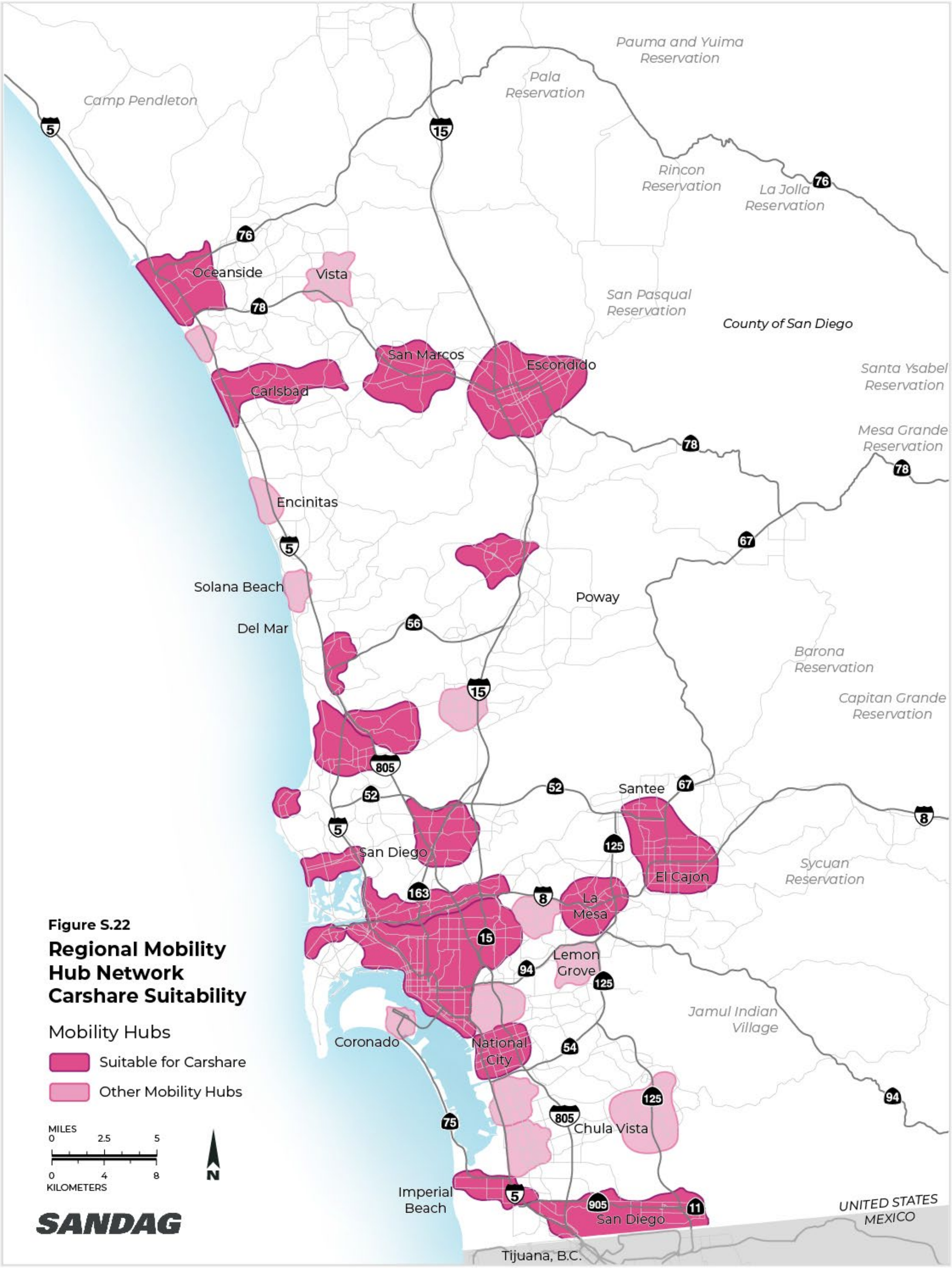
[13] Martin, E. and S. Shaheen (2016). Impacts of car2go on Vehicle Ownership, Modal Shift, Vehicle Miles Traveled, and Greenhouse Gas Emissions. An Analysis of Five North American Cities.

[14] Le Vine, S., M. Lee-Gosselin, A. Sivakumar, J. Polak. (2014). "A new approach to predict the market and impacts of round-trip and point-to-point carsharing systems: Case study of London." Transportation Research Part D: Transport and Environment, Vol. 32, pp. 218–229.

[15] Transportation Sustainability Center (2018), Carshare Market Outlook. its.berkeley.edu/node/13158.

[16] Cervero, R. A. Golub, and Nee (2007) "City CarShare: Longer-Term Travel-Demand and Car Ownership Impacts," Presented at the 87th Transportation Research Board Annual Meeting, Washington, D.C.

Figure S.22: Regional Mobility Hub Network – Carshare Suitability



These maps show generalized regional Mobility Hub boundaries for planning purposes and are not intended to be binding or precise. Mobility Hub boundaries are subject to refinement in close coordination with the affected jurisdiction(s).

The carshare program off-model GHG-reduction methodology estimates that carsharing in the region will grow to include over 25,000 members by 2035. Given the popularity of on-demand ridehailing and mobility-as-a-service, it is assumed that carsharing services may sunset before 2050. VMT- and GHG-reduction estimates due to carsharing were determined using the following approach:

1. Define geographic areas (Master Geographic Reference Areas) and target markets (e.g., Mobility Hubs, colleges/universities, military) deemed suitable for carsharing based on existing trends.
2. Estimate “eligible adult population” within carshare coverage areas through 2035 using SANDAG Series 14 population forecast. Segment the population within coverage area into higher-density areas (>17 persons/acre) or lower-density areas (≤17 persons/acre) based on local carshare participation research.
3. Estimate carshare participation by applying the participation rate to eligible populations. Carshare participation = eligible adult population [2] × carshare participation rates (2% in high-density areas or 0.5% in low-density areas).
4. Estimate VMT reduction = total carshare membership [3] × round-trip carshare VMT reduction.

Table S.20: Carshare Off-Model Results

Carshare Off-Model Results		
	2035	**2050**
Carshare Membership	25,271	—
Daily VMT Reduction	176,896	—
Daily Total CO_2 Reduction (short tons)	82.0	—
Daily Per Capita CO_2 Reduction	0.17%	—

Pooled Rides

Strategy Overview

The SANDAG iCommute Program launched a Carpool Incentive Program in 2017. The program encourages the formation of pooled rides (or carpools) throughout the San Diego region by providing trip incentives to commuters that carpool to and from work. iCommute partnered with Waze Carpool, a technology company that links drivers with passengers headed in the same direction through the Waze Carpool smartphone app. Waze Carpool is a form of on-demand rideshare that allows someone to request a ride in real time using a mobile app. Ridesharing that uses mobile apps to match drivers and passengers can quickly fill empty seats, reducing congestion and auto emissions. For people whose schedules and destinations match up in the morning and evening, on-demand rideshare is a convenient and reliable transportation option.

The SANDAG Carpool Incentive Program provides trip incentives to employees for forming new carpoolers (passengers and drivers). To date, more than 200 employees have participated in the SANDAG Carpool Incentive Program, and about 130 rides have been completed through the incentive program. Outside of the Carpool Incentive Program, iCommute and Waze have implemented other promotions as part of Rideshare Week or with specific employers, like the military, to encourage pooling to work. SANDAG envisions encouraging pooling though continued incentives and outreach with iCommute and a technology partner. Participants in the SANDAG Carpool Incentive Program can also leverage Managed Lanes and HOVs for travel and can take advantage of priority parking for rideshare at employment sites and within Mobility Hubs.

Off-Model Calculator Assumptions and Methodology

The pooled rides off-model calculator accounts for the VMT and GHG benefits of the SANDAG Carpool Incentive Program. Data and research on pooled trips are limited due to lack of data sharing from on-demand rideshare companies that offer pooled services. To help remedy this, SANDAG, in partnership with the Metropolitan Transportation Commission (MTC) and SCAG, received a Caltrans planning grant to conduct a statewide ridehailing survey. The survey, known as the 2019 Transportation Study, evaluates the impact of ridehailing activity, including pooled ridehailing trips, throughout the state. Data from the 2019 Transportation Study informed the development of the pooled rides off-model calculator.

The off-model methodology for pooled rides is structured around the Waze Carpool model, in which the driver and passenger(s) are matched based on their similar origin and destination and meet at a common pick-up location, thereby mitigating route deviations or additional trip links. Building on the success of the existing SANDAG Carpool Incentive Program, the pooled rides off-model calculator assumes that the Carpool Incentive Program will continue to provide a minor trip subsidy that will lower the cost of pooling per trip for the user. Non-work trips will not be subsidized by SANDAG.

The calculator employs a reimbursement model based on the Waze Carpool service to compute a pooled ride index factor representing the cost ratio of pooling to driving alone.

Similar to the vanpool off-model calculator, the pooled rides off-model calculator also assumes that commuters that pool in the San Diego region can leverage the exclusive use of Managed Lanes (HOV and I-15 Express Lanes) to shorten their commute time during peak travel periods. The reliability of the Managed Lanes makes pooling an attractive option. As the region's Managed Lane network expands, commuters who choose to pool to work are likely to experience shorter travel times than commuters driving alone, which will encourage a shift from driving alone to carpooling. While both the vanpool and pooled rides calculator focus on the commuting population, the target market within the pooled rides off-model calculator focuses on the workforces that commute short distances to work (ten miles one way on average) rather than the longer-distance commuters captured within the vanpool off-model calculator.

The pooled rides program off-model estimates VMT and GHG reductions as follows:

1. Estimate a baseline app-enabled pooling market = drive-alone trips × pooled ride mode share based on 2019 Transportation Study.
2. Estimate increase in pooled rides due to Managed Lane investments. Travel time savings are calculated via ABM2+ and defined as the difference between the travel time experienced when using all available highways, and the travel time experienced using general-purpose lanes only (excluding HOV and Express Lanes). The elasticity of pooling with respect to travel time = (marginal disutility wrt travel time) × (travel time) ⁄ (1 − probability of pooling). Compute the demand induced by travel time savings by applying the demand elasticity formula to the app-enabled pooling market. New app-enabled pooled rides = elasticity wrt travel time × % change in travel time.
3. Total pooled ride trips = baseline pooling market [1] + pooled trips induced by Managed Lane time savings [2].
4. Estimate vehicle trips required to serve the person trips = total pooled ride trips [3] ⁄ minimum vehicle occupancy required per Carpool Incentive Program.
5. Estimate vehicles replaced by pooling = total pooled ride trips [3] − vehicle trips required to serve pooled trip demand [4].
6. Estimate person miles traveled reduced by pooled trips = total pooled ride trips [3] × average trip distance based on SANDAG ABM2+.
7. Estimated VMT reduction = total person miles [6] × proportion of vehicles eliminated by pooled riding [5/3].

Table S.21: Pooled Rides Off-Model Results

Pooled Rides Off-Model Results		
	2035	**2050**
Daily VMT Reduction	11,658	11,540
Daily Total CO_2 Reduction (short tons)	5.6	5.5
Daily Per Capita CO_2 Reduction	0.01%	0.01%

Regional Transportation Demand Management Ordinance

Strategy Overview

The SANDAG iCommute Program works with more than 200 employers on a voluntary basis to implement commuter benefit programs. The iCommute Employer Program is composed of a team of Account Executives who work with employers of all sizes throughout the region. Employers survey their employees to track their mode share over time and gain recognition through the iCommute Diamond Awards for measurably reducing single-occupant vehicle trips by employees. On average, the employers who work with iCommute have reduced their drive-alone mode share by 10%.

As part of the 2021 Regional Plan, SANDAG is exploring the development of regional TDM ordinance that would require employers with more than 250 employees to implement and monitor a commuter program that encourages employees to reduce drive-alone trips to work. Employers would demonstrate the achievement of these drive-alone reduction targets through application of one or more of the following TDM strategies, including, but not limited to:

- **Commuter Services:** Offering programs like secured bike lockers and free rides home in case of an emergency can make it easier for commuters to use transit and other alternatives to driving alone.
- **Financial Subsidies and Incentives:** Financial incentives and pre-tax commuter benefits for commuters can lower the out-of-pocket cost for commuters who choose alternatives to driving alone.
- **Marketing, Education, and Outreach:** Outreach events, educational campaigns, and marketing strategies help raise awareness of alternative commute options.
- **Parking Management:** Employers can offer cash incentives or transit passes in lieu of a parking space, and preferred parking for HOVs as incentives to choosing an alternative commute option. Charging for parking at the workplace can act as a disincentive to driving alone.
- **Telework and Flexible Work Schedules:** Employers can develop workplace policies that promote telework, flexible schedules, and/or compressed work schedules to reduce peak commute trips.

- **On-Site Amenities:** Secured bike lockers and showers can offer convenience for commuters who choose to bike to work.
- **Employer-Provided Transit:** Employer-provided transit can help serve the first- and last-mile connections to transit and/or provide direct pooling options for employees traveling from the same direction.

Prior to implementation, SANDAG will need to conduct research and outreach to develop a policy and legislative framework. This framework will inform a pilot program with employers, after which the program will be evaluated and refined for full implementation in the region.

Off-Model Calculator Assumptions and Methodology

The TDMO would require that employers must demonstrate that their employees (as a group) are meeting their proposed drive-alone reduction targets. SANDAG intends to expand existing iCommute Employer Program offerings to assist employers with implementing and monitoring their TDM programs. Further, it is assumed that the ordinance would only apply to specific employers, namely larger employers with at least 250 employees. These employers would be provided with options from a set of TDM strategies to achieve the target. It is assumed that the suite of strategies available to employers will be flexible and build upon other SANDAG commuter programs like the Vanpool Program, Carpool Incentive Program, Try Transit Program, and more.

Given the success of the voluntary iCommute Employer Program, with which employers have reduced their drive-alone rate by 10%, SANDAG anticipates that the TDMO program will achieve an average drive-alone reduction target of 15% by 2035. Since the options in the TDMO program include employer-sponsored vanpool and pooled-ride programs, the calculator allows for the trip reductions computed by the vanpool and pooled-ride calculators for large employers to be subtracted from the computed excess to avoid double-counting.

The TDMO off-model VMT and GHG reduction methodology is as follows:

1. Estimate fraction of peak commute trips (a.m. and p.m.) associated with large employers (LEs) based on ABM2+ model runs.
2. Calculate the number of drive-alone peak commute trips associated with LEs = number of drive-alone trips from ABM2+ × fraction of peak commute trips [1].
3. Compute TDMO drive-alone mode share reduction targets (15% reduction in 2035 and 25% in 2050).
4. Establish LE drive-alone peak commute trip threshold by applying drive-alone reduction targets to drive-alone trips associated with LEs. Drive-alone peak commute threshold = TDMO drive-alone mode share reduction target [3] × forecasted total work trips from ABM2+ × fraction of peak commute trips [1].

5. Estimate TDMO trip reductions. Based on the assumption that the number of trips that exceed the established drive-alone peak commute trip threshold in the target year are reduced by the TDMO. TDMO trip reductions = number of drive-alone peak commute trips [2] – drive-alone peak commute trip threshold [4]. If this value is less than zero, the ABM2+ forecast exceeds the TDMO target, so the TDMO will not reduce additional trips and the reductions are set to zero for this period.
6. Estimate TDMO VMT reduction = TDMO trip reductions [5] × average trip distance from ABM2+.
7. Total VMT reduction = TDMO VMT reduction – vanpool and pooled rides VMT reductions.

Table S.22: Regional Transportation Demand Management Ordinance Off-Model Results

Regional Transportation Demand Management Ordinance Off-Model Results		
	2035	**2050**
TDMO Drive-Alone Reduction Target	15%	25%
Daily VMT Reduction	366,196	581,285
Daily Total CO_2 Reduction (short tons)	173.9	274.5
Daily Per Capita CO_2 Reduction	0.37%	0.56%

Electric Vehicle Programs Calculator

Strategy Overview

In the 2021 Regional Plan/SCS, SANDAG will consider two types of EV programs: a Regional EV Charger Program (RECP) and a Vehicle Incentive Program (VIP). The RECP, which was included in the 2015 Regional Plan, would incentivize the installation of public and workplace Level 2 charging. The 2015 Regional Plan assumed that the RECP would incentivize Level 1 and Level 2 charging. Based on market changes since 2015, the RECP is now focused only on Level 2 charging. The investment in charging infrastructure would extend the electric range for plug-in hybrid electric vehicles (PHEVs) and lead to a reduction in GHG emissions beyond what is estimated in EMFAC. The VIP would offer rebates for the purchase of EVs. The vehicle rebates would be in addition to the state's investment in the Clean Vehicle Rebate Project, and GHG emission reductions would be proportional to regional and state rebate amounts.

The 2015 Regional Plan called for SANDAG to establish an incentive program in 2020 for public EV chargers as a GHG-reduction measure for the SCS and as a GHG-mitigation measure in the Environmental Impact Report. SANDAG also committed $30 million from 2020–2050 for the program to achieve the GHG reductions. Since the 2015 Regional Plan was adopted, SANDAG received a Caltrans Sustainable Communities Planning Grant in 2018 (that ended in June 2020) to research and develop the charger incentive program. This project helped SANDAG establish partnerships with the San Diego County Air Pollution Control District and the California Energy Commission's (CEC's) California Electric Vehicle Infrastructure Project (CALeVIP) to offer a more comprehensive rebate program as the San Diego County Incentive Project (SDCIP).

In September 2019, the SANDAG Board of Directors approved the establishment of Overall Work Program (OWP) 3502000 in the SANDAG Program Budget for the Regional Electric Vehicle Charging Program with a budget of $9 million for FYs 2020–2025. SDCIP partners have committed budgets for three years to start, and SANDAG will seek to continue partnerships with state and local cofunders for future program years and will coordinate with the local utility San Diego Gas & Electric (SDG&E). SDCIP opened on October 27, 2020, to great demand. A project requirements webinar was held August 27, 2020; a pre-launch webinar for participants was held October 6, 2020; and a workforce training webinar for electricians and a permit streamlining webinar for local governments were held October 22, 2020, and October 20, 2020, respectively. News about these and future SDCIP events will be available at the SDCIP website. Eligible rebate applicants will be able to apply for up to $80,000 per DC fast charger and up to $6,000 per Level 2 charger. With a three-year combined incentive budget of about $21.7 million, SDCIP is expected to help fund approximately 1,100 Level 2 chargers and 250 DC fast chargers in the San Diego region. On opening day, SDCIP's three-year budget was fully reserved, with wait-list applications exceeding $70 million in projects. As of October 15, 2021, 47% of applications have been reserved for projects in disadvantaged and/or low-income communities.

Since the 2015 Regional Plan, SANDAG ran the Plug-in San Diego (Plug-in SD) project through two consecutive CEC grants. Plug-in SD implemented recommendations from the Regional EV Readiness Plan through a combination of resource development, training, and technical assistance through an EV Expert. SANDAG is continuing some of this technical assistance in SDCIP to ensure a successful infrastructure incentive program. Since 2016, SDG&E's Power Your Drive (PYD) Program has also added about 3,000 EV chargers at workplaces, fleets, and multifamily residences in the region. SANDAG serves on the Program Advisory Council for SDG&E's PYD and other EV infrastructure programs. SDG&E and SANDAG are coordinating on future EV infrastructure planning and investments.

Off-Model Calculator Methodology and Assumptions

The EV off-model calculator estimates the CO_2 reductions and costs associated with implementation of both an RECP and VIP. Both programs are included in a single calculator to account for the interactions between the two programs. The calculator expands upon MTC's EV off-model methodology and applies a similar methodology to calculate emission reductions from SANDAG's proposed version of the RECP and VIP. Recent policies, research, studies, and models used to develop the 2021 Regional Plan EV off-model calculator include:

- Executive Order (EO) B-16-12 and EO B-48-18, which set a target of 1.5 million zero-emissions vehicles (ZEVs) and 5 million ZEVs in the state by 2025 and 2030, respectively.
- California Plug-In Electric Vehicle Infrastructure Projections: 2017–2025, published by the CEC in March 2018, including projections of the plug-in electric vehicle (PEV) vehicle fleet mix, charger inventory, and charging demand by county that would achieve the 1.5 million ZEV statewide target by 2025 established in EO B-16-12 and 250,000 EV chargers statewide, including 10,000 DC Fast Chargers, by 2025 established in EO B-48-18 (CEC 2018).
- Electric Vehicle Infrastructure Projection Tool (EVI-Pro), released in early 2018 by the National Renewable Energy Laboratory (NREL) and CEC, which estimates the public charging infrastructure needed to support a targeted PEV mix by 2025 for various regions across the state by county. Although this tool is not publicly available at this time, NREL and CEC released a web-based data viewer that summarizes the results of the tool for California, including anticipated charger counts and charger loads. The results of EVI-Pro were used to develop projections in CEC's California Plug-In Electric Vehicle Infrastructure Projections: 2017–2025 report (NREL 2018a, NREL 2018b).
- EMFAC2017 was released in late 2017 by CARB, which updates the statewide vehicle population, emissions, and VMT forecasts by fuel type, vehicle class, and other factors, accounting for adjusted ZEV forecasts that are generally more conservative than previously assumed in EMFAC2014 (CARB 2017b). EMFAC2017 also accounts for a minimum regulatory compliance scenario under the ZEV mandate in the state's Advanced Clean Cars Program. This mandate requires vehicle manufacturers to produce an increasing number of ZEVs for model years 2018 through 2025.

EV Off-Model calculator includes the following key methods and assumptions used in the model's calculations. The differences from MTC's approach resulted in a more complex calculator, but also one that accounts for San Diego–specific factors.

- CO_2 reductions from the RECP and VIP were calculated in two key steps. First, the difference was taken between the total eVMT supported by each respective program and the eVMT anticipated in a business-as-usual (BAU) forecast for a given milestone year. In cases where the program's eVMT would result in more eVMT than the BAU forecast, the additional eVMT was attributed to the displacement of the same VMT from equivalent gasoline light-duty vehicles (LDV), which was then translated to CO_2 reductions associated with the reduced gasoline LDV vehicle miles traveled. Second, the resulting CO_2 reductions were scaled to SANDAG-related efforts by applying the ratio of SANDAG incentives to non-SANDAG incentives on a dollar-per-dollar basis. To avoid double-counting reductions between the RECP and VIP, the calculator assumes that the reductions from additional PHEVs under VIP would be a subset of any additional PHEV eVMT supported by RECP because the RECP is assumed to extend the electric range of any PHEVs purchased under the VIP.

- The BAU forecast was based on a combination of 2018 vehicle populations from DMV registration data, EMFAC2017 ZEV growth rates, and adjustment of EMFAC's daily VMT per vehicle forecasts to SANDAG travel demand modeling.
- CO_2 reductions from the RECP were based on the difference between the total eVMT supported by a targeted number of all non-residential chargers, including existing and new chargers, in the SANDAG region and the eVMT anticipated in the BAU forecast for the SANDAG region for a given milestone year. The targeted total number of chargers in the SANDAG region was calculated using local PEV-to-charger ratios estimated by CEC's EVI-Pro analysis. EVI-Pro estimates that these ratios would change over time and vary by PEV type. The targeted total number of chargers would be equal to the sum of all existing chargers as of 2018 and any new chargers added starting from 2018. To estimate the number of chargers needed to be incentivized by SANDAG, the number of existing non-residential chargers was subtracted from the targeted number of all non-residential chargers in the region.
- EV chargers were assumed to charge both battery EVs and PHEVs. The eVMT provided to each type of vehicle per charger by non-residential charger type (e.g., public versus workplace) reflect the findings and assumptions in CEC's 2018 study and EVI-Pro runs.
- CO_2 reductions from the VIP were based on the difference between the targeted EV population for a given milestone year and the EV population anticipated in the BAU forecast. Average VMT and eVMT per vehicle per day were based on EMFAC2017 defaults, which vary by calendar year and vehicle type.
- As California Senate Bill 375 (Steinberg, 2008) only requires MPOs to address tailpipe emissions; upstream emissions from additional electricity demand from EVs are ignored.

Table S.23: Electric Vehicle Programs Off-Model Results

Electric Vehicle Programs Off-Model Results		
Regional EV Charger Program	**2035**	**2050**
Level 2 Chargers Incentivized	33,000	29,000
Charger Incentive (estimation)	$5,000	$3,000
Admin, Education, and Outreach	8%	5%
Total Program Cost	$178 million	$91 million
Vehicle Incentive Program	**2035**	**2050**
ZEVs Incentivized	112,000 (beyond EMFAC)	—
Vehicle Incentive (estimation)	$5,000	—
Admin, Education, and Outreach	7%	—
Total Program Cost	$604 million	—
Total	**2035**	**2050**
Combined Program Cost	$783 million	$91 million
Daily Total CO_2 reduction (short tons)	1,010	836
Daily Per Capita CO_2 Reduction	2.15%	1.72%

Attachments

Attachment 1: Institute of Transportation Studies at UC Irvine Academic Advisory Panel: Peer Review and Validation of the Five Big Moves

Attachment 2: WSP TDM Off-Model Memo

Attachment 3: Ascent Environmental Electric Vehicle Calculations Memo

Attachment 1:

Institute of Transportation Studies at UC Irvine Academic Advisory Panel: Peer Review and Validation of the Five Big Moves

UCI Institute of Transportation Studies

Academic Advisory Panel: Peer Review and Validation of the Five Big Moves

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Introduction

This report documents the work conducted by the Institute of Transportation Studies at UC Irvine (ITS-Irvine) for the San Diego Association of Governments (SANDAG) under contract 5005881 between February 20th, 2020 and November 30th, 2020. This project focused on providing SANDAG with the latest research, data, and tools that can be used to support the development of the SANDAG 2021 Regional Transportation Plan (RTP), with a focus on identifying how the advances in technology, coupled with public policy can enable the region to rethink and to maximize the coordination between land use and transportation planning and, in particular, operationalizing off-model methodologies for use in SANDAG's submission of the Sustainable Communities Strategy (SCS) methodology to the California Air Resources Board (CARB).

SANDAG uses an Activity Based Model (ABM) in its modeling and forecasting of transportation demand and its effect on the supply of transportation services. SANDAG calibrates the ABM using observed data, often in the form of user behavior collected from surveys and traffic and ridership counts. When observed data is not available, SANDAG must rely on available research and industry feedback to develop reasonable assumptions as model inputs. As SANDAG developed version 2 of its ABM in support of a planned 2019 SCS submission to CARB, it contracted with WSP, Inc. and Ascent Environmental, Inc. to develop a set of off-model calculators to project the vehicle miles traveled (VMT) and greenhouse gas (GHG) impacts for modes not accounted for in the ABM, following CARB recommended practices.

However, in February of 2019, the SANDAG Board of Directors took action to request additional time to develop a new long-term vision prior to its next SCS for the region. In October of 2019, Governor Newsom signed Assembly Bill 1730, which granted SANDAG two additional years for this process. The resulting vision is structured around what SANDAG terms as Five Big Moves that are designed to help provide compelling and real alternatives to the private automobile. Recognizing that new modeling methods were needed to analyze the Five Big Moves, SANDAG initiated an upgrade to its ABM this to use latest survey data to better reflect travel characteristics, system impacts, and land use changes to ensure that the transportation plan meets, or exceeds, the state mandated target of 19 percent per capita reduction in GHG by 2035. ABM2+, as it is called, was developed throughout 2019 and was reviewed by a Technical Advisory Committee (TAC) made up of academic leaders, peer agencies, and modeling consultants, who were tasked with providing input on potential ABM improvements that would better prepare the model for the 2021 Regional Plan and evaluating the readiness of ABM2+ for 2021 RP applications.. The final TAC review was completed in March of 2020, roughly coinciding with the start of this contract. In addition, further adjustments and improvements were made per TAC's suggestions, and the first ABM2+ version was released in September 2020.

Where the TAC technical review was primarily focused on confirming the methodologies employed in ABM2+, SANDAG still needed to evaluate their representation of the Five Big Moves in ABM2+. Further, the modeling updates also required a re-assessment of the off-model strategies that were developed for ABM2, to confirm that they were still needed and relevant, and to determine what updates to these off-model strategies were needed. These goals were the primary purpose of the work covered by this report.

The work was conducted over four tasks as follows:

1. **Review of assumptions underlying SANDAG's modeling**, which focused on conducting a general assessment of SANDAG's modeling methods using documentation and reports from the ABM2+ Technical Advisory Committee (TAC) to confirm that SANDAG's translation of their land-use and transportation strategies were methodologically sound.
2. **Assessment of needs for off-model calculators**, which assessed the existing off-model calculators that were developed for use with the prior version of SANDAG's delayed 2019 SCS update, and recommended modifications, deletions, or additions to the off-model methodologies.
3. **Updating off-model calculators**, which implemented the recommendations from Task 2.
4. **Final Report and off-model calculator delivery**, which involved working with SANDAG to finalize the calculators, liaising with CARB regarding their application, and reporting the results of the project in this document.

The work conducted under each of these tasks is described in the sections below. This report, along with the attached appendices, delivered software, and engagement activities carried out since the beginning of the contract, are submitted to fulfill all of the required deliverables under this contract.

Task 1. Review of assumptions underlying SANDAG's modeling

Deliverable	Date
1.1 Draft report assessing the assumptions underlying SANDAG's general modeling approach for representing the Five Big Moves.	Delivered as draft PowerPoint presentations in May 2020. Converted to report form in this section of the final report.

Summary of Work Performed

The work in this task focused on reviewing the policies, programs, and land use scenarios developed by SANDAG that will inform transportation investments and land use changes and development patterns. The primary objective of this effort is to justify the use of the model in the development of their Sustainable Communities Strategy (SCS). To conduct this review, we focused on two main subtasks. First, we conducted a review of SANDAG's Five Big Moves to better understand the specific modeling needs for the RTP and SCS. Second, we conducted a review of ABM2+ to understand the embedded modeling approaches, the data inputs and outputs, and the general application of the model to the RTP. The focus of this review was primarily to obtain sufficient understanding of the model to support Task 2, which focused on how ABM2+ could (and could not) be used to represent the features of the RTP that comprise the Five Big Moves for the 2021 SCS. The deliverable associated with this task is a report assessing the assumptions underlying SANDAG's general modeling approach for representing the Five Big Moves, which is included in this section below.

Review of SANDAG's Five Big Moves

ITS-Irvine conducted a review of documentation provided by SANDAG detailing the *Five Big Moves* (SANDAG, 2020d, 2020b, 2020c, 2020e, 2020a) and its draft 2021 Regional Transportation Plan policy and programs (SANDAG, 2020g). The focus of this review was to identify the proposed policies and transportation modes that need to be modeled. Generally, the *Five Big Moves* represent bundles of elements that SANDAG envisions will improve the region's ability to meet economic and climate goals while providing effective mobility to the population. SANDAG defines the *Five Big Moves* as follows:

- **Complete Corridors:** The backbone of a complete transportation system that improves connectivity and actively manages traffic and leverages technology and pricing to maximize the use of existing highways and local roads. Complete Corridors increase capacity, efficiency and safety; provide dedicated space for high-speed transit and other pooled services; and manage demand in real-time. Local roads are designed and operated to equally accommodate all users, including transit, bikes, and pedestrians.

- **Transit Leap:** A complete network of high-capacity, high-speed, and high-frequency transit services that incorporates new transit modes and improves existing services. These routes will connect travelers to their homes, jobs, and other major destinations as fast or faster than driving.

- **Mobility Hubs:** Places of connectivity where a variety of travel options converge to deliver a seamless travel experience. Mobility Hubs are aligned with the Transit Leap and offer numerous shared mobility services, enhanced bike and pedestrian infrastructure, and supporting amenities that work for every traveler and trip, all in the heart of the communities where people live, work, and play.

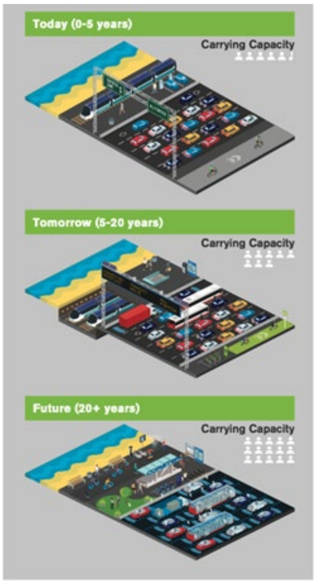
- **Flexible Fleets**: On-demand, shared, electric vehicles that connect to transit and travel between Mobility Hubs along the network of Complete Corridors. Diverse vehicles including micromobility, like bikes and scooters, microtransit, and rideshare provide personalized solutions for different types of trips and environments.

- **Next Operating System**: An integrated transportation management system that collects, aggregates, and analyzes data from public and private transportation services, as well as data from smart infrastructure, and uses that data in real-time to integrate transportation services, manage performance, and provide traveler information for the public on mode and route choice. The system also will provide users with a seamless travel experience by facilitating an integrated travel app for trip planning, booking, and payment across public and private modes (Mobility as a Service).

The elements included in the *Five Big Moves* relate to a range of policies and programs spanning a number of subcategories in the Regional Transportation Plan. Our assessment of the *Five Big Moves* looked at the relationships between specific programming elements and each of the *Five Big Moves*, as well as how those elements spanned multiple *Moves*, creating linkages between them. We summarize our findings related to each *Move* in the following subsections.

Figure 1. The Features of SANDAG's Complete Corridors Concept.

Complete Corridors



- The backbone of a complete transportation system that accommodate all modes of transportation to maximize the use of existing roadways

- Associated modules in ABM2+ Models and Off-Model Calculators
    - ABM2+: Infrastructure, Pricing, CVs, Curb Management
    - OMC: EV, Vanpool, and Car-sharing

Feature[e)]	Complete Corridors	Transit leap	Mobility hub	Flexible Fleets	Next OS
Managed Lanes	✓	✓			✓
Active Transportation and Demand Management	✓				✓
Connected Vehicles and Infrastructure	✓				✓
Priority for transit, active transportation, and shared mobility	✓				
Curb Management	✓	✓	✓	✓	✓
ZEV Infrastructure	✓				
Congestion Pricing	✓				✓

Complete Corridors

The RTP elements that relate to *Complete Corridors* are shown in Figure 1. In this figure, and the ones that follow for the other *Moves*, the primary features are shown in the "Feature" column, while secondary linkages for each of the primary features for this *Move* to the other *Moves* is illustrated via check marks in the table. We can see the primary features that are associated with this *Move* include a range of supply side and operational actions (Managed Lanes, Connected Vehicles and Infrastructure, among several others) as well as demand-side and pricing actions (Active Transportation and Demand Management, Congestion Pricing, etc.). Our review noted that the Curb Management element is cross cutting across all of the *Five Big Moves*, which suggests that it is a central feature in SANDAG's plan. With that said, it is worth pointing out that these assessments, the magnitude of the relationships between the *Moves* and the elements is not represented. In this sense, though Curb Management is central to SANDAG's planning, it is still a concept that is being developed for implementation and is generally not yet implemented in SANDAG's models.

Another point that stands out is the cross-cutting nature of Next OS concept with its secondary relationships to the Complete Corridors features. This suggests that Complete Corridors are highly linked to a successful implementation of Next OS, making it a potential critical path for long term success of the plan.

In this initial assessment, we also noted that representing Complete Corridors will require features from both ABM2+ and off-model strategies, with some features, such as optimized operation via Connected Vehicle and Infrastructure and Curb Management being noted as potentially challenging to represent.

Figure 2. The Features of SANDAG's Transit Leap Concept.

Transit Leap

- A complete network of high-capacity, high-speed, and high-frequency transit services that improve on existing services to move travelers as fast or faster than driving

- Associated modules in ABM2+ Models and Off-Model Calculator
  - ABM2+: High-speed transit, Service time, Pricing, AVs
  - OMC: EVs (with incentive program), Community based TDM outreach

Feature[g)]	Complete Corridor	Transit Leap	Mobility hub	Flexible Fleets	Next OS
High-speed transit		✓			
Expanded service times		✓			
Transit priority	✓	✓			
More personalized services		✓		✓	
Better integration with other services		✓	✓		✓
Transition to electric or alternative fuels		✓	✓	✓	

Transit Leap

Figure 2 shows the relationship between the Transit Leap *Move* and specific features of the RTP. Here, we noted an emphasis on improving service through a combination of expanded and tailored capacity (additional service times, personalized and better integrated transit services) along with system efficiency enhancements (high-speed transit and transit priority). Secondary linkages through these features to other *Moves* include the importance of the Mobility Hub network and NextOS to improving integration across services, the availability of Flexible Fleets for implementing more personalized services, and the reliance on Complete Corridors for implementing transit priority (and by extension, as we've seen, an additional secondary reliance on the NextOS concept). The transition to alternative fuels is also a central feature of this *Move* as transit operations offer attractive targets for transitioning vehicle operations (including heavy-duty transit buses) to more environmentally friendly solutions, but also is tied to the Mobility Hubs concept through the need for infrastructure integration.

In terms of representing the Transit Leap in using SANDAG's modeling suite, our initial assessment noted potential challenges with characterizing the impacts optimized operation as well as multimodal routing.

Figure 3. The Features of SANDAG's Mobility Hubs Concept

Mobility Hubs

- Places of connectivity where a variety of travel options converge to deliver a seamless travel experience

- Associated modules in ABM2+ Models and Off-Model Calculators
  - ABM2+: Land use, Infrastructure, Pricing, Shared Mobility
  - OMC: EVs, Community based TDM outreach, Pooled Ride, Vanpool, Bikeshare, Carshare, Microtransit
  - ABM2+&OMC: EVs, Pooled Ride, Vanpool, Bikeshare

Feature	Complete Corridors	Transit Leap	Mobility Hubs	Flexible Fleets	Next OS
Walking and biking infrastructure			✓		
Shared mobility	✓	✓	✓	✓	
Support services (real-time travel information, charging, multimodal wayfinding, and so on)		✓	✓	✓	✓
Intelligent Transportation Systems (ITS)	✓	✓	✓	✓	✓
Supportive land uses					
Equity (Flexible Fleets and automated vehicles)			✓	✓	

Mobility Hubs

The characteristics of the Mobility Hubs concept are shown in Figure 3. This concept is central to enabling efficiencies in both transportation demand and supply and represents the most direct linkage between land-use planning and the transportation system in SANDAG's *Five Big Moves*. The provision of supportive land uses in the context of a broader, transit-oriented design for the region offers a major step forward for providing true, performance compatible alternatives to personal vehicle-centric transportation. The inherent land-use/transportation linkages embodied by this concept supports additional modes of transportation enabled by upgraded walking and biking infrastructure, shared-mobility options, and other first-mile/last-mile connections to transit options linked to the *Hubs*. Furthermore, equity needs can be better served given the increased densities supported by the hubs, making support services and provision of paratransit more cost effective.

In much the same way that Mobility Hubs link the many dynamics governing transportation, they are also central to SANDAG's *Five Big Moves*. This can be seen in the large number of secondary connections to the other *Moves*. In particular, the effectiveness of the Transit Leap and Flexible Fleets concepts are tightly linked to the successful deployment of Mobility Hubs as an organizing feature of the region.

SANDAG's modeling capabilities appear to be generally well suited to representing the land-use/transportation linkages at the heart of the Mobility Hubs concept. The changing land uses dictated by this concept tie directly into the core features of ABM2+ for representing combined activity-travel choices in the context of broader activity pattern decisions governed by long-term household choices. With that said, as with the Transit Leap concept, some of the operational features associated with mobility hubs centered on optimized routing and optimization supported by real-time traveler information may prove challenging to represent directly in SANDAG's modelling suite.

Figure 4. The Features of SANDAG's Flexible Fleets Concept

Flexible Fleets

- Diverse services that provide personalized transportation for diverse types of trips and passenger needs

- Associated modules in ABM2+ Models and Off-Model Calculator
  - ABM2+: Micromobility, Rideshare, Ridehailing, TNC
  - OMC: EV, Community based TDM outreach, Pooled Ride, Vanpool, Bikeshare, Carshare Microtransit

Feature	Complete Corridors	Transit Leap	Mobility Hubs	Flexible Fleets	Next OS
Micromobility		✓	✓	✓	
Rideshare	✓		✓	✓	
Microtransit		✓	✓	✓	
Pooled-Rides	✓	✓	✓	✓	
Last Mile Delivery			✓	✓	

Flexible Fleets

SANDAG's flexible fleets concept embraces the new mobility options enabled by the sharing economy and other innovations. Figure 4 illustrates the main features related to this concept, which include ridehailing as enabled by Transportation Network Companies (TNCs) such as Uber and Lyft, but also ridesharing options enabled through a variety of programs, whether traditional carpooling approaches and more recent app-enabled ridesharing and carpooling options. In addition, various micromobility modes are supported along with microtransit and last mile delivery.

Generally the Flexible Fleets are viewed as transportation alternatives that can provide quick and convenient connections to the Mobility Hub network, and this is reflected in the persistent secondary linkages represented in this figure. These linkages support greater accessibility to high-quality and equitable mobility options to a greater fraction of the population in the San Diego Region.

With the exception of Last Mile Delivery, which is outside the scope of the current SCS and therefore this review, SANDAG's suite of models---including many of the enhancements made in the transition from ABM2 to ABM2+---appears particularly well suited to representing the impact of Flexible Fleets and their relationship to the land-use and transportation system.

Figure 5. The Features of SANDAG's NextOS Concept

Next OS

- The "brain" of the entire transportation network, managing all services in real-time to promote sustainability, efficiency, and safety

- Associated modules in ABM2+ Models and Off-Model Calculators
  - ABM2+: Equity, Cost reduction
  - OMC: Not applicable

Feature[i)]	Complete Corridors	Transit Leap	Mobility Hubs	Flexible Fleets	Next OS
Customer Experiences	✓	✓	✓	✓	✓
Optimization	✓	✓	✓	✓	✓
Collaboration	✓		✓		✓
Equity (access to a wide range of transportation services)			✓		✓
Cost reduction		✓	✓	✓	✓

NextOS

The NextOS concept is central to SANDAG's planning for the management, optimization, and delivery of efficient transportation in the region. As shown in Figure 5, these are the primary features provided by NextOS, along with enhanced customer experiences, equity improvements, and cost reductions.

Further, the importance of NextOS is highlighted in its numerous secondary relationships to the other *Moves* in the plan. For instance, the optimization of the system that must be enabled by the data collection and management provided by NextOS, cuts across all of the *Moves.* Furthermore, each of the primary features of NextOS are secondary features for the Mobility Hubs concept, implying that success of the latter is highly dependent on the successful implementation of the former.

Though it is centrally important to SANDAG's broader plans, our initial assessment is that the specific features that comprise NextOS are difficult to explicitly represent within SANDAG's modeling suite. However, NextOS exists as the *Move* that enables all of the other *Moves* that lead to measurable impacts on reaching positive economic and environmental outcomes in the region, and therefore is implicitly included in the model as a facilitating factor.

With these broad assessments of SANDAG's *Five Big Moves* and the features of the RTP that they represent, we can now turn to our specific assessment of SANDAG's suite of models for representing their impacts.

Review of ABM 2+

As noted, at the start of this contract, the ABM2+ TAC was just finalizing its review of the model. ITS-Irvine team members attended the final TAC review workshop on March 10, 2020 to begin familiarization with the model. Using the TAC review report (ABM2+ TAC, 2020), as well as consultant reports from RSG, Inc. detailing the development of ABM2+ (RSG Inc., 2020), ITS-Irvine reviewed the components of ABM2+ in order to assess its general capabilities and limitations, with a view toward how it may or may not represent the specific elements of the RTP that would be addressed in the next step. Because the TAC's technical review was comprehensive and because the bulk of this contract was focused on assessing and developing off-model strategies, ITS-Irvine relied heavily on the TAC's findings regarding technical merit and focused mainly on assessing the model's suitability for supporting the 2021 SCS submission to CARB.

ITS-Irvine primarily focused on assessing the combined use of ABM2+ and their off-model calculators for representing the GHG impacts of the Five Big Moves in the coming decades. First of all, ITS-Irvine reviewed the travel behavior and land use assumptions underlying SANDAG's model system, with a particular focus on the relationship between the set of inputs and outputs produced by the complete model system.

Overall, our analysis found that the ABM 2+ is capable of simulating the *Five Big Moves* and its supporting policies and programs. In particular, relative to land use assumptions, the population synthesizer module of ABM2+ uses land use scenario inputs in which transportation investments, along with policies and programs incorporated influence land use changes and development patterns. This sensitivity is critical to capture some of the core features in the *Five Big Moves*---for instance, it is capable of capturing the impact of Mobility Hubs on producing a more interactive relationship between the land use and transportation system, potentially leading to more realistic distribution of available capacity.

The review of ABM2+ was also to identify which specific strategies can be modeled in ABM 2+ and which strategies would need off-model quantification to be included in the SCS presented to CARB. ITS-Irvine recommended micromobility (bikesharing) and microtransit off-model calculator be modeled using ABM 2+. GHG emissions of some strategies cannot be measured by ABM 2+; thus, ITS-Irvine recommended the continued usage of off-model calculators.

Review of Choice Models

SANDAG's travel demand model (RSG Inc., 2020) is a state-of-the-art activity-based travel demand model belonging to the Coordinated Travel–Regional Activity Modeling Platform (CT-RAMP) family of models (Davidson *et al.*, 2010). This is a complex model system with many interconnected components making an exhaustive review outside the scope of this project, which is primarily to review the need of off-model strategies to account for policies and programs that impact the number of vehicle trips and their associated VMT occurring in the region in order to reduce the greenhouse gas emissions attributable to transportation. As such, our review focused on models related to mode choice behavior, which are most likely to forecast trips and VMT related to off-model calculations.

ABM 2+ is a collection of models covering a variety of travel markets including a resident travel model along with a set of special travel models for visitors, airport travel (ground access and cross-border), commercial vehicles, external passenger travel, and external heavy trucks (SANDAG, 2019). The focus in this project is exclusively on the resident model, which is structured around representing individual and household travel choices, including intra-household interactions between household members. The choice models employed by ABM 2+ resident model, as well as the off-model calculators, represent travelers' mode and route choice behavior using a system of choice models. These include an Auto Ownership Model, Transponder Ownership Model, Telecommute Choice Model, Coordinated Daily Activity Pattern (CDAP) Model, Non-mandatory Tour Destination Choice Model, Tour Mode Choice Model, Trip Mode Choice Model and the Micro-mobility Choice Model.

Table 1 summarizes mode choice models incorporated into ABM2+, which consist of the main tour mode choice and the trip choice model. The tour mode choice model (upper-level choice) is based on a nested logit model and its alternatives include Auto, Non-motorized, Transit, Mobility as a Service (MaaS), and School bus. The trip mode choice model is a lower-level choice conditional upon the tour mode choice. The micromobility mode is determined in the trip mode choice model versus walk mode and walk as an access/egress mode to transit. The telecommute model is implemented in the resident travel demand models and is associated with the CDAP model, the mandatory tour generation model, and non-mandatory tour frequency model. A multinomial logit model was used for telecommute frequency predictions based on household and person variables.

Our review of the validation reports for ABM2+ (SANDAG, 2020f) led us to concur with the Technical Advisory Committee's findings (ABM2+ TAC, 2020) that ABM2+ remains "well beyond the state-of-the-practice" in regional transportation demand modeling. The sensitivity analyses demonstrate the general efficacy of the model system, and specifically as it relates to characterizing complex household travel choices distributed across a range of modes that include conventional personal vehicle and transit modes, but also active transportation and new mobility options that have entered the marketplace in recent years and are likely to play an increasingly important role in providing transportation supply into the foreseeable future.

Table 1. Summary of Choice Models in SANDAG's ABM2+

Model	Choice Category	Choice model	Data sources
ABM 2+	Main tour mode	Nested logit	2016-17 San Diego Regional Transportation Study, 2019 TNC Travel Survey and the 2015 Transit On-board Survey
	Trip mode	Nested logit	
	Micromobility (walk and e-scooter)	Minimum utility	

	Telework	A multinomial logit model	

With that said, there are policy and programmatic features of the RTP that are not explicitly represented in ABM2+. The significance of this depends on how the model is being applied, so we will address this issue in more detail as we discuss the need for off-model strategies to support the development of the SCS in Task 2.

Additional Review of Telework Assumptions

In addition to a review of the underlying assumptions of ABM2+ and its suitability for representing the *Five Big Moves*, SANDAG requested that ITS-Irvine conduct a review of the telework assumptions included in ABM2+. The results of this review are detailed in the appendix *Review of SANDAG's Telework Assumptions for the 2021 Regional Transportation Plan*. We provide a brief summary of our findings here.

Our review focused on the assumptions outlined in the Telework Assumptions Memo developed by SANDAG (SANDAG, 2020h). The memo addresses a range of travel substitution concepts that are collectively characterized as teleworking: telecommuting, working at home (always or primarily), and working at home occasionally. SANDAG's activity-based model (ABM2+) now includes a newly developed telecommute model that forecasts telecommute frequency for people with job types other than "work at home". Specifically:

> *The SANDAG Activity-Based Model explicitly accounts for this reduction by identifying the work location of some workers as "home". In the SANDAG ABM 2+, persons who work primarily from home do not make work trips, but they can make other trips during the simulation day. In addition, ABM 2+ considers persons who telework occasionally, and these people make fewer work trips. The purpose of this memorandum is to recommend a target for work from home, based on recent telecommuting data from the San Diego region.* (SANDAG, 2020h)

SANDAG's memo updates work originally performed for SANDAG in 2018 by WSP Inc (Picado, 2018). The updated memo recommends a target for work from home, based on recent telecommuting survey data including: the 2013 Employee Commute Survey, the 2017 Regional Transportation study, the 2017 National Household Travel Survey (NHTS), the 2018 American Community Survey, and most notably, SANDAG's 2018 Commuter Behavior Survey.

We assess the core assumptions of the SANDAG's memo versus available internal data and externally published results, and ultimately apply methods from recent research (Dingel and Neiman, 2020) to provide a reality check on SANDAG's recommendations. We find that the base year telework target for ABM2+ is a conservative and justifiable estimate of the actual ratio of workers who would be telecommuting on any given workday.

We further assess the use of a trendline to extrapolate teleworking propensity into the future by adapting the work by Dingel and Neiman (2020) to estimate the theoretical capacity for telework in the San Diego region based upon the mix of employment types, which we found to be approximately 40%. Given that the trend analysis indicates that the total proportion of regular and occasional teleworkers in 2050 is assumed to be 27.5%, the actual number of teleworkers could increase by nearly 50% before the theoretical teleworking capacity was met. As such we conclude that the application of telework trends to forecast future ratios described in SANDAG's memo is a reasonable assumption of the region's capacity for telework.

Note that we do not address the potential impacts of the COVID-19 pandemic on future teleworking trends, but do recommend that future research be dedicated to this question.

Task 2. Assessment of needs for off-model calculators

Deliverable	Date
2.1 Draft report assessing each existing off-model calculator in the context of changes between ABM2 and ABM2+, including recommendations for how to delete or update them.	Delivered as draft PowerPoint presentations in June 2020. Converted to report form in this section of the final report.
2.2 Participate in conference call with SANDAG and CARB staff	Participated in call on July 17th, 2020

The work conducted under Task 2 was focused on determining what features of SANDAG's RTP could be fully captured by the newly updated ABM2+ and what features would need to be represented using off-model strategies if they were to be part of the SCS submitted to CARB. This work began with a review of the SCS process to determine CARB's modeling expectations and then proceeded with the assessment of on- and off-model needs, which are summarized in the sections below.

Review of Sustainable Communities Strategies Process

SCS development under SB 375 is a long-term and iterative process, as SB 375 requires CARB to update GHG emission reduction targets and MPOs to update their regional transportation plans and sustainable communities strategies regularly. Specifically, MPOs are required to adopt an "action-oriented" SCS, which serves as an integrated regional land-use, housing, and transportation plan that is part of each MPO's federally required RTP. These RTP/SCS plans are typically backed by a regional transportation model that can forecast transportation demand and associated system performance for regional land use and transportation scenarios for a range of target years. In the event that this model system does not have sufficient resolution to characterize the effects of a particular strategy proposed by the MPO, SB 375 allows for the use of off-model calculations to quantify the effectiveness of the strategy (CARB, 2019a).

This strategy-based SCS evaluation process enhances the transparency of the strategies within the SCS, makes it easier to track an MPO's commitment to the strategies over time, and makes it possible to determine how much the proposed strategies support the GHG emissions reductions. Documentation of the technical methodology used in the SCS is critical to acceptance of the plan by CARB. Figure 6 summarizes CARB's submission guidance, which outlines the specific steps that should be included in the submission.

Figure 6. Technical Methodologies Submission Guidance (adapted from CARB, 2019a)

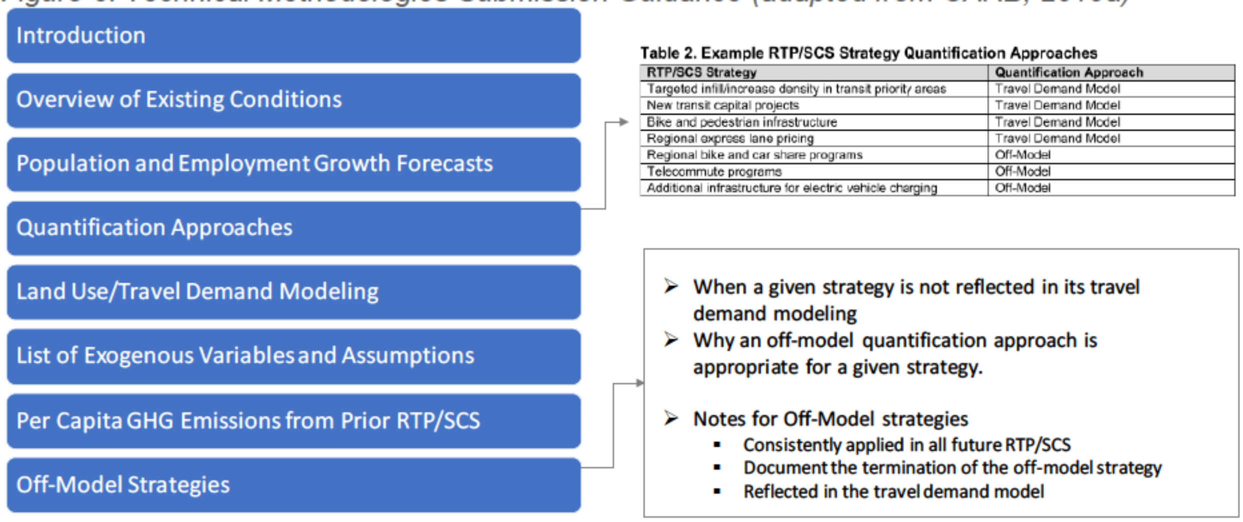


Table 2. Example RTP/SCS Strategy Quantification Approaches

RTP/SCS Strategy	Quantification Approach
Targeted infill/increase density in transit priority areas	Travel Demand Model
New transit capital projects	Travel Demand Model
Bike and pedestrian infrastructure	Travel Demand Model
Regional express lane pricing	Travel Demand Model
Regional bike and car share programs	Off-Model
Telecommute programs	Off-Model
Additional infrastructure for electric vehicle charging	Off-Model

For the purposes of this project, the two most critical pieces of this process are the documentation of quantification approaches (on versus off-model) and the documentation of off-model strategies being employed. The work in Task 2 aligned with justifying the quantification approaches, which are described below with a focus on those elements of the plan that require off-model quantification. The strategy-based approach to SCS evaluation means that CARB seeks continuity between versions of an MPO's SCS. Thus, a starting point for off-model consideration is always the last approved SCS since the off-model strategies used there must either be continued or a justification given for their termination. The work in Task 3, described later, will build on the recommendations generated in Task 2 to update and/or implement required off-model calculators for specific strategies in the RTP.

Our review of quantification approaches for the SCS looked at individual elements included in the RTP in five main categories:

- Land-Use Scenarios
- Strategies and Pricing Scenarios
- Mobility Services
- Demand Management
- Infrastructure and Technologies

These correlate with the features of the *Five Big Moves* discussed in Task 1. We assessed the characteristics of each element, as described in the RTP documentation, and evaluated whether these characteristics could be represented in ABM2+, or whether off-model quantification should be considered. We address each of these categories below.

Recommended Analysis Tools for Land Use Scenarios

Figure 7. Quantification of RTP Land-Use Scenarios and Relationships to Five Big Moves

Scenarios: Land Use

- ABM2+ Sensitivity Testing Report
  - Job/housing balance(jobs close to housing), mix of land use, street pattern via intersection density, residential density

Elements	RP Policies and Programs	5 Big Moves					Analysis Tool	
		Complet e Corridor	Transit leap	Mobility Hubs	Flexible Fleets	Next OS	ABM 2+	Off-model Calculators
Employment Centers	1) Land Use			✓			Land Use and Geological Info(densities)	Carshare, Microtransit
Transit Priority Areas	1) Land Use	✓		✓			✓	
Active Transportation Facilities	1) Land Use	✓		✓				
Smart Parking	1) Land Use, 6) Parking Policy	✓		✓		✓	✓	
Flexibly managed curb space	1) Land Use, 5) Curb Management	✓	✓	✓	✓		✓	
Transit-Oriented Development (mobility hub)	1) Land Use	✓		✓	✓		✓	Microtransit
TransNet Environmental Mitigation Program (preserve and manage open space)	1) Land Use						✓	
Walkable and Bikable Communities	2) Climate Action Planning						✓	CBTP

The ability to represent land use scenarios in ABM2+ was evaluated using the results of the sensitivity testing report, which demonstrated that the model captured the dynamics of job/housing balances, mixed-land uses, network topology, and residential density. Figure 7 shows our findings that support on-model quantification of most strategies focused on the impacts of land-use policies on travel choices and resulting behavior. This means that the impact of a range of elements should be faithfully represented in ABM2+, including approaches to increasing activity densities to better coincide with transit-oriented development. However, some of the secondary relationships supporting these scenarios via the *Mobility Hub* concept rely on programs that cannot currently be represented in ABM2+. The off-model calculators column shows the existing calculators developed for the delayed 2019 SCS update. Specifically the new mobility options of app-based carsharing and microtransit services play an important role in increasing the impact of land-use strategies by facilitating the linkages to the transit network. In addition, SANDAG's plans for community based travel planning (CBTP) would also need off-model representation, though as we'll discuss later, SANDAG's plans in this area switched to an employer focused approach via a Travel Demand Management Ordinance (TDMO).

Recommended Analysis Tools for Strategies and Pricing Scenarios

Figure 8. Quantification of Pricing Strategies and Relationships to Five Big Moves

Scenarios: Strategies & Pricing

- ABM2+ Sensitivity Testing Report
  - Transit headways, self-owned E-Bike
  - Mileage-based fee via Auto Operating Cost (AOC), transit fare, managed land/toll price, parking costs

Elements	RP Policies and Programs	5 Big Moves					Analysis Tool	
		Complete Corridor	Transit leap	Mobility hub	Flexible Fleets	Next OS	ABM 2+	Off-model Calculators
Clean Cars, Clean Transit, and Sustainable Freight	2) Climate Action Planning, 8) Zero Emission Vehicles	✓	✓	✓	✓	✓	✓	✓
Housing Policies with transportation initiatives	4) Housing		✓	✓	✓			
More mobility options	4) Housing		✓	✓	✓			
Affordable housing	4) Housing		✓	✓	✓			
Minimum Zoning near Transit	4) Housing			✓			✓	
Parking space requirement for housing near transit	4) Housing, 6) Parking Policy		✓	✓	✓		✓	
Curb pricing	5) Curb Management		✓	✓	✓		✓	
Real-time Curb information	5) Curb Management		✓	✓	✓	✓		
Unbundled parking	6) Parking Policy						✓	
Parking Pricing	6) Parking Policy, 7) TDM						✓	

Because of its choice-model structure, ABM2+ excels at representing the impacts of costs on travel behavior. With demonstrated sensitivity to transit fares, auto operating cost, as well as various direct pricing approaches, virtually all elements in the RTP related to pricing strategies can be effectively represented on-model, as shown in Figure 8. This is critical as one of the most effective approaches to altering behavior is through direct or indirect pricing as a way of shaping both near-term decisions (model choice, parking, etc.) and long term choices (e.g., housing choice). The one element not directly represented in ABM2+ is the impact of alternative fueled vehicles. Representing household and firm choices of alternative fueled vehicles is an active area of academic research for which effective models are still under development. As such, programs aimed at increasing alternative fueled vehicle uptake in the region, such as electric vehicle incentive programs, need to be represented off-model. Additionally, some mobility options involve pricing strategies that may or may not be represented on model. We address these in the Mobility Services section next.

Recommended Analysis Tools for Mobility Services

Figure 9. Quantification of Mobility Services and Relationships to Five Big Moves

Scenarios: Mobility Services

- ABM2+ Sensitivity Testing Report
  - TNC cost, Pooled TNC cost
  - TNC wait time
  - Micromobility speed, micromobility focus, access to micromobility, micromobility cost
  - TNC optimization, AV and TNC combos

Elements	RP Policies and Programs	5 Big Moves					Analysis Tool	
		Complete Corridor	Transit leap	Mobility hub	Flexible Fleets	Next OS	ABM 2+	Off-model Calculators
Micromobility	7) Transportation Demand Management (TDM)		✓	✓	✓		✓	
Ridesharing	7) Transportation Demand Management (TDM)			✓	✓	✓	✓	Carpool, Vanpool
Microtransit	7) Transportation Demand Management (TDM)		✓	✓	✓	✓		Microtransit
Pooled-rides	7) Transportation Demand Management (TDM)		✓	✓	✓	✓	✓	Pooled-rides
Last mile delivery	7) Transportation Demand Management (TDM)			✓	✓			

One of the major enhancements of SANDAG's model system between ABM2 and ABM2+ is the ability to represent new mobility services including ridehailing, some forms of ridesharing (intra-household), and micromobility options. Figure 9 shows this improved coverage, including numerous demonstrations of sensitivity to TNC costs and performance variables. With that said, mobility services continue to rapidly evolve, with a seemingly continuous stream of new business models entering the market. Some of these models did not make it into ABM2 but do have the potential to be impactful into the future. These strategies include app-based carpooling, subsidized regional vanpools facilitated by SANDAG. The representation of microtransit requires a more nuanced discussion. The delayed 2019 SCS update included a microtransit off-model calculator targeted at both Neighborhood Electric Vehicles (NEVs) and commuter-oriented microtransit services. However, SANDAG has indicated that they do not wish to pursue this approach as a strategy and instead added a microtransit component as a first last mile option in ABM2+. This makes the microtransit off-model calculator unnecessary, as we'll see below in the calculator-specific discussions below.

Recommended Analysis Tools for Demand Management

Figure 10. Quantification of Demand Management and Relationships to Five Big Moves

Scenarios: Demand Management

- ABM2+: "Telecommuting model is in adjustments made to the Coordinated Daily Activity Pattern (CDAP) model, the mandatory tour generation model, and the non mandatory tour frequency model"
- OMC: CBTM is a residential-based approach to TDM outreach – customized information, incentives, and support to encourage the use of transportation alternatives

Elements	RP Policies and Programs	5 Big Moves					Analysis Tool	
		Complete Corridor	Transit leap	Mobility hub	Flexible Fleets	Next OS	ABM 2+	Off-model Calculators
Commuter Benefits (secured bike locker, free rides in an emergency)	7) Transportation Demand Management (TDM)							CBTM
Financial Subsidies for not drive alone or Parking	7) Transportation Demand Management (TDM)						✓	
Marketing, Education, and Outreach	7) Transportation Demand Management (TDM)							CBTM
TDM Policy	7) Transportation Demand Management (TDM)						✓	
Flexible Work Schedule (Telework)	7) Transportation Demand Management (TDM)						✓	

Travel Demand Management (TDM) is likely the broadest category of strategies considered by SANDAG in terms of modeling requirements. These focus on various targeted approaches to shaping travel behavior, which typically focus on commute trips. Some programs in this category can be represented on-model. For instance, we previously discussed the telework model in ABM2+, which captures both permanent and occasional telework and is calibrated to match regional telecommuting trends that we've shown are reasonable given the mix of employment types in the San Diego region. The impacts of other programs, including financial subsidies to avoid driving alone and other related TDM policies, typically have a pricing component that we noted previously is a demonstrated strength of ABM2+.

With that said, other elements falling in the TDM strategy category have subtle impacts that are difficult to directly quantify in ABM2+'s choice models. The impact of qualitative or transient benefits that improve the comfort or reduce perceived risk of alternative transportation choices are illustrative. Benefits such as providing bike lockers to protect commuter's assets and free rides for emergency situations facilitate these choices, but are difficult to represent in the choice models, which typically will not be based upon surveys that have collected data on the existence of these types of programs. Similarly, the impact of Marketing and strategies aimed at increasing commuter awareness of available options are notoriously difficult to capture in travel models, which tend to be premised on assumptions that travelers are utility maximizers who will ultimately find optimal solutions from among the universe of feasible alternatives that they are assumed to perfectly perceive. As such, the delayed 2019 SCS update planned to represent these impacts using an off-model calculator for Community-Based Travel Planning. As we'll discuss below, these plans changed in the interim in favor of a Travel Demand Management Ordinance (TDMO), which has a different structure, but still will require off-model quantification due to its similarly qualitative impacts.

Recommended Analysis Tools for Infrastructure and Technologies

Figure 11. Quantification of Mobility Services and Relationships to Five Big Moves

Scenarios: Infrastructure & Technologies

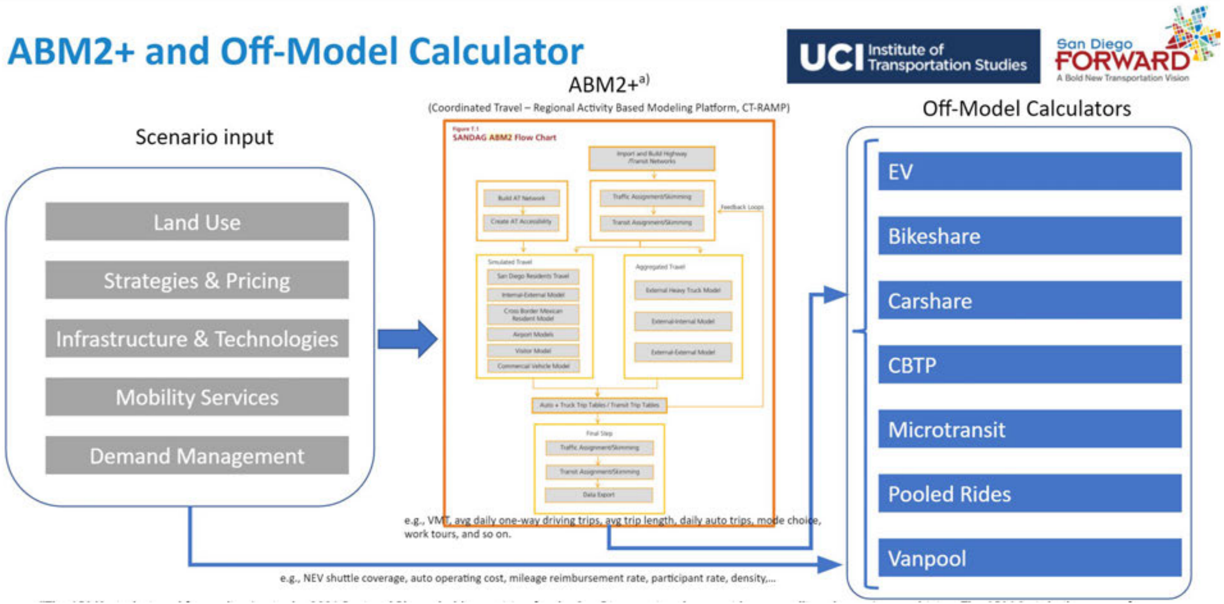
Elements	RP Policies and Programs	5 Big Moves					Analysis Tool	
		Complete Corridor	Transit leap	Mobility hub	Flexible Fleets	Next OS	ABM 2+	Off-model Calculators
The safety and maintenance of roads and infrastructure	9) Fix it First	✓						
Road Design and Engineering	10) Vision Zero	✓						
Safety on all local project	10) Vision Zero	✓						

The last bundle of RTP elements considered in our review relate to Infrastructure and Technology improvements. As conceived in the plan and illustrated in Figure 11, these elements focus primarily on maintenance and safety as part of the "Fix it First" and "Vision Zero" programs respectively. Though safety is among the highest priority goals for transportation system operators, it only has an indirect impact on travel behavior choices. First, in an operational sense, improved safety often correlates with smoother operation and therefore a lower propensity for system disruptions that impact capacity and increase travel costs. However, planning models focus on time scales that smooth out such operational fluctuations by using macroscopic relationships between demand and performance. Similarly, the impact of maintenance and improved system engineering may have some general impacts that incrementally improve system performance. Some of these, such as better signal optimization or large-scale infrastructure changes, are representable during the assignment step of the transportation model, but in most cases these elements of the RTP are probably not significant for the SCS submission.

Assessment of Draft 2019 Off-Model Calculators

As we've seen above, SANDAG's ABM2+ is a state-of-the-art modeling system that is capable of representing the vast majority of the elements of SANDAG's *Five Big Moves* that shape the 2021 RTP. Nonetheless, certain elements remain unrepresented in the model system and require off-model representation. In this section, we consolidate our assessment of which elements of the RTP must be represented off-model. To provide some background, Figure 12 shows the relationship between ABM2+ and the off-model calculators. It is worth noting that the purpose of the calculators is to represent specific features of the RTP that cannot be quantified in ABM2+, and specifically, that they are needed to quantify greenhouse gas emission changes attributable to specific programs. We discuss the specifics of SCS process in the Task 3 discussion, but at this point it is sufficient to note that the off-model calculators are designed to modify the forecasts from ABM2+ to reflect programmatic impact.

Figure 12. Relationship Between ABM2+ and Off-Model Calculators



With that understanding, we turn to the specific calculators that were prepared for the delayed 2019 SCS update. These included a set of Travel Demand Management calculators developed by WSP, Inc. as well as electric vehicle and charger incentive calculators developed by Ascent Environmental, Inc.

Pooled Rides

The 2019 pooled rides calculator specifically represents the impacts of a carpool incentive program that encourages pooling by facilitating trip incentives via app-enabled rideshare services, such as UberPool or Waze Carpool. This is a submarket of the broader set of pooled ride services that facilitates inter-household pooling and may play an important role into the future in increasing the occupancy of TNC-operated services, which may mitigate the increased VMT caused by deadheading (TNC trips made without passengers). ABM2+ includes enhancements to capture the other major submarket in this category: pooled TNC rides in which professional TNC drivers pick up multiple fares. Together, these two categories represent the dominant pooled ride concepts and should collectively capture this strategy. Our recommendation, shown in Figure 13, is that the draft pooled rides calculator be used for the 2021 SCS in order to capture the app-enabled inter-household pooled-rides submarket. We suspect the market share for this sector has significant growth potential so including it is prudent. The remaining pooled rides markets can be represented sufficiently in ABM2+.

Vanpool

SANDAG has operated a successful vanpool program with participating employers for over 25 years, which has demonstrated sustained success at reducing drive alone trips on certain corridors. The delayed 2019 SCS update included the development of an off-model calculator to capture the impacts of this program on GHG emissions. ABM2+ added no capability to represent these programs (see Figure 13), so we recommend this calculator be adapted for use in the 2021 SCS.

Figure 13. Recommendation for Pooled Rides Off-Model Calculator

	ABM2+					
Type	(1) Does not capture	(2) In progress (ABM2+)	(3) Partially	(4) Sufficiently	Recommendation	Comment
Pooled Rides			✓ (only pooled TNC)		Off-model	Pooled (private) rides
					ABM2+	Pooled TNC
Vanpool	✓				Off-model	

Microtransit

The microtransit off-model calculator developed for the delayed 2019 SCS update represented two types of microtransit services. The first was a system of neighborhood electric vehicles (NEVs) for servicing short trips (with a range of about 1 mile). The second involved specific commuter-oriented microtransit services targeted to serve areas that had poor or no transit services (with a range of about 30 miles). In the interim, SANDAG's updates to ABM2+ added the ability to represent microtransit services that provide first and last mile connections to transit within mobility hubs. As a result, the features of the microtransit off-model calculator can now either be represented on-model or are no longer expected to be part of the future system. As such, we recommend the microtransit calculator be retired (see Figure 14). Since it was never part of a SCS submission, no justification for this is required for the 2021 SCS submission.

Figure 14. Recommendation for Microtransit Off-Model Calculator

	ABM2+					
Type	(1) Does not capture	(2) In progress (ABM2+)	(3) Partially	(4) Sufficiently	Recommendation	Comment
Microtransit		✓ (commuter)			Discard off-model	NEV, non-commuter
					ABM2+	Transit/m-hub anchored

Bikeshare

The delayed 2019 SCS update included a calculator representing the impact of bikeshare operations, which support a range of trip types in the San Diego region through bikeshare and other micromobility operators. Due to its increasing prevalence, this is another of the new mobility options that were included in the upgrades to ABM 2+ from ABM2. The sensitivity reports provided to the TAC demonstrated sufficient model sensitivity to this mode that there is no longer a need to explicitly model these services off-model. As such, our recommendation (Figure 15) is that the Bikeshare off-model calculator be retired. Again, since this calculator was never used in a SCS, no justification is necessary in the 2021 SCS submission.

Figure 15. Recommendation for Bikeshare Off-Model Calculator

	ABM2+					
Type	(1) Does not capture	(2) In progress (ABM2+)	(3) Partially	(4) Sufficiently	Recommendation	Comment
Bikeshare				✓	ABM2+	

Carshare

The delayed 2019 SCS update also included an off-model calculator representing carsharing services operating in the San Diego region. Of the various types of carsharing models: roundtrip, one-way (free-floating or station-based), and peer-to-peer services, SANDAG's carsharing calculator only considers roundtrip carsharing since other types of carsharing services have either exited the market or are not available in San Diego. The uncertain nature of this market and its relative immaturity partially explain why ABM2+ has no capacity for representing these types of services. However, there is sufficient evidence to suggest that these services may play a role in making it easier for households to forego car ownership. As such, including carsharing as an off-model calculator is forward-looking and allows SANDAG to continue to consider innovative mobility options in its RTP and we recommend using this calculator for the 2021 SCS as shown in Figure 16.

Figure 16. Recommendation for Bikeshare Off-Model Calculator

	ABM2+					
Type	(1) Does not capture	(2) In progress (ABM2+)	(3) Partially	(4) Sufficiently	Recommendation	Comment
Carshare	✓				Off-model	

CBTP/TDMO

As discussed earlier, the representation of community-based travel planning strategies like personalized trip planning and door-to-door outreach encourage the adoption of alternative transportation options. These features are difficult to represent in even state-of-the-art transportation demand models such as ABM2+. As a result, we recommend this type of programming be represented off-model. However, SANDAG has altered how they intend to implement travel demand management programming from a community-based approach to an employer-based approach using a Travel Demand Management Ordinance (TDMO) that focuses on working with large employers to reduce their employee's share of drive-alone commute trips. This shift in focus means that the 2019 draft CBTP off-model calculator developed by WSP, Inc. no longer represents this strategy. We recommended to further study the development of a new calculator representing the impacts of the proposed TDMO (Figure 17).

	ABM2+					
Type	(1) Does not capture	(2) In progress (ABM2+)	(3) Partially	(4) Sufficiently	Recommendation	Comment
CBTP	✓				Delete	Per SANDAG
TDMO	✓				Study	This would be a new calculator

Electric Vehicles

The final set of calculators developed for the delayed 2019 SCS update included a pair of interrelated calculators representing a regional electric vehicle incentive program and a regional electric charging infrastructure program. As noted earlier, ABM2+ does not have the capability to represent household alternative fueled vehicle choice, meaning that the impacts of an electric vehicle incentive program must be modeled off-model. The same is true for the electric charging incentive program, as infrastructure investments of this type are outside the scope of ABM2+. The calculators developed by Ascent Environmental, Inc. are highly advanced compared to the methods employed by other MPOs in California. As such, we recommend using these calculators for the 2021 SCS (Figure 18).

Figure 18. Recommendation for EV Calculators

	ABM2+					
Type	(1) Does not capture	(2) In progress (ABM2+)	(3) Partially	(4) Sufficiently	Recommendation	Comment
Electric Vehicles	✓				Off-model	Review AOC

Task 3. Updating off-model calculators

Deliverable	Date
Participate in conference call with SANDAG and CARB staff.	This was conducted on October 22nd, 2020
Draft report detailing off-model calculator work	Delivered via email as a set of memos in October 2020 and attached in the appendix
Draft set of updated off-model calculators	Delivered via email October 2020

The off-model calculator methodological review and recommendations from Task 2 defined the specific scope of work for Task 3 for updating SANDAG's off-model calculators (OMCs). As summarized in Figure 19, recall that the review recommended:

- Keeping and updating three of the six original Travel Demand Management (TDM) OMCs, including the Pooled Rides, Vanpool, and Carshare calculators
- Retiring the Microtransit and Bikeshare calculators as they are now represented in ABM2+
- Replacing the Community-Based Travel Planning calculator with a new calculator representing a Travel Demand Management Ordinance
- Keeping the electric vehicle incentive program (VIP) and regional electric charger program (RECP) calculators

Recognizing that new methods, data, and research may have become available since the existing calculators were created for the delayed 2019 SCS update, we conducted a thorough review of each of the calculators that were being recommended for the 2021 SCS submission using the following steps for each of the existing calculators

1. Conduct a methodological review to confirm approach
2. Build on methodological review to identify key parameters for update
3. Identify most recent data and literature for guidance and potential updates
4. Consolidate into recommendations, review, and update

In addition, ITS-Irvine developed a new calculator for representing the impact of SANDAG's proposed Travel Demand Management Ordinance based upon original work.

The details of the updates to the existing calculators and the development of the new TDMO calculator are detailed in memos included in the appendix. In the following sections, we summarize the general characteristics of the choice models included in the TDM calculators.

Figure 19. Calculator Update Summary

	ABM2+					
Type	**(1) Does notcapture**	**(2) In progress (ABM2+)**	**(3) Partially**	**(4) Sufficiently**	**Recommendation**	**Comment**
Pooled Rides			✓ (only pooled TNC)		Off-model	Pooled (private) rides – interhousehold pooling
					ABM2+	Pooled TNC
Vanpool	✓				Off-model	
Microtransit		✓			Remove	NEV & Commuter off-model calculator obsolete
					ABM2+	Connections to/from transit; to/from Mobility Hubs
Bikeshare				✓	ABM2+	
Carshare	✓				Off-model	
Electric Vehicles	✓				Off-model	Review AOC
CBTP	✓				Remove	Replace CBTP with TDM ordinance
TDM Ordinance	✓				Add off-model	This would be a new calculator

Review Summary of Off-Model Calculator Choice Models

As with ABM2+, the TDM off-model calculators, with the exception of the TDMO calculator, estimate the participation of travelers in specific RTP programs using choice models as shown in Table 2. This section provides a general overview of the approach used in these calculators, but note that additional details are available in the calculator-specific memos in the appendix. Each calculator's choice behavior model is calibrated by utilizing the most up-to-date data. ITS-Irvine validated the assumptions and methodologies, and suggested updating parameters based upon the recent data sources and recent findings in the literature.

The Vanpool OMC choice model is designed to consider the impact of SANDAG's Regional Vanpool Program, which provides a monthly subsidy to offset the cost of vanpooling and encouraging rideshare in the region. The OMC also incorporates the effect of managed and high-occupancy vehicle lanes for travel that provides travel time savings for pooled services, thereby encouraging the formation of vanpools. Vanpool growth is estimated based on SANDAG employment forecasts for each vanpool market (federal, military, and non-federal). The target market of the Vanpool program are commuters that drive alone and travel long distances to work (50-mile one-way on average) and that typically work for large employers that have fixed schedules.

The Carshare OMC choice model estimates the impacts of carshare services that are intended to expand and operate within mobility hubs, universities, and military bases. The OMC is based on the carshare participation rate with respect to the population density of only round-trip and peer-to-peer services that exist in the San Diego region. Although there are other types of carsharing such as one-way carshare service, ITS-Irvine and SANDAG reviewed the possible services and agreed that considering existing service is reasonable under current market conditions where one-way carshare services such as Car2Go has terminated its operations in North America. Our review found that the assumptions summarized in the table are based upon valid research and data sources that have not been superseded by any literature we could identify. The eligibility population of this program includes the general population within the defined carshare coverage areas, college staff and students in each college/university campus, and military within the region's military bases corresponding to the employment at each base.

The Pooled-rides OMC measures the impact of the SANDAG carpool incentive program, which encourages inter-household carpooling or "pooling" via an app-based rideshare service. As with the vanpool OMC, this off-model calculator also incorporates the impacts of managed lane investments in the region on encouraging pooling. The OMC choice model utilizes a binomial logit model and a demand elasticity parameters. ITS-Irvine recommended the updated model parameters by referring to newer San Diego-specific data on revealed pooled ride mode shares that is available from the 2019 TNC-User Travel Survey (vs the 2016 survey used in the original methodology created by WSP).

Table 2. Choice Model Characteristics of the Off-Model Calculators

Model	Choice Category	Choice model	Source
Off-model Calculator	Vanpool	Growth factor and elasticity from time savings of HOV incentives	Current Vanpool Inventory (as of May 20, 2020)
	Carsharing	Carshare participation rate	2016-2017 San Diego Regional Transportation Study, Petersen, E., Y. Zhang, and A. Darwiche (2016)
	Pooled-rides	Binomial logit and elasticity from time savings of HOV incentives	2019 TNC-User Travel Survey

EV Calculators

ITS-Irvine conducted a review of SANDAG's EV off-model calculator in comparison to CARB's recommended methodology as well as the methods employed by the other three large MPOs in California. We looked specifically at off-model methodologies for both EV incentive programs and EV charger programs, and compared the relative reductions that each MPO is computing with their off-model adjustments. ITS-Irvine concluded that the methods employed in the EV calculator were methodologically more advanced than SANDAG's sibling MPOs: specifically its use of the CEC's EVI-Pro tool to estimate charger demand and the embedded relationships between the vehicle incentive program and the charger program. Though we consulted with experts in the field and looked for potential updates to input data sources and assumptions, we could not identify any significant updates that warranted inclusion. We did, however, update the forecasts produced by ABM2+ used as inputs to the calculator.

We also advised SANDAG on two questions, the details of which can be found in the EV calculator memo included in the Appendix.

1. What did other MPOs do for their EV program analyses?
2. What targets and incentive costs (for vehicles) were recommended?

TDMO Calculator

In the Task 2 assessment, ITS-Irvine recommended studying the development of a calculator for representing the impacts of a planned Travel Demand Management Ordinance proposed in the SANDAG 2021 Regional Transportation Plan. In reviewing the requirements, ITS-Irvine concluded that it could develop the calculator as a conceptual update to the CBTP calculator. The TDMO memo in the Appendix discusses the motivation for the development of this calculator and describes both its methodological design and specific implementation. The implementation differs from the other TDM calculators in that instead of using choice models to reflect traveler behavior from the bottom up, it is based upon assumed targets that will be met by the employees of large employers in the region as a response to the TDMO.

Task 4. Final Report and off-model calculator delivery

Deliverable	Date
4.1 Prepare draft Technical Methodology for SANDAG submission to CARB, per SB 375	Contributed to Technical Methodology between July and October 2020.
4.2 Participate in conference call with SANDAG and CARB staff	The call has not yet been scheduled. ITS-Irvine team members will continue to be available as needed.
4.3 Final Report	This document, delivered Nov 24th, 2020.
4.4 Final off-model calculators	Delivered via email Nov 10th, 2020

Task 4 encapsulated the primary reporting and software deliverable tasks of this project. The original timelines for this project shifted during contract execution, which itself was administratively delayed. The COVID-19 pandemic had indirect impacts on the scope and timeline. Planned in-person meetings were conducted remotely. Deadlines for tasks and deliverables were formally amended in August to extend the contract from August 31st, 2020, to November 30th, 2020. Details regarding the specific final deliverables are addressed below.

Prepare draft Technical Methodology for SANDAG submission to CARB, per SB 375

ITS-Irvine participated in the development of the Technical Methodology for SANDAG submission to CARB per SB 375 guidelines between July and September 2020. The outline of the Technical Methodology was provided by CARB staff, with ITS-Irvine staff responsible for characterizing the off-model strategies as assessed in Task 2 and implemented in Task 3. Final edits to the initial submission to CARB were completed by ITS-Irvine on September 25th. Simultaneously, a series of memos were developed detailing the assessments, updates, and, in the case of the TDMO calculator, development of the TDM and EV calculators. Per discussions with SANDAG, it was agreed that these memos would be attached as appendices to the Technical Methodology submission.

Participate in Conference Call with SANDAG and CARB Staff

Following the submission, ITS-Irvine participated in the coordination conference call between SANDAG and CARB staff on October 22nd, 2020 to receive feedback on what changes to the technical methodology were needed. The broad comments provided by CARB indicated that more methodological detail was required for the main Technical Methodology document rather than being deferred to the appendices. ITS-Irvine continued to collaborate with SANDAG on modifying the technical methodology for the final submission to SANDAG, which was completed on November 17th, 2020.

Final Off-Model Calculators

Following feedback received from both SANDAG regarding the off-model calculators developed in Task 3, including QA/QC feedback and requests for additional documentation, ITS-Irvine made final modifications to the calculators on November 10th, 2020 and delivered them to SANDAG.

Final Report

This report represents the final deliverable under this contract 5005881. It includes all documentation deliverables under the contract either in the report body (the sections describing tasks 1 and 2) or in the appendices (the off-model calculator memos associated with task 3).

References

ABM2+ TAC (2020) *SANDAG ABM2+ Technical Advisory Committee Peer Review* .

Davidson, W. *et al.* (2010) 'CT-RAMP Family of Activity-Based Models', in *Australasian Transport Research Forum 2010 Proceedings*.

Picado, R. (2018) *Telework Assumptions Memo, Future Mobility Research Program*.

RSG Inc. (2020) *SANDAG TRAVEL MODEL ENHANCEMENTS TO SUPPORT 2021 LONG-RANGE TRANSPORTATION PLAN*.

SANDAG (2019) *San Diego Forward, THE 2019 FEDERAL REGIONAL TRANSPORTATION PLAN - Appendix T: SANDAG Travel Demand Model and Forecasting Documentation*.

SANDAG (2020a) *5 Big Moves: Complete Corridors Fact Sheet*.

SANDAG (2020b) *5 Big Moves: Flexible Fleets Fact Sheet*.

SANDAG (2020c) *5 Big Moves: Mobility Hubs Fact Sheet*.

SANDAG (2020d) *5 Big Moves: NextOS Fact Sheet*.

SANDAG (2020e) *5 Big Moves: Transit Leap Fact Sheet*.

SANDAG (2020f) *ABM2+ Report Appendix: Detailed Validation Results*.

SANDAG (2020g) *Draft 2021 Regional Plan Policy and Program Documents*.

SANDAG (2020h) *Telework Assumptions Memo*.

Appendices

Review of SANDAG's Telework Assumptions for the 2021 Regional Transportation Plan

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November 17th, 2020

Summary

This document provides a review of SANDAG's Telework Assumptions Memo (SANDAG, 2020). The memo addresses a range of travel substitution concepts that are collectively characterized as teleworking: telecommuting, working at home (always or primarily), and working at home occasionally. SANDAG's activity-based model (ABM2+) now includes a newly developed telecommute model that forecasts telecommute frequency for people with job types other than "work at home." Specifically:

> *The SANDAG Activity-Based Model explicitly accounts for this reduction by identifying the work location of some workers as "home." In the SANDAG ABM2+, persons who work primarily from home do not make work trips, but they can make other trips during the simulation day. In addition, ABM2+ considers persons who telework occasionally, and these people make fewer work trips. The purpose of this memorandum is to recommend a target for permanent telework and occasional telework, based on recent teleworking data from the San Diego region. (SANDAG, 2020)*

SANDAG's memo updates work originally performed for SANDAG in 2018 by WSP Inc. (2018). The updated memo recommends a target for work from home based on recent telecommuting survey data, including: the 2013 Employee Commute Survey, the 2017 Regional Transportation study, the 2017 National Household Travel Survey (NHTS), the 2018 American Community Survey, and, most notably, SANDAG's 2018 Commuter Behavior Survey.

The purpose of this memo is to assess the methodology of the 2020 SANDAG Telework Memo. To do this, we assess the core assumptions of the SANDAG Telework Memo versus available internal data and externally published results and apply methods from recent research (Dingel and Neiman, 2020) to provide a reality check on SANDAG's recommendations. Note that we do not address the potential impacts of the COVID-19 pandemic on future teleworking trends but do recommend that future research be dedicated to this question.

Review of SANDAG's Telework Assumptions

ITS Irvine's review of the SANDAG Telework Memo included comparing statistics of telecommuting and the forecast produced by ABM2+. The memo recommended the ratio of teleworking to the total employees for the model, then evaluated these impacts on transportation networks and greenhouse gas reductions in travel demand models. ABM2+ was enhanced to include a telecommute model, which was estimated from 2017 household travel survey data and implemented in the residential travel models.

The telecommuting model considers various factors affecting telecommuting behavior, such as occupation type, age, parking costs, the number of children in the household, income, working distance, vehicle ownership, and whether a person is a non-worker, part-time worker, full-time worker, retired, or a college student.

Table 1: Raw and expanded workers by final telecommute frequency

Telecommute Frequency	Raw		Expanded	
	Freq.	Percent	Freq.	Percent
Never or less than 4 days per month	4,889	87%	983,812	92%
1 day per week	323	6%	42,735	4%
2–3 days per week	312	6%	35,798	3%
4 or more days per week	120	2%	9,218	1%
Total	**5,644**	**100%**	**1,071,564**	**100%**

Source: SANDAG ABM2+ report (RSG Inc., 2020)

Table 2: ABM2+ Telecommute choice model calibration results

Telecommute Choice	Targets	%Target	Model	%Model
Never	983,812	91.80%	1,312,160	91.70%
1 day per week	42,735	4.00%	57,720	4.00%
2–3 days per week	35,798	3.30%	47,000	3.30%
4 or more days per week	9,218	0.90%	13,340	0.90%

Source: SANDAG ABM2+ report (RSG Inc., 2020)

Table 1 summarizes the calibration targets for the ABM2+ occasional telecommuting model, showing the raw and expanded frequencies derived from "a careful analysis of actual commute frequency for each response category [to explain survey response variation] with fewer categories of telecommute frequency" (SANDAG, 2020). Table 2 shows the model calibration results indicating the targets were met.

Table 3 compares the 8% baseline for occasional teleworkers to the three SANDAG surveys as well as the American Community Survey (2018) and the National Household Travel Survey (2017). The comparisons indicate that this target is at the low end of the range of the commute ratio produced by these surveys, though direct comparison of ABM2+'s "one or more days per week" of telecommuting to the survey results is imprecise. For instance, SANDAG's Regional Transportation Survey (2016–2017) and Commute Behavior Survey (2018) found that those who "work at home only" comprise 6% and "teleworkers working more than 30 hours" comprise 9%, respectively, while the ACS found a ratio of 6.5% for those who "work at home." ABM2+ also considers two types of telework type: "work at home" and "occasional telecommuting." ABM2+ "work at home" model estimates is 7.1% of the base year 2016 (ACS) and "occasional telecommuting" model is calibrated to 8% (2017 household survey). It is noteworthy that "occasional telecommuting" in ABM2+ is defined as one or more day per week (but less than every day). For less-frequent teleworkers, such as those who telework once a month, their travel patterns on an average workday is similar to a non-teleworker. In ABM2+, less-frequent teleworkers are treated the same as non-teleworkers because ABM2+ represents an average workday, not a "rare" telework day.

The ratios of two types of telework in ABM2+ are generally consistent with SANDAG's Regional Transportation survey and Commute Behavior Survey (2018). Even though there are minor discrepancies, these are due to the definition variations of telework (i.e., telework frequencies).

Table 3: Comparisons of telework frequency: Surveys and ABM2+

	SANDAG Employee Commute Survey (2013)		SANDAG Commute Behavior Survey (2018)	SANDAG Regional Transportation Study (2016–2017)		ACS (2018)	NHTS (2017)			ABM2+
Telework Type	Always or primarily teleworks	Teleworks on occasion	Always or primarily teleworks	Job location type is work at home	Teleworks on occasion	Means of transportation to work is "Work at Home"	Primary work location address type is "Home"	Usually works from home	Has worked from home in the past 30 days (but not a usual telecommuter)	1) Works at home 2) Teleworks one or more days per week (not primary)
Detail	Same	Teleworked on survey week, did not telework on survey week	Do you typically work from home, or do you typically commute to a work location outside of your home?	Job type: Work at home only (only telework or self-employed)	Job type is not telework (all the time)					raw: 12%,
Telework Ratio	7%	23%	11.8%	6%	28%	6.5%	16.6%	15.2%	21%	Work at home: 7.1% Occasional telework: 12% (raw) 8% (expanded)
Note	only surveyed employees who work more than 30 hours per week		baseline of 9% (employees working more than 30 hours)							

Given these assessments, we can now consider SANDAG's recommended telework assumptions for the San Diego Forward: The 2021 Regional Plan. The memo combines a trend analysis of ACS data with recent research on telecommuting trends from Dingel and Nieman (2020) and Mas and Pallias (2020) to infer a 1.2% per decade increase in the "primarily teleworks" rate and a 2% per decade increase in the "occasionally teleworks" rate. Extrapolating from this trend, including some adjustments in the baseline drawn from the 2018 SANDAG Commute Behavior Survey produces the targets in Table 4.

Table 4: Weekday telework recommendation for San Diego County

Year	Primarily teleworks	Occasionally teleworks	Total
2016	7.1%	8%	15.1%
2020	9.2%	8.8%	18%
2025	9.7%	9.8%	19.5%
2035	10.9%	11.8%	22.7%
2050	12.7%	14.8%	27.5%

Source: SANDAG Telework Assumptions Memo (2020)

Again, comparing these trends to the ABM2+ results leads to definitional challenges, whereby the rates only align with ABM2+'s calibration target of 8% if it is assumed that "occasionally teleworks" means less than once per week (or specifically, that they do not have home as their work location, which is captured by the permanent telecommuter model). ABM2+ also includes "work at home," which takes 7.1%; thus, the total ratio of telework is 15.1%. Compared with NHTS data, the 15.1% telework target for ABM2+ is a conservative and justifiable estimate of the actual ratio of workers who would be telecommuting on any given workday.

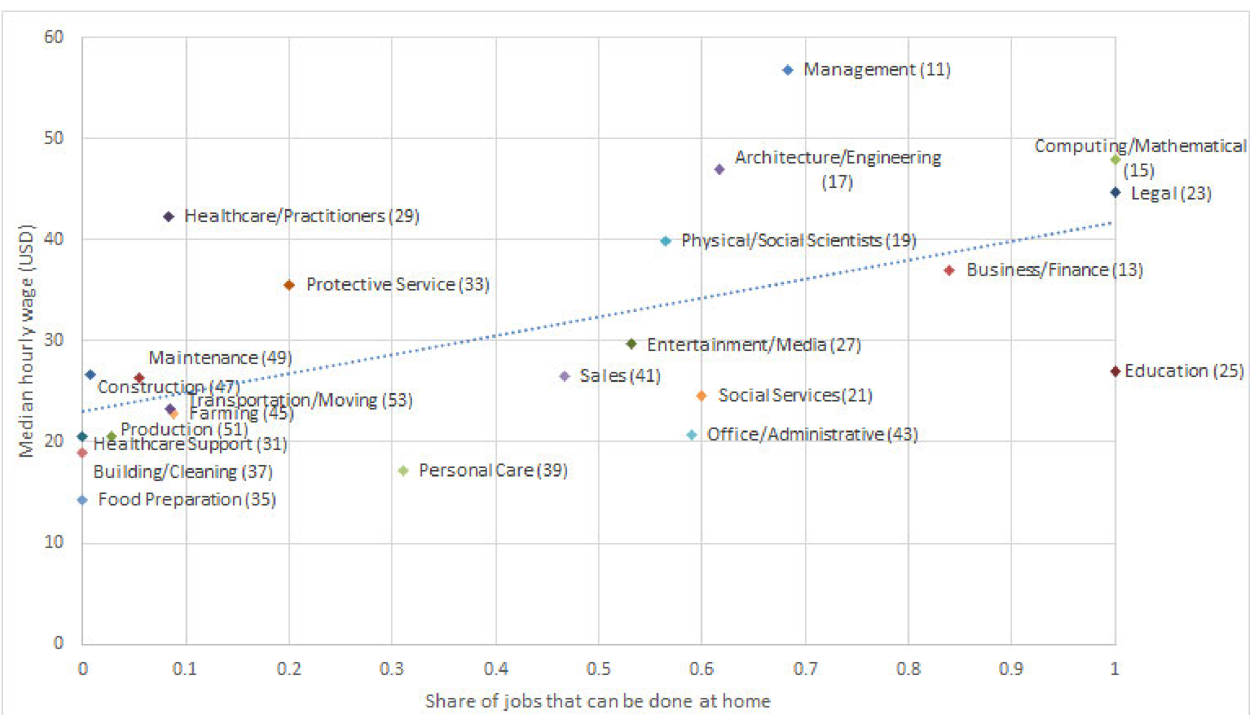
Discussion

There is always a risk of using trend lines to make forecasts of human behavior. First, the use of general ACS trends, for instance, may not capture the fact that the ratio of telework varies across industries. Second, the underlying structural features that dictate the observed trends may change over time and, in fact, may lead to specific restrictions on possible growth. In this case, one such risk is that not all types of employment are amenable to telecommuting; some jobs, such as those in the service industry, simply require employees to be on site and, therefore, to commute to work. Forecasting by trend may lead to telework ratios that are unrealistic for a region's job base.

To assess the reasonableness of the telework trend assumptions, ITS Irvine adapted the work by Dingel and Neiman (2020) that was identified in the SANDAG memo. Dingel and Neiman found that around 37% of total U.S. workers in occupations have the potential work at home based upon their job requirements. To determine this, they utilized the 2018 American Time Use Survey and O*NET occupations with information from the U.S. Bureau of Labor Statistics in aggregation by occupation categories. The O*NET database includes more than 700 occupation titles and two survey results. The "Work Context Questionnaire" includes questions about physical and social factors related to the nature of work, while the "Questionnaire in the Generalized Work Activity" survey deals with interaction with others, mental processes, and work output. Combining results from these surveys, they identify occupations that can and cannot be performed at home.

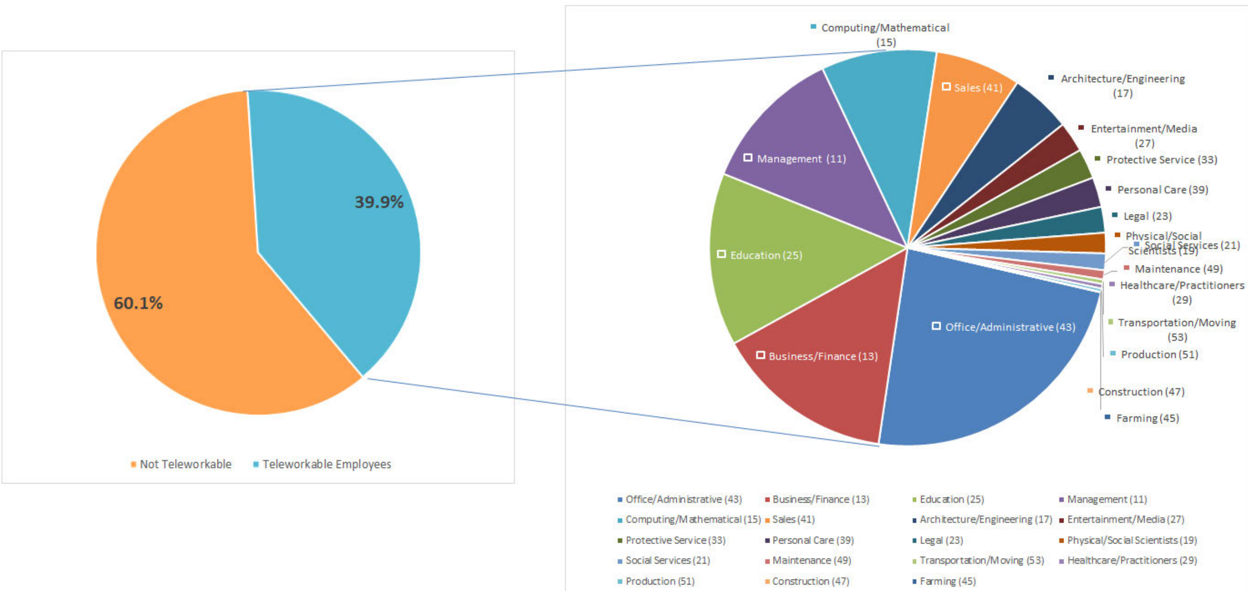
Because Dingel and Neiman (2020) provide data and code for detailed analysis, ITS Irvine was able to apply their methodology to analyze the potential for teleworkability in San Diego. Figure 1 shows the relationship between the median hourly wage and the share of jobs that can be done at home. Each point in Figure 1 indicates job type. The high teleworkability group includes Computing/Mathematical, Legal, Management, Business/Finance, and Education. Low teleworkability job types are Healthcare Practitioners, Production, Transportation, Food Preparation, Building/Cleaning, Movers, etc.

Figure 1: Jobs that can be done at home typically earn higher wages in San Diego



Combining these results with data from the U.S. Bureau of Labor Statistics' 2018 Occupational Employment Statistics to map job type classifications to the SANDAG's employment data allows us to estimate how many employees can work at home in San Diego. ITS Irvine's analysis, summarized in Figure 2, shows that 39.9% of jobs in San Diego can be performed at home. Dingle and Neiman (2020) indicate that 37% of jobs in the United Stated are teleworkable, so this analysis suggests the San Diego region has a higher capacity for telework than the national average.

Figure 2: Teleworkable employees in San Diego



Based upon this analysis and assuming that the general trends San Diego's mix of industries remains relatively constant over the forecast period, we can assess SANDAG's weekday telework recommendations from Table 4. Here, the total proportion of regular and occasional teleworkers in 2050 is assumed to be 27.5% based upon the trend analysis described above, which is substantially lower than the theoretical capacity of about 40% determined by ITS Irvine's analysis. In short, even at the 2050 horizon, the actual number of teleworkers could increase by nearly 50% before the theoretical teleworking capacity was met. As such, we conclude that the application of telework trends to forecast future ratios described in SANDAG's memo is a reasonable assumption of the region's capacity for telework.

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Pooled rides Off-Model Methodologies Review

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11/13/2020

Summary

This document provides a review of SANDAG's Pooled rides off-model calculator that was originally developed by WSP Inc. (WSP, 2019). The pooled program subsidizes eligible employees that currently drive alone to work and are not suitable candidates for commuting by vanpool, microtransit, or transit. In addition to subsidy, as the region's managed lane network expands, commuters/non-work related travelers who choose to pool will experience shorter travel times than commuters driving alone. This travel time savings will further encourage a shift from driving alone to pooling. We compare the calculator to CARB's recommended methodology (CARB 2019a, 2019b) and use the 2019 TNC survey commissioned by SANDAG (RSG, 2019) for calibrating the off-model calculator. We find that the calculator is methodology consistent with best practices and, with the parameter updates, uses the most recent data available to estimate the anticipated behavior of the population with respect to the pooled ride mode in the presence of incentives and managed lane investments. Updates to the calculator using the 2019 TNC Survey lead to smaller estimated GHG reductions than WSP's (2019) original calculator. Though the results produce nominal reductions to the ABM2+ forecasts, we recommend maintaining the calculator for the 2021 Sustainable Communities Strategy and reassessing the performance of pooled rides during the next cycle as this is still an evolving mode that may gain future acceptance with changes in population attitudes.

Review of the SANDAG Pooled Ride Calculator

ITS-Irvine's review of the SANDAG pooled ride calculator included assessing what parameter changes were appropriate based upon any changes to the literature since the calculators were developed by WSP (2019).

The core modeling inputs to the pooled rides calculator include:

- EMFAC 2014 Emission factors
- EMFAC 2014 VMT
- SANDAG population forecasts (to compute per capita GHG changes)
- SANDAG regional trips
- SANDAG travel time skim data

- SANDAG VMT RTP/SCS totals (to compute an adjustment factor for EMFAC VMT for the BAU baseline)

No methodological changes to these inputs were deemed necessary in our review other than updating the population and travel forecasts (trips, skims, and VMT) from SANDAG's ABM2+ model.

Table 1 summarizes the parameters and assumptions used by the calculator. ITS-Irvine's review assessed whether parameter changes were appropriate based upon any changes to the literature since the calculators were developed by WSP (2019). We found that the assumptions and parameters are up to date and defensible based upon the current state of the practice, with the following notes:

- Newer San Diego-specific data on revealed pooled ride mode shares is available from the 2019 TNC-User Travel Survey (vs the 2018 survey used by WSP), which is reflected in this table and was used to update the calculator as described in following sections.
- The marginal disutility of travel time was updated to be consistent with the most recent ABM 2+ forecasts.
- The remaining assumptions and parameters remaining justifiable either via policy or by being based upon the most recent appropriate data sources.

Table 1. Parameters and assumptions of SANDAG pooled rides calculator

Parameter	**Source**	**Details**
Pooled ride mode shares	2019 TNC-User Travel Survey (San Diego)	The mode-specific constant is calibrated based on the observed proportions of pooled ride use reported in the 2019 survey.
Pooled ride average vehicle occupancy	Draft San Diego Forward: The 2019-2050 Regional Plan	In lieu of observed data, the calculator assumes the minimum occupancy to qualify as a pooled ride trip (3 persons per car)
Marginal disutility of travel time	SANDAG ABM 2+	Used in the calculation of demand elasticity
Median value of time	Preliminary Series 14 Forecast	Derived value ($9.80/hr.), estimated as one-third median household income for San Diego region ($61,400), expressed as an hourly wage rate ($29.52/hr.). The value of time is used to calculate an average coefficient of cost, for the demand elasticity formula.
Pooled ride mode-specific constant	Calibrated from the 2019 TNC-User Travel Survey (San Diego)	Mode-specific constants asserted to reflect the county-wide pooled app-enabled rideshare utilization (mode share) reported by the 2019 TNC-User Travel Survey (San Diego)

Auto operating cost	SANDAG ABM 2+	Used to calculate the cost of driving-alone; accounts for fuel and vehicle maintenance. Expressed in cents per mile in (2010 $).
Pooled rides cost per mile	Internal Revenue Service, 2016 standard mileage reimbursement rate for travel in personally-owned automobile.	Expected pooled ride service fare, in cents per mile, including subsidies. Separate values for work and non-work trips, to reflect work-trip subsidies.

GHG Emission Calculator Methodology

ITS-Irvine also reviewed the core methodology employed by the calculator and found that it follows CARB's (2019a, 2019b) Final Sustainable Communities Strategy Program and Evaluation Guidelines. The inputs include detailed strategies associated with pooled rides, such land use and transportation (managed lanes, ridematching programs), location (origin and destination and travel times), and subsidy for pooled rides (new mobility). In addition, the calculator avoids double-counting by taking vehicle trips required to serve the trips, which implies that the shift from drive-alone trips to pooled rides is the amount of the total estimated trips excluding the number of pooled ride drivers.

The calculator computes the CO2 reduction attributed to pooled rides using the following procedures.

Computing pooled (app-enabled) trips within the region:

1. Based on the SANDAG ABM2+ predictions for each scenario year, sum the number of drive-alone person trips by origin MSA, destination MSA, purpose (work/other), time period(AM/PM peak, non-peak), and household auto ownership category.
2. Lookup the average travel time for each MSA-to-MSA origin/destination market, based on the travel time skims produced by the SANDAG ABM2+ for drive-alone trips and carpool trips, respectively.
3. Lookup the average trip distance for each MSA-to-MSA origin/destination market, based on the distance skims produced by the SANDAG ABM2+ for drive alone trips.
4. Estimate the cost of driving alone by applying the auto operating cost to the average trip distance.
5. Estimate the cost of pooled-riding by applying the indexed mileage reimbursement rate to the average trip distance and any trip subsidies as proposed in the Regional Plan.
6. Estimate the proportion of pooled rides in each trip market listed above, using the binomial mode choice model (a binomial logit model). This model is solely a function of

the difference in trip cost between driving alone and pooling and a pooled-ride mode-specific constant that captures the overall preference expressed by the observed pooled-ride mode shares.

7. Estimate the additional pooled ride trips that will be incentivized by managed lane investments (travel time savings), applying the demand elasticity formula (Train 1993).

Computing pooled rides VMT and GHG reductions:

8. Calculate pooled ride VMT based on the average MSA-to-MSA trip distance and pooled ride prediction, assuming an average pool ride auto occupancy of 3 persons per car. The pooled ride occupancy corresponds with the minimum HOV requirements being recommended as part of the Regional Plan's managed lane investments.

9. Calculate the pooled ride VMT reduction. Since the shift is from drive alone to pooled ride, the difference between the total person trips and the vehicle trips used for pooled-riding is equal to the vehicles removed from highways by the availability of ride-pooling.

10. Calculate the corresponding CO2 reduction corresponding to the VMT reduction, using the EMFAC 2014 CO2 emission rates.

The behavior of travelers in Pooled ride calculator is based on two assumptions:

1. Drive-alone trips will shift to pooled rides if a subsidy is provided. A binary logit model is used to model this behavior. The explanatory variables of this logit model are travel distance, auto operation cost, pooled ride cost that is subsidized, and mode specific constants.

2. Travel time savings of pooled rides from the usage of managed lanes will better attract pooled rides from drive-alone trips. This behavior is modeled by elasticity, originated from a binary logit model.

For the calibration of logit models, SANDAG requested that we utilize data from the recent TNC-User Travel Survey (2019), which focused on respondents from San Diego County. Table 1 shows the weighted mode share of pooled rides recorded by the survey. It is noteworthy that we also include all types of pooled rides such as Uber-pool, Lyft pool and other app-based ride services, since the Waze carpool activity in the survey is not likely to reflect SANDAG's incentive program. Although ABM 2+ includes pooled TNCs, the purpose of the off-model calculator is to capture the impacts of the carpool incentive program and managed lane investments in the region where it leads to increasing inter-household pooling. Furthermore, subsidies for the Waze type of pooled rides are to be extended to on-demand ridehailing solutions such as Uber/Lyft, which ABM2+ does not consider.

Total Pooled	Work-related	Nonwork	total

0	0.076%	0.275%	**0.261%**
1	0.043%	0.198%	**0.164%**
2+	0.010%	0.048%	**0.040%**
Total	**0.019%**	**0.091%**	**0.076%**

The survey results indicate that the mode share of Carpool matches is only 0.076% (10,366 trips over a total of 13,614,928 trips). However, the original version of the pooled-ride calculator estimates 8,536 pooled ride trips versus a total of 4,859,394 drive-alone trips (0.176%) in 2020.

ITS-Irvine re-calibrated the mode-specific constants of a binary logit model in the pooled rides calculator using the weighted trip frequencies from the 2019 TNC survey that show the aggregated mode share for pooled ride matches. To do this, ITS-Irvine developed a mode-specific constant calibrator as an excel spreadsheet that estimates target mode share by scaling down the OMC's mode share from the ratio of the difference between calculator's predicted mode share for 2020 (which acts as a calibration base year) and the 2019 TNC survey mode share for pooled rides. The implied assumption is that the 2019 survey data aligns with behavior that would be expected in the 2020 base year. The current version uses the excel solver with ordinary least squares for the calibrations. If raw data from the 2019 survey is available, the constants can be more precisely calibrated to match shares for household size and vehicle ownership groups.

The constants found from the calibrator, shown in Table 3 in comparison to the constants from the 2018 survey, were then used to update those in the pooled ride calculator. The mode specific constants are lower than the original calculator. Specifically, the constants for zero car households for both work trips and non-work trips are much lower than the original value, which leads to the expectation that the mode share of both categories will be significantly lower than in the original calculator.

Table 3. Updated mode specific constants

Pooled rides alternative-specific		Original (2018 San Diego Commute Behavior Survey)	Updated (2019 TNC-User Travel Survey-San Diego)
work trips	Zero cars	-2.60	-7.29
	One car	-5.90	-7.86
	Two or more cars	-7.90	-9.34

non-work trips	Zero cars	-2.90	-5.93
	One car	-6.30	-6.25
	Two or more cars	-8.40	-7.68

Table 4 shows a summary of pooled ride demand as computed by the calculator. ITS-Irvine also compared the estimated pooled ride demand with the original calculator, as shown in Table 5. Because of decreased mode specific constants, the updated calculator estimates lower pooled ride ridership except for non-work trips associated with households having more than one car. The updated calculator estimates that travel time savings from managed lane investments have insignificant impacts on pooled ride ridership, in part because the travel time savings of managed lanes in ABM 2+ is lower than the previous data, as shown in Table 6.

Table 4. Estimated Pooled ride demand of the updated calculator

Variable	2020	2035	2050	Notes
Pooled ride person trips, base demand				
Work trips (AM and PM Periods), zero car households	19	13	11	The demand for pooled rides is estimated by applying a mode shift model to the base drive alone trips. The mode shift model was calibrated to observed mode shares [1,6]. This model is segmented by household auto ownership, consistent with the differences in aggregate mode shares in the observed data.
Work trips (AM and PM Periods), one car households	158	129	114	
Work trips (AM and PM Periods), two+ car households	132	110	101	
Non-work trips (all time periods), zero car households	165	195	198	
Non-work trips (all time periods), one car households	1,228	1,327	1,293	
Non-work trips (all time periods), two+ car households	1,173	1,267	1,294	
Pooled ride person trips, demand due to managed lane investments				
Work trips (AM and PM Periods), zero car households	0	0	0	Investments in managed lanes that reduce travel time for carpoolers can further incentivize pooled ride transpiration options. The percent change in demand as a function of travel time savings is estimated based on the elasticity of demand for pooled rides with respect to travel time. The elasticity of demand varies by origin-destination market and by time period.
Work trips (AM and PM Periods), one car households	0	0	0	
Work trips (AM and PM Periods), two+ car households	0	0	0	
Non-work trips (all time periods), zero car households	0	0	0	
Non-work trips (all time periods), one car households	0	0	0	
Non-work trips (all time periods), two+ car households	0	0	0	
Pooled ride person trips, base and induced				
Work trips (AM and PM Periods), zero car households	19	13	11	Total pooled ride trips = base trips + trips induced by managed lane time savings
Work trips (AM and PM Periods), one car households	159	129	114	
Work trips (AM and PM Periods), two+ car households	132	110	102	
Non-work trips (all time periods), zero car households	165	195	198	
Non-work trips (all time periods), one car households	1,229	1,327	1,293	
Non-work trips (all time periods), two+ car households	1,174	1,267	1,294	
Total pooled ride trips				
Total person trips	2,877	3,041	3,013	*= sum of all pooled ride trips*
Vehicle trips required to serve the person trips	959	1,014	1,004	*= pooled ride trips / average vehicle occupancy*
Vehicles replaced by pooled ride service	1,918	2,027	2,008	Since the shift is from drive alone to pooled ride, the difference between the total person trips and the vehicle trips used for pooled-riding is equal to the vehicles removed from highways by the availability of ride-pooling.

Table 5. Estimated Pooled ride demand of the original calculator

Variable	2020	2035	2050	Notes
Pooled ride person trips, base demand				
Work trips (AM and PM Periods), zero car households		1,036	1,351	The demand for pooled rides is estimated by applying a mode shift model to the base drive alone trips. The mode shift model was calibrated to observed mode shares [1,6]. This model is segmented by household auto ownership, consistent with the differences in aggregate mode shares in the observed data.
Work trips (AM and PM Periods), one car households		1,062	1,200	
Work trips (AM and PM Periods), two+ car households		320	323	
Non-work trips (all time periods), zero car households		2,545	3,564	
Non-work trips (all time periods), one car households		1,544	1,771	
Non-work trips (all time periods), two+ car households		454	483	
Pooled ride person trips, demand due to managed lane investments				
Work trips (AM and PM Periods), zero car households		20	23	Investments in managed lanes that reduce travel time for carpoolers can further incentivize pooled ride transpiration options. The percent change in demand as a function of travel time savings is estimated based on the elasticity of demand for pooled rides with respect to travel time. The elasticity of demand varies by origin-destination market and by time period.
Work trips (AM and PM Periods), one car households		16	18	
Work trips (AM and PM Periods), two+ car households		6	6	
Non-work trips (all time periods), zero car households		10	11	
Non-work trips (all time periods), one car households		5	5	
Non-work trips (all time periods), two+ car households		2	1	
Pooled ride person trips, base and induced				
Work trips (AM and PM Periods), zero car households		1,056	1,374	Total pooled ride trips = base trips + trips induced by managed lane time savings
Work trips (AM and PM Periods), one car households		1,078	1,218	
Work trips (AM and PM Periods), two+ car households		326	329	
Non-work trips (all time periods), zero car households		2,555	3,575	
Non-work trips (all time periods), one car households		1,550	1,776	
Non-work trips (all time periods), two+ car households		456	485	
Total pooled ride trips				
Total person trips		7,020	8,756	*= sum of all pooled ride trips*
Vehicle trips required to serve the person trips		2,340	2,919	*= pooled ride trips / average vehicle occupancy*
Vehicles replaced by pooled ride service		4,680	5,837	Since the shift is from drive alone to pooled ride, the difference between the total person trips and the vehicle trips used for pooled-riding is equal to the vehicles removed from highways by the availability of ride-pooling.

Table 6.Comparisons of travel times between ABM2+ and ABM14.0 (original calculator)

		Average one-way weekday travel time					
		AM peak		PM peak		Midday peak	
Data	Year	mixed flow lanes	managed lanes	mixed flow lanes	managed lanes	mixed flow lanes	managed lanes
ABM 2+	2035	14.95	14.90	13.47	13.41	9.81	9.80

	2050	15.02	14.96	13.55	13.48	9.81	9.80
	2035	17.78	17.14	15.86	15.42	11.07	10.96
Original	2050	17.65	17.09	15.82	15.39	11.04	10.95

Table 7 shows the estimated VMT and GHG reduction results of the updated pooled ride OMC. Compared with the estimated results of the original OMC, shown in Table 8, the changes in mode specific constant and input data had a notable impact on daily per capita GHG reduction.

The updated calculator estimates a lower impact on GHG reductions due to pooled rides, which is mainly due to the lower mode share of pooled rides measured in the 2019 TNC survey. Lower managed lane travel time savings estimated from ABM 2+ also affects the GHG reductions, compared to the original calculator. Compared with the updated vanpool OMC, pooled rides are less affected by managed lanes since pooled rides have shorter travel distances than vanpool.

Table 7 Estimated VMT and GHG Reduction Results of the updated pooled ride OMC

Variable	2020	2035	2050	Notes
Plan CO2 Emissions				
Daily CO2 emissions (short tons)	38,881	38,199	38,777	*= Sum of running emissions and trip start emissions trip start emissions*
Daily emissions per capita (lbs.)	22.98	21.10	20.70	*= Daily emissions (short tons) / regional population * 2000 lbs / 1 short ton*
Daily person miles traveled, pooled ride trips				
Work trips, zero car households	153	102	94	
Work trips, one car households	1,221	993	896	*= pooled ride person trips * distance traveled*
Work trips, two+ car households	1,168	956	903	
Non-work trips, zero car households	867	1,039	1,088	calculated over origin-destination Metropolitan Statistical Areas (MSA)
Non-work trips, one car households	6,288	6,714	6,554	
Non-work trips, two+ car households	6,240	6,596	6,707	
Total person miles traveled, pooled ride trips	15,936	16,400	16,242	
Total vehicle miles reduced by pooled rides	10,624	10,933	10,828	*= total person miles * proportion of vehicles eliminated by pooled-riding*
Total vehicle trips reduced by pooled rides	1,918	2,027	2,008	
GHG reductions				
Total daily GHG reductions (short tons)	5.17	5	5	*= vehicle trip reductions * trip start emission factor + VMT reduction * running emission factor*
Daily per capita GHG reductions (lbs./person)	0.00	0.00	0.00	*= per capita GHG emission reductions*
Daily per capita GHG reduction	-0.0133%	-0.0136%	-0.0131%	*= percent change in per capita GHG reduction*

Table 8 Estimated VMT and GHG Reduction Results of the original pooled ride OMC

Variable	2020	2035	2050	Notes
Plan CO2 Emissions				
Daily CO2 emissions (short tons)	38,663	42,139	43,371	*=Sum of running emissions and trip start emissions trip start emissions*
Daily emissions per capita (lbs.)	22.92	22.72	21.87	*=Daily emissions (short tons) / regional population * 2000 lbs / 1 short ton*
Daily person miles traveled, pooled ride trips				
Work trips, zero car households		8,668	11,471	
Work trips, one car households		8,392	9,597	*=pooled ride person trips * distance traveled*
Work trips, two+ car households		2,839	2,911	
Non-work trips, zero car households		14,242	20,251	calculated over origin-destination Metropolitan Statistical Areas (MSA)
Non-work trips, one car households		8,068	9,228	
Non-work trips, two+ car households		2,447	2,609	
Total person miles traveled, pooled ride trips		44,657	56,067	
Total vehicle miles reduced by pooled rides		29,771	37,378	*=total person miles * proportion of vehicles eliminated by pooled-riding*
Total vehicle trips reduced by pooled rides		4,680	5,837	
GHG reductions				
Total daily GHG reductions (short tons)		14	18	*=vehicle trip reductions * trip start emission factor + VMT reduction * running emission factor*
Daily per capita GHG reductions (lbs./person)		0.01	0.01	*=per capita GHG emission reductions*
Daily per capita GHG reduction		-0.03%	-0.04%	*=percent change in per capita GHG reduction*

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Vanpool Off-Model Methodologies Review

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11/13/2020

Summary

This document provides a review of SANDAG's Vanpool off-model calculator (OMC) that was originally developed by WSP Inc. (WSP, 2019) as compared to CARB's recommended methodology (CARB 2019a, 2019b). The methods were found to be consistent with best practices. In addition to the review the vanpool OMC was updated to reflect the most recent SANDAG Vanpool Program Data (from May 2020) and the most recent ABM 2+ forecasts. There were 590 registered vanpools in May 2020, which reflects decreases in program participation due to both major employers who have withdrawn support and to COVID-19 impacts at the time. Over the past five years, the number of active vanpools has fluctuated between 680 and 720 vehicles. The recent active Vanpool demand dropped to 590 van pools, which is likely to be affected by COVID-19. Current vanpool program requires at least 80 % of occupancy for the benefit and at least 20 miles of travel distances within the County. The recent growth of teleworking is likely to affect the decrease in vanpools, though any easing of the COVID-19 pandemic may have the opposite effect in terms of an increased demand for mobility. Since is it too early to know how these potential changes will interact in terms of a trend going forward, it is reasonable to use the May 2020 results as an intermediate point of reference. The results of the updates produce a somewhat lower per capita reduction (0.35% reduction vs the original 0.46% reduction), which is to be expected given the lower vanpool participation rates found in May of 2020. Though this performance is diminished, the calculator's GHG reduction estimates are still significant and may evolve over time.

Review of the SANDAG Vanpool Calculator

ITS-Irvine reviewed models, assumptions, and modeling inputs. Overall, the vanpool OMC follows CARB's (2019b) recommendations from its Final Sustainable Communities Strategy Program and Evaluation Guidelines-Appendices. This includes specific methodological recommendations such as accounting properly for interregional travel and double counting with other calculators. For instance, the vanpool OMC excludes the portion of SCAG's VMT in Internal-External trip (IX) and External-Internal trip (XI), depending on the origin, destination coordinates and gateways for origins and destinations. Furthermore, the vanpool calculator resolves a double-counting issue by considering average occupancy excluding drivers, thus emissions from vans are counted.

The core modeling inputs to the Pooled rides calculator include:

- EMFAC 2014 emission factors
- EMFAC 2014 VMT
- SANDAG employment forecasts by industry category and region (SANDAG ABM classification)
- SCAG employment forecasts by county (SANDAG ABM classification)
- SANDAG population forecasts (to compute per capita GHG changes)
- SANDAG travel time skim data(military/nonmilitary base destinations)
- SANDAG VMT RTP/SCS totals (to compute an adjustment factor for EMFAC VMT for the BAU baseline)
- Average vanpool mileage (as of May 20, 2020, SANDAG Vanpool Program)
- Average van capacity (seats)
- Average van occupancy
- Postal zip code centroid coordinates (used to approximate the distance traveled by vanpools outside San Diego County)
- County gateway centroids (Used to approximate the distance traveled by vanpools outside San Diego County)

No methodological changes to these inputs were deemed necessary by our review other than updating the population and travel forecasts (trips, skims, and VMT) from SANDAG's ABM2+ model and the vanpool statistics from the recent program data.

Table 1 shows the additional parameters and assumptions used in the calculator. ITS-Irvine's review of the SANDAG Vanpool calculator assessed whether parameter changes were appropriate based upon any changes to the literature since the calculators were developed by WSP (2019).   We found that the assumptions (i.e., the marginal disutility of travel time and the person trips suitable for vanpooling assumptions) are up to date and are consistent with the ABM 2+, though parameter updates to the vanpool inventory using the most recent data available from SANDAG was warranted.

Table 1. Parameters and assumptions of SANDAG Vanpool calculator

Parameter	**Source**	**Details**
Current vanpool inventory	Active vanpools as of May 20, 2020, SANDAG Vanpool Program)	Required data for each vanpool includes trip origin, trip destination, employment industry (federal military, federal non-military, non-federal), van capacity, roundtrip mileage. Trip origin and destination aggregated to MSAs if inside San Diego County, and to County if outside San Diego County.
Marginal disutility of travel time	SANDAG ABM 2+ Trip mode choice model, Work tours	In-vehicle time coefficient of the work trip mode choice model, SANDAG ABM 2+ (the same as ABM14.0.1)

Total person trips that are suitable for vanpooling	U.S. Census Bureau (2016). American Community Survey, 2016 1-Year Release.	Used to calculate vanpool mode market share, an input to the demand elasticity formula (value rounded to 1.6 million workers).

GHG Emission Calculator Methodology

ITS-Irvine also reviewed the core methodology employed by the calculator and found it to be consistent with CARB's (2019) Final Sustainable Communities Strategy Program and Evaluation Guidelines. The calculator computes CO2 reductions following the procedure described below.

Establish the current vanpool demand:

1. The vanpool demand was then tabulated in a trip origin-destination matrix, where the trip origin represented the home location and the trip destination was the work location. Home and work locations were then identified at the level of Metropolitan Statistical Areas (MSA) if they fell within San Diego County, or at the county level if they fell outside San Diego County.

Vanpool demand due to regional employment growth:

2. The total number of vanpools were multiplied within the destination MSA by the employment growth rate at the MSA, which was calculated as future year employment divided by 2016 employment. The new vanpools due to employment growth were then distributed to origin MSAs in the proportions observed in 2016.

Vanpool demand due to managed lane infrastructure investments:

3. Compute demand elasticity with respect to travel time. In lieu of observed demand elasticities, elasticity of demand was estimated using a logit mode choice model formulation.

4. Calculate average MSA to MSA travel time savings, defined as the difference between the travel time experienced when using all available highways, and the travel time experienced using general purpose lanes only (excluding HOV and Express Lanes). For trip origins outside of San Diego County, the travel time savings are computed only over the portion of the trip that occurs within San Diego County. Since the specific location of military bases is known, the travel time savings associated with military vanpools is computed specifically to the zones that comprise the military bases, rather than an average over all of the MSA destinations.

5. Compute the demand induced by travel time savings by applying the demand elasticity formula to the estimated number of vanpools for each scenario year, after accounting for employment growth.

Vanpool VMT and GHG reductions:

6. Calculate VMT reduction, which for each van is equal to the average round trip distance within San Diego County, multiplied by the number of passengers (excluding the driver). It is noteworthy that the calculator only accounts for vanpool travel within San Diego County only. Out-of-county distance approximated based on home zip code coordinates.

7. Calculate the CO_2 reduction corresponding to the VMT reduction and reduction in trip starts using the Emission Factors (EMFAC) 2014 CO_2 emission rates.

The main assumptions underlying the number of vanpool program participants are based on two factors:

1. Employment growth: it is assumed that the participant rates over employment remain the same in the future, thus the number of vanpoolers is a function of the number of employees.

2. Mode shift from travel time savings. Vanpool incentives include the exclusive use of managed lanes including High Occupancy Vehicle and the Interstate-15 Express Lanes). The shifted demand is measured from the elasticity approach, which is derived from a logit model. Travel time savings from managed lanes attract more vanpoolers, which could reduce VMT by mode shift from drive alone.

Table 2 shows a summary of the calculated vanpool demand both due to regional employment growth and the impact of managed lane investments.

Table 2 Estimated vanpool demand

Vanpool Program Growth Estimates

1. Vanpool demand due to regional employment growth	2020	2035	2050	Notes
	Total vanpools due to regional employment growth			
Vanpool Industry				
Military	228	244	248	Assumes that the number of vanpools changes proportionally with employment at the destination MSA (County if vanpool destination is outside San Diego County).
Federal Non-Military	115	126	135	
Non-Federal	247	281	302	
TOTAL	590	651	685	
2. Vanpool demand due to managed lane investments	**2020**	**2035**	**2050**	**Notes**
	Total vanpools due to managed lane infrastructure			
Vanpool Industry				
Military	-	9	14	Induced demand for vanpools as the region builds managed lanes which result in travel time savings relative to traveling on general purpose lanes. Travel time savings vary by trip origin and destination, and by scenario year.
Federal Non-Military	-	8	11	
Non-Federal	-	15	21	
TOTAL	-	32	45	
TOTAL VANPOOLS	**2020**	**2035**	**2050**	**Notes**
Vanpool Industry				
Military	228	253	262	
Federal Non-Military	115	134	146	
Non-Federal	247	296	323	
TOTAL	**590**	**683**	**730**	

Table 3 shows the estimated VMT and GHG reduction results of the updated vanpool OMC. Compared with the estimated results of the original OMC, shown in Table 4, the changes in input data had a notable impact on daily per capita GHG reduction because both active vanpools and the VMT forecasts have decreased since the updates to the regional model. Although the travel time saving of the simulation run from ABM2+ is higher than that of the original OMC, the reduction in vanpool participants of the active vanpool program in 2020 have significantly affected the results, leading to a smaller per capita GHG reduction in all target years versus the original calculator.

Table 3 Estimated VMT and GHG Reduction Results of the updated Vanpool OMC

VMT and GHG Reduction Results			
Variable	**2020**	**2035**	**2050**
Plan CO2 Emissions			
Regional population	3,383,955	3,620,349	3,746,077
Daily CO2 emissions (short tons)	38,881	38,199	38,777
Daily emissions per capita (lbs)	22.98	21.10	20.70
Total daily vehicle trip reduction	6,012	6,967	7,452
Total daily VMT reduction	307,133	355,422	379,780
VMT reduced in San Diego County	259,598	300,336	320,910
GHG reduction due to cold starts (short tons)	0.6	0.6	0.7
GHG reduction due to VMT (short tons)	121.9	137.3	145.5
Daily Total GHG reduction (short tons)	122.5	137.9	146.2
Daily Per capita GHG reduction (lbs/person)	-0.072	-0.076	-0.078
Daily Per capita GHG reduction	-0.31%	-0.36%	-0.38%

Table 4 Estimated VMT and GHG Reduction Results of the original Vanpool OMC

VMT and GHG Reduction Results			
Variable	**2020**	**2035**	**2050**
Plan CO2 Emissions			
Regional population	3,374,125	3,709,575	3,967,090
Daily CO2 emissions (short tons)	38,652	42,139	43,371
Daily emissions per capita (lbs)	22.91	22.72	21.87
Total daily vehicle trip reduction	6,669	8,106	8,547
Total daily VMT reduction	386,286	469,271	493,683
VMT reduced in San Diego County	334,101	405,763	426,853
GHG reduction due to cold starts (short tons)	0.6	0.8	0.8
GHG reduction due to VMT (short tons)	160.8	189.1	194.3
Daily Total GHG reduction (short tons)	161.4	189.8	195.1
Daily Per capita GHG reduction (lbs/person)	-0.096	-0.102	-0.098
Daily Per capita GHG reduction	-0.42%	-0.45%	-0.45%

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Carsharing Off-Model Methodologies Review

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Summary

This document provides a review of SANDAG's Carsharing off-model calculator (OMC), originally developed by WSP, Inc. (WSP, 2019), compared to CARB's recommended methodology (CARB 2019a, 2019b). Generally, the calculator follows the quantification methodology steps of CARB's guidelines and is based upon valid assumptions and up-to-date parameters from the literature. The calculator was updated using the most recent ABM 2+ forecasts and reflect significant changes to coverage areas in 2035. The combined impacts of these updates lead to approximately double (0.20% reduction vs 0.10% reduction) the estimates per capita GHG in the updated calculator versus the original calculator.

Review of the SANDAG Carsharing Calculator

Upon initial review, we realized it was important to note that there are several types of carsharing services, including roundtrip, one-way (either a free-float carshare service or station-based model), and peer-to-peer, that are relevant for quantification methodologies in CARB's SCS Evaluation Guidelines. SANDAG's carsharing calculator only considers roundtrip carsharing since other types of carsharing services do not exist in San Diego. Car2go, a free-float carshare service that was previously operating in San Diego, ceased operation in the region in 2016 and left all North American markets in 2020.

Once establishing the submarket that the calculator is targeting, we reviewed the general methodology, which is described in more detail below, and found it consistent with CARB guidelines. We also reviewed the core modeling inputs to the Pooled rides calculator, which include:

- EMFAC 2014 Emission factors
- EMFAC 2014 VMT
- SANDAG employment forecasts
- SANDAG population forecasts (to compute population density and per capita GHG changes)

- SANDAG travel time skim data(military/nonmilitary base destinations)
- SANDAG MGRA residential area (acres)
- SANDAG MGRA college student enrollment
- Carshare coverage (1 if carshare operates in MGRA, 0 otherwise)
- Carshare College/university coverage (1 if carshare operates in college)
- Carshare Military base coverage (1 if carshare operates on base, 0 otherwise)

No methodological changes to these inputs were deemed necessary by our review other than updating the population and travel forecasts (trips, skims, and VMT) from SANDAG's ABM2+ model and reviewing the carshare coverage indicators to confirm their correctness.

Our review also included assessing what parameter changes were appropriate based upon any changes to the literature since the calculators were developed by WSP Inc. (2019). Table 1 indicates the parameters and assumptions of the calculator. Our review found that the assumptions summarized in the table are based upon valid research and data sources that have not been superseded by any literature we could identify.

Table 1. Parameters and assumptions of SANDAG carsharing calculator

Parameter	**Source**	**Details**
Carshare participation rate in higher density areas	SANDAG (2017). 2016-2017 San Diego Regional Transportation Study.	For each scenario year:proportion of urban population that will become carshare members
Carshare participation rate in lower density areas	Petersen, E., Y. Zhang, and A. Darwiche (2016).	For each scenario year: proportion of suburban population that will become carshare members
Membership rate,	Assumed equal to higher density area carshare participation rates or 2 percent of the eligible population	For each scenario year: proportion of college employees that will become carshare members
Daily VMT reduction, roundtrip carshare	Cervero, R. A. Golub, and Nee (2007)	For each scenario year: VMT reduction per roundtrip carshare member

We reviewed models, assumptions, and modeling inputs and found that the carsharing OMC follows CARB's Final Sustainable Communities Strategy Program and Evaluation Guidelines and Appendices in terms of data sources, supporting literature for assumptions, and efforts avoiding double counting. For instance, to avoid overestimation and to ensure that GHG emission reductions associated with fleet efficiencies are only captured in the SANDAG Electric

Vehicle Programs off-model calculator, the carshare methodology does not account for fuel-efficiency of carshare vehicle fleets. Furthermore, the carsharing OMC drops the impact of carsharing service in 2050 by assuming that a carsharing service will no longer be available in 2050 and will instead be replaced by a fleet of shared and autonomous vehicles by the year 2050.

GHG Emission Calculator Methodology

The CO_2 reduction attributed to the three carshare markets—general population, colleges, and military bases—is calculated following the procedures described below for each of the markets;

Carshare participation:

1. Identify the carshare service coverage areas. In support of regional mobility hub planning efforts, the SANDAG TDM program seeks to promote and encourage the provision of Carshare within neighborhoods that exhibit similar supporting land uses as those where carsharing is provided today such as the region's employment centers, colleges, and military bases:

    a. Mobility hubs (General Population): Define agglomerations of MGRAs and aggregated by MSA. The coverage areas vary by scenario year, reflecting increasing land use density and a maturing carshare industry.

    b. College/Universities (College Staff and Students): Identify colleges and university areas where carshare services will operate in each scenario year. These areas are defined as agglomerations of MGRAs and aggregated by MSA.

    c. Military (Military personnel on base): Identify military bases where carshare services will operate in each scenario year. The military bases are defined as agglomerations of MGRAs and aggregated by MSA.

2. Calculate the eligible population for carsharing:

    a. General Population: Estimate the eligible population for carsharing, which reside within the defined carshare coverage area boundaries and are persons older than 18 years old and younger than 65 years old.

    b. College Staff and Students: The eligible student population that is potential carshare participants corresponds to the total students enrolled (full-time and part-time) in each college/university campus and total staff employed at each campus.

    c. Military: Estimated Carshare participants within the region's military bases correspond to the employment at each base.

3. Calculate the carshare participation, defined as 2 percent of the eligible population in higher density areas and 0.5 percent of the eligible population in lower-density areas.

The population density thresholds that support carshare participation in the region are based on the Car2Go service area prior to their exit from the San Diego market. Colleges and military bases, participation rates are assumed equal to higher density area carshare participation rates or 2 percent of the eligible population.

Carshare VMT and GHG reductions:

4. Calculate the VMT reduction from roundtrip carshare, assuming a daily average reduction of seven miles per day per roundtrip carshare member (Cervero et al, 2007).

5. Calculate the CO2 reduction corresponding to the VMT reduction, using the EMFAC 2014 CO2 emission rates.

The main assumptions regarding carsharing membership are based on the population density and the carshare service coverage area. Table 2 and Table 3 show the eligible employment and estimated carshare participation in 2020 and 2035, respectively. The enlarged coverage of Carshare services in 2035 increases the estimated Carshare participation. The carshare service coverage substantially increases to 6,743 MGRAs (Master Geographic Reference Areas) from 31 MGRA in 2020. As such, it is expected that in 2035 employment centers will have 15,026 participants. College staff and student participation will increase to 1,735 and 6,607 respectively. Military bases will include 2,256 participants while there are no participants in 2020.

Table 2. Eligible employments and estimated Carshare participation in 2020

	Strategy Inputs -- Year 2020																			
	Employment Centers							Colleges - Staff				Colleges - Students				Military Bases				
MSA	MGRAs in employment center coverage area	Eligible adult population within the coverage area (thousands)	Eligible adult population in higher density areas within the coverage area (thousands)	Eligible adult population in lower density areas within the coverage area (thousands)	Carshare participation rate, higher density areas [4]	Carshare participation rate, lower density areas [5]	Estimated carshare participation	MGRAs in college coverage area	College / University employment	Carshare participation rates, college staff [4]	Estimated carshare participation	MGRAs in college coverage area	College / University enrollment	Carshare participation rates, college students [4]	Estimated carshare participation	MGRAs in military base coverage area	Military base employment	Carshare participation rates, military bases [4]	Estimated carshare participation
Central	26	4	3	0	2.0%	0.50%	68	10	13,027	2.0%	261	10	42,732	2.0%	855	-	-	2.0%	-
North City	5	0	0	0	2.0%	0.50%	2	17	30,822	2.0%	616	17	44,222	2.0%	884	-	-	2.0%	-
South Suburban	-	-	-	-	2.0%	0.50%	-	-	-	2.0%	-	-	-	2.0%	-	-	-	2.0%	-
East Suburban	-	-	-	-	2.0%	0.50%	-	-	-	2.0%	-	-	-	2.0%	-	-	-	2.0%	-
North County West	-	-	-	-	2.0%	0.50%	-	-	-	2.0%	-	-	-	2.0%	-	-	-	2.0%	-
North County East	-	-	-	-	2.0%	0.50%	-	3	4,534	2.0%	91	3	16,627	2.0%	333	-	-	2.0%	-
East County	-	-	-	-	2.0%	0.50%	-	-	-	2.0%	-	-	-	2.0%	-	-	-	2.0%	-
Total	31	4	3	0			70	30	48,383		968	30	103,581		2,072	-	-		-

Table 3. Eligible employments and estimated Carshare participation in 2035

	Strategy Inputs -- Year 2035																			
	Employment Centers							Colleges - Staff				Colleges - Students				Military Bases				
MSA	MGRAs in employment center coverage area	Eligible adult population within the coverage area (thousands)	Eligible adult population in higher density areas within the coverage area (thousands)	Eligible adult population in lower density areas within the coverage area (thousands)	Carshare participation rate, higher density areas [4]	Carshare participation rate, lower density areas [5]	Estimated carshare participation	MGRAs in college coverage area	College / University employment	Carshare participation rates, college staff [4]	Estimated carshare participation	MGRAs in college coverage area	College / University enrollment	Carshare participation rates, college students [4]	Estimated carshare participation	MGRAs in military base coverage area	Military base employment	Carshare participation rates, military bases [4]	Estimated carshare participation
Central	2,671	336	288	48	2.0%	0.50%	6,004	14	15,709	2.0%	314	14	71,360	2.0%	1,427	9	59,189	2.0%	1,184
North City	1,167	217	179	39	2.0%	0.50%	3,771	21	53,260	2.0%	1,065	21	111,642	2.0%	2,233	11	9,808	2.0%	196
South Suburban	352	72	51	21	2.0%	0.50%	1,132	1	464	2.0%	9	1	24,768	2.0%	495	-	-	2.0%	-
East Suburban	959	108	72	35	2.0%	0.50%	1,623	2	2,507	2.0%	50	2	38,770	2.0%	775	-	-	2.0%	-
North County West	635	45	27	18	2.0%	0.50%	623	2	1,158	2.0%	23	2	21,745	2.0%	435	6	43,788	2.0%	876
North County East	959	127	83	44	2.0%	0.50%	1,873	4	12,665	2.0%	253	4	62,067	2.0%	1,241	-	-	2.0%	-
East County	-	-	-	-	2.0%	0.50%	-	-	-	2.0%	-	-	-	2.0%	-	-	-	2.0%	-
Total	6,743	905	700	205			15,026	44	85,763		1,715	44	330,352		6,607	26	112,785		2,256

Table 4 shows the estimated VMT and GHG reduction results of the updated carshare OMC. We also compared it with the results of the original calculator developed by WSP (2019) that are shown in Table 5. This comparison indicates that the changes in input data had a notable impact on Daily per capita GHG reduction. This is because of the population and the carshare service coverages. The number of MGRAs covered by the carshare service in 2035 is 6,743 MGRAs and its estimated Carshare participation is 25,604 members. However, the original OMCs estimated 12,068 members from 1,192 MGRAs in the same year.

Table 4 Estimated VMT and GHG Reduction Results of the updated Carshare OMC

VMT and GHG Reduction Results			
Variable	2020	2035	2050
Plan CO2 Emissions			
Daily CO2 emissions (short tons)	38,881	38,199	Given the rapid trend towards automation, it is assumed that a carsharing service will no longer be available in 2050 and will instead be replaced by a fleet of shared and autonomous vehicles by the year 2050.
Daily emissions per capita (lbs)	22.98	21.10	
Daily VMT reduction			
Roundtrip carshare	21,764	179,225	
Total VMT reduction	21,764	179,225	
Total daily GHG reductions (short tons)	10.2	81.9	
Daily per capita GHG reduction (lbs/person)	0.0060	0.0453	
Daily per capita GHG reduction	-0.03%	-0.21%	

Table 5 Estimated VMT and GHG Reduction Results of the original carshare OMC

VMT and GHG Reduction Results			
Variable	2020	2035	2050
Plan CO2 Emissions			
Daily CO2 emissions (short tons)	38,663	42,139	Given the rapid trend towards automation, it is assumed that a carsharing service will no longer be available in 2050 and will instead be replaced by a fleet of shared and autonomous vehicles by the year 2050.
Daily emissions per capita (lbs)	22.92	22.72	
Daily VMT reduction			
Roundtrip carshare	78,331	88,395	
Total VMT reduction	78,331	88,395	
Total daily GHG reductions (short tons)	37.7	41.2	
Daily per capita GHG reduction (lbs/person)	0.0223	0.0222	
Daily per capita GHG reduction	-0.10%	-0.10%	

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EV Program Off-Model Methodologies Review

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Summary

This document provides a review of SANDAG's EV off-model calculator in comparison to CARB's recommended methodology as well as the methods employed by the other three large MPO's in California. We look specifically at off-model methodologies for both EV incentive programs and EV charger programs, and compare the relative reductions that each MPO is computing with their off-model adjustments.

SANDAG has also requested an answer to specific questions, which are addressed in detail in the document, but summarized here:

What changes, if any, ITS-Irvine did to the EV OMC Excel sheets?
This is addressed in the last section of this document. Specifically, we updated the SANDAG population and VMT forecasts to the most recent data provided by SANDAG staff from August 2020 model runs. These updates improve the total per capita GHG reductions due to EV programs from 0.48% to 0.60% in the "90% CEC scenario." We also discuss how SANDAG might go about systematically selecting the scenario to use in the SCS/RTP, by selecting the one that maximizes the GHG reductions with incentive levels set within the bounds of the other MPOs in order to control total costs to within SANDAG targets.

What did other MPOs do for their EV program analyses?
In summary, we had the most information about SCAG's approach, which followed CARB recommendations quite literally. SCAG's calculators are very simple in comparison to SANDAGs and likely overestimate potential reductions. MTC's calculators also closely follow CARBs methods, though they used the second of two potential methods for EV charger programs (based upon total incentivized kWh), where SCAG used the first. MTC's approach is similar to SANDAG's, except that SANDAG has a more sophisticated approach to determining required charging infrastructure. Technical details on SACOG's programs were limited.

Were utility programs counted by the MPOs
MTC appears to have counted 7,500 charger installations by PG&E in their reductions. We didn't identify any indication that they included vehicle incentives by utilities in their

reductions. SCAG's calculators are quite basic and don't appear to have the capability to distinguish utility participation. One note in SCAG documentation implies that they assume that they can take credit for facilitating charger installations with partners (including utilities) that are represented in the chargers required to support VMT reductions in the off-model calculator.

What targets and incentive costs (for vehicles) were recommended.
MTC notes that they assumed $1,500/PHEV and $2,500/BEV on average, but that the actual levels would depend on many factors. SCAG uses a flat incentive level of $7,500/vehicle in their calculator (and an additional $2,230 from outside sources that scales their impact down).

Changes to date to SANDAG EV Calculators by ITS-Irvine

ITS-Irvine's review of the SANDAG calculators included assessing what parameter changes were appropriate based upon any changes to the literature since the calculators were developed by Ascent Environmental (2019). Since both of these calculators are integrated into a single spreadsheet, we address the changes for both calculators together.

The core modeling inputs to the EV calculator include:

- EMFAC 2017 fleet characteristics
- EMFAC 2017 VMT
- Core EVI-Pro assumptions regarding charging characteristics
- EVI-Pro model results regarding PEV demand for the SANDAG region
- SANDAG population forecasts (to compute per capita GHG changes)
- SANDAG VMT RTP/SCS totals (to compute an adjustment factor for EMFAC VMT for the BAU baseline)

We reviewed these modeling inputs and assumptions and determined that we could not recommend any updates to the EMFAC data (there is not an alternative), nor the EVI-Pro assumptions or model results. In the latter case, since the EVI-Pro model has not been updated since Ascent Environmental's original work, there is no need to re-run the scenarios since the data, and associated trend-line projections will remain the same.

We did, however, update the SANDAG population forecasts and VMT totals using data provided by SANDAG staff (Ziying). These changes had a notable impact because the VMT forecasts have decreased since the updates to the regional model. Ascent's original work (shown in Figure 1) shows both higher population and VMT totals for the 2035 and 2050 target years than the most recent forecast (Figure 2). The specific cells modified were G13:H14.

Figure 1. SANDAG Population and VMT forecasts from Ascent Environmental's original work.

	A	B	C	G	H
9	**EV Off-Model Inputs**				
10	**Years**			**2035**	**2050**
11					
12	**2019 RTP/SCS Forecasts**				
13		Population in SANDAG		3,853,698	4,068,759
14		Daily VMT in SANDAG (2019 RTP/SCS)	mi/day	91,312,706	96,050,942
15		*Daily VMT in SANDAG (EMFAC 2017) (for comparison)*	*mi/day*	*100,763,492*	*107,809,171*
16		*EMFAC/SANDAG VMT Adjustment*		*0.91*	*0.89*
17					

Figure 2. SANDAG Population and VMT forecasts updated August, 2020 using data from SANDAG staff

	A	B	C	G	H
8					
9	**EV Off-Model Inputs**				
10	**Years**			**2035**	**2050**
11					
12	**2020 RTP/SCS Forecasts**				
13		Population in SANDAG		3,620,349	3,746,077
14		Daily VMT in SANDAG (2019 RTP/SCS)	mi/day	86,652,774	89,296,419
15		*Daily VMT in SANDAG (EMFAC 2017) (for comparison)*	*mi/day*	*100,763,492*	*107,809,171*
16		*EMFAC/SANDAG VMT Adjustment*		*0.86*	*0.83*
17					

These reductions lower the EMFAC/SANDAG VMT Adjustment factor, which in turn increases the reductions attributable to SANDAG's EV programs. **These updates improve the total per capita GHG reductions due to EV programs from 0.48% to 0.60% in the "90% CEC scenario."**

We note that the SANDAG SCS/RTP is based upon EMFAC 2014 while the EV calculator uses EMFAC 2017 data for fleet and VMT information, including the VMT baseline that is important here. However, this adjustment factor is intended to capture the impact of the deviations between the SCS/RTP forecast and EMFAC and those adjustments will compensate for the differences between EMFAC 2014 and 2017.

The scenario inputs to the EV calculator are:

- The selection of the target PEV/ZEV Population Scenario, which determines the demand for PEVs that, in turn, determines the demand and performance for chargers and vehicles (and their incentives)
- Charger and vehicle incentive levels

The specific scenarios available are described in Ascent Environmental's (2019) technical memorandum:

- **State Targets**: The State Targets under EO B-16-12 and EO B-48-18 to achieve 1.5 million EVs by 2025 and 5 million EVs by 2030 were apportioned to the SANDAG region based on the ratios between the EV population in SANDAG and the state as a whole, as modeled by EMFAC2017.

- **CEC Forecast**: The CEC's forecast scenario is based on what the CEC anticipates the PEV population will be like for the SANDAG region in order to meet State Targets for 2025, including the statewide target of having 250,000 EV chargers statewide by 2025. The CEC forecast scenario also accounts for a variety of economic and organizational factors that influence PEV usage. The model assumes that the CEC forecast trends would continue past 2025.

- **CSE Forecast**: The Center for Sustainable Energy (CSE) Forecast scenario is based on either a linear or second-order polynomial trend of the PEV population in SANDAG based on historical sales. The second-order polynomial forecast is currently the preferred CSE Forecast scenario per SANDAG staff, though the user has the option to change the trend assumption in the background calculations

Though all results discussed in this document have used the scenario "90% of CEC forecasts", SANDAG may want to experiment with identifying the most favorable of the scenarios based upon agency priorities, which certainly include maximizing GHG reductions, but may also include wanting to control the resulting cost of the incentive program. Between the three options, both the CEC and CSE forecasts are based upon modeling with trends. The CEC trends are extended from the EVI-Pro forecasts, which only go out to 2025. In the modeled time span (2017-2025), the CEC forecasts are likely the most rigorous method for determining the scenario. Beyond that, the use of trend forecasting makes them less reliable. The CSE forecast, which is based upon sales trends also suffers from this potential weakness. In some respects, the State Targets, should they be backed by state policy via regulatory action, may have the best case for use as the target scenario since they represent the statewide goals that are driving policy.

Determining the appropriate incentive levels for an EV program that is 10 years into the future is challenging at best since it would rely on knowing technology costs at that horizon and beyond. As noted in the discussion above, CARB has accepted EV programs with incentive levels ranging from $1,500/vehicle for PHEV incentives (MTC 2017) up to $7,500 for PHEV incentives (CARB 2020). As such, we recommend selecting the scenario that maximizes GHG reductions, while setting the incentive levels that are comparable to other MPOs while still meeting SANDAG's budgetary targets.

For instance, if you set a $250M cap on SANDAG vehicle incentives for 2035 and assume a specific ratio between BEV, PHEV, and FCEV incentives that matched assumed external incentive levels as in Table 1.

Table 1. Assumed external vehicle incentive levels in the baseline SANDAG EV calculator

Average Incentive per BEV	$/vehicle	$ 2,500

Average Incentive per PHEV	$/vehicle	$ 1,000
Average Incentive per FCEV	$/vehicle	$ 5,000

Then you can solve for the BEV incentive level under forecast different scenarios (e.g., 100% CEC, 100% state mandate, and CSE forecast) that would result in a total of $250M in cumulative vehicle incentives in 2035. The results in Table 2 show computed vehicle incentive levels along with the associated per capita GHG reductions for the RECP, VIP, and total.

Thus, if you adopt the CSE forecast scenario and set a $250M cap, you can obtain a total 1.78% per capita reduction with BEV incentives of $642, PHEV incentives of $257, and FCEV incentives of $1,285.

Table 2. Computed incentive levels and associated GHG reductions for 3 different demand scenarios in the SANDAG EV calculator assuming a $250M vehicle incentive cap by 2035.

Scenario:	100% state	100% CEC	CSE forecast
BEV incentive	$ 623	$ 3,287	$ 642
PHEV incentive	$ 249	$ 1,315	$ 257
FCEV incentive	$ 1,246	$ 6,574	$ 1,285
RECP GHG red	0.00%	0.09%	0.46%
VIP GHG red	1.21%	0.76%	1.32%
Total GHG red	1.21%	0.85%	1.78%

Comparison between SANDAG EV calculators and other MPOs

ITS-Irvine also assessed the off-model programs used by California's four major MPOs: SANDAG, SCAG, MTC, and SACOG to determine whether EV incentive or charging programs were included in their plans and whether technical information was available about the methods employed. Any direct comparisons of performance in this document are based upon the 2035 target year. The most readily available reporting and supplemental data associated with non-SANDAG EV off-model calculators came from the following:

- SCAG's recently approved SoCal Connect 2020 RTP/SCS (SCAG 2020a; SCAG 2020b), which includes both a regional electric vehicle incentive program and an electric vehicle charging program. Full documentation, results, and calculator spreadsheets available.

- MTC's BayArea 2040 RTP/SCS (MTC 2017), which includes both a regional electric vehicle incentive program and an electric vehicle charging program. Methodological documentation and results available, but not calculator spreadsheets.
- SACOG's 2020 RTP/SCS (SACOG 2020a), which lists both electric vehicle and charging programs as a strategy. Estimated results are available. The 2020 RFP/SCS refers to the 2012 and 2016 technical methodology for its EV program calculations, but limited information regarding the specific technical methodology could be found.

Table 3 shows the comparison of the off-model EV program GHG reductions for the four major California MPOs. It is evident that SANDAG's programs are under-performing relative to both SCAG and MTC and roughly on par with SACOG. In the following sections, we describe the methods each MPO used for their EV off-model calculations (where they are available) and compare them to SANDAG's results.

Table 3. Comparison of off-model EV program per-capita GHG reductions for major california MPOs

MPO	Vehicle Incentives	Charging Incentives	Total
SANDAG (draft)	0.52%	0.08%	0.60%
SCAG (2020)	0.60%	1.20%	1.80%
MTC (2017)	0.44%	1.42%	1.86%
SACOG (2020)			+/- 0.50%

EV Charging Programs

CARB Recommendations

The CARB Sustainable Communities Strategies Program and Evaluation Guidelines document (SCAG 2020a) offers two methodological approaches for computing the GHG reductions associated with Regional EV Charging Programs.

A. Estimate CO2 emission reductions from PHEV eVMT based on estimated average VMT shift per PHEV from gasoline to electricity (cVMT to eVMT) as a result of increased workplace and public charges

B. Estimate CO2 emission reductions from reduced gasoline consumption based on estimated electricity consumption increase as a result of increased workplace and public charges

SCAG (2020)

SCAG's program is summarized as providing the following financial incentives:

As part of this strategy, the following financial incentives would be provided:

- A one-time financial subsidy offered to employers for the purchase and installation of workplace EV charging infrastructure.
- When gasoline is cheaper than electricity on a per-mile basis, on-going incentives offered to employers to subsidize PHEV-driving employees to charge their cars with EV vehicle infrastructure to help dis-incentivize the operation of PHEVs in gasoline operating mode.

The calculation method employed by SCAG directly uses CARB's recommended method (A) based on estimating the average VMT shift per PHEV from gasoline to electricity. As shown in Table 4, the EV Charging Infrastructure program is SCAG's most impactful off-model strategy, accounting for a 1.2% reduction in GHG emissions vs the 2005 baseline.

Table 4. SCAG 2035 Off-Model GHG Reductions per capita (vs 2005 baseline) from Emerging Technologies Programs (SCAG 2020c)

GHG Reductions	2035
EV Charging Infrastructure	1.2%
EV Incentive Program	0.6%
Bike Share/Micro-mobility	0.3%
Carshare	0.4%
Transit/TNC Partnerships	0.04%
Total	2.54%

Inclusion of Utility-based EV programs in SCAG's charging calculator

There is no indication in any of SCAG's reports (that we could find) that specifically indicated that SCAG's off-model calculators incorporated utility-based programs. The information provided in this case is somewhat ambiguous.

- SCAG's charger incentive calculator computes a required number of chargers to incentivize based upon the EMFAC-estimated population of PHEVs in the SCAG region in the target year, and an assumed number of vehicles per charger. No discussion of funding is included in the calculator.

- In SCAG's SCS submittal tables (SCAG, 2020b), there is mention of a number of efforts that SCAG is taking to facilitate the installation of EV charging stations, but most of these are procedural and not financial. The one mention of funding sources notes, "SMM GHG-3: SCAG shall continue working with partners including universities, utilities, regulating agencies, the private sector and NGO's, and member agencies to support deployment of electric vehicle (EV) charging in the region. SCAG shall provide resources to member agencies and supply them with available information and data so that they can better take advantage of legislation and funding for EV charging"

The latter note implies that SCAG is assuming that they can take credit for facilitating charger installations with partners (including utilities) that are represented in the chargers required to support VMT reductions in the off-model calculator.

MTC (2017)

MTC's 2017 SCS assumes the following:

> "A network of regional charging infrastructure will further increase the percentage of miles that PHEVs travel in electric mode and the methodology assumes:
>
> - Each charger deployed through the Regional Charger Network serves multiple vehicles each day over the course of a four-hour charging shift
> - The chargers deployed are Level 2 chargers that deliver electricity with a rating of 5 kW; and
> - The average electric vehicle consumes 0.35 kWh/mi.
>
> A ratio of approximately **one charger for every five vehicles** over the program years is assumed, consistent with charger-to-vehicle ratios estimated by Electric Power Research Institute (EPRI) for workplace and public charging opportunities and research conducted by ICF regarding charging optimization.

These assumptions are used to compute the total amount of workplace charging capacity available due to the program. We don't have access to assess the

Inclusion of Utility-based EV programs in MTC's vehicle charging incentive calculator

MTC's supplemental report on their Bay Area 2040 plan notes that:

> "PG&E's expected investment to deploy 7,500 chargers in the Bay Area was also incorporated along with the assumption that MTC would fund additional chargers after PG&E's initial investment" (MTC 2017)

As such, it appears to have explicitly incorporated this deployment in their off-model reduction.

SACOG (2020)

SACOG's 2020 MTP/SCS only makes limited mention of the planned EV-related programs with specific note about Policy 6 in their plan, that will "Pursue new funding and planning opportunities to support electric vehicle infrastructure and programs for both private vehicles and public transit fleets" (SACOG 2020a). The plan performance document (SACOG 2020b) notes that "For the impact of local EV deployment programs, which are locally funded programs to increase the rate of EV market penetration within the SACOG region were qualitatively assessed, and translated into percentage change in GHG, over-and-above the much larger state programs." And specifically that for, "the last two factors, the technical assumptions and calculations have been reviewed by CARB as part of the 2012 and 2016 Sustainable Community Strategy submissions." Specific documentation of the calculations for the 2016 SCS were found in Technical Appendix T5 of the Takecharge II strategy document (SACOG, 2016). These indicate that the strategy is based upon target setting for EV penetration in the region. In 2016, the regional target for EVs in 2035 was set to 75,000 vehicles, which were proportionally distributed to counties by existing light duty vehicle proportions. The resulting fraction of VMT attributable to these vehicles were then computed as a proportion of the VMT attributable to the total population. No explicit consideration of varying BEV vehicle ranges is included. Savings are computed as the difference between VMT-generated (running) emissions with and without the target EV fleet.

SANDAG

SANDAG's Regional EV Charging Program (RECP) calculator uses a version of CARB's method B, focusing on estimating CO2 emission reductions from reduced gasoline consumption based on estimated electricity consumption increase as a result of increased workplace and public chargers. Specifically:

> "CO2 reductions from the RECP were based on the difference between the total eVMT supported by a targeted number of all non-residential chargers, including existing and new chargers, in the SANDAG region and the eVMT anticipated in the BAU forecast for the SANDAG region for a given milestone year. The targeted total number of chargers in the SANDAG region was calculated using local PEV-to-charger ratios estimated by CEC's EVI-Pro analysis. EVI-Pro estimates that these ratios would change over time and also vary by PEV type. The targeted total number of chargers would be equal to the sum of all existing chargers as of 2018 and any new chargers added starting from 2018. To estimate the number of chargers needed to be incentivized by SANDAG, the number of existing non-residential chargers" Ascent Environmental (2019).

The use of EVI-Pro to estimate the PEV-to-charger ratios is both unique amongst the California MPOs and consequential, as we'll discuss below. The calculated PEV/charger ratio is used to estimate to the total kWh of charging available to the vehicle population and the target population of PEVs (using both EMFAC 2017 estimates and increases due to the sibling vehicle incentive program), which is distributed between BEV and PHEV based on estimates of relative charging time, and then used to determine the shift from cVMT (gas) to eVMT (electric). This shift is counted as off-model VMT reduction and converted to GHG reduction.

More details and specific critiques of the calculator method are included in the SANDAG section of the vehicle incentive calculator comparison section.

Charging Program Discussion

SCAG's EV charger incentive program accounts for a significant reduction in GHG emissions (1.2% per capita) in SCAG's SCS. As such, we thought it would be useful to investigate the difference between SCAG and SANDAG's calculators. Notably, SCAG and SANDAG apply two different methods, with SCAG opting for CARB's method A that computes the average estimated shift from gasoline-based cVMT to electric eVMT and uses that to determine the reduction. SANDAG's method, like MTC's, adopts SCAG's method B, which estimates electricity consumption increase due to increased chargers to estimate the cVMT to eVMT shift.

SANDAG's method is the most methodologically complex of the three methods, but is based upon more rigorous modeling of public EV charging infrastructure needed to meet a given PEV target by using the CEC's Evi-Pro model to estimate region-specific infrastructure requirements. Since Evi-Pro only forecasts out to 2025, the infrastructure requirements are projected using a trend analysis. For the 2035 target year (and assuming the default 90% CEC scenario), 10 chargers per PEV is forecast to meet the PEV charging demand. This results in a per-capita reduction due to the RECP of 0.08%. SCAG's calculator assumes 7 chargers per PEV (though the calculator is actually insensitive to this parameter and it is just used to compute the total number of chargers that would be needed). The resulting per-capita reduction is 1.2%.

However, if we override the Evi-Pro calculation of required chargers per PEV in SANDAG's calculator and manually set this ratio to 7 to match SCAG's assumption, the per-capita reduction improves to 0.47% vs the 0.08% reduction obtained from the 10 PEV/charger ratio (in bold) as shown in Table 5. Thus, we can see that SANDAG's calculator is quite sensitive to the PEV/charger ratio. It's worth noting that this would increase the required number of chargers in SANDAG from 19,398 in the (10 veh/charger) Evi-Pro scenario to 28,914 in the SCAG-equivalent (7 veh/charger) calculation. This would obviously increase the cost of the program to SANDAG. We also applied the assumed ratio of 5 vehicle/charger from the 2017 MTC EV charger program and note that this results in the same improvement as the 7 PEV/charger ratio because the available capacity exceeds the demand. Sensitivity analysis shows that the SANDAG EV charger off-model calculator no longer produces improvements at around 7.84

veh/charger (that is, at levels below the 7.84 ratio, the GHG reduction per capita remains at 0.47%).

Table 5. Sensitivity of SANDAG EV RECP calculator to PEV/charger value

MPO	PEV/ charger	Est. Chargers	EMFAC 2017 regional PHEV	Program PHEV (incl VIP impacts)	Gas VMT reduction	GHG reduction per cap
SANDAG	5	40,479	104,064	131,792	1,520,268	0.47%
SANDAG	7	28,914	104,064	131,792	1,520,268	0.47%
SANDAG	**10**	**19,398**	**104,064**	**131,792**	**678,113**	**0.08%**

Since the SCAG methodology is relatively straightforward, we can also apply that methodology to SANDAG's RECP by simply altering the fraction of statewide eVMT that occur in the region. SCAG's fraction per EMFAC 2014. Table 6 summarizes the EMFAC 2014 VMT splits by MPO and is taken directly from SCAG's EV calculator (2020e), and shows that the fraction of statewide eVMT associated with SANDAG is 0.085 (8.5%)---substantially less than SCAG's 48%. However, applying this fraction in SCAG's calculator produces the results in Table 7, which also varies the PEV/charger ratio to show the variation in required chargers. As you can see, applying SCAG's method to SANDAG results in a per-capita GHG reduction of 0.28%---better than the results obtained using Evi-Pro trends for PEV/charge in the SANDAG calculator, but not as good as if SCAG's 10 PEV/charger parameter is used in the SANDAG calculator in lieu of the Evi-Pro trendline.

Table 6. Fraction of Statewide VMT associated with each MPO (SCAG 2020e and EMFAC 2014).

Area	Fract of State VMT
AMBAG	0.017
BCAG	0.004
COFCG	0.016
KCAG	0.004
KCOG	0.027
MCAG	0.008
MCTC	0.005
MTC	0.187
None	0.033
SACOG	0.063
SanDAG	0.085
SBCAG	0.012
SCAG	0.480
SCRTPA	0.006
SJ COG	0.022
SLOCOG	0.009
StanCOG	0.010
TCAG	0.009
TMPO	0.001

Table 7. Application of SCAG EV charger methodology to SANDAG

MPO	State PHEV 2035	Reg. frac	EMFAC region PHEV	PEV/ charger	Estimated Chargers	mi/ PHEV	Gas VMT reduction	per cap
SCAG	1,000,000	48%	480,000	7	68,571	13	6,240,000	1.20%
SANDAG	1,000,000	8.5%	85,000	7	12,143	13	1,105,000	0.28%
SCAG	1,000,000	48%	480,000	10	48,000	13	6,240,000	1.20%
SANDAG	1,000,000	8.5%	85,000	10	8,500	13	1,105,000	0.28%

EV Vehicle Incentive Programs

CARB Recommendations

CARB's recommendations for EV incentive program off-model calculations are summarized as follows:

> "The overall approach to quantifying GHG emission reductions from the Electric Vehicle Incentive strategy is to first establish the total funding allocated to the subsidy/rebate program established by the MPO, as well as the amount(s) offered for individual subsidies/rebates. Once these two values have been set, the total number of new ZEV's that may be purchased under the incentive program can then be estimated. Based on the number of vehicles purchased under the incentive program and average trip lengths for the region, total VMT associated with the incentive program can be calculated. GHG emission reductions associated with the incentive program can then be estimated using the calculated VMT and emission factors derived from the most recent version of EMFAC" (CARB 2019).

SCAG (2020)

SCAG's off-model EV incentive calculator follows CARB's recommendations exactly. The specific steps and assumptions are as follows:

1. Total and annual incentive funding for vehicle incentives are set to $2B for the 2030-2045 period, and this is converted to $125M/year for the 6 year 2030-2035 period
2. An EV incentive level is set at $7,500/vehicle (without any supporting justification)
3. The annual number of vehicles that can be incentivized with these funds is determined as 100,000 vehicles/year
4. Average vehicle VMT is obtained from EMFAC 2014 as 49.8 miles/vehicle
5. The average mileage is combined with the annual incentivized vehicles to compute total incentivized VMT.
6. The emissions for new PEVs are computed (0g/mi)
7. The fraction of the vehicle incentives attributable to the MPO (vs other incentive programs) is calculated (~77%)
8. The total GHG reductions attributable to the MPO's incentivization is computed by applying the MPO incentive fraction to the difference between the non-EV emissions and the PEV emissions that replace them to obtain total VMT reductions, which is about 3.2M VMT.

The 3.2M VMT reduction translates to a 0.6% reduction in per capita GHG emissions relative to the 2005 baseline.

What targets and incentive costs (for vehicles) were recommended.

SCAG submitted SCS documentation does not mention specific incentivization levels directly. However, the calculator provides some insights behind the reductions shown in Table 1. Specifically, the calculator assumes a total of $125M/year will be available in EV incentives from 2030 through 2045, and that the **incentive level will be $7,500/vehicle**. Using these values, it determines that **100,000 new EVs will be incentivized from 2030 through 2035** (6 years), and generally, that 16,667 vehicles will be incentivized per year from 2030 through 2045 at the $7,500/vehicle level. SCAG's assumed EV incentive of $7,500/vehicle accounts for an estimated 77.1% of incentivization, assuming an additional $2,230 in incentives per vehicle is available from other programs (though no documentation is provided for this assumption).

To add some context, a note in SCAG's SCS submittal tables added that:

> "SCAG will work with local partners to identify revenue streams to provide local EV purchase incentives. This effort is currently in the initial scoping stages to identify appropriate public and private partners as well as to initiate a needs assessment and opportunities analysis." (SCAG 2020b)

This implies that the level of incentivization is still under development.

The Trip and Emissions Data Needs document submitted in support of SCAG's SCS (SCAG 2020d) notes that "mileage-based user fees and local pricing strategies identified in [SCAG's] 2020 RTP/SCS, are anticipated to support SCAG's regional initiatives" (SCAG 2020d). Thus, funding for the incentive programs is contingent on the implementation of these fee and pricing strategies.

What targets and incentive costs (for vehicles) were recommended.

The calculator assumes $7,500/vehicle as an incentive level, as well as an additional $2,230/vehicle from external sources. No justification for these values could be found in the available reports.

Inclusion of Utility-based EV programs in SCAG's vehicle incentive calculator

As noted previously, there is no indication in any of SCAG's reports (that we could find) that indicated that SCAG's off-model calculators incorporated utility-based programs and the information available implies that SCAG does **not** consider utility-based programs in their vehicle incentive program:

- SCAG's vehicle incentive program calculator (SCAG 2020f) determines the fraction of vehicle incentivization attributable to SCAG by computing the ratio (SCAG incentives) / (SCAG incentives + other incentives). SCAG's incentives per vehicle are set to $7,500, with other incentives set to $2,230, resulting in a ratio of approximately 77.1%. We've not yet found a justification for the $2,230 number in the documentation. This is following CARB's recommended method A and with the requirement that "if other rebate or incentive programs are utilized for the Electric Vehicle Incentive strategy (e.g., CVRP), calculate the MPO's fraction of overall EV incentives provided" (CARB 2019; SCAG 2020f). As such, we conclude that SCAG does not include utility-based EV programs in their off-model reductions

- As noted above wrt/charging programs, SCAG anticipates using "mileage-based user fees and local pricing strategies identified in [SCAG's] 2020 RTP/SCS" to support SCAG's regional initiatives, which implies that utility-based programs are not included in the off-model adjustments.

MTC (2017)

MTC's Vehicle Buyback & PEV Incentive program is described in their supplemental report (MTC 2017), with the following assumptions:

- Implementation of this program will begin in 2020.
- 94,000 additional PEVs will be on the road by 2035. This is a modest annual increase of about 1.5% in new vehicle sales attributable to the buyback incentive program.
- For the initial analysis, the deployed vehicles are evenly split between PHEVs and BEVs.

The method is summarized as:

> "To calculate CO2 reductions due to the introduction of PEVs, the methodology:
>
> 1. Determined the difference between the daily CO2 emissions attributable to the PEV versus the emissions that would have otherwise occurred using an average conventional gasoline vehicle. For PHEVs this depends on the assumed proportion of time spent in charge depleting mode versus gas/diesel mode.
> 2. Multiplied the result by the number of new PEVs expected to be deployed due to the program" (MTC 2017).

What targets and incentive costs (for vehicles) were recommended.

MTC's supplemental report notes that:

> "The average incentive levels are $1,500 per PHEV and $2,500 per BEV. However, the actual incentive will vary based on the MPG of the vehicle being traded in as well as the technology of the vehicle being purchased" (MTC 2017

This suggests that the assumption is that incentive levels will be determined by specifics at the time, presumably to match the $1,500/$2,500 averages. No supplemental analysis was found to justify these averages.

Inclusion of Utility-based EV programs in SCAG's vehicle incentive calculator

There is no indication that utility-based EV programs are included in the off-model calculator results.

SACOG (2020)

As with the EV charger program, we were unable to find technical details on the off-model calculations related to SACOG's EV programs. AGain, SACOG's 2020 MTP/SCS only makes limited mention of the planned EV-related programs with specific note about Policy 6 in their plan, that will "Pursue new funding and planning opportunities to support electric vehicle infrastructure and programs for both private vehicles and public transit fleets" (SACOG 2020a). Specific documentation of the methods assumptions could not be found.

What targets and incentive costs (for vehicles) were recommended.

We could not identify any specific targets and incentive costs for SACOG's EV programs. The technical methodology described (SACOG 2016) appears to be strictly focused on EV targets that would be pursued via a range of unspecified funding options.

Inclusion of Utility-based EV programs in SACOG's vehicle incentive calculator

We could not identify explicit inclusion of utility-based programs in SACOG's EV calculator. However, because this calculator is based upon an assumed target that will be met through a range of programs spanning infrastructure and vehicle incentives and other support, which appear to include utility-based programs based upon the programmatic examples offered in their methodology. As such, we conclude that SACOG's calculator does include programs that would be utility sponsored.

SANDAG

SANDAG's EV incentive calculator deviates from the CARB recommendation in that it does not start with a total amount of incentive funding available. Rather, it uses a PEV population target scenario selected by the user. The default scenario assumes 90% of the CEC forecast obtained from EVI-Pro (discussed above in the SANDAG EV charging section). Once the target PEV population is selected, the EV incentive calculator, the "CO2 reductions associated with the VIP are essentially a comparison of the new eVMT that would occur from the additional BEVs and PHEVs incentivized under the program beyond the BAU forecast" (Ascent Environmental 2019). Essentially, instead of determining the number of incentivized vehicles by assuming a total amount of incentive funding and an incentive level per vehicle, this calculator takes the projected PEV demand from forecasts and uses this to determine the number of incentivized vehicles. From that point forward, the calculator follows the CARB methodology. Given either incentive funding available and/or incentives per vehicle, the reciprocal can be calculated directly.

In that this target population is based upon a best-available forecast of regional EV demand, this methodology has significant advantages to the CARB default if realistic projections are the goal. Possible methodological issues with this calculator are that:

- It is not clear that the EVI-Pro projections are sensitive to incentivization levels. Additional funding for EVs may increase demand and therefore the PEV forecast totals that drive the calculator.

- Because the EVI-Pro projections are limited to the year 2025, a trend-line projection is used to estimate demand for the following years. With the rapidly changing EV market in California, it is risky to rely on prior trends to forecast future demand.

With these potential concerns noted, we still feel that the SANDAG calculator's approach to using demand-based forecasts to determine PEV population totals are more reliable than the default CARB methodology. Further, Ascent Environmental's work includes comparisons to EMFAC forecasts that demonstrate consistency.

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Methodology and Implementation of Transportation Demand Management Ordinance (TDMO) Off-model Calculator

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1 Background

As part of its 2021 regional transportation plan, the San Diego Association of Governments (SANDAG) is developing Transportation Demand Management Ordinance (TDMO) program. Per SANDAG's definition:

> "Transportation Demand Management (TDM) refers to policies and programs designed to help reduce commute traffic congestion. This is typically accomplished through sharing information, encouragement and incentives to help people know about and use all the efficient and sustainable transportation options available to them. Typical TDM programs promote carpooling, vanpooling, public transportation, biking and walking to work, and other alternatives to driving alone. These alternatives, along with parking management, telework, and compressed work schedules, can significantly reduce congestion on our regions roadways. Moreover, TDM ordinances can serve as a tool that governments - cities, counties, regions and states—use to reduce commute trips. They can achieve this through targeting area employers or land use development on new and renovated projects." (SANDAG, 2020)

SANDAG's new Transportation Demand Management Ordinance (TDMO) plan builds upon the the SANDAG iCommute Employer Program that works with over 200 employers on a voluntary basis to implement commuter benefit programs. Since the adoption of the 2015 Regional Plan, the iCommute Employer Program has expanded to a team of seven account executives that work with employers of all sizes throughout the region. Employers survey their employees to track their mode share over time. Employers are rewarded and recognized through the iCommute Diamond Awards for measurably reducing single occupant vehicle trips by employees. On average, the employers that work with iCommute have reduced their drive alone mode share by 10 %. As part of the 2021 Regional Plan, SANDAG is exploring a regional TDMO that would require employers with over 250 employees to implement and monitor a Travel Demand Management (TDM) plan in order to achieve an established average vehicle ridership (AVR). An employer's TDM program could include the following (SANDAG, 2020):

- **Commuter services** Offering programs like secured bike lockers and free rides home in case of an emergency can make it easier for commuters to use transit and other alternatives to driving alone.
- **Financial Subsidies and Incentives** Financial incentives and pre-tax commuter benefits for commuters can lower the out-of-pocket cost for commuters who choose alternatives to driving alone.
- **Marketing, Education, and Outreach** Outreach events, educational campaigns, and marketing strategies help raise awareness of alternative commute options.
- **Parking Management** Employers can offer cash incentives, transit passes in lieu of a parking space, and preferred parking for high-occupancy vehicles can act as an incentive to choosing an alternative commute option. Charging for parking at the workplace can act as a disincentive to drive alone.
- **Telework and Flexible Work Schedules** Employers can develop workplace policies that promote telework, flexible schedules, and/or compressed work schedules in order to reduce peak commute trips.
- **On-Site Amenities** Secured bike lockers and showers can offer convenience for commuters who choose to bike to work.
- **Employer Provided Transit** Can help to serve the first mile/last mile connection to transit and/or provide direct pooling options for employees traveling from the same direction.

SANDAG proposes to develop and implement the TDMO in phases. In the near term, SANDAG will conduct outreach with employers and stakeholders that will help develop the policy and framework for the Regional TDMO Program. Regional stakeholders include the region's 19 local governments and advisory boards such as the San Diego County Air Pollution Control District. It is anticipated that the later phases would include a pilot period, during which larger employers would initially participate, and a later broader evaluation period with tentative timelines for these phases as follows:

- Near-Term (2020-2025): Outreach and Policy Development

- Mid-Term (2025-2035): “Pilot” approach (800+ employers in the region)
- Long-Term (2035-2050) : Program Evaluation

Since the impact of this type of program cannot be modeled in SANDAG’s regional travel demand forecasting model, Activity-Based Model v2+ (ABM2+)[1], due to the varied and qualitative nature of its impacts on commuter mode choice behavior, capturing the impacts of a TDMO program for SANDAG’s Sustainable Communities Strategy submission to the California Air Resources Board (CARB) requires the development of an off-model calculator, which we discuss below.

2 Proposed Methodology

The TDMO will be employer-based, meaning that the regulations will require that employers demonstrate that their employees (as a group) are meeting AVR negotiated between the business and SANDAG. SANDAG intends to expand existing iCommute Employer Program offerings to assist employers with implementing and monitoring their TDM programs. Further, it is assumed that the ordinance will only apply to specific employers, namely larger employers with at least some minimum number of employees, currently assumed to be 250 or more with the final threshold dependent on the outcome of the Outreach and Policy Development phase. These employers will be provided with options from a set of TDM strategies, as discussed above, to achieve the target.

The method described below computes how many aggregate reduced drive alone trips and associated vehicle-miles traveled (VMT) will be attributable to large employers (LEs) collectively taking action to meet their AVR individual targets. The approach computes the difference between the estimated drive alone and total commute trips between each pair of zones that are associated with LEs in the absence of any TDMO, and compares that to the drive alone totals that would exactly match the AVR target for LEs, which we call a TDMO cap in this discussion. If the estimated difference is greater than the cap, it is assumed that the TDMO program will induce a shift of those excess trips from drive alone to some other mode, thus removing them and their associated VMT from the forecast. To implement this, we assume that we are given the following:

M is the minimum number of employees an employer must have for the TDMO to apply.

α is the maximum drive alone share, which is the fraction of an employer’s commute trips that can use the drive alone mode if the TDMO

[1] ABM2+ (Resource Systems Group, Inc., 2020) is a state-of-the-art activity-based travel demand model belonging to the Coordinated Travel–Regional Activity Modeling Platform (CT-RAMP) family of models (Davidson et al., 2010).

applies to that employer. For instance, $\alpha = 0.65$ means that a maximum of 65 % of the employees can drive alone and still have the employer be compliant with the TDMO. This is a direct proxy for AVR.

B_j is the set of employers in zone j

x_{ijk} is the number of work trips between zones i and j by all modes for employer $k \in B_j$.

x_{ijk}^{DA} is the number of work trips between zones i and j for employer $k \in B_j$ using a drive-alone mode.

Let B_j^L be the subset of LEs in zone j (those with M employees or more). Note that $B_j^L \subseteq B_j$.

Now, if the TDMO was applied and effective, then no more than α of the trips associated with each LE in zone j could be drive alone trips. Specifically:

$$\sum_i x_{ijk}^{DA} \leq \alpha \sum_i x_{ijk} \quad , \forall k \in B_j^L, \forall j \tag{1}$$

Since the trip variables x represent behavior in the absence of TDMO, we can rearrange the inequality to define the difference between the TDMO requirement for drive alone trips and what the model predicts as:

$$\sum_i x_{ijk}^{DA} - \sum_i y_{ijk}^{DA} = \alpha \sum_i x_{ijk} \quad , \forall k \in B_j^L, \forall j \tag{2}$$

and rearranging:

$$\begin{aligned} y_{jk}^{DA} &= \sum_i y_{ijk}^{DA} = \sum_i x_{ijk}^{DA} - \alpha \sum_i x_{ijk} \quad , \forall k \in B_j^L, \forall j \\ &= \sum_i y_{ijk}^{DA} = \sum_i \left(x_{ijk}^{DA} - \alpha x_{ijk} \right) \quad , \forall k \in B_j^L, \forall j \end{aligned} \tag{3}$$

where y_{jk}^{DA} is the excess drive alone trips to zone j associated with employer k beyond the limit set by the TDMO.

If y_{jk}^{DA} is positive, that means that the TDMO would require employer k to use TDM programs available to it to reduce its employees' drive alone trips by at least that amount. If it is negative, then employer k's employee work trips to zone j already meet the α threshold and the TDMO would have no impact.

At this point it is worth noting that ABM2+ does not have the resolution to tell us the fraction of work trips between pairs of zones down to the employer level (let alone the drive alone work trips). Instead, ABM2+ will only be able to provide the total number of work and drive alone work trips between each zonal pairing i and j, or x_{ij} and x_{ij}^{DA} respectively. Summing equation 3 over all LEs $k \in B_j^L$ we get:

$$\begin{aligned} y_j^{DA,LE} &= \sum_{k\in B_j^L}\sum_i y_{ijk}^{DA} &&= \sum_{k\in B_j^L}\sum_i \left(x_{ijk}^{DA} - \alpha x_{ijk}\right) &&,\forall j \\ &= \sum_i y_{ij}^{DA,LE} &&= \sum_i \left(x_{ij}^{DA,LE} - \alpha x_{ij}^{LE}\right) &&,\forall j \end{aligned} \tag{4}$$

where

$y_j^{DA,LE}$ is the excess number of work trips associated with LEs traveling to zone j, which the TDMO will target if it is a positive value.

x_{ij}^{LE} is the number of work trips associated with LEs traveling from zone i to zone j.

$x_{ij}^{DA,LE}$ is the number of drive alone work trips associated with LEs traveling from zone i to zone j.

ABM2+ does not provide x_{ij}^{LE} or $x_{ij}^{DA,LE}$ directly. Instead, we must estimate the fraction of a zone j's total and drive alone trips that are associated with LEs. The most reasonable proxy we have for that is the total number of employees. Specifically, we have:

E_{jk} is the total number of employees in zone j working for employer k.

Now define the total number of employees in zone j as

$$E_j = \sum_{\forall k\in B_j} E_{jk}$$

and the total number of employees in zone j working for LEs as

$$E_j^L = \sum_{\forall k\in B_j^L} E_{jk}$$

If we assume that the total number of trips associated with LEs in a zone is proportional to the fraction of employment associated with LEs in that zone, we can estimate x_{ij}^{LE} or $x_{ij}^{DA,LE}$. Specifically, define the fraction of employment in zone j associated with LEs as

$$\beta_j = \frac{E_j^L}{E_j} \tag{5}$$

The total number of employees in a given zone for all forecast years can be obtained from SANDAG's I-LUDEM employment forecast. However, data on LEs is only available for the base year, and only for employers that reside within SANDAG-designated *employment centers* that are distributed throughout the region. As such, we conservatively assume that all LEs reside within employment centers and compute the ratio β_j on that basis. Then we can define

$$\begin{aligned} x_{ij}^{LE} &= \beta_j x_{ij} \\ x_{ij}^{LE,DA} &= \beta_j x_{ij}^{DA} \end{aligned} \tag{6}$$

Substituting into equation 4, we have

$$\begin{aligned} y_j^{DA,LE} &= \sum_i \left(\beta_j x_{ij}^{DA} - \alpha \beta_j x_{ij}\right) \quad ,\forall j \\ &= \beta_j \sum_i \left(x_{ij}^{DA} - \alpha x_{ij}\right) \quad ,\forall j \\ &= \frac{E_j^L}{E_j} \sum_i \left(x_{ij}^{DA} - \alpha x_{ij}\right) \quad ,\forall j \end{aligned} \tag{7}$$

Where $y_j^{DA,LE}$ represents the required TDMO reduction in trips for zone j defined in terms of total and large employer zonal employment (E_j and E_j^L) and total and drive alone trips to the zone (x_{ij} and x_{ij}^{DA}), both of which are available from ABM2+.

Note that here we are assuming that the behavior of the population working in that zone is consistent across all employers. For example, the collective employers in a given zone j could be meeting the TDMO threshold, but the drive alone trip reductions might be distributed unequally between them. As a simple example, a zone with two equal sized employers might have a 90 % drive alone fraction, but that could be because employer one has 80 % drive alone and employer two has 100 % drive alone. In this case, the TDMO would reduce the drive alone fraction associated with the zone from $\frac{80\%+100\%}{2} = 90\%$ to $\frac{80\%+90\%}{2} = 85\%$. However, since the ABM2+ model won't be able to provide the employer by employer breakdown, we make the more conservative assumption that the share is equal across all employers in the zone.

Note also that since the drive alone totals in the absence of a TDMO might be smaller than what might be required by a TDMO, it is possible that $y_j^{DA,LE}$ might be a negative number, meaning that there are a surplus of non-drive alone trips relative to the TDMO. Since a TDMO is unlikely to encourage a shift to *more* drive alone trips, this surplus should be disregarded. As such, let's define the required trip reduction for all LEs k in each zone j as

$$z_j = \max\left(y_j^{DA,LE}, 0\right), \forall j$$

and the total reduction in work trips across all zones due to the TDMO as:

$$z = \sum_j z_j \tag{8}$$

Finally, the impacts of some of the the TDMO options, such as regional vanpool program, are already modeled by other off-model calculators, so care is required to avoid double counting the reductions by TDMO and the regional vanpool operations. The most conservative approach is be to modify equation 8 to remove any trip reductions attributable to explicitly modeled programs that would count against the TDMO caps:

$$z = \sum_j \max\left(\left(z_j - \sum_{l \in OM} z'_{jl}\right), 0\right) \tag{9}$$

where

OM is the set of independent off-model calculators representing TDM strategies

z'_{jl} is the trip reduction estimated for zone j by the calculator for TDM strategy l versus the TDMO phasing year[2].

3 Calculating emissions reductions

The method described above computes the total number of trip reductions that will be attributable to the TDMO.

VMT reductions can be obtained by defining:

d_{ij} is the average distance in miles to travel between zones i and j

and weighting the trip reductions in equation 4:

$$v_j^{DA,LE} = \sum_i v_{ij}^{DA,LE} = \sum_i d_{ij} \left(x_{ij}^{DA,LE} - \alpha x_{ij}^{LE}\right) \quad , \forall j \tag{10}$$

where:

$v_j^{DA,LE}$ is the VMT reduction attributable to the TDMO for work trips to zone j.

Given total trip reductions $y_j^{DA,LE}$ and total VMT reductions $v_j^{DA,LE}$, emissions factors from EMission FACtors (EMFAC) can be applied to estimate emissions reductions due to cold starts (per trip) and running emissions (by VMT).

[2]Here we note that since the TDMO targets will be set on the basis of a given phasing year, the trip reductions due to other programs such as vanpool and pooled rides (and computed in those calculators) will be computed as the difference between the reductions attributable to that program for the phasing year and the reductions for that program in the target year, because the phasing year assessments will account for trips already participating in those programs.

4 Implementation

This off-model calculator is implemented as a spreadsheet model in *Microsoft Excel* that uses SANDAG's employment growth forecasts (SANDAG, 2015) and mode- and purpose-specific regional trip forecasts for each scenario year, which are obtained from ABM2+ v14.2.0 as shown in Table 1. As described above, these forecasts are used to determine the share of commute trips by Metropolitan Statistical Area (MSA) associated with LEs that would therefore be subject to TDMO regulation, which is then used to compute the regulated reduction in drive alone trips. Once these reductions are determined and converted into VMT reductions, the emissions factors from the EMFAC 2014 model is applied to compute the reduction in emissions associated with fewer cold start and running emissions.

The detailed steps of the TDMO off-model GHG spreadsheet are as follows:

1. Estimate the fraction of AM and PM trips associated with LEs (see equation 5).

   (a) Estimate eligible employees impacted by TDMO ordinance program based on employment center major statistical area (MSA) analyses

   (b) The fraction of employees impacted for each MSA is the number of employees working for firms with > 250 employees divided by the number of employees working for all firms.

   (c) The fraction of AM and PM trips impacted for each MSA pair is assumed to be the same as the fraction of employees associated with LEs at the employment end of the trip. The employment end of trips in a period (the fraction of trips going for which work is the origin and the fraction for which work is the destination) is determined from work trip-directionality analysis of the OD and period obtained from the ABM2+ forecast. The LE work trip fraction is computed as a weighted average of the LE fractions for each side of the MSA OD pair.

2. Forecast the number of drive alone (DA) AM/PM trips associated with LEs for each MSA Origin-Destination (OD) pair, computed as the period-specific fraction of LE OD trips times the forecast number of drive alone OD trips during that period (equation 6).

3. Compute target drive-alone trip share (α) for LE work trips in the AM and PM periods between each MSA origin and destination. This is determined by assuming a 15 % reduction in ABM2+ forecast drive alone shares in 2035 and a 25 % reduction in 2050 (equation 7).

4. Establish LE drive alone trips allowance for each MSA OD pair by applying drive alone reduction targets to drive alone trips associated with LEs. This is computed

Table 1: Principal Inputs to TDMO greenhouse gas (GHG) Emissions Calculations

Data	**Source(s)**	**Notes**
Regional trips	SANDAG ABM 2+	Regional trips for each scenario year by: • Strategy year • O/D MSAs • Time period (AM, PM) • Trip mode (drive alone, carpool, non-motorized, and transit) • Trip purpose (Work) • Household auto ownership (0, 1, 2+)
Travel time and distance	SANDAG ABM 2+	For each scenario year: • TAZ-to-TAZ drive alone distance, general purpose lanes • TAZ-to-TAZ drive alone travel time, general purpose lanes
Work directionality	SANDAG ABM 2+	For each scenario year: • TAZ-to-TAZ share of work trips traveling TO and FROM work for each OD pair and time period
Large Employer Fraction	Share of employment associated with LEs within in each TAZ	Computed from employment center data detailing the total employment and employment center employment associated with LEs.
Emission factors	EMFAC 2014	For each scenario year: • Trips (cold starts) regional emissions (ton) • Running CO_2 regional emissions (ton) • Regional VMT • Regional trips

as target drive alone LE work trip splits [step 3] times the forecast total work trips (from ABM2+) times the large employer fraction [step 1] (also see equation 7).

5. Estimate TDMO trip reductions by assuming that ABM2+ forecast trips exceeding the established drive alone allowance in the target year are reduced by the TDMO. TDMO-required reductions in AM/PM drive alone work trips for each MSA OD pair, which are computed as the difference between the forecast [step 3] and the allowance [step 4]. If this value is less than zero, the ABM2+ forecast reductions exceed the TDMO target, so the TDMO will not reduce additional trips and the reductions are set to zero for this period (see equation 9).
6. Estimate baseline VMT reduction as the TDMO trip reductions [step 5] times average MSA to MSA trip distance based on SANDAG ABM2+ (see equation 10).
7. Deduct other calculator drive alone work trip and VMT reductions (vanpool and pooled rides) between TDMO phasing year (assumed to be 2025 by default, and interpolated if necessary) and target year to avoid double counting. These deductions are computed on a TAZ-to-TAZ basis since the TDMO will operate at the employer level. As such, reductions from existing programs such as vanpool associated with employers in one MSA should not be deducted from TDMO impacts associated with employers in another MSA. In addition, if the performance of an existing program degrades between the phasing year and the future year (e.g., fewer commuters are vanpooling in 2035 versus the phasing year), it is assumed that the impacted employers will need make up that difference in the target year via other TDMO programs.

5 Representative Results

Though the results submitted with SANDAG's regional transportation plan and Sustainable Communities Strategy will depend on final forecast numbers from ABM2+ and related models, Figure 1 shows representative results of from the calculator to illustrate the results of the calculator using draft data. As can be seen, the TDMO calculator estimates a total of 44,559 fewer DA trips in 2035 due to the TDMO (after adjusting for the impacts of programs represented by other calculators). These removed DA trips reduce the total commute VMT by 362,611 and ultimately result in a per-capita VMT reduction of 0.44 %. The reductions attributable to TDMO improve to 0.67 % in the 2050 target year.

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Variable		2020	2035	2050
TDMO reduction target		0%	15%	25%
Regional population		3383955	3620349	3746077
Average pooled ride vehicle occupancy		3.0	3.0	3.0

TDMO trip reduction targets

Variable		2020	2035	2050
TDMO trip reductions				
Work trips (AM and PM Periods), all households		0	44,605	67,245

VMT and GHG Reduction Results

Variable		2020	2035	2050
Plan CO2 Emissions				
Daily CO2 emissions (short tons)		38,881	38,199	38,777
Daily emissions per capita (lbs.)		22.98	21.10	20.70
Net vehicle trips reduced by vanpool vs 2025 baseline				
Daily DA trips removed by TDMO				
Total vehicle trips reduced by TDMO requirements		0	44,605	67,245
Vehicle trip reductions from existing pooled rides		43	34	31
Net vehicle trips reduced by pooled rides vs 2025 baseline		-	(6)	(10)
Vehicle trip reductions from existing vanpool		691	770	816
Net vehicle trips reduced by vanpool vs 2025 baseline		-	53	98
Net vehicle trips reduced by TDMO requirements		0	44,559	67,156
Daily person miles traveled, for DA trips removed by TDMO				
Total vehicle miles reduced by TDMO requirements		0	364,902	561,486
VMT reductions from existing pooled rides		1,694	1,367	1,262
Net VMT reduced by pooled rides vs 2025 baseline		-	(218)	(324)
VMT reductions from existing vanpool		33,904	37,668	39,828
Net VMT reduced by vanpool vs 2025 baseline		-	2,509	4,669
Net VMT reduced by TDMO requirements		0	362,611	557,140
GHG reductions				
Total daily GHG reductions (short tons)		0.00	169.90	258.84
Daily per capita GHG reductions (lbs./person)		0.00	0.0939	0.1382
Daily per capita GHG reduction		0.00%	-0.44%	-0.67%

Figure 1: Representative TDMO calculator results.

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Attachment 2:

WSP TDM Off-Model Memo

MEMO

TO: SANDAG TDM and Modeling Staff

FROM: Rosella Picado, WSP

SUBJECT: Draft TDM Off-Model Methodology—March 2019 Revision

DATE: March 20, 2019

Introduction

SANDAG uses the Activity Based Model (ABM) to estimate performance measures and to evaluate the transportation network included in the Regional Plan (SANDAG's Regional Transportation Plan and Sustainable Communities Strategy (RTP/SCS). However, some strategies that contribute towards the reductions of greenhouse gas (GHG) emissions are not fully captured by the SANDAG ABM or the California Air Resources Board (ARB) Emissions Factor model.

The four largest MPOs in California (SANDAG, the Metropolitan Transportation Commission and Association of Bay Area Governments, the Sacramento Area Council of Governments, and the Southern California Association of Governments) have partnered to establish the Future Mobility Research Program. The purpose of the program is to jointly fund research on the potential impacts of transportation technologies, study key policy issues, and identify appropriate roles for the MPOs in relation to emerging transportation technologies. This cooperative effort ensures a consistent approach to evaluating the range of potential changes to travel behavior associated with emerging technologies and will provide recommendations on how to model travel behavior and incorporate technology into each MPO's RTP/SCS. The FMRP partnered in this effort to have a consistent approach in considering strategies whose GHG impacts are not captured through traditional modeling.

For SANDAG's Regional Plan, the off-model analysis included evaluating such strategies as carshare, electric vehicle charging stations, and carpool assumptions. The draft Transportation Demand Management (TDM) off-model strategies which are the focus of this memo, are as follows[1]:

- Vanpool
- Carshare
- Bikeshare
- Microtransit
- Pooled rides
- Community-based travel planning

[1] The Community-Based Travel Planning strategy was prepared by SANDAG staff. All other calculators referenced in this memo were developed in collaboration with WSP.

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Methodology

The inputs and assumptions listed within this methodology are draft and are subject to change, pending the selection of a preferred network scenario and the final regional growth forecast developed to inform the 2019 Regional Plan. Furthermore, the draft model data used in the draft calculators is subject to change, pending the selection of the preferred network scenario.

The draft off-model greenhouse gas emissions reduction strategies included in this off-model methodology memo are Transportation Demand Management (TDM) strategies which includes programs or services that encourage the use of transportation alternatives. Strategies proposed in this methodology includes programs facilitated and administered by SANDAG as well as services operated by third-parties. These programs and services include a vanpool subsidy program; transit solutions; regional support for shared mobility services, like bikeshare and carshare; incentives for pooled rides, and commuter outreach.

This memorandum documents the methodology for estimating vehicle miles traveled (VMT) and GHG emission reductions from vanpool, carshare, bikeshare, microtransit, pooled rides, and community-based travel planning. The methodology for estimating GHG emission reductions is a series of Excel spreadsheet calculators that estimate average VMT reductions for each program or shared mobility service type. The VMT reductions are based on historic data, applicable research, and case study findings, as documented in the "References" section within each strategy. Where possible and if available, local data was used to inform the assumptions used in the methodology. To minimize double counting, the methodology intentionally employs a conservative approach to estimate reasonable program impacts. While the off-model calculators utilize mode-based inputs from the ABM to estimate program impacts, calculator outputs remain off-model and do not interact or feed back into the ABM.

In general, the research is used to estimate the following methodology parameters:

a. Population that has access to the mobility service, or market. The market may be defined in terms of persons or households.

b. Level of supply/geographic extent. The level of supply may be defined as a function of cities or neighborhoods in which the program or service is available.

c. Regional infrastructure improvements. Regional investments in transportation infrastructure may help facilitate use of a mobility service and induce demand.

d. Baseline VMT. An estimate of the average VMT per person or per household, among persons/households that do not participate in the program or mobility service.

e. Project VMT. An estimate of the average VMT per person or per household expected among persons per households that participate in the program or mobility service. This could be estimated directly from average trip lengths, indirectly from mode shifts, changes in car occupancy, and/or reductions in average number of trips.

f. GHG emission factors. Based on total trip and Carbon Dioxide (CO_2) forecasts produced by the SANDAG ABM 14.0.1.

Summary

The six off-model greenhouse gas reduction strategies described in this memo will be considered during the transportation network development process of the 2019 Regional Plan. During the analysis, reductions in daily VMT and corresponding daily CO_2 emissions reductions will be reported using the draft companion calculators appended to this memo. Following this summary are the detailed methodologies of each of the six individual strategies.

VANPOOL PROGRAM

Program Description

Vanpooling is a flexible form of public transportation that provides groups of 5–15 people with a cost-effective and convenient rideshare option for commuting. SANDAG has been operating a regional vanpool program since 1995, and currently comprises of approximately 700 vans. The SANDAG Vanpool Program provides a subsidy of up to $400 per month for eligible vanpoolers to offset the cost of the lease of the vanpool vehicle and works with the vanpool vendors to conduct marketing and outreach through employers in the region to grow participation in the Program. All vanpools in the program are subsidized by SANDAG using Congestion Mitigation Air Quality (CMAQ) funds.

Per the Vanpool Program Guidelines, participating vanpools must have origins or destinations within San Diego County, operate at 80 percent occupancy, and travel a minimum of 20 one-way vehicle miles on San Diego County's highways. Vanpools may have an origin or destination outside of the San Diego County but must demonstrate that they meet the travel distance minimum on the region's highways. While the congestion and environmental benefits of vanpooling expand beyond San Diego County, the travel impacts and GHG emission reduction estimates accounted for in this methodology only account for vanpool travel that occurs within San Diego County. Based on historical program data, participants of the program are those that typically were driving alone to work and travel over 55 miles one-way to work[2].

The SANDAG TDM program, iCommute, has an Employer Services Program that works with major employers throughout the region to develop and implement commuter benefit programs. As part of their work plan, the Employer Services program conducts targeted outreach to host vanpool formation events at employer sites that are suitable candidates for vanpooling. Vanpools in the program represent commuters from diverse employer industries in the region including military, manufacturing, and technology or professional services. Currently one-half of all the vanpools comprise persons that work for the federal government. In addition to the subsidy provided by SANDAG, the federal government subsidizes their commute-related expenses through the federal Transportation Incentive Program (TIP), which is why a substantial number of vanpools in the San Diego region are federal employees. However, any employer contributions, TIP or other, are not tracked or administered by our program. All participants in the SANDAG Vanpool Program receive a monthly subsidy of up to $400 per vanpool and therefore all program impacts are entirely attributed to the SCS.

Assumptions

The following assumptions were incorporated into the off-model calculator for the Vanpool Program. The calculation of VMT reductions was based on the Regional Vanpool Program data specific to the vanpool fleet, as of June 30, 2018. This data included the total number of active vanpools, vehicle type, vanpooler industries, commute trip origin and destination, distance traveled within San Diego County, and vehicle occupancy. Future growth assumptions were based on two growth drivers:

a. Employment growth. Based on existing vanpool program trends, the proportion of vanpoolers relative to the total workers employed in San Diego County will remain approximately constant. Therefore, as the region adds jobs within industries that have historically had higher rates of vanpooling (i.e. military, biotech, federal employers, etc.), it is assumed that enrollment in the Vanpool Program will proportionally grow.

b. Travel time savings. Vanpools in the San Diego region can leverage the exclusive use of managed lanes (High Occupancy Vehicle (HOV), Interstate-15 (I-15) Express Lanes), to shorten their commute time during

[2] Based on FY 2018 Vanpool Program data, the average vanpooled travels a total roundtrip distance of 116 miles. Only vanpool travel that occurs in the San Diego region is accounted for in the off-model calculator. Miles traveled outside of the San Diego County are discounted from the final VMT estimates.

peak travel periods. Nearly half of the participants currently in the Vanpool Program travel in the I-15 Express Lanes. The reliability of the managed lanes makes vanpooling an attractive option. As the region's managed lane network expands, commuters who choose to vanpool, are likely to experience shorter travel times than commuters driving alone. This travel time savings will encourage a shift from driving alone to vanpooling.

Based on historical program participation data, three vanpool markets were defined based on the vanpoolers' employer industry: military vanpools, federal non-military vanpools, and non-federal vanpools. This segmentation was used to calculate employment growth factors that are specific to each of these industries. The travel time savings methodology also varies depending on industry type, since the destinations of the future military vanpools are defined. Other inputs, such as average distance traveled and average vehicle occupancy, also vary by type of industry.

The off-model employed for the Vanpool Program utilize mode-based inputs from the ABM to estimate program impacts, however the calculator outputs remain off-model and do not interact with the ABM. A summary of the principle assumptions underlying the CO_2 emission reduction calculation for vanpools is shown in Table 1.

Table 1. Principle Approach to Vanpool CO_2 Emissions Calculations

Quantity	Overall Approach	Inputs and Source

Market / Market Growth	• The primary market for vanpooling are commuters with home-to-work trips that are longer than 50 miles one way
	• Vanpool trip origins and destinations are expected to follow the existing trend
	• Vanpool program growth will occur proportionally with employment growth in the region
		• SANDAG Vanpool Program data, aggregated by origin/destination Metropolitan Statistical Area (MSA)
		  ○ Number of vans in program (FY 2018) by zip code of trip origin and trip destination, and type of employer (federal military, federal non-military, non-federal)
		• SANDAG growth forecast, aggregated by origin/destination MSA
		  ○ Population and employment by employer industry in each forecast year

Regional Infrastructure Improvements	• Proposed regional managed lane infrastructure investments (HOV lanes and Express Lanes) offer travel time savings to vanpools and are likely to increase demand for vanpooling
	• Change in demand calculated based on elasticity of demand with respect to travel time
		• SANDAG Vanpool Program data
		  ○ Estimated number of vanpool trips per month
		• SANDAG ABM data
		  ○ Average one-way weekday travel time (minutes), based on existing vanpool trip origins and destinations
		  ○ Average travel time savings by trip origin and destination in each forecast year future year, relative to 2016
		  ○ Marginal disutility of time, in-vehicle time coefficient

Baseline VMT	• Assume that vanpool participants would commute by car in single-occupant vehicles (SOVs), if vanpool is unavailable • Estimate average trip length based on existing program participation	• SANDAG Vanpool Program data ○ Average trip length
Program VMT	• Estimate Program VMT, based on estimated number of vanpools in forecast year and average vanpool occupancy	• SANDAG Vanpool Program data ○ Average vanpool occupancy

Quantity	Overall Approach	Inputs and Source
GHG Emission Factors		• SANDAG ABM 14.0.1

GHG Emission Calculator Methodology

CO_2 reductions were calculated following the procedure described below; the principle parameters and data items underlying this method are listed in Table 2.

Vanpool demand due to regional employment growth:

1. To establish the current vanpool demand due to regional employment growth, data was obtained directly from SANDAG's Vanpool Program, reflecting active vanpools as of June 30, 2018. This demand was assumed to be representative of the vanpool fleet during the 2016 baseline year. Over the past five years, the number of active vanpools has fluctuated between 680 and 720 vehicles. The vanpool demand was then tabulated in a trip origin-destination matrix, where the trip origin represented the home location and the trip destination was the work location. Home and work locations were then identified at the level of Metropolitan Statistical Areas (MSA) if they fell within San Diego County, and County, if they fell outside San Diego County.

2. The total number of vanpools were multiplied within the destination MSA by the employment growth rate at the MSA, which was calculated as future year employment divided by 2016 employment. The new vanpools due to employment growth were then distributed to origin MSAs in the proportions observed in 2016.

Vanpool demand due to managed lane infrastructure investments:

3. Compute demand elasticity with respect to travel time. In lieu of observed demand elasticities, elasticity of demand was estimated using a logit mode choice model formulation (see below for details about this formulation).

4. Calculate average MSA to MSA travel time savings, defined as the difference between the travel time experienced when using all available highways, and the travel time experienced using general purpose lanes only (excluding HOV and Express Lanes). For trip origins outside of San Diego County, the travel time savings are computed only over the portion of the trip that occurs within San Diego County. Since the specific location of military bases is known, the travel time savings associated with military vanpools is computed specifically to the zones that comprise the military bases, rather than an average over all of the MSA destinations.

5. Compute the demand induced by travel time savings by applying the demand elasticity formula to the estimate number of vanpools for each scenario year, after accounting for employment growth.

Vanpool VMT and GHG reductions:

6. Calculate VMT reduction, which for each van is equal to the average roundtrip distance within San Diego County, multiplied by the number of passengers (excluding the driver).

7. Calculate the CO_2 reduction corresponding to the VMT reduction and reduction in trip starts using the Emission Factors (EMFAC) 2014 CO_2 emission rates.

Elasticity of Demand Methodology

Elasticity of demand with respect to travel time:

The elasticity of demand for vanpooling with respect to travel time was approximated using the formula for point elasticity derived from a logit model (Train, 1993):

*Elasticity = (coefficient of in-vehicle time) * average travel time * (1 – probability of vanpooling)*

The coefficient of in-vehicle time was obtained from the SANDAG ABM and reflects the value of the mode choice in-vehicle time coefficient for trips on work tours (-0.032 utils/minute).

The *probability of vanpooling* in the region represents the share of daily work trips that are suitable candidates for vanpooling. Based on historical program data and trends, the vanpool program is a suitable and convenient option for commuters that travel a one-way distance of 50 miles or more. Results from SANDAG's 2018 Commute Behavior Survey reveal commuters that exhibit these longer trip characteristics are representative of 2.7 percent of the San Diego employed population (SANDAG, 2018). Given a total employed population in 2016 of approximately 1.6 million workers (Census Bureau, 2016), this resulted in a total of 86,400 work trips that are suitable vanpool candidates. Based on program data, it is assumed that approximately 7,995 vanpool trips occur on an average weekday (699 vans x observed vanpool occupancy of 73% x two trips per day per vanpool participant). The *probability of vanpooling* is then reflected as a share of the actual vanpool trips divided by total work trips that are candidates for vanpooling, or 9.3% (7,995 vanpool trips / 86,400 work trips).

Table 2. Methodology Parameters, Vanpool CO2 Emissions Calculator

Parameter	Source	Details
Current vanpool inventory	Active vanpools as of June 30, 2018, SANDAG Vanpool Program	Inventory of vanpools in operation during base year (2018). Required data for each vanpool includes trip origin, trip destination, employment industry (federal military, federal non-military, non-federal), van capacity, roundtrip mileage. Trip origin and destination aggregated to MSAs if inside San Diego County, and to County if outside San Diego County
Coefficient of in-vehicle travel time	SANDAG ABM 14.0.1 Trip mode choice model, Work tours	SANDAG ABM value (-0.032 utils/minute) used to calculate elasticity of demand with respect to travel time and with respect to trip cost. Input to the demand elasticity formula
Total 2016 San Diego County workers	American Community Survey (2016, 1-Year Release)	Used to calculate vanpool mode market share, an input to the demand elasticity formula (estimated value of 1.6 million workers)
Probability of vanpooling	American Community Survey (2011-2016 5-Year Release); SANDAG Vanpool Program SANDAG 2018 Commute Behavior Survey	Used as an input to calculate elasticity of demand with respect to travel time. Estimated as the proportion total daily work trips that are suitable for vanpooling. Based on vanpool program market trends, it is assumed that daily work trips that are longer than 50 miles (one-way) are suitable for vanpooling .
Average work trips per month		Assumed at 44 work trips per month (22 work days, 2 trips per day). Used to calculate average lease cost per trip (input to demand elasticity calculation)
Average one-way vanpool mileage	SANDAG Vanpool Program Data. Active vanpools as of June 30, 2018. Salesforce report.	Based on SANDAG Vanpool Program data, *excluding distance traveled outside of San Diego County*
Average van capacity (seats)	SANDAG Vanpool Program Data. Active vanpools as of June 30, 2018. Salesforce report.	Based on SANDAG Vanpool Program data
Average van occupancy	SANDAG Vanpool Survey for National Transit Database Reporting, FY 2017/2018	Based on SANDAG Vanpool Program data
Postal zip code centroid coordinates	ESRI USPS zip code area boundary shapefile: https://www.arcgis.com/home/item.html?id=8d2012a2016e484dafaac0451f9aea24	Used to approximate the distance traveled by vanpools outside San Diego County

Parameter	Source	Details
County gateway centroids	US Census Bureau TIGER line file https://www.census.gov/geo/maps-data/data/tiger-line.html	Used to approximate the distance traveled by vanpools outside San Diego County. Gateways are assumed as follows, based on home county: • Los Angeles and Orange counties: Interstate 5 • Riverside and San Bernardino counties: Interstate 15 • Imperial county: Interstate 8

Calculator Inputs

Table 3 summarizes the calculator inputs for each future year scenario.

Table 3. Scenario Inputs, Vanpool CO2 Emissions Calculator

Data Item	Source	Required Input Data
Employment forecast	Draft Series 14: 2050 Regional Growth Forecast/San Diego Forward: The Regional Plan in ABM 14.0.1	For each scenario year and MSA: • Jobs by industry category
Regional Population Forecast	Draft Series 14: 2050 Regional Growth Forecast/San Diego Forward: The Regional Plan in ABM 14.0.1	For each scenario year: • Total employment
Travel times, non-military base destinations	SANDAG ABM 14.0.1	For each scenario year[3]: • TAZ-to-TAZ travel time, general purpose lane (AM_SOVGPM_TIME) • TAZ-to-TAZ travel time, managed lane (AM_HOV2TOLLM_TIME)
Travel times, military base destinations	SANDAG ABM 14.0.1	For each scenario year[4]: • TAZ-to-TAZ travel time, general purpose lanes (AM_SOVGPM_TIME) • TAZ-to-TAZ travel time, managed lanes (AM_HOV2TOLLM_TIME)
Emission factors	EMFAC 2014, SANDAG ABM 14.0.1	For each scenario year: • Trips (cold starts) regional emissions (ton) • Running CO2 regional emissions (ton) • Regional VMT • Regional trips

[3] Vanpool travel times were averaged to the MSA at both the trip origin and destination using an R Script, see traveltimesavings.R

[4] Since military base locations are known, the travel times of military vanpools were averaged to the MSA at the trip origin and base location TAZ(s) using an R Script, see traveltimesavings.R

Results

Table 4 summarizes the vehicle trip results, VMT and CO2 reductions attributed to the Regional Vanpool Program for each future year scenario.

Table 4: Regional Vanpool Program VMT and GHG Emission Reductions

Variable	2025	2035	2050
Total daily vehicle trip reductions	Final results pending selection of the preferred network scenario		
Total daily VMT reductions			
GHG reduction due to cold starts (short tons)			
GHG reduction due to VMT (short tons)			
Total daily GHG reduction (short tons)			
Total population			
Daily per capita GHG reduction (lbs/person)			
Daily per capita GHG reduction, change in percent			

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CARSHARE

Program Description

Carshare is a shared mobility service highlighted in San Diego Forward: The 2019-2050 Regional Plan and an important component of the Regional Mobility Hub Strategy. Mobility hubs are places of connectivity where different modes of travel – walking, biking, transit, and shared mobility – converge and where there is a concentration of employment, housing, shopping, and/or recreation.

Carshare can provide connections to transit or fill gaps in a region's transit services, by providing an efficient transportation alternative that reduces reliance on the private automobile. By providing members with access to a vehicle for short-term use, a carshare service provides some of the benefits of a personal vehicle without the costs associated with owning one. As of January 2019, the San Diego region currently has two carshare service providers, Zipcar and Getaround. Zipcar provides roundtrip carshare service and Getaround operates a peer-peer carsharing service. Shared vehicles are distributed across a network of locations (or specified service area) within communities. Members can access the vehicles at any time with a reservation and are charged by time or by mile. In support of regional mobility hub planning efforts[5], the SANDAG TDM program seeks to promote and encourage the provision of carshare within the region's employment centers, colleges, and military bases.

Assumptions

The carsharing methodology described in this memo only accounts for VMT and GHG emission benefits associated with roundtrip carshare service. The peer-peer carshare service provider, Getaround, has only been operating in San Diego since November 2018 and observed impacts in the region are unknown. Car2go, a free-float carshare service provider in San Diego, ceased operations in the region in 2016 leaving Zipcar as the only carshare service provider in the region at the time. While the off-model calculator is able to account for the VMT reduction impacts of free-floating carshare service, it is assumed that this type of service will not return to the San Diego region due to the rise and popularity of on-demand ride-hailing service providers like Uber, Lyft, and Waze Carpool.

Research indicates that households that participate in carsharing tend to own fewer motor vehicles than non-member households (Martin et al, 2016). With fewer cars, carshare households shift some trips to transit and non-motorized modes, which helps to contribute to overall trip-making reductions. Estimates of the VMT reductions attributed to carshare participation have been reported to be seven fewer miles per day (Cervero, 2007) and up to 1,200 miles per year (Martin and Shaheen, 2010) for roundtrip carshare. A survey of car2go users in five North American cities, including San Diego[6], found that carshare households reported decreases in VMT ranging from 6 to 16 percent, with San Diego users reporting an average 10 percent VMT reduction, or approximately 1.4 miles per day (Martin and Shaheen, 2016). Similar behavior has been reported for participants in London's free-floating carshare service, with carshare members exhibiting a net decrease in VMT of approximately 1.5 miles per day (LeVine et al, 2014).

Based on market trends in the San Diego region, it is expected that carshare will remain a viable transportation option in neighborhoods that exhibit similar supporting land uses as those where carsharing is provided today. In support of regional mobility hub planning efforts, the SANDAG TDM program seeks to promote and encourage the provision of carshare within the region's employment centers, colleges, and military bases (Figure 1). Given the rapid trend towards automation, it is assumed that carsharing will be replaced by a fleet of shared and autonomous vehicles by the year 2050, therefore carshare coverage areas are only defined up until 2035. Within these defined carshare service areas, it is assumed that participation in the carshare program may vary depending on the supporting density characteristics (Transportation Sustainability Center, 2018). The population density thresholds that support carshare

[5] To learn more about SANDAG mobility hub efforts, visit www.sdforward.com/mobilityhubs

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participation in the region are based on the Car2Go service area prior to their exit from the San Diego market. Based on the 2016-2017 San Diego Regional Transportation Study (SANDAG, 2017) and available research on carshare participation rates, it is assumed that areas with a population greater than 17 people/acre will have a 2 percent participation rate. Areas with a population density lower than 17 people/acre will have a 0.5 percent participation rate. These density thresholds are specific to carshare trends exhibited in the San Diego region.

Carshare fleets are typically comprised of vehicles that are more fuel-efficient than the personally-owned vehicles. Some carshare providers offer a fleet at least partially comprised of zero-emission vehicles (ZEVs). The vehicle efficiency gains have been reported at 29 percent for roundtrip carshare (Martin and Shaheen, 2010) and 45 percent for one-way carshare (Martin and Shaheen, 2016). To avoid overestimation and to ensure that GHG emission reductions associated with fleet efficiencies are only captured in the SANDAG Electric Vehicle Programs off-model calculator, the carshare methodology does not account for fuel-efficiency of carshare vehicle fleets.

A summary of the principle assumptions underlying the CO2 emission reduction calculation for carshare is shown in Table 5.

Table 5: Principle Approach to Carshare CO2 Emissions Calculations

Quantity	**Overall Approach**	**Inputs and Source**

Market / Market Growth	• Estimate future carshare users based on population living in areas dense enough to support carsharing
	• Estimate carshare demand within three types of markets:
	  ○ Employment centers
	  ○ Colleges and universities
	  ○ Military bases
		• Define carshare coverage areas that are projected to offer carshare services
		  ○ Employment centers
		  ○ Colleges and universities
		  ○ Military bases
		• SANDAG ABM data
		  ○ Driving-age population in each future year by MSA
		• Share of the population that participates in carshare (2 percent in higher density areas and 0.5 percent in lower density areas based on data from the 2016-2017 San Diego Regional Transportation Study (SANDAG, 2017) and Puget Sound Region (Petersen et al, 2016)
		• A density threshold of 17 persons per acre is used to differentiate between participation in higher density and lower density areas based on the car2go service area prior to their exit from the San Diego market

Project VMT	• Estimate carshare VMT reduction based on roundtrip and one-way carshare case studies ○ It is assumed that free-float carshare service like Car2go will not return to the San Diego region due to the rise and popularity of on-demand ride-hailing service providers like Uber, Lyft, and Waze Carpool.	• 7 miles per day, traditional carshare (Cervero et al, 2007) • 1.1 miles per day, one-way (Martin and Shaheen, 2016)[7]
GHG Emission Factors	Note: No efficiency gains assumed relative to the region's carshare vehicle fleet. Emission reductions associated with vehicle fleet types are	SANDAG ABM 14.0.1

[7] Since there is currently no one-way carshare service provider in the region, the off-model calculator does not account for a VMT or GHG reduction from a one-way or free-floating service.

	captured in the Electric Vehicle Programs off-model calculator	

GHG Emission Calculator Methodology

The CO2 reduction attributed to the three carshare markets—general population, colleges, and military bases—is calculated following the procedures described below; the principle parameters and data items underlying these methods are listed in Table 6.

Carshare participation:

1. Identify the carshare service coverage areas. In support of regional mobility hub planning efforts, the SANDAG TDM program seeks to promote and encourage the provision of carshare within neighborhoods that exhibit similar supporting land uses as those where carsharing is provided today such as the region's employment centers, colleges, and military bases (Figure 1):

    a. General Population: These areas are defined as agglomerations of MGRAs and aggregated by MSA. The coverage areas could vary by scenario year, reflecting increasing land use density and a maturing carshare industry.

    b. College Staff and Students: Identify colleges and university areas where carshare services will operate in each scenario year. These areas are defined as agglomerations of MGRAs and aggregated by MSA.

    c. Military: Identify military bases where carshare services will operate in each scenario year. The military bases are defined as agglomerations of MGRAs and aggregated by MSA.

2. Calculate eligible population for carsharing:

    a. General Population: Estimate the eligible population for carsharing, which reside within the defined carshare coverage area boundaries and are persons older than 18 years old and younger than 65 years old.

    b. College Staff and Students: The eligible student population that are potential carshare participants corresponds to the total students enrolled (full-time and part-time) in each college/university campus and total staff employed at each campus.

    c. Military: Estimated carshare participants within the region's military bases corresponds to the employment at each base.

3. Calculate the carshare participation, defined as 2 percent of the eligible population in higher density areas and 0.5 percent of the eligible population in lower density areas. The population density thresholds that support carshare participation in the region are based on the Car2Go service area prior to their exit from the San Diego market.. Colleges and military bases, participation rates are assumed equal to higher density area carshare participation rates or 2 percent of the eligible population.

Carshare VMT and GHG reductions:

4. Calculate the VMT reduction from roundtrip carshare, assuming a daily average reduction of seven miles per day per roundtrip carshare member (Cervero et al, 2007).

5. Calculate the CO2 reduction corresponding to the VMT reduction, using the EMFAC 2014 CO2 emission rates.

Figure 1: Draft 2035 Carshare Coverage Areas

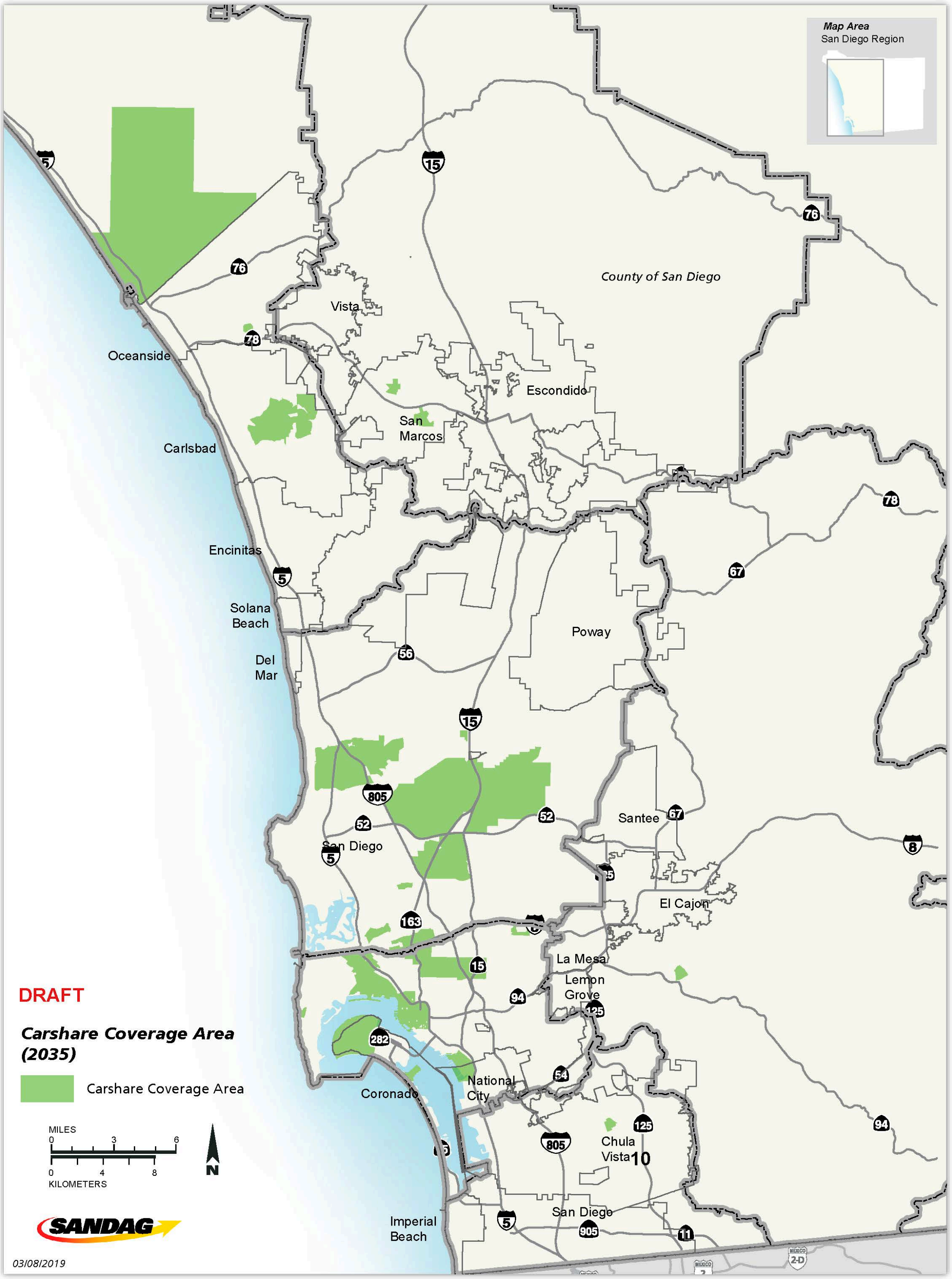

Table 6: Methodology Parameters, Carshare CO2 Emissions Calculator

Parameter	Source	Details
Carshare participation rate, higher density areas	2016-2017 San Diego Regional Transportation Study (SANDAG, 2017)	The 2016-2017 San Diego Regional Transportation Study reports that approximately 2 percent of the San Diego population are carshare participants. In the San Diego region, coverage areas with a population density greater than 17 persons per acre are assumed to reflect these participation rates.
Carshare participation rate, lower density areas	Petersen et al, 2016	Data for the Puget Sound region indicates that carshare participation in the Seattle-Bellevue-Redmond area is 2 percent in urban neighborhoods and 0.5 percent in suburban neighborhoods. In the San Diego region, coverage areas with a population density less than 17 persons per acre are assumed to reflect the participation rates of lower density neighborhoods in the Puget Sound region.
Carshare participation rates, college employees and students		Local data on the carshare participation at colleges is unavailable. Participation rates are assumed equal to higher density area carshare participation rates.
Carshare participation rates, military bases		Local data on the carshare participation at military bases is unavailable. Participation rates are assumed equal to higher density area carshare participation rates.
Daily VMT reduction, roundtrip carshare	Cervero et al, 2007	Estimated based on data for San Francisco's City CarShare service (7.0 miles per day)

Calculator Inputs

Table 7 summarizes the calculator inputs for each future year scenario.

Table 7: Scenario Inputs, Carshare CO2 Emissions Calculator

Data Item	Source	Required Input Data
Population and employment	Draft Series 14: 2050 Regional Growth Forecast/San Diego Forward: The Regional Plan in ABM 14.0.1	For each scenario year and MGRA: • Total population • Adult population (population 18-65 years old) • Total employment • Population density (total population / MGRA area in acres) • College student enrollment
Emission factors	EMFAC 2014, SANDAG ABM 14.0.1	For each scenario year: • Trips (cold starts) regional emissions (ton) • Running CO2 regional emissions (ton) • Regional VMT • Regional trips
Carshare coverage, General population	Draft San Diego Forward: The 2019-2050 Regional Plan	For each scenario year: o Carshare flag (1 if carshare operates in MGRA, 0 otherwise)
Carshare coverage, Colleges and universities	Draft San Diego Forward: The 2019-2050 Regional Plan	For each scenario year: o College/university flag (1 if carshare operates in college/university)
Carshare coverage, Military bases	Draft San Diego Forward: The 2019-2050 Regional Plan	For each scenario year: o Military base flag (1 if carshare operates on military base, 0 otherwise)

Results

Table 8 summarizes the vehicle trip, VMT and CO2 reductions attributed to carshare for each future year scenario.

Table 8: Carshare VMT and GHG Emission Reductions

Variable	2025	2035	2050
Total daily vehicle trip reductions	Final results pending selection of the preferred network scenario		
Total daily VMT reductions			
GHG reduction due to cold starts (short tons)			
GHG reduction due to VMT (short tons)			
Total daily GHG reduction (short tons)			
Total population			
Daily per capita GHG reduction (lbs/person)			
Daily per capita GHG reduction, change in percent			

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BIKESHARE

Program Description

Shared bicycle (bike) systems, also known as bikeshare, provide members of the public access to a fleet of bicycles for short trips in exchange for a fee. Bikeshare initially started out as station-based systems, in which the bicycles were borrowed from, and returned to designated docking stations. More recently, bikeshare providers have deployed bicycles and scooters equipped with payment technology and locks to allow users to pick them up, ride them, and drop them off anywhere within the service area. These systems are known as dockless bikeshare and scootershare systems.

The first bikeshare system in San Diego County, Discover®Bike, started operating in 2014, with plans to operate 1,800 bicycles and have 180 stations (City of San Diego, 2013). In 2017, Lime (formerly known as LimeBike), Mobike and ofo entered the San Diego market, offering traditional and pedal-assist dockless bikeshare and scootershare, expanding the bikeshare supply from a few hundred units to 3,000 to 5,000 units in less than one year of operations[8]. Additionally, several electric scootershare services (Razor, Bird, and others), established dockless operations within the City of San Diego in 2018. As of January 2019, Mobike and ofo ceased their dockless operations within San Diego. In March 2019, the City of San Diego announced that it had terminated its contract with station-based bikeshare provider, Discover®Bike, leaving only two dockless bikeshare providers, Lime and JUMP (Bowen, 2019). Lime offers traditional dockless bikes, electric scooters, and pedal-assist (electric) bikes; JUMP operates an all-electric bikeshare fleet.

SANDAG launched a Regional Micromobility Coordination effort among municipalities, transit agencies, universities, and military to establish best practices for effective micromobility operations. Micromobility refers to services like dockless bikeshare, e-scooters, and neighborhood electric vehicles (NEVs). At the March 7, 2019 Regional Micromobility Coordination meeting, local jurisdictions that partner with Lime announced that Lime is retiring traditional pedal bikes from its fleet and will be transitioning to an all-electric service.

Assumptions

The following assumptions informed the development of the bikeshare off-model calculator. It is assumed that bikeshare reduces GHG emissions by enabling users to take short-distance trips by bicycle instead of by automobile. In some cases, bikeshare can eliminate longer trips by enabling users to connect to transit. The shared service could also displace some walk trips, particularly when electric-assist options are available. The average trip distance of station-based bikeshare deployed for transit integration varies in the 1.3 to 2.4-mile range (Hernandez, 2018). In the 2017 Year End Report, ofo indicated that 80 – 90% of trips are less than 3 miles, which aligns with trip distances reported by bikeshare systems operating in other U.S. metropolitan areas in the 2.0 to 4.5-mile range. In San Diego County, anonymized and aggregated data from bikeshare operations indicated an average distance of 1.2 miles per pedal bike in 2018. Although other bikeshare operators within the U.S. reflect longer bikeshare trip distances, the data provided by local bikeshare operators was used to inform VMT & GHG reduction estimates to ensure bikeshare trip making assumptions conservatively reflect the San Diego market. An average car substitution rate of 20% for non-pedal assist bicycles is based on data from eight bikeshare systems operators in the U.S. (Table 10).

It is also assumed that the increasing availability of pedal-assist e-bikes and scooters will extend the range of bikeshare trip distances, facilitating travel by bike and scooters, opposed to driving alone in an automobile. Research conducted in North America and Europe that has tracked the utilization of pedal-assist bicycles owned or leased by their users, indicates that the average trip distance of e-bike trips is twice the distance traveled with regular bicycles (Cairns et al, 2017). In San Diego County, anonymized and aggregated data from bikeshare operators indicate an average distance

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[8] Based on fleet estimates provided by Transit App in April 2018. Estimates were based on the number bikes that were available and not reserved at 5:00 AM P.T.

of 1.7 miles for e-bikes and e-scooters combined in 2018. Similarly, recent case study research on the JUMP bikeshare system in San Francisco, which also operates in the San Diego region, estimates that the average e-bike trip distance is 1.9 miles per trip. E-bike owners report car substitution rates of 37 percent for non-commute trips and 64 percent for commute trips (MacArthur et al, 2018), which are more than twice the average car substitution rates reported by various station-based traditional bikeshare systems. In its 2018 End of Year Report, Lime reports an average substitution rate of 37 – 40% based on operations in Los Angeles, Austin, Seattle, Atlanta, and Kansas City.

As part of the development of the Regional Plan and Sustainable Communities Strategy (SCS), SANDAG is planning for an expansion of the regional bikeway network. The attractiveness of biking in general, and bikeshare more specifically, will grow as cities build infrastructure that separates bicyclists from moving motor vehicles. The SANDAG ABM accounts for the impact of bikeway investments on personally-owned bike trip generation. However, this only accounts for the impact on personally-owned bike trips and not bikeshare trips resulting from these investments. Recently published research on New York's Citi Bikeshare system indicates that each new lane-mile of dedicated bike infrastructure results in an average of 102 additional bikeshare trips per day (Xu and Chow, 2018).

Based on the success of current bikeshare operations within San Diego County, coverage areas were defined to delineate where bikeshare operations are projected to be available (Figure 2). The bikeshare coverage areas are based on staff knowledge of interest or plans to pursue bikeshare operations within certain jurisdictions, in colleges and universities, military bases and SANDAG Smart Growth Opportunity Areas[9], which reflect a similar mix of land uses and density observed in current bikeshare operations. Staff is currently working with the cities in the North County Coastal region to deploy a bikeshare program and is actively involved in bikeshare deployment via SANDAG's Regional Micromobility Coordination Working Group. Through this working group, SANDAG is in the process of developing a micromobility data sharing clearinghouse to facilitate data collection and analysis of micromobility service operations in the region. This data will support regional planning activities and evaluation of micromobility travel patterns that may be used to augment this methodology in the future.

A summary of the principle assumptions underlying the CO2 emission reduction calculation for bikeshare is shown in Table 9.

Table 9: Principle Approach to Bikeshare CO2 Emissions Calculations

Quantity	Overall Approach	Inputs and Source
Market / Market Growth	• Estimate utilization from experience of bikeshare systems in operation in U.S. cities	• Define coverage areas that are projected to offer bikeshare services • SANDAG ABM data ○ Population in coverage area for each forecast year by MSA
Supply	• Number of bikes per 1,000 persons in bikeshare coverage area	• Average bike supply for U.S. bikeshare systems (The Bikeshare Planning Guide and other sources) • Higher bike supply density assumed in parts of the county by MSA to reflect providers responding to more demand (The Bikeshare Planning Guide)
Regional Infrastructure Improvements	• Estimate increase in bikeshare trips due to regional bicycle infrastructure investments (new bike lane miles)	• An additional 102 bikeshare trips induced for each additional bike lane mile (Xu and Chow, 2018) • SANDAG ABM data ○ Miles of bike lanes for each forecast year based on 2016 Active Transportation Networks

[9] SANDAG Smart Growth Opportunity Areas. https://www.sandag.org/uploads/projectid/projectid_296_13994.pdf

Quantity	Overall Approach	Inputs and Source
Program VMT	• VMT reduction estimated based on substitution rate of auto trips, and average bikeshare trip length	• Inputs obtained from reported data for various U.S. bikeshare systems: ○ Average bikeshare trips per bike (pedal and e-bike) ○ Percent of trips that would have used a car ○ Average trip length • Differentiate utilization of traditional bikes and e-bikes, given research that indicates the latter are used for longer trips (Cairns et al, 2017)
GHG Emission Factors		• SANDAG ABM 14.0.1

GHG Emission Calculator Methodology

The CO2 reduction attributed to bikeshare and scootershare was calculated following the procedures described below.

Bikeshare membership within the region:

1. Identify the bikeshare service coverage areas. The bikeshare coverage areas reflect a similar mix of land uses observed in current bikeshare operations including SANDAG Smart Growth Opportunity Areas, colleges and universities, military bases, and ongoing local agency initiatives to deploy bikeshare operations. These areas are defined as agglomerations of MGRAs and aggregated by MSA. The coverage areas could vary by scenario year, reflecting increasing land use density and a maturing bikeshare industry (Figure 2).

2. Calculate the total population in the bikeshare coverage area, including persons living in non-institutional group quarters (e.g., college dormitories).

3. Estimate the projected bicycle supply, given the size of the population in the bikeshare area. The recommended minimum supply of bicycles, based on station-based system data, is 10-30 bicycles per 1,000 persons (ITDP, 2014). A supply of ten bicycles per person was assumed for the most urbanized and well-visited areas of San Diego County (Central and North City MSAs), while a supply of five bicycles per person was assumed for the other less-dense areas.

4. Estimate the total number of daily bikeshare trips. Based on data reported by various U.S. bikeshare systems, the bikeshare daily trip rates for the San Diego region are estimated to be within 1.2 – 2.3 daily trips per bike. The derivation of these trip rates is described below in the *Bikeshare System Trip Rates* section. Recent research conducted on San Francisco's bikeshare services, revealed that the JUMP bikeshare system observed an average of 2.8 average daily trips per bike (Lazarus, J. et al, 2019). Although higher than the trip rates input used in this off-model methodology, this research helps to further validate the conservative approach and inputs employed in this methodology.

Bikeshare demand due to bikeway infrastructure and fleet types:

5. Estimate the induced demand for biking resulting from investments in bicycling infrastructure. An induced demand of 102 daily bikeshare trips per new bike lane-mile was estimated based on data from Citi Bikeshare (Xu and Chow, 2018).

6. Estimate the number of bikeshare trips that are taken in pedal-assist bicycles. Based on e-bike data provided by local operators and shared mobility industry trends that favor more electric-assisted devices in the future, SANDAG staff estimates that 100 percent of all bikeshare trips will be made via an e-bike or e-scooter by 2020. As of March 2019, the San Diego region will have two primary bikeshare operators, Lime and JUMP. As of early in 2019, Lime is transitioning its fleet to all-electric (pedal-assist and e-scooters) while JUMP

operates an all-electric fleet (pedal-assist and e-scooters) in the region. Given the industry trend towards fleet electrification since bikeshare operations initiated in 2014 in the region, staff estimates that 100 percent of the fleet will be electric in 2020.

Bikeshare VMT and GHG reductions:

7. Calculate the proportion of bikeshare trips that replace a car trip. Car substitution rates are assumed to be 20 percent for traditional bikeshare and 37 percent for pedal-assist bikes, following the rates reported in the research cited above.
8. Calculate the VMT reduction resulting from the car trips replaced by bikeshare trips. Based on anonymized and aggregated data from 2018 bikeshare operations in the region, the average trip length for traditional pedal bikes is 1.2 miles and 1.7 miles for pedal-assist bikes and scooters, combined.
9. Calculate the corresponding CO2 reduction corresponding to the VMT reduction, using the EMFAC 2014 CO2 emission rates.

Bikeshare System Trip Rates

Since bikeshare trip generation rates for the San Diego region are unavailable, trip rate estimates are based on information from other U.S. bikeshare systems. Bikeshare operators in the San Diego region did not provide bikeshare trip generation estimates. Table 10 presents the relevant data gathered from multiple sources and is documented in the References section. A regression model was estimated using the following form:

$$\frac{Trips}{bicycle} = \beta \times \frac{Bikes}{1{,}000\ Persons}$$

Bikeshare trip information from operations in the U.S. resulted in a trip rate multiplier (β) of 0.23 applied to the bike supply density (bicycles per 1,000 persons in the coverage area).

The principle parameters and data items underlying the bikeshare CO2 emission calculations are listed in Table 11.

Table 10: Bikeshare System Utilization Data

City	Bikeshare System	Population in bikeshare coverage area	Annual members	Number of bicycles	Average daily bikeshare trips	Bikes per 1000 persons in coverage area	Average daily rides per bicycle
Washington DC	Capital Bikeshare	225,000	18,000	1,800	5,502	8.0	3.1
Minneapolis	Nice Ride Minnesota	190,000	3,500	1,325	735	7.0	0.6
Seattle	Seattle DOT	600,000	n/a	1,200	1,929	2.0	1.6
Portland	Portland BOT	210,000	3,519	464	858	2.2	1.9
New York	Citi Bike	814,000	19,692	9,242	57,897	11.4	6.3
Boston	Blue Bikes	179,904	14,577	1,800	3,600	10.0	2.0
Denver	Denver Bikeshare	190,242	2,111	800	972	4.2	1.2
San Antonio	San Antonio Bikeshare	33,281	11,488	500	179	15.0	0.4

Figure 2: Draft 2035 Bikeshare Coverage Areas

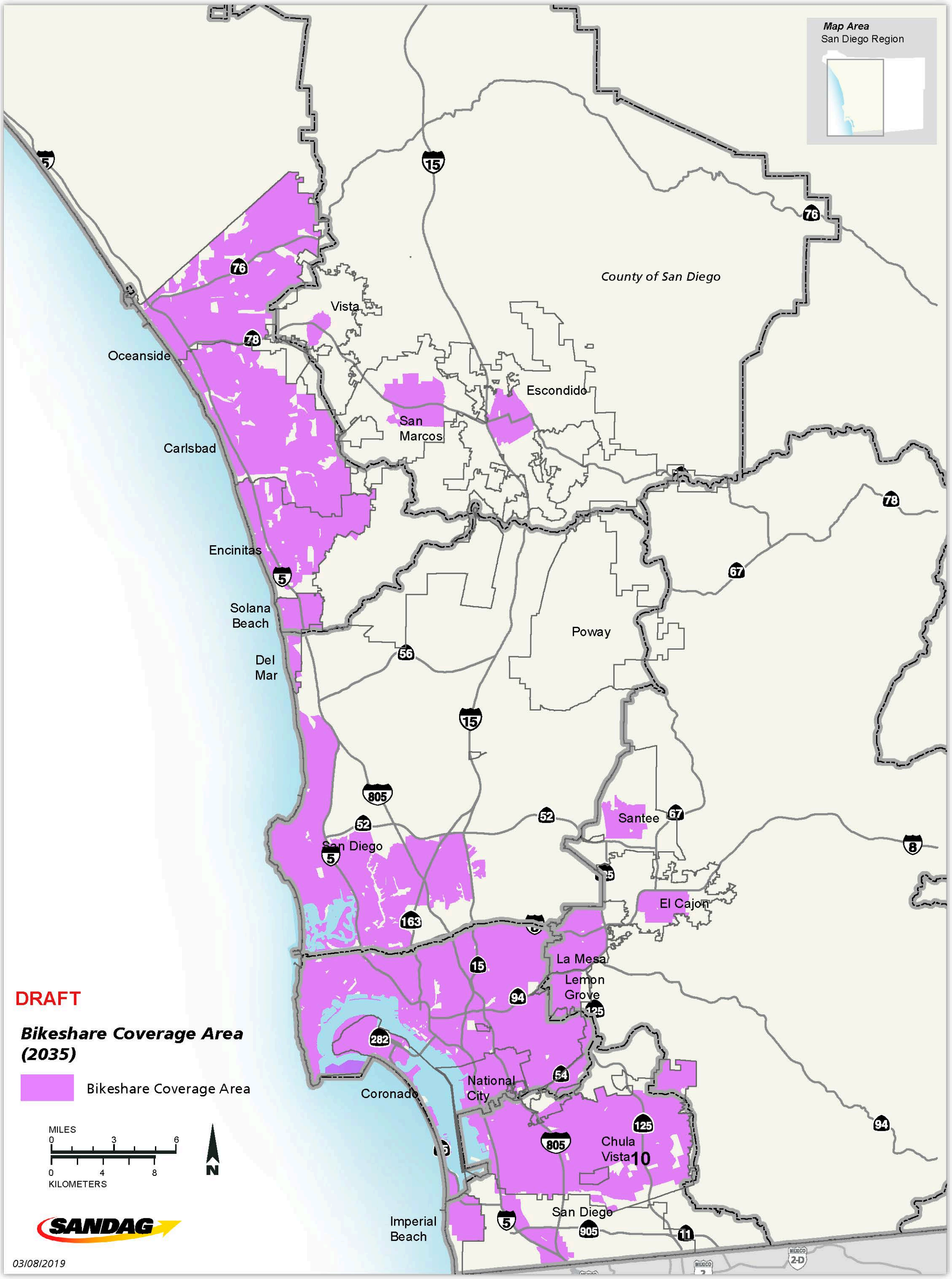

Table 11: Methodology Parameters, Bikeshare CO2 Emissions Calculator

Parameter	Source	Details
Bikeshare trip rate	Capital Bikeshare, 2012 Nice Ride Minnesota, 2010 Seattle DOT, 2018 Portland BOT, 2017 NYC Citi Bike, 2017 Blue Bikes Boston, 2017 Denver Bikeshare, 2016 San Antonio Bikeshare, 2017	Based on the estimated bikeshare fleet size within the respective MSA, the bikeshare trip rate is estimated at 2.3 daily trips per bike for Central and North City MSA, 1.2 daily trips per bike for the rest of MSAs.
Bikeshare bike supply	Bikeshare Planning Guide (ITDP, 2014)	Assumed at 10 bicycles per 1,000 persons in the Central and North City areas, and at 5 bicycles per 1,000 persons elsewhere in San Diego County.
Induced demand due to bike-lane infrastructure	Xu and Chow, 2018	Estimated at 102 additional daily bikeshare trips per bike lane-mile.
Percent of electric-assisted bikes and scooters	Draft San Diego Forward: The 2019-2050 Regional Plan	Based on the market trend towards more electric assisted devices in the future and local operator shift towards operating primarily all-electric bike fleets.
Car substitution rate, traditional bicycles	Capital Bikeshare, 2012 Nice Ride Minnesota, 2010 Seattle DOT, 2018 Portland BOT, 2017 NYC Citi Bike, 2017 Blue Bikes Boston, 2017 Denver Bikeshare, 2016 San Antonio Bikeshare, 2017	Estimated as the average car substitution rate of U.S. bikeshare systems, or 20 percent.
Car substitution rate, pedal-assist bicycles	MacArthur et al, 2018 Lime Year-End Report 2018.	Estimated at 37 percent, based on reported utilization of shared e-bikes across multiple pilot studies. In the 2018 End of Year Report, Lime reports an average substitution rate of 37 – 40% based on its operations in Los Angeles, Austin, Seattle, Atlanta, and Kansas City.
Average trip distance, traditional bicycles	Based on anonymized and aggregated data provided by bikeshare operators in the region	Based on anonymized and aggregated data from 2018 bikeshare operations in the region, the average trip length for traditional pedal bikes is 1.2 miles. Similarly, TCRP 2018 research on average trip distance for station-based bikeshare ranges from 1.3 to 2.4 miles per trip (Hernandez et al, 2018).
Average trip distance, pedal-assist bicycles	Based on anonymized and aggregated data provided by bikeshare operators in the region	Based on anonymized and aggregated data from 2018 bikeshare operations in the region, the average trip length for pedal-assist bikes and scooters 1.7 miles. Similarly, e-bike trip characteristics from JUMP bikeshare in San Francisco, California indicate that the average e-bike trip distance is 1.9 miles per trip (Lazarus, J. et al, 2019).

Calculator Inputs

Table 12 summarizes the calculator inputs for each future year scenario.

Table 12: Scenario Inputs, Bikeshare CO2 Emissions Calculator

Data Item	Source	Required Input Data
Population and employment	Draft Series 14: 2050 Regional Growth Forecast/San Diego Forward: The Regional Plan in ABM 14.0.1	For each scenario year and MGRA: • Total population
Bikeway lane miles	Draft San Diego Forward: The 2019-2050 Regional Plan	For each scenario year and MSA: • Total bikeway lane miles in each MSA (Class I, Class II, and Class III bikeway segments)
Bikeshare coverage	Draft San Diego Forward: The 2019-2050 Regional Plan	For each scenario year: • Bikeshare flag (1 if bikeshare operates in MGRA, 0 otherwise)
Emission factors	EMFAC 2014, SANDAG ABM 14.0.1	For each scenario year: • Trips (cold starts) regional emissions (ton) • Running CO2 regional emissions (ton) • Regional VMT • Regional trips

Results

Table 13 summarizes the vehicle trip, VMT and CO2 reductions attributed to bikeshare.

Table 13: Bikeshare VMT and GHG Emission Reductions

Variable	2025	2035	2050
Total daily vehicle trip reductions	Final results pending selection of the preferred network scenario		
Total daily VMT reductions			
GHG reduction due to cold starts (short tons)			
GHG reduction due to VMT (short tons)			
Total daily GHG reduction (short tons)			
Total population			
Daily per capita GHG reduction (lbs/person)			
Daily per capita GHG reduction, change in percent			

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POOLED RIDES

Program Description

The pooled rides strategy utilizes application (app)-enabled services to facilitate carpooling in the region by matching drivers with passenger who are traveling in the same direction. These app-enabled services have the potential to fill empty seats, increase average vehicle occupancies, and reduce traffic congestion. GHG reductions would be realized whenever travelers shift from driving alone to app-enabled carpooling; without adequate policies in place, pooled ride users may also shift from other modes, like transit, bike, or walking.

There are a few common examples of app-enabled pooling services to date. Transportation Network Companies (TNC) offer the option of pooling rides from independent travel parties that share a similar trip origin and destination. The "pooled" ride options offered by Uber and Lyft (Uber Pool and Lyft Line, respectively) incentivize carpooling by offering a discount on the price of individual rides. Similarly, Waze Carpool provides dynamic ridesharing services by matching drivers with potential carpool partners on a per-ride basis. Passengers reimburse the driver based on the miles traveled and the IRS mileage reimbursement rate.

SANDAG recently launched a carpool incentive program with technology partner, Waze. The carpool incentive program provides a trip subsidy to eligible employees to help encourage carpooling. The SANDAG ABM model accounts for some carpool travel within the model's shared ride mode categories. However, due to insufficient and limited data, the model is unable to explicitly account for the impact of carpool incentive programs or carpooling activity associated with new app-enabled services. SANDAG plans for the continued implementation of a carpool incentive program based on the Waze Carpool model that will provide a small trip subsidy to passengers, further incentivizing the use of carpooling. It is assumed that participation in the program will be administered by the iCommute Employer Services team, which will determine program eligibility for the carpool trip subsidy. The program will subsidize eligible employees that currently drive alone to work and are not suitable candidates for commuting by vanpool, microtransit, or transit.

Assumptions

The following assumptions were incorporated into the pooled rides off-model calculator. To date, there is very little research information on pooled rides. TNCs that offer pooled services do not share adequate trip data on pooling activity. Uber reports that 20 percent of their rides globally, and 30 percent of the rides in New York and Los Angeles, are on Uber Pool (Tech Crunch, 2016), however, it is not necessarily the case that a ride on Uber Pool is, in fact, a pooled ride. Moreover, the total number of rides served by Uber and Lyft in San Diego is unknown. Therefore, the off-model methodology for pooled rides only accounts for pooled services following the Waze carpool model. To estimate the impacts of app-enabled pooled rides throughout the region, regional survey data of app-enabled ridesharing activity was used as a proxy to estimate pooled ride use. The survey data collected did not differentiate between the different app-enabled rideshare models that were used for travel; such as dynamic carpooling like Waze Carpool or on-demand ride-hailing services like Uber or Lyft.

SANDAG used app-enabled pooled ride utilization data that was gathered through the 2016-2017 San Diego Regional Transportation Study and 2018 Commute Behavior Survey. As shown in Table 14, the app-enabled rideshare mode share decreases with increasing auto ownership. Self-administered internet-based surveys conducted in several U.S. metropolitan areas reported that on-demand ride-hailing use was predominantly for discretionary travel, with few users indicating it was their primary mode for work trips (Clewlow and Mishra, 2017). Contrary to this expectation, the 2016-2017 San Diego Regional Transportation Study reports that app-enabled ride-hailing utilization is higher for work than for non-work trips. A second difference relates to how utilization is reported; the nationwide study reports the frequency of ride-hailing, while the limited availability of San Diego data was used to estimate app-enabled ride-hailing mode shares. Since work trips account for roughly only 20 percent of all person trips, in terms of trip frequency, there are more discretionary trips than work trips, even if the relative mode share of ride-hailing for discretionary trips is lower than for work trips.

The 2016-2017 San Diego Regional Transportation Study did not ask respondents to indicate whether they hailed a shared or pooled app-enabled trip. However, limited information on app-enabled ride-hailing use was available from the 2018 Commute Behavior Survey. As shown in Table 14, the proportion of all app-enabled ride-share trips that were pooled is highest for workers from 0-car households and decreases rapidly with increasing auto ownership. The total number of pooled rides taking place in the San Diego region was calculated by applying the mode shares in Table 14 to estimates of total person trips predicted by the SANDAG ABM.

Table 14: Pooled Ride Mode Shares, San Diego Region

	2018 Commute Behavior Survey	**2016-2017 San Diego Regional Transportation Study**	
Ride-hailing mode	Work trips	Work trips	Non-work trips
All app-enabled ride-hailing trips			
0-car household	5.97%	19.28%	8.10%
1-car household	1.87%	0.87%	0.32%
2+ car household	0.20%	0.36%	0.11%
Proportion of ***pooled*** app-enabled ride-hailing trips			
0-car household	50%		
1-car household	43%	n/a	n/a
2+ car household	14%		

Based on ABM data, a two-step process was applied to predict the number of app-enabled pooled ride trips in future years. First, a simple mode choice model was developed to predict the likelihood of using an app-enabled pooled ride service as opposed to driving alone, assuming no difference in travel times between driving alone and pooling. No difference in travel time is based on the assumption that a pooled trip would occur similar to pooling via the Waze Carpool app, in which the driver & passenger(s) are matched based on their similar origin and destination and meet at a common pick-up location, thereby mitigating route deviations or additional trip links. In this first step, the likelihood of pooling is solely a function of the difference in trip cost between driving alone and pooling and a pooled-ride mode-specific constant that captures the overall preference expressed by the observed pooled-ride mode shares. The second step applied a demand elasticity formula to predict the increase in pooling that would result from investments in managed lanes. As the region's managed lane network expands, commuters who choose to pool will experience shorter travel times than commuters driving alone. This travel time savings will further encourage a shift from driving alone to pooling.

The assumptions underlying the level of service calculations for each modal option are shown in Table 15. Based on the SANDAG ABM, the cost of driving alone is 16.30 cents per mile in 2016 (in 2010 $) and is projected to increase to 26 cents per mile by 2035. Since the cost of a pooled ride is not known with certainty, it is assumed that the cost of pooling will utilize the reimbursement model currently used by Waze Carpool. Waze Carpool reimburses drivers based on the Internal Revenue Service (IRS) standard mileage reimbursement rate for travel in personally-owned automobiles, which was 54 cents per mile in 2016 or 49 cents in 2010 $. The auto operating costs used in the model only account for variable costs (gas, tire, maintenance); whereas the IRS mileage reimbursement rate accounts for both variable and fixed costs (insurance, license, registration, taxes, depreciation). Based on historical data from the

Bureau of Transportation Statistics (BTS), variable costs account for approximately 28% of the total cost per mile. Based on this assumption, variable costs associated with the IRS mileage reimbursement rates in 2016 are estimated to be 15 cents per mile in 2010 $ (49 cents x .28 = 13.72 cents). It is assumed that the cost of pooling in future years will remain the same as the cost ratio of pooling to driving alone in 2016 (16.3 cents/13.7 cents = 1.188). This pooled ride index factor of 1.188 is applied to model-based auto operating costs to estimate the cost of pooling in future years for consistency with ABM auto operating costs assumptions. The SANDAG carpool incentive program will provide a minor trip subsidy that will lower the cost of pooling per trip. Non-work trips will not be subsidized by SANDAG. To calculate travel time savings, the calculator uses the travel times predicted by the SANDAG ABM for each scenario year, for drive-alone and carpool vehicles, respectively.

Table 15: Pooled Ride Level of Service Assumptions

Level of service attribute	Drive alone, 2016—2050	Pooled ride, 2016—2050
Travel time	General purpose lane travel times	HOV and Managed lane travel times
Trip cost (cents/mile)		
Work trips	16.3 – 18.70 [1]	9.72 cents – 11.74 [2]
Non-work trips		13.0 cents – 15.74

[1] Auto operating cost assumed in the SANDAG ABM; varies based on scenario year

[2] Pooled ride costs based on estimated pooled ride costs; indexed with auto operating costs to account for variable costs only (gas, tire, maintenance) in future years. Cost for pooled work trips includes minor trip subsidy from SANDAG.

A summary of the principle assumptions underlying the CO2 emission reduction calculation for pooled rides is shown in Table 16.

Table 16: Principle Approach to Pooled Rides CO2 Emissions Calculations

Quantity	Overall Approach	Inputs and Source
Market / Market Growth	• Estimate total number of pooled app-enabled ride-hailing trips as a share of drive alone trips and segmented by household auto ownership	• SANDAG ABM data, for each scenario year o Drive alone trips predicted in each future year auto ownership category o Auto operating cost • 2016-2017 San Diego Regional Transportation Study o Utilization frequency--percentage of users that use a ride-hail service, work and non-work trips • 2018 Commute Behavior Survey o Proportion of ride-hail trips that are pooled
Regional Infrastructure Improvements	• Proposed regional managed lane infrastructure investments (HOV lanes and Express Lanes) offer travel time savings for carpooling and will increase demand for app-enabled pooling • Change in demand calculated based on elasticity of demand with respect to travel time	• SANDAG ABM data, for each scenario year o Average drive alone and carpool travel times o Average value of time o Marginal disutility of time, in-vehicle time coefficient • Internal Revenue Service (IRS) o 2016 mileage reimbursement rate
Program VMT	• Estimate program VMT based on estimated number of pooled rides in	• SANDAG ABM data, for each scenario year o Average drive-alone trip distance, work and non-work trips • Average vehicle occupancy

	forecast year and average vehicle occupancy	
GHG Emission Factors		• SANDAG ABM 14.0.1

GHG Emission Calculator Methodology

The CO2 reduction attributed to pooled rides was calculated following the procedures described below. The principle parameters and data items underlying the pooled rides CO2 emission calculations are listed in Table 17.

Pooled (app-enabled) trips within the region:

1. Based on the SANDAG ABM predictions for each scenario year, sum the number of drive-alone person trips by origin MSA, destination MSA, purpose (work/other), time period, and household auto ownership category
2. Lookup the average travel time for each MSA-to-MSA origin/destination market, based on the travel time skims produced by the SANDAG ABM for drive-alone trips and carpool trips, respectively
3. Lookup the average trip distance for each MSA-to-MSA origin/destination market, based on the distance skims produced by the SANDAG ABM for drive alone trips.
4. Estimate the cost of driving alone by applying the auto operating cost to the average trip distance
5. Estimate the cost of pool-riding by applying the indexed mileage reimbursement rate to the average trip distance and any trip subsidies as proposed in the Regional Plan.
6. Estimate the proportion of pooled rides in each trip market listed above, using the binomial mode choice model described below
7. Estimate the additional pooled ride trips that will be incentivized by managed lane investments, applying the demand elasticity formula

Pooled rides VMT and GHG reductions:

8. Calculate pooled ride VMT based on the average MSA-to-MSA trip distance and pooled ride prediction, assuming an average pool ride auto occupancy of 3 persons per car. The pooled ride occupancy corresponds with the minimum HOV requirements being recommended as part of the Regional Plan's managed lane investments.
9. Calculate the pooled ride VMT reduction. Since the shift is from drive alone to pooled ride, the difference between the total person trips and the vehicle trips used for pooled-riding is equal to the vehicles removed from highways by the availability of ride-pooling.
10. Calculate the corresponding CO2 reduction corresponding to the VMT reduction, using the EMFAC 2014 CO2 emission rates.

Pooled ride mode shifting model

Both the 2016-2017 San Diego Regional Transportation Study and 2018 Commute Behavior Survey provide some information about the current utilization of app-enabled pooled rides. To predict how utilization might change in response to a cost subsidy, a mode choice model was specified and calibrated to the current observed utilization. The model takes the form of a binomial logit mode choice model, with two choices—drive alone and pooled riding. The utility of each mode is a function of trip cost and a mode-specific constant that captures un-included attributes or preferences:

$$Utility = \alpha + \beta \times trip\ cost$$

Given this utility specification and the assumption of logit error terms, the probability of pooled-riding is then given by:

$$Probability\ (pooled\ ride) = \frac{1}{1 + e^{U(drive\ alone) - U(pooled\ ride)}}$$

By convention, the mode-specific constant (α) for the drive alone mode was set as zero. The trip cost coefficient (β) was computed from the definition of value of time, derived from regional median household income, and the in-vehicle time coefficient used in the SANDAG ABM for trips on work tours. The mode-specific constant for the pooled-ride mode was calibrated so that when the model is applied in 2016, assuming no subsidies, it predicts the mode shares observed in the 2016-2017 San Diego Regional Transportation Study and 2018 Commute Behavior Survey. The calibrated constants are shown in Table 17.

Elasticity of demand with respect to travel time savings:

The elasticity of demand for pooled rides with respect to travel time was approximated using the formula for point elasticity derived from a logit model (Train, 1993):

*Elasticity w.r.t. travel time= (coefficient of in-vehicle time) * average travel time * (1 – probability of app-enabled pooling)*

The coefficient of in-vehicle time was obtained from the SANDAG ABM and reflects the value of the mode choice in-vehicle time coefficient for trips on work tours (-0.032 utils/minute). The probability of pooled rides was calculated for each scenario year, using the pooled ride mode choice model while the average travel time was based on the single-occupant vehicle travel time.

The change in demand resulting from travel time savings is then equal to:

*Percent change in app-enabled pooled ride trips = elasticity w.r.t travel time * percent change in travel time*

The percent change in travel time was calculated based on the average weekday travel time savings associated with the use of managed lanes from the ABM.

Table 17: Methodology Parameters, Pooled Ride CO2 Emissions Calculator

Parameter	Source	Details
Observed pooled ride mode shares	SANDAG (2017). 2016-2017 San Diego Regional Transportation Study. SANDAG (2018). 2018 Commute Behavior Survey.	The observed ride-hailing mode share and the share of ride-hail pooled options, were used to estimate the total number of pooled app-enabled trips in the San Diego region for the base year (2016). This trip estimate serves as the calibration target for the pooled ride mode shifting model
Pooled ride average vehicle occupancy		In lieu of observed data, the calculator conservatively assumes the minimum occupancy to qualify as a pooled ride trip (3 persons per car). The pooled ride occupancy corresponds with the minimum HOV requirements being recommended as part of the Regional Plan's managed lane investments.
Coefficient of in-vehicle travel time (utils/minute)	SANDAG ABM 14.0.1 Trip mode choice model, work tours	SANDAG ABM value (-0.032 utils/minute). Used to calculate elasticity of demand with respect to travel time. Input to the demand elasticity formula and mode choice model
Average value of time	Preliminary Series 14 Forecast	Derived value ($9.80/hour), estimated as one-third median household income for San Diego region ($61,400), expressed as an hourly wage rate ($29.52/hour). The value of time is used to calculate an average coefficient of cost, for the pooled ride mode choice model
Pooled ride mode-specific constant		Mode choice model pooled ride constants were calibrated by trip purpose and auto ownership category: • Work trips

Parameter	Source	Details
		○ 0-car household: -2.60 ○ 1-car household: -5.90 ○ 2+ car household: -7.90 • Non-work trips ○ 0-car household: -2.90 ○ 1-car household: -6.30 ○ 2+ car household: -8.40

Calculator Inputs

Table 18 summarizes the calculator inputs for pooled rides for each future year scenario.

Table 18: Scenario Inputs, Pooled Rides CO2 Emissions Calculator

Data Item	Source	Required Input Data
Drive alone person trips	SANDAG ABM 14.0.1	For each scenario year, origin MSA and destination MSA: • Strategy year • Origin MSA • Destination MSA • Time period (AM, Midday, PM) • Trip mode (Drive Alone) • Trip purpose (Work, School, Other) • Household auto ownership (0, 1, 2+) • Person trips
Auto operating cost (cents/mile)	SANDAG ABM 14.0.1	Used to calculate the cost of driving-alone; accounts for fuel and vehicle maintenance. Auto operating cost varies from 16.3 cents/mile (2010 $) in 2016 to 18.7 cents/mile (2010 $) in 2050.
Pooled ride mileage cost (cents/mile)	Internal Revenue Service, 2016 standard mileage reimbursement rate for travel in personally-owned automobile.	IRS mileage reimbursement rate used to calculate the cost of a pooled ride trip based on the Waze Carpool model; equal to 13.72 cents/mile in 2016 (2010 $). The cost of pooling is estimated using the pooled rides index factor in future years.
Pooled rides index factor		Used to estimate the cost of pooling in future years based on ABM auto operating costs, which account for variable costs (gas, tire, maintenance) only. It is assumed that the cost of pooling in future years will remain the same as the rate of pooling to driving alone in 2016 (16.3/13.7 = 1.188)
Travel times and trip distance	SANDAG ABM 14.0.1	For each scenario year, origin MSA and destination MSA: • Strategy year • Origin MSA • Destination MSA • Time period (AM, Midday, PM) • Average one-way weekday travel time, drive-alone, general purpose lanes, (minutes) • Average one-way weekday travel time, drive-alone, managed lanes, (minutes) • Average one-way weekday trip distance, drive alone, general purpose lanes (miles)
Emission factors	EMFAC 2014, SANDAG ABM 14.0.1	For each scenario year: • Trips (cold starts) regional emissions (ton) • Running CO2 regional emissions (ton) • Regional VMT • Regional trips

Results

Table 19 summarizes the vehicle trip, VMT and CO2 reductions attributed to app-based pooled rides.

Table 19: Pooled Ride VMT and GHG Emission Reductions

Variable	2025	2035	2050
Total daily vehicle trip reductions	Final results pending selection of the preferred network scenario		
Total daily VMT reductions			
GHG reduction due to cold starts (short tons)			
GHG reduction due to VMT (short tons)			
Total daily GHG reduction (short tons)			
Total population			
Daily per capita GHG reduction (lbs/person)			
Daily per capita GHG reduction, change in percent			

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MICROTRANSIT

Program Description

Microtransit services utilize real-time ride-hailing, mobile tracking and app-based payment (Faigon et al., 2018) to provide demand-based service to users. Microtransit services are flexible and can operate vehicles that range from small sport utility vehicles (SUV) to large shuttle buses to provide transit-like services. In San Diego County, a type of microtransit service called the Free Ride Everywhere Downtown (FRED) has been operating in downtown San Diego since 2016. The FRED service is managed by Civic San Diego, the City of San Diego's non-profit entity that oversees downtown development. FRED operates a fleet of neighborhood electric vehicles (NEVs) within a defined service area that can be hailed in real-time or via an app-based reservation system and fulfills rides that are typically less than two miles long (Steele, 2017). The service is free to users and is paid for by advertisers, parking meter revenues, and grants. Through conversations with the FRED service provider, it is anticipated that FRED will expand its service to other parts of the region that have similar land uses and visitor destinations as Downtown San Diego. In support of regional mobility hub planning efforts[10], the SANDAG TDM program seeks to promote and encourage the provision of NEV microtransit to provide critical connections to and from mobility hubs.

In addition to the NEV shuttle service, other types of microtransit services operate as a crowd-sourced, route-deviation, demand responsive form of transit, such as Bridj, and Via that operate international microtransit services. These services help to reduce GHG emissions by providing an alternative to automobile travel in areas where traditional fixed-route transit does not operate, where service is relatively infrequent, or where demand for transit exceeds the capacity provided by public transit agencies. SANDAG is proposing to incentivize the deployment of a commuter-oriented microtransit service in areas not currently well-served by fixed-route transit. The provision of an operational subsidy that reduces the cost of a trip would make this a cost-effective alternative for commuters. As with the vanpool program, the SANDAG Employer Services Program will conduct targeted outreach with major employers throughout the region to identify employees that may be suitable candidates for the commuter shuttle service as proposed in this methodology.

With the exception of FRED and a few privately sponsored employer shuttles, the emergence of microtransit is a new concept in the San Diego region. Without sufficient empirical data on microtransit use the SANDAG ABM is unable to consider microtransit as a transportation mode, therefore the GHG emission reductions of NEV and commuter shuttle trips are unaccounted for by the model.

The methodology presented in this memo accounts for two microtransit services:

- Neighborhood electric vehicles (NEVs) that operate within a defined service area and can be hailed in real-time to fulfill rides that are less than two miles long; and
- Commuter shuttle services that provide a feasible alternative to automobile travel in areas where traditional fixed-route transit is poor or does not operate.

This calculator does not address microtransit services that could be designed to interface with other transit services (trunk line or local).

Assumptions

To estimate impacts resulting from the deployment of NEV shuttle service, it is assumed that these shuttle services will operate very similarly to the FRED service in downtown San Diego. The NEV shuttle would be deployed within

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[10] To learn more about SANDAG mobility hub efforts, visit www.sdforward.com/mobilityhubs

designated areas to provide critical connections to high-frequency transit stations, corresponding to the regional mobility hub network[11] (Figure 3), and will fulfill short trips that are less than two miles in length. The off-model calculator assumes that the NEV shuttle mode shares will be similar to the FRED mode share observed today, or 0.41 percent. This mode share is estimated based on the number of rides reported by FRED (Van Grove, 2019) and the total person trips in the current FRED service area, as predicted by the SANDAG ABM. It's assumed that NEV microtransit services, like FRED, reduce GHG emissions by offering an emissions-free alternative for short trips that could otherwise be completed by car, bicycle, transit, or walking. As such, it is assumed that one-third of the NEV shuttle trips would have otherwise been automobile trips, should this service not exist. The auto substitution rate is consistent with auto substitution rates reported for e-bike users (37%), a motorized service that also primarily fulfills short trips (less than 2 miles) and deemed comparable to NEVs. Staff is working to establish a micromobility data clearinghouse and hopes to partner with FRED to collect and evaluate trip data that may be used to inform this methodology in the future.

The other type of microtransit service accounted for in this off-model methodology will provide commuters with a viable transportation option to the region's major employment centers (Figure 4) from areas where there is currently no or poorly fixed-route transit available, where traditional transit service is very infrequent, and/or there are long walk-access distances. The commuter shuttle service will use 15-passenger vehicles to fulfill trips that are less than thirty miles one-way to the region's top employment centers and military bases. Commuters with trips that are over thirty miles one-way are not considered microtransit candidates and filtered out of the trip estimates as these types of trips are assumed to be more viable for the SANDAG Vanpool Program[12]. Unlike vanpools, which are typically comprised of employees from the same company, the commuter shuttles will group commuters with similar travel patterns independently of their employer. Additionally, participation in the Vanpool Program is not restricted by a geographical boundary, meaning that a vanpooler's employers could be located anywhere throughout the region. Participation in the commuter shuttle service, however, is constrained by the employer's location, which must be located within the pre-defined coverage areas (see Table 23) including Downtown San Diego, Sorrento Valley, East Carlsbad, Kearny Mesa, Camp Pendleton, and more.

The commuter shuttles will pick up commuters, based on their trip origin and destination, at a common pick up location. It is assumed that shuttle users will travel a maximum of 5-minutes to-and-from the origin and destination either via biking or walking, consistent with SANDAG mobility hub planning efforts. A minimum level of demand is required for the shuttles to operate and was assumed to be 80 percent, consistent with the occupancy threshold for the SANDAG Regional Vanpool Program, or 12 passengers per vehicle per hour, corresponding to 36 trips over the 3-hour AM peak period.

A summary of the principle assumptions underlying the CO2 emission reduction calculation for microtransit is shown in Table 20.

Table 20: Principle Approach to Microtransit CO2 Emissions Reduction Calculations

Quantity	Overall Approach	Inputs and Source
Market / Market Growth	• Estimate potential microtransit users for two microtransit service types within the region: (1) NEV shuttle service that fulfills short trips (~two miles max) within mobility hubs	• Define NEV shuttle coverage areas (based on regional mobility hub network) • Define commuter shuttle coverage areas (dense employment centers) • SANDAG ABM data

[11] More information on the regional mobility hub network methodology is available in Attachment A

[12] Based on FY 2018 Vanpool Program data, the average vanpooled travels a roundtrip distance of 116 miles or 58 miles one-way.

	(2) commuter shuttle service to high density employment centers for commuters with no or poor fixed-route transit available and where trips are less than 30 miles to the employment centers • Estimate microtransit trips within the NEV shuttle and commuter shuttle coverage areas	○ Person and daily auto trips less than two miles long that start and end within the NEV shuttle coverage areas ○ Home to work drive alone person trips to commuter shuttle coverage areas with no or poor fixed-guideway transit service and less than 30 miles • NEV shuttle mode share • Commuter shuttle mode share dependent on time and cost, as compared to driving alone
Supply; Regional Infrastructure Improvements	• Refine microtransit trip estimates based on projected commuter shuttle travel time and fares. Assumes commuter shuttle service can leverage managed lane infrastructure for travel	• Commuter shuttles priced comparatively to the cost of single ride transit fare in the region. • Commuter shuttles travel at prevailing highway speeds
Program VMT	• Program VMT based on predicted microtransit trip and trip lengths in forecast year • Assumes that only some of the demand is shifting from driving alone	• SANDAG ABM data ○ Average trip length of trips that switch to microtransit • Auto substitution rate
GHG Emission Factors		• SANDAG ABM 14.0.1

GHG Emission Calculator Methodology

The CO2 reduction attributed to microtransit was calculated following the procedures described below.

NEV shuttle service:

1. Identify the areas where the NEV shuttles will operate by scenario year (Figure 3) These areas are defined as agglomerations of MGRAs and aggregated by MSA. The coverage areas could vary by scenario year, reflecting increasing land use density that could support NEV shuttle service.

2. Based on the SANDAG ABM, compute the total number of daily person and daily auto trips that start and end within the NEV shuttle coverage areas and are two miles long or shorter. Aggregate totals by MSA and scenario year.

3. Compute the number of NEV shuttle person trips by applying the observed mode share of 0.41 percent to the person trip totals.

4. Compute the proportion of NEV shuttle trips that switched from driving alone by applying the car substitution rate to the total NEV shuttle trips. It is assumed that one-third of the NEV shuttle trips would have been auto trips, should this service not exist. The auto substitution rate is consistent with auto substitution rates reported for e-bike users (37%), a motorized service that also primarily fulfills short trips (less than 2 miles) deemed comparable to NEVs.

5. Based on trip estimates provided by FRED, average trip distances vary between 1 - 1.7 miles per ride. To not overestimate trip distances, an average trip distance of 1 mile per trip is used. It is assumed that trip distances in future years will reflect existing trip trends given that NEV services would be deployed within defined areas and primarily continue to fulfill trips less than 2 miles.

6. Based on the SANDAG ABM, compute the average trip distance of auto trips less than two miles long within the specified coverage areas for each scenario year.

NEV shuttle VMT and GHG reductions:

7. Compute the NEV shuttle VMT by applying the average trip distance to the estimated NEV shuttle trips (trips that replaced autos only).
8. Calculate the corresponding CO2 reduction corresponding to the VMT and trip reduction reductions, using the EMFAC 2014 CO2 emission rates.

Commuter shuttle microtransit:

9. Identify the employment centers that will be served by the commuter shuttle service (Figure 4).
10. Based on the SANDAG ABM predictions for each scenario year, sum the number of drive-alone home-to-work person trips by origin MGRA and destination MGRA.
11. Find the best transit path from each origin MGRA to each destination MGRA in the trip universe.
12. Lookup the in-vehicle and out-of-vehicle transit travel time (including walk access and egress time) for each MGRA-to-MGRA origin/destination trip market, based on the transit skims produced by the SANDAG ABM for premium transit trips.
13. Lookup the average trip distance for each MGRA-to-MGRA origin/destination market, based on the distance skims produced by the SANDAG ABM for drive alone trips.
14. Filter out trips in MGRA-to-MGRA markets with high fixed-route transit productivity. The remaining trips are the market for microtransit trips.
15. Apply the microtransit mode choice model to the pool of trips that makeup the microtransit market. This mode choice model is described below.
16. Summarize the predicted microtransit demand by origin MSA and destination employment center.
17. Refine microtransit estimates, based on minimum demand threshold. Filter out trips in (origin MSA, destination employment center) pairs with fewer than 36 trips, corresponding to 12 one-way passenger trips per hour over the 3-hour AM peak period.

Commuter shuttle VMT and GHG reductions:

18. Estimate microtransit VMT based on the average MSA-to-employment center trip distance and microtransit demand. Since the microtransit mode choice model is applied to drive alone trips only, each microtransit trip represents one less vehicle on the road.
19. Estimate the total microtransit VMT reduction as twice the reduction computed for home-to-work trips, to account for the return trip from work to home.
20. Calculate the corresponding CO2 reduction corresponding to the VMT and trip reduction, using the EMFAC 2014 CO2 emission rates.

Commuter shuttle mode choice model

The commuter shuttle market consists of home to work drive-alone person trips with a destination in one of the identified employment centers. This pool of drive alone trips was obtained from the SANDAG ABM predictions for each scenario year. Since the commuter shuttles will be deployed to augment where transit service is nonexistent or poor, it is necessary to filter out from the pool of drive alone trips those that already have a good fixed-route transit path. Since the SANDAG ABM model does not report the alternative transit option of trips for which the chosen mode is auto, a likely transit path was reconstructed for each drive alone trip. Using a somewhat simplified level of service criteria, yet consistent with the stop-to-stop transit skims and MGRA-to-stop walk paths produced by the SANDAG ABM, the best transit path for each origin/destination MGRA pair was found and associated with each drive alone trip in the microtransit market. The current average speed for fixed-route transit is 9 mph, including stop wait time and walk access/egress time or 0.15 miles per minute. The estimated microtransit trips which held a low average speed, meaning for which the fixed-route transit speed was higher, were filtered out from the microtransit market to account for microtransit trips that may directly compete with transit and may actually be more suitable transit trips.

To predict the commuter shuttle utilization, a simple drive alone versus transit mode choice model was specified and applied to the drive alone trips in the microtransit service markets. The model takes the form of a binomial logit mode choice model, with two choices—drive alone and microtransit. The utility of each mode is a function of trip cost, travel time (including in-vehicle and out-of-vehicle time) and a mode-specific constant that captures un-included attributes or preferences.

$$Utility = \alpha + \beta_c \times trip\ cost + \beta_{ivt} \times in\ vehicle\ time + \beta_{ovt} \times out\ of\ vehicle\ time$$

Given this utility specification and the assumption of logit error terms, the probability of choosing transit is then given by:

$$Probability\ (transit) = \frac{1}{1 + e^{U(drive\ alone) - U(transit)}}$$

By convention, the mode-specific constant (α) for the drive alone mode was set at zero. The value of the SANDAG ABM in-vehicle time coefficient for trips on work tours was used for β_{ivt}, while β_{ovt} was set at 2.5 times the value of β_{ivt}. The trip cost coefficient (β_c) was computed from the definition of value of time ($VOT = \beta_{ivt}/\beta_c$), with value of time estimated from median wage data for the San Diego region. The microtransit alternative specific constant was asserted at a value equivalent to 20 minutes of in-vehicle time (-0.64). For reference, when this model is applied to predict the fixed-route transit mode share, it results in a calibrated transit constant equivalent to 12 minutes of in-vehicle time (-0.40). The more negative constant value asserted for microtransit correlates to a more conservative assumption, essentially indicating that the model assumes that microtransit is perceived less favorably than fixed-route transit, all else equal. The level of service attributes for driving alone and commuter shuttle are shown in Table 21, and the calibrated constants and other calculator parameters are shown in Table 22.

Table 21: Commuter Shuttle Level of Service Attributes

Level of service attribute	Driving alone	CB shuttle
Trip cost	Based on trip distance and auto operating cost for the scenario year (16.3 - 26.0 cents per mile) from SANDAG ABM model	$3.37 per trip, or 50 percent premium over the San Diego Metropolitan Transit System (MTS) fixed-route bus and light rail full boarding fare of $2.25 A fare analysis of areas where microtransit service providers Chariot & Bridj operate revealed that the cost per trip for microtransit is on average 50 percent higher than single bus fare within that service area

In-vehicle time	Based on trip distance and average speed of 30 mph	Based on trip distance and average speed of 30 mph, based on the average speed of select MTS *Rapid* bus service routes. *Rapid* provides high-frequency, limited-stop bus service throughout the San Diego region. Routes 235, 280, and 290 leverage managed lane infrastructure to fulfill trips, similar to the proposed commuter shuttle service
Out-of-vehicle time	n/a	7.5 minutes of average wait time and 10 minutes of walk access and egress time (5 minutes at the origin and 5 minutes at the destination)

Figure 3: Draft 2035 NEV Microtransit Coverage Areas

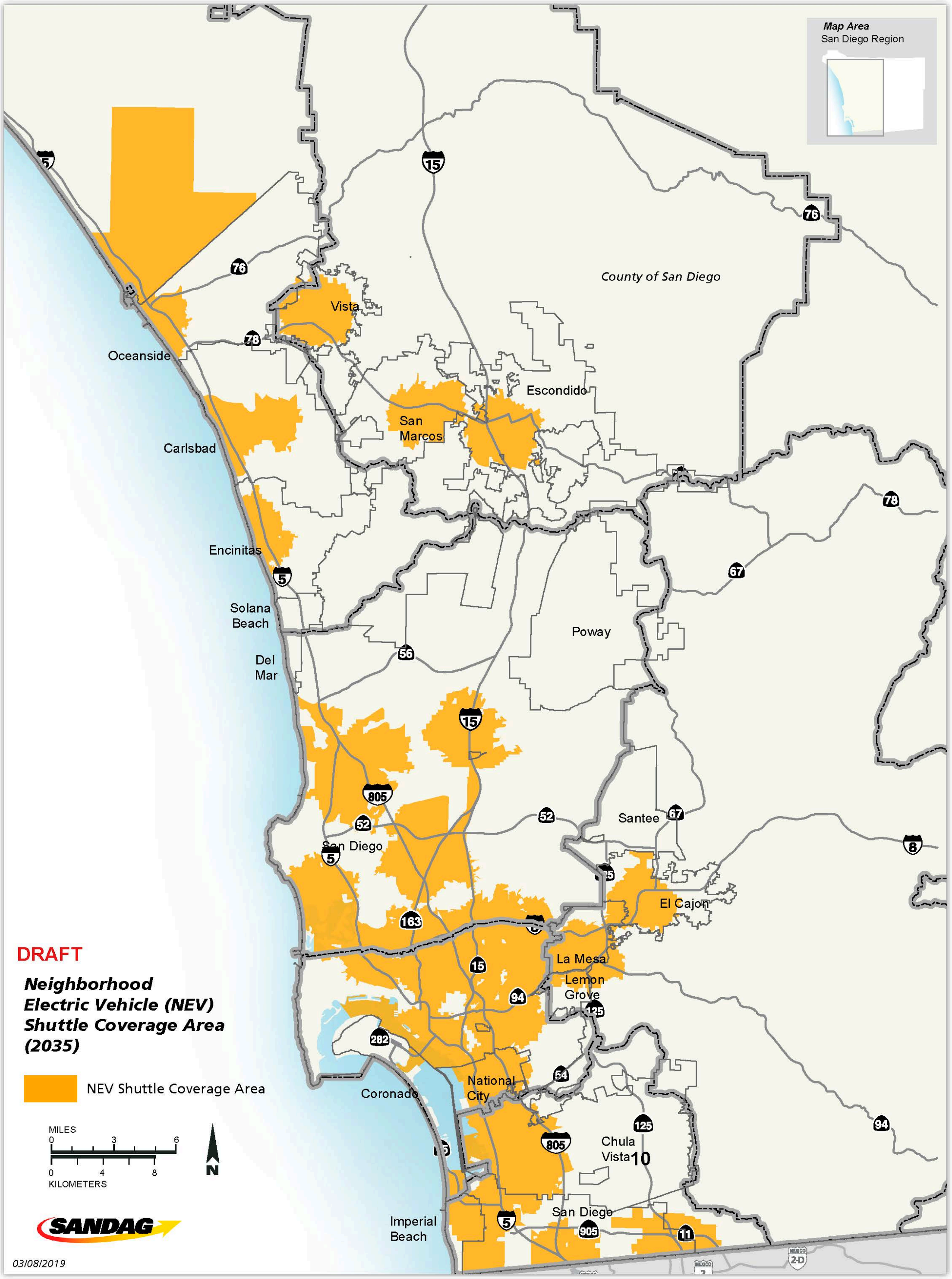

Figure 4: Draft 2035 Commuter Shuttle Microtransit Coverage Area

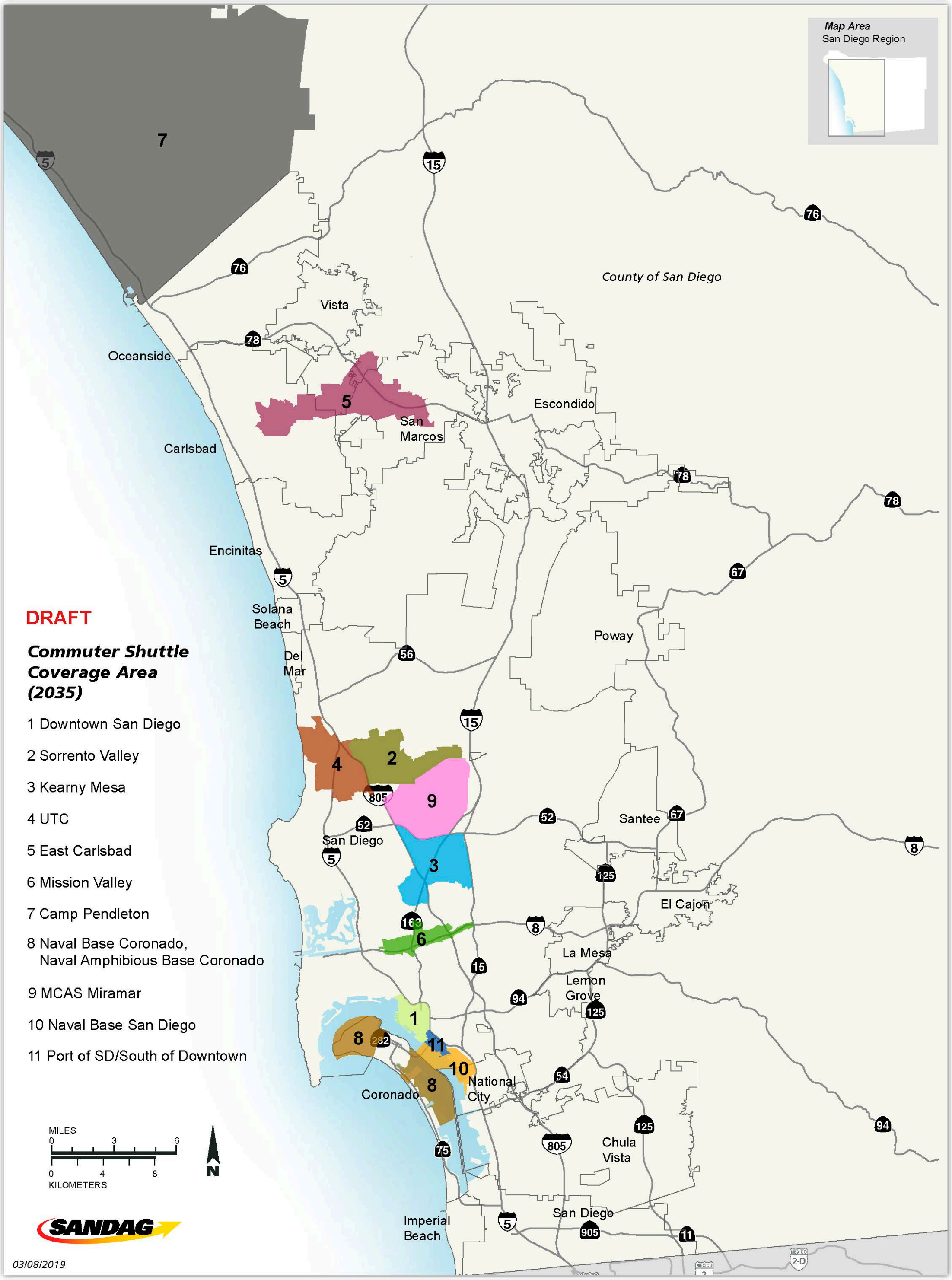

Table 22: Microtransit Commuter Shuttle Mode Choice Parameters, Microtransit CO2 Emissions Calculator

Parameter	Source	Details
Average NEV trip distance		Based on trip estimates provided by FRED, 2/11/19, average trip distances vary between 1 - 1.7 miles per ride. It is assumed that trip distances would reflect current trends given that NEV services would be deployed within defined areas and primarily fulfill trips less than 2 miles
NEV shuttle mode share	Van Grove, 2019 SANDAG ABM 14.0.1	Estimated based on FRED reported utilization of approximately 17,500 monthly rides in 2018 (Van Grove, 2019), person trips that are 2-miles or shorter in the existing NEV shuttle service area, and an average of 30 service days per month
Coefficient of in-vehicle travel time (civt) (utils/minute)	SANDAG ABM 14.0.1 Trip mode choice model, work tours	SANDAG ABM value (-0.032 utils/minute). Used to calculate elasticity of demand with respect to travel time. Input to the demand elasticity formula and mode choice model
Ratio of out of vehicle to in vehicle time coefficient		Ratio (2.5) reflects best practices for travel demand models
Average value of time	Preliminary Series 14 Forecast	Derived value ($9.80/hour), estimated as one-third median household income for San Diego region ($61,400), expressed as an hourly wage rate ($29.52/hour). The value of time is used to calculate an average coefficient of cost, for the commuter shuttle mode choice model
Cost coefficient		Derived value (-0.0020) from the definition of value of time (marginal disutility of time / marginal disutility of cost); 0.6 is a unit conversion factor required because VOT is in $/hour, civt is in minutes, and cost should be expressed in cents
Microtransit mode-specific constant		The commuter shuttle microtransit alternative specific constant was asserted at a value equivalent to 20 minutes of in-vehicle time (-0.64)

Calculator Inputs

Table 23 summarizes the calculator inputs for each future year scenario.

Table 23: Scenario Inputs, Microtransit CO2 Emissions Calculator

Data Item	Source	Required Input Data
Microtransit coverage area (NEV and Commuter Shuttle services)	Draft San Diego Forward: The 2019-2050 Regional Plan	For each scenario year and Master Geographic Reference Area (MGRA): • MSA Id • TAZ Id • Area (acres) • NEVSHUTTLE_FLAG -- NEV shuttle service flag (1 if service operates in MGRA, 0 otherwise) • CBSHUTTLE_FLAG – Commuter shuttle service flag: o 1 if Downtown San Diego o 2 if Sorrento Valley o 3 if Kearny Mesa o 4 if UTC o 5 if East Carlsbad o 6 if Mission Valley o 7 if Camp Pendleton o 8 if Naval Base Coronado, Naval Amphibious Base Coronado o 9 if MCAS Miramar o 10 if Naval Base San Diego o 11 if Port of San Diego/South of Downtown o 0 otherwise • OP_YEAR_NEVSHUTTLE -- Year that NEV shuttle service becomes operational in this MGRA • OP_YEAR_CBSHUTTLE -- Year that commuter shuttle service becomes operational in this MGRA
Population and employment	Draft Series 14: 2050 Regional Growth Forecast/San Diego Forward: The Regional Plan in ABM 14.0.1	For each scenario year and Master Geography Reference Area (MGRA): • Strategy year • NEVSHUTTLE_FLAG -- NEV shuttle service flag (1 if service operates in MGRA, 0 otherwise) • CBSHUTTLE_FLAG -- Commuter shuttle service flag (see Microtransit Coverage input item above) • Total employment • Total population
Regional trips, NEV shuttle	SANDAG ABM 14.0.1	For each scenario year: • indivTripData_3.csv (SANDAG ABM 14.0.1 output) • TAZ-to-TAZ drive alone distance, general purpose lanes, median VOT, AM Peak (SANDAG ABM 14.0.1 output) • Process trip data file with SANDAG_microtransitCalculatorTables.R to produce this summary of trips less than 2 miles long o Origin MSA o Origin MSA NEV shuttle service flag o Destination MSA o Destination MSA NEV shuttle service flag o Sum of person trips less than 2 miles long o Sum of auto trips less than 2 miles long
	SANDAG ABM 14.0.1	For each scenario year:

Data Item	Source	Required Input Data
Regional trips, Commuter shuttle		• indivTripData_3.csv (SANDAG ABM 14.0.1 output) • TAZ-to-TAZ drive alone distance, general purpose lanes, AM Peak (SANDAG ABM 14.0.1 AMF output) • TAP-to-TAP commuter rail walk to transit skim, AM Peak (SANDAG ABM) • walkMGRATAPEquivMinutes.csv • SANDAG_TAP_TAP_to_MAZ_MAZ_IVT_OVT.R generates home to work trips • Process trip data file with [SANDAG ABM Transit Mode Share.xlsx] to produce these summary matrices of home to work trips: o Home MSA to employment center destination, total home-to-work drive alone trips o Home MSA to employment center destination, total home-to-work drive alone trips with origins with no or poor transit service o Home MSA to employment center destination, total home-to-work microtransit trips, full fare o Home MSA to employment center destination, total home-to-work average microtransit trip distance, full fare o Home MSA to employment center destination, total home-to-work microtransit trips, subsidized fare o Home MSA to employment center destination, total home-to-work average microtransit trip distance, subsidized fare
Emission factors	EMFAC 2014, SANDAG ABM 14.0.1	For each scenario year: • Running CO2 regional emissions (short tons) • Regional vehicle-miles traveled (VMT) • Regional vehicle trip starts • Trip start CO2 regional emissions (short tons)
Commuter shuttle service operations	Draft San Diego Forward: The 2019-2050 Regional Plan	These assumptions define the level of service for commuter shuttle service. • Commuter shuttle fare (cents) • Average vehicle travel speed (mph) • Average time waiting for a ride (min) • Average access/egress time, total (min) • Maximum trip distance (miles) • Minimum demand per origin MSA (trips)

Results

Table 24 summarizes the vehicle trip, VMT and CO2 reductions attributed to microtransit.

Table 24: Microtransit VMT and GHG Emission Reductions

Variable	2025	2035	2050
Total daily vehicle trip reductions	Final results pending selection of the preferred network scenario		
Total daily VMT reductions			
GHG reduction due to cold starts (short tons)			
GHG reduction due to VMT (short tons)			
Total daily GHG reduction (short tons)			
Total population			
Daily per capita GHG reduction (lbs/person)			
Daily per capita GHG reduction, change in percent			

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COMMUNITY BASED TDM OUTREACH

The Community-Based Travel Planning strategy was prepared by SANDAG staff.

Program Description

Community-based travel planning (CBTP) is a residential-based approach to TDM outreach and a proven method for encouraging sustained travel behavior change. CBTP provides households with customized information, incentives and support to encourage the use of transportation alternatives. The approach involves a team of trained 'Travel Advisors' engaging residents at-home or in their communities to offer information, incentives, and advice about how members of households can travel in alternative ways that meet their needs. Teams of trained Travel Advisors visit all households within a targeted geographic area, have tailored conversations about residents' travel needs, and educate residents about the various transportation options available to them. Travel Advisors are trained in motivational interviewing techniques that helps to facilitate intrinsic motivation to inspire changed behaviors.

Following the one-on-one conversation with a Travel Advisor, residents receive resources and incentives that are relevant to their transportation needs that can reduce the barriers to trying transportation alternatives. Examples of incentivized packets include:

- A trial transit pass, assistance with transit trip planning and a free bikeshare membership to provide a first and last mile solution to transit
- Regional vanpool program information and ride-matching assistance coupled with a "first month free" vanpool promotion.

Travel Advisors not only provide information, but they also play a key role in educating residents on how to use transportation services by providing step-by-step support with planning a transit trip, accessing and using shared mobility programs, using online trip planning tools, enrolling in the vanpool or carpool program, etc. Within twelve weeks of the initial doorstep conversation and incentive distribution, Travel Advisors follow-up with all participating households with a survey to see how travel behavior has changed, what their experience has been, and if any additional support is needed.

SANDAG partnered with a consulting firm to conduct a small CBTP pilot project in Encinitas, California in March 2014. The project was branded as "Travel Encinitas" and targeted nearly 400 households to encourage residents to try transportation alternatives for commuting purposes or for local trips. The "Travel Encinitas" pilot demonstrated that CBTP has good potential for the San Diego region, with participants indicating that they drove less and walked, biked, and carpooled more frequently as a result of the pilot. Based on the success of the "Travel Encinitas" CBTP pilot, SANDAG is proposing to expand community based TDM outreach to target households that are typically within a 5-minute bike shed around select high-frequency transit stations or major regional bikeway investments within the region in 2025 and 2035 (Figure 5). In a few instances, the CBTP boundary was expanded beyond a 5-minute bike shed due to the transit-oriented nature of the community, which may be more conducive to driving to and parking at a local transit station. Households targeted for CBTP outreach include households near the Mid-Coast Trolley, Barrio Logan Transit Station, City Heights Mid-City Centerline Station, Iris Trolley Station, South Bay Rapid stations, Grantville Trolley Station, 8th Street Station, Costal Rail Trail, and Inland Rail Trail. Surveys before and after CBTP participation will be implemented to track program performance.

The coverage areas listed within this document are subject to change, pending the selection of a preferred network scenario.

Assumptions

In addition to the San Diego data from the "Travel Encinitas" pilot project, data from CBTP initiatives in Portland, Oregon, Pleasanton, California, Mill Creek, Washington, and King County, Washington was used to estimate VMT and GHG reductions associated with a regional Community-based TDM Outreach program. Based on data from nine CBTP cases studies, between 10 and 30 percent of households typically agree to participate and actively engage with a Travel Advisor, which results in an average 12 percent reduction in SOV trips. These program assumptions were applied to model-based outputs of households within the defined CBTP areas (number of daily driving trips and driving trip distance for participating households) to estimate VMT impacts. Evaluations of CBTP programs typically focus on impacts during the year after programs are implemented via short surveys; long-term evaluations that provide information on how long behavior change persists due to PTP programs is limited.

The principle parameters and data items underlying the CBTP CO2 emission calculations are listed in Table 25.

Table 25: Methodology Parameters, CBTP CO2 Emissions Calculator

Quantity	Overall Approach	Inputs and Source
Market / Market Growth	• Target households typically within a 5-minute bike shed around select high-frequency transit stations or regional bikeway investments	• SANDAG ABM data, for each scenario year ○ Households typically within 5-minute bike shed including Mid-Coast Trolley, Barrio Logan Transit Station, City Heights Mid-City Centerline Station, Iris Trolley Station, South Bay *Rapid* stations, Grantville Trolley Station, 8th Street Station, Costal Rail Trail, and Inland Rail Trail.
Supply	• Based on national CBTP case studies, estimates participation rate, cost, and impact of households that participate in CBTP	• CBTP Case Studies ○ Decrease in SOV trips for households participating in CBTP ○ CBTP participation rate ○ Cost per households targeted for CBTP
Program VMT	• Estimate VMT reduction based on average household trips and trip length	• SANDAG ABM data, for each scenario year ○ Average daily one-way driving trips per household ○ Average one-way trip length for driving trips (miles)
GHG Emission Factors		• SANDAG ABM 14.0.1

GHG Emission Calculator Methodology

The CO2 reduction attributed to CBTP was calculated following the procedures described below.

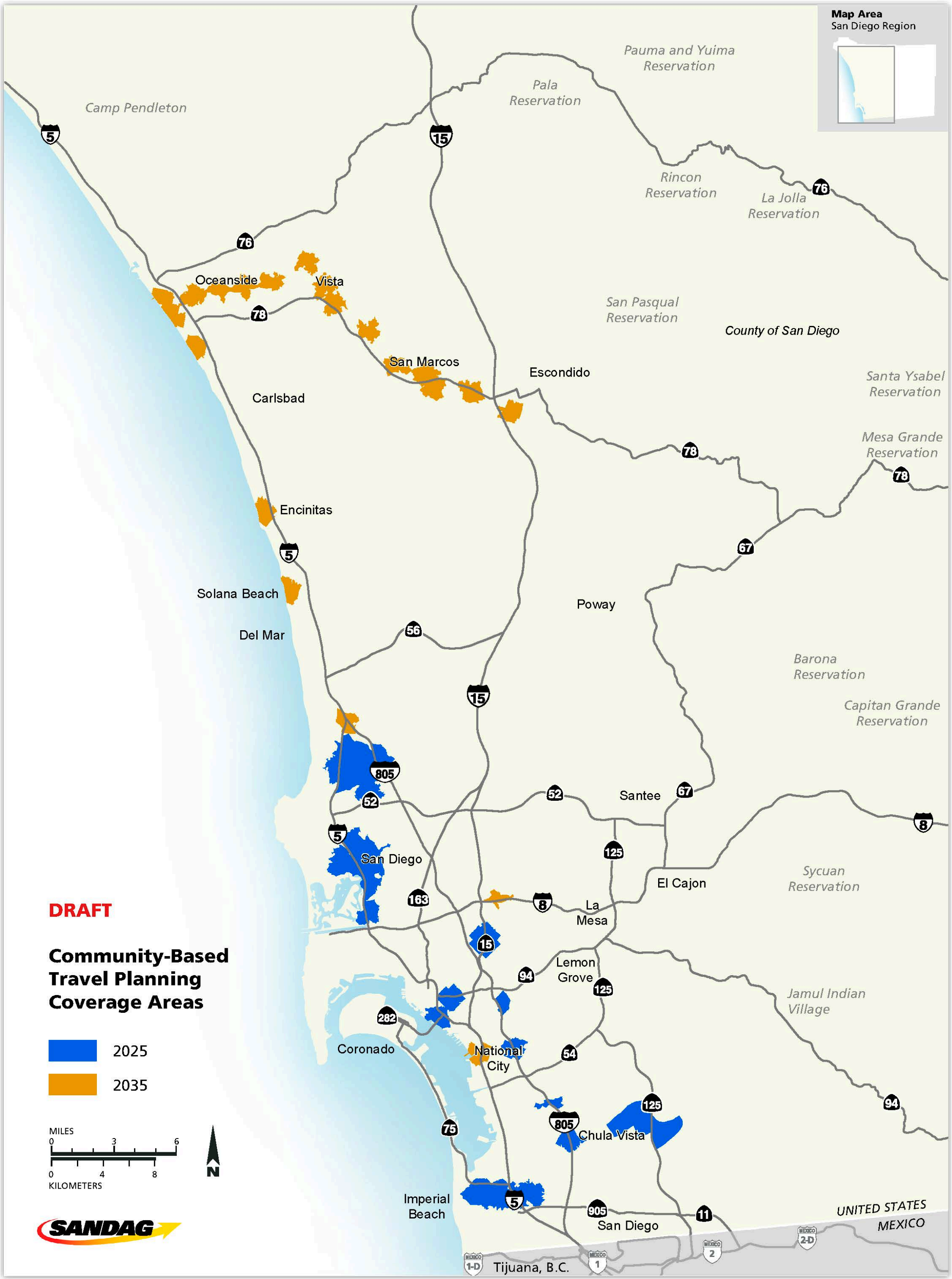
1. The number of households was identified within the designated target areas for CBTP to determine the number of households participating in CBTP. Based on nine CBTP case studies, it was assumed that an average 17 percent of targeted households would participate.

2. The total number of participating households was multiplied by the average reduction in SOV trips among participants. The average daily one-way driving trips affected was used to calculate the average daily number of vehicle trips reduced by participants.

3. The daily vehicle trips reduced was multiplied by the average one-way trip length for driving to calculate average daily VMT reductions.

4. The corresponding CO_2 reduction factor was calculated corresponding to the VMT and trip reduction, using the EMFAC 2014 CO_2 emission rates.

Figure 5: Draft 2035 – 2050 CBTP Coverage Areas



Calculator Inputs

Table 26 summarizes the Carbon Dioxide emissions calculator inputs for each future year scenario. Table 26 summarizes the Carbon Dioxide emissions calculator inputs for each future year scenario.

Table 26: Scenario Inputs, CBTP CO2 Emissions Calculator

Parameter	Source	Details
Average cost per household targeted for CBTP	Portland SmartTrips; Salmon Friendly Trips, 2017; Smart Trips Pleasanton, 2016; Green Lake in Motion, 2015; Renton in Motion, 2014; Burien in Motion, 2014; Curb @ Home, 2017; Travel Encinitas, 2014	The cost per household targeted for CBTP can vary depending on households and level of investment. On average, the cost per household targeted for CBTP costs $20.56. This is used to estimate annual program costs in 2025 and 2035.
Number of households targeted for CBTP	Draft Series 14: 2050 Regional Growth Forecast/San Diego Forward: The Regional Plan in ABM 14.0.1	The total number of households within the defined CBTP coverage areas.
Average participation rate	Portland SmartTrips; Salmon Friendly Trips, 2017; Smart Trips Pleasanton, 2016; Green Lake in Motion, 2015; Renton in Motion, 2014; Burien in Motion, 2014; Curb @ Home, 2017; Travel Encinitas, 2014	On average, 17 percent on households targeted for CBTP participate
Average reduction in SOV trips for participating households	Portland SmartTrips; Salmon Friendly Trips, 2017; Smart Trips Pleasanton, 2016; Green Lake in Motion, 2015; Renton in Motion, 2014; Burien in Motion, 2014; Curb @ Home, 2017; Travel Encinitas, 2014	On average, households that participate in CBTP decrease their SOV trips by 12 percent
Average daily one-way driving trips per household	SANDAG ABM 14.0.1	The average daily one-way trips vary by scenario year: 2016, 2020, and 2025 data is from no-build scenario and 2035 is from Scenario E from ABM 14.0.1
Average one-way trip length for driving trips (miles)	SANDAG ABM 14.0.1	The average one-way trip length for driving trips varies by scenario year: 2016, 2020, and 2025 data is from no-build scenario and 2035 is from Scenario E from ABM 14.0.1
Emission factors	EMFAC 2014, SANDAG ABM 14.0.1	For each scenario year: • Running CO2 regional emissions (short tons) • Regional vehicle-miles traveled (VMT) • Regional vehicle trip starts • Trip start CO2 regional emissions (short tons)

Results

Table 27 summarizes the vehicle trip, VMT and CO2 reductions attributed to CBTP.

Table 27: CBTP VMT and GHG Emission Reductions

Variable	2025	2035	2050
Total daily vehicle trip reductions	Final results pending selection of the preferred network scenario		
Total daily VMT reductions			
GHG reduction due to cold starts (short tons)			
GHG reduction due to VMT (short tons)			
Total daily GHG reduction (short tons)			
Total population			
Daily per capita GHG reduction (lbs/person)			
Daily per capita GHG reduction, change in percent			

Attachment 3:

Ascent Environmental Electric Vehicle Calculations Memo

Memo

600 B Street, Suite 300
San Diego, CA 92101
916.444.7301

Date: February 7, 2019

To: Susan Freedman and Allison Wood, San Diego Association of Governments

From: Brenda Hom and Honey Walters

Subject: **SANDAG Electric Vehicle Off-Model Calculator Methodology for SCS Compliance – 2019 San Diego Forward: The Regional Plan – February 2019 Revision**

The San Diego Association of Governments (SANDAG) tasked Ascent with preparing a carbon dioxide (CO_2) emissions calculator for regional electric vehicle (EV) programs that would be considered "off-model" greenhouse gas (GHG) reduction strategies in San Diego Forward: The 2019-2050 Regional Plan (2019 Regional Plan). The 2019 Regional Plan is SANDAG's third Regional Transportation Plan and Sustainable Communities Strategy (RTP/SCS) pursuant to Senate Bill (SB) 375.

SB 375, signed into law in 2008, aligns regional transportation planning efforts and land use and housing allocation with overall State GHG reduction goals. Assembly Bill (AB) 32 (2006) and Executive Order (EO) S-3-05 (2005) established targets for the State to reduce its GHG emissions to 1990 levels by 2020 and 80 percent below 1990 levels by 2050. SB 32, signed in 2016, set an intermediate target of reducing statewide emissions to 40 percent below 1990 levels by 2030. Given that transportation accounts for nearly 40 percent of the state's emissions, the efforts in SB 375 to reduce regional transportation-related emissions are key to supporting the State's GHG reductions goals. (California Air Resources Board [CARB] 2017, 2018a).

SB 375 requires metropolitan planning organizations (MPOs), such as SANDAG, to adopt an SCS or Alternative Planning Strategy, showing land use allocation in each MPO's Regional Transportation Plan. The California Air Resources Board (CARB), in consultation with the MPOs, provides each affected region with per capita reduction targets for GHGs emitted by passenger cars and light trucks in their respective regions for 2020 and 2035. SANDAG serves as the MPO for San Diego county and adopted San Diego Forward: The 2015 Regional Plan in October 2015. In March 2018, CARB adopted the Target Update for the SB 375 targets tasking SANDAG to achieve a 15 percent and a 19 percent per capita reduction in CO_2 emissions from 2005 levels by 2020 and 2035, respectively (CARB 2018a).

In order to ensure that the emissions reductions are solely attributed to MPO actions, CARB sets a number of stipulations in its recommended SB 375 SCS GHG reduction methodology (CARB 2011). CARB recommends that MPOs use a post-processed set of vehicle emissions factors in CARB's EMissions FACtor (EMFAC) model that prevent MPOs from taking credit from improving State and federal vehicle efficiency standards to achieve the assigned targets. This stipulation generally leads MPOs to reduce emissions by reducing vehicle miles traveled (VMT) through land use and transportation planning strategies. Although planning efforts may account for the majority of CO_2 emission reductions under SB 375, CARB allows for the inclusion of "off-model" strategies where MPOs can take emissions reductions credit for transportation programs and other activities that are not fully captured in the regional transportation model, such as SANDAG's Activity Based Model (CARB 2011). The "off-model" strategy programs may include transportation demand management (TDM) and EV incentive programs, which are not generally correlated with land use planning. The "off-model" quantification of the emissions reductions from SANDAG's EV incentive programs under the 2019 Regional Plan is the subject of this memorandum.

2019 REGIONAL PLAN EV OFF-MODEL APPROACH

Background and Purpose

EVs will play a significant role in meeting California's climate goals to reduce GHG emissions from transportation, which accounted for 41 percent of the state's emissions in 2016 (CARB 2018b). The Midterm Review of Advanced Clean Cars Program report confirmed that existing vehicle programs and vehicle emission standards will add at least 1 million zero emission vehicles (ZEVs) on the state's roads and highways by 2025. In the report, CARB also recommended that California make a major push to develop new post-2025 standards while working with automakers, federal regulators and partner states to further develop the market for electric cars. CARB projects that the ZEV market will see more than 20 new electric and plug-in model introductions with greater driving range at mass-market prices and more choices of body styles, brands, and consumer utility in the next few years (CARB 2017a).

In planning for a cleaner statewide vehicle fleet after 2025, EO B-48-18, signed by Governor Brown in January 2018, directs all State entities to work with the private sector to have at least 5 million ZEVs on the road by 2030, as well as install 200 hydrogen fueling stations and 250,000 electric vehicle charging stations by 2025. It specifies that 10,000 of the electric vehicle charging stations should be direct current (DC) fast chargers. Therefore, the population of ZEVs will likely grow at a faster pace than current adoption rates based on CARB's analysis and the direction in EOs. The state and individual regions within the state can significantly exceed the projected number of ZEVs in EMFAC with the successful blend and implementation of regulations, incentives, infrastructure, public-private partnerships, and education and outreach campaigns (International Council on Clean Transportation 2016). The analysis presented in this memorandum provides the GHG emission reductions from the increased displacement of conventional gasoline vehicles with EVs in the SANDAG region, based on proposed EV incentive programs under the 2019 Regional Plan.

In preparation for development of the EV off-model calculator, Ascent reviewed methods used by other MPOs in California, including the Association of Bay Area Governments (ABAG) and Metropolitan Transportation Commission (MTC), Southern California Association of Governments (SCAG), and Sacramento Area Council of Governments (SACOG). In 2013, MTC was one of the first MPOs to develop an EV off-model methodology that accounted for specific EV incentive programs (CARB 2014). MTC used the same approach again in 2017 for Plan Bay Area 2040 (MTC 2017). SCAG's 2016 RTP/SCS adopted MTC's EV methodology to develop their off-model calculations (SCAG 2015). SACOG used the difference in EV market penetration forecasts between two versions of EMFAC (EMFAC2011 and EMFAC2014) to calculate EV off-model reductions relative to EMFAC2011 (SACOG 2015).

The EV programs considered by SANDAG for the 2019 Regional Plan would be most similar to MTC's approach, which quantified CO_2 reductions from a regional EV charger program and a vehicle incentive program. The regional charger program would increase the percentage of electric vehicle miles travelled (eVMT) in the region by increasing the use of battery electric vehicles (BEV) and extending the electric range of plug-in hybrid electric vehicles (PHEV) through the addition of public, workplace, and Direct Current (DC) Fast chargers. The vehicle incentive program would encourage faster turnover of gasoline passenger vehicles to BEVs and PHEVs through rebates relative to default vehicle populations based on EMFAC PEV growth rates and existing vehicle populations. Similar to MTC, SANDAG is considering a Regional EV Charger Program (RECP) and Vehicle Incentive Program (VIP) as part of 2019 Regional Plan to increase the share of eVMT and plug-in electric vehicle (PEV) population in the region.

In reviewing MTC's approach and recent EV studies released by governmental and non-governmental research groups, Ascent found that a number of assumptions used in prior calculators could be expanded upon and better substantiated. Recent EV research includes new charging infrastructure studies specific to California and the SANDAG region, as listed in the bulleted section below. Thus, Ascent updated MTC's approach to include these studies to allow for further variability and substantiation of the assumptions and data used in the calculations. The resulting calculator replaces the EV off-model methodology used in San Diego Forward: The 2015 Regional Plan.

It should be noted that PHEVs and BEVs are herein referred together as PEVs. PEVs and hydrogen fuel cell electric vehicles are together referred to as ZEVs.

The purpose of this EV off-model calculator is to estimate the CO_2 reductions and costs associated with implementation of SANDAG's proposed RECP and VIP. The estimated reductions would contribute towards meeting SB 375 regional CO_2 reduction targets for 2020 and 2035, updated by CARB in March 2018 (CARB 2018a). This calculator expands upon MTC's EV off-model methodology and applies a similar methodology to calculate emission reductions from SANDAG's proposed version of the RECP and VIP. MTC's approach was first developed as part of Plan Bay Area, MTC's 2013 Metropolitan Transportation Plan and Sustainable Communities Strategy (MTP/SCS). At the time MTC's MTP/SCS was being developed, data and studies related to EV charging, travel, and market behavior were limited because PEVs had only been mass produced for about three years in the U.S., starting with the 2010 Nissan Leaf. SANDAG's EV off-model calculator for 2019 Regional Plan takes advantage of more recent and locally-specific research on the EV market and EV travel and charging behavior. Recent policies, research, studies, and models used to develop the 2019 Regional Plan EV off-model calculator include:

- EO B-16-12 and EO B-48-18, which set a target of 1.5 million ZEVs and 5 million ZEVs in the State by 2025 and 2030, respectively.
- *California Plug-In Electric Vehicle Infrastructure Projections: 2017-2025*, published by the California Energy Commission (CEC) in March 2018, which includes projections of the PEV vehicle fleet mix, charger inventory, and charging demand by county that would achieve the 1.5 million ZEV statewide

target by 2025 established in EO B-16-12 and 250,000 EV chargers statewide, including 10,000 DC Fast Chargers, by 2025 established in EO B-48-18 (CEC 2018);

- *Plug-in Electric Vehicle Market Growth Analysis*, prepared by the Center for Sustainable Energy (CSE) for SANDAG in March 2018, which forecasts PEV sales in the San Diego region based on historical PEV sales trends in the area (CSE 2018);

- Electric Vehicle Infrastructure Projection Tool (EVI-Pro), released in early 2018 by the National Renewable Energy Laboratory's (NREL) and CEC, which estimates the public charging infrastructure needed to support a targeted PEV mix by 2025 for various regions across the state by county. Although this tool is not publicly available at this time, NREL and CEC released a web-based data viewer that summarizes the results of the tool for California, including anticipated charger counts and charger loads. The results of EVI-Pro were used to develop projections in CEC's *California Plug-In Electric Vehicle Infrastructure Projections: 2017-2025* report. (NREL 2018a, NREL 2018b);

- EMFAC2017, released in late 2017 by CARB, which updates the statewide vehicle population, emissions, and VMT forecasts by fuel type, vehicle class, and other factors, accounting for adjusted ZEV forecasts that are generally more conservative than previously assumed in EMFAC 2014 (CARB 2017b). EMFAC2017 also accounts for a minimum regulatory compliance scenario under the ZEV mandate in the State's Advanced Clean Cars Program. This mandate requires vehicle manufacturers to produce an increasing number of ZEVs for model years 2018 through 2025.

With respect to the RECP, SANDAG's EV off-model approach is the first among the MPOs to use CEC's EVI-Pro's region-specific results to account for how changes to the targeted PEV population would affect the recommended number of chargers needed. The EVI-Pro tool, mentioned above, uses real-world travel data from mass market consumers to determine the charging infrastructure needed for residential, workplace, and public areas under a variety of scenarios (Alternative Fuels Data Center [AFDC] 2018). CEC's EVI-Pro runs also accounted for county-level PEV distributions and forecast, charger densities, travel behavior, and land use profiles. Additional higher-level factors included fuel sensitivities and range anxiety. Ascent used EVI-Pro results for San Diego County. EVI-Pro's results are limited to forecast years through 2025, which anticipate a maximum PEV share of 4.3 percent of the light-duty fleet in the SANDAG region. In comparison, under EO B-16-12 and EO B-48-18, the targeted statewide EV population mix is approximately five percent by 2025 and 16 percent by 2030. For modeling purposes, Ascent assumed that the trend in charger-to-PEV ratios and other charging behavior anticipated by EVI-Pro through 2025 for San Diego County would continue through 2050.

Key Methods and Assumptions

SANDAG's EV Off-Model includes the following key methods and assumptions used in the model's calculations. The differences from MTC's approach resulted in a more complex calculator, but also one that accounts for San Diego-specific factors.

- CO_2 reductions from the RECP and VIP were calculated in two key steps. First, the difference was taken between the total eVMT supported by each respective program and the eVMT anticipated in a business-as-usual (BAU) forecast for a given milestone year. In cases where the program's eVMT would result in more eVMT than the BAU forecast, the additional eVMT was attributed to the displacement of the same VMT from equivalent gasoline light-duty vehicles (LDV), which was then translated to CO_2 reductions associated with the reduced gasoline LDV VMT. Second, the resulting CO_2 reductions were scaled to SANDAG-related efforts by applying the ratio of SANDAG incentives to non-SANDAG incentives, on dollar-per-dollar basis. To avoid double counting reductions between the RECP and VIP, Ascent assumed that the reductions from additional PHEVs under VIP would be a subset of any additional PHEV eVMT supported by RECP because the RECP is assumed to extend the electric range of any PHEVs purchased under the VIP.

- The BAU forecast was based on a combination of 2018 vehicle populations from DMV registration data, EMFAC2017 ZEV growth rates, and adjustment of EMFAC's daily VMT per vehicle forecasts to SANDAG travel demand modeling.

- CO_2 reductions from the RECP were based on the difference between the total eVMT supported by a targeted number of all non-residential chargers, including existing and new chargers, in the SANDAG region and the eVMT anticipated in the BAU forecast for the SANDAG region for a given milestone year. The targeted total number of chargers in the SANDAG region was calculated using local PEV-to-charger ratios estimated by CEC's EVI-Pro analysis. EVI-Pro estimates that these ratios would change over time and also vary by PEV type. The targeted total number of chargers would be equal to the sum of all existing chargers as of 2018 and any new chargers added starting from 2018. To estimate the number of chargers needed to be incentivized by SANDAG, the number of existing non-residential chargers was subtracted from the targeted number of all non-residential chargers in the region.

- EV chargers were assumed to charge both BEVs and PHEVs. The eVMT provided to each type of vehicle per charger by non-residential charger type (e.g., public vs. workplace) reflect the findings and assumptions in CEC's 2018 study and EVI-Pro runs.

- CO_2 reductions from the VIP were based the difference between the targeted EV population for a given milestone year and the EV population anticipated in the BAU forecast. Average VMT and eVMT per vehicle per day were based on EMFAC2017 defaults, which varies by calendar year and vehicle type.

- As SB 375 only requires MPOs to address tailpipe emissions, upstream emissions from additional electricity demand from EVs are ignored.

Other assumptions include:

- Chargers have a 90 percent charging efficiency;

- Level 2 and DC Fast Chargers would be rated at 6.6 kilowatt (kW) and 105 kW, respectively, starting in 2025;

- PHEVs would not have the ability to use DC Fast Charging; and

- CEC's EVI-Pro analysis defines a charger as "a connector that can serve a vehicle at the full rated power capacity without any operational limitations" (CEC 2018:4). SANDAG's EV off-model tool adopts this definition.

Regardless, the calculator allows the user to adjust these inputs and assumptions in light of evolving research. Other specific assumptions used in the calculator are detailed in the rest of this memorandum.

Model Inputs

The calculator is set up such that the user can input basic program assumptions for the regional charger and vehicle incentive programs (RECP and VIP) for each milestone year (2020, 2025, 2030, 2035, and 2050). Default assumptions included in the background calculations for RECP and VIP can also be changed by the user, if necessary. For each program, the user can choose a target scenario based on preprogrammed inputs or choose a custom target scenario. SANDAG's chosen scenario should reflect the desired exceedance above BAU EV forecasts in order to appropriately assign GHG reduction credits and incentive costs to SANDAG efforts. All scenarios should be based on daily VMT forecasts from the version of SANDAG's regional transportation model that aligns with the applicable Regional Plan.

<u>Scenarios</u>

The tool allows the user to select a different forecast scenario for either the RECP or VIP to determine the total charger or PEV population that SANDAG hopes to achieve under those programs. The preprogrammed inputs include full and partial iterations of three preset scenarios based on State EV targets under EO B-16-12 (State Targets), CEC's EV forecast in EVI-Pro (CEC forecasts), and EV forecasts anticipated in CSE's market study (CSE forecasts). For example, the user can select the full CEC forecast scenario or a 70 percent CEC forecast scenario, which scales down the PEV and charger targets that would have occurred under the CEC forecast scenario by 70 percent. The following describe the three preprogrammed scenarios and the custom scenario option in the tool.

- **State Targets:** The State Targets under EO B-16-12 and EO B-48-18 to achieve 1.5 million EVs by 2025 and 5 million EVs by 2030 were apportioned to the SANDAG region based on the ratios between the EV population in SANDAG and the state as a whole, as modeled by EMFAC2017.

- **CEC Forecast**: The CEC's forecast scenario is based on what the CEC anticipates the PEV population will be like for the SANDAG region in order to meet State Targets for 2025, including the statewide target of having 250,000 EV chargers statewide by 2025. The CEC forecast scenario also accounts for a variety of economic and organizational factors that influence PEV usage. The model assumes that the CEC forecast trends would continue past 2025.

- **CSE Forecast:** The CSE Forecast scenario is based on either a linear or second-order polynomial trend of the PEV population in SANDAG based on historical sales. The second-order polynomial forecast is currently the preferred CSE Forecast scenario per SANDAG staff, though the user has the option to change the trend assumption in the background calculations.

- **Custom Inputs:** The model also allows the user to input custom charger or PEV population targets or custom scenarios based on a chosen fraction of either the State Targets or the CEC forecasts.

Regional Electric Vehicle Charger Program

The RECP CO_2 calculations require the user to select a target scenario of the number of PEVs to be supported by the charger program. This calculator utilizes CEC's results from EVI-Pro (average charger counts based on the default scenario) to calculate a PEV-to-charger ratio for each charger destination type (e.g., workplace, public) that is characteristic of the SANDAG region's EV charging behavior. This provides a recommended number of chargers needed to support the targeted PEV population. Alternatively, the model allows the user to decide on the specific number of chargers to be installed under the program based on fiscal or administrative limitations. The number of average active hours of charging per charger specific to each PEV type and charger type was calculated from CEC's EVI-Pro model results.

With respect to program costs, the user can input the average capital and administrative costs associated with each new charger funded or incentivized by the program. The average costs can be varied or remain constant over time depending on how SANDAG designs the program.

Vehicle Incentive Program

Similar to the RECP calculations, the VIP calculations require the user to either select a target PEV scenario or choose a custom targeted number of vehicles that would be incentivized under the program. If a custom target is chosen, the user can input the number of BEVs or PHEVs that would be incentivized by each milestone year starting with 2020. Once the number of PEVs is selected, the calculator utilizes the average VMT per PEV per day and the default PHEV utility factor (UF) used in EMFAC2017 to estimate the total eVMT associated with VIP. The PHEV utility factor (UF) is defined as the percent of PHEV VMT that is electric. To estimate the CO_2 reductions, the total eVMT from the population of EVs under the VIP is subtracted by the eVMT from population of EVs in the BAU forecast. The additional eVMT under the VIP is assumed to offset emissions from equivalent gasoline LDVs.

With respect to program costs, the user can input the average capital and administrative costs associated with each vehicle incentive. The average costs can be varied or remain constant over time depending on how SANDAG designs the program.

Comparison to State Targets

The calculator allows for the user to evaluate how SANDAG's EV program contributes to the region's overall per-capita CO_2 reduction targets under SB 375 and how the resulting PEV populations compares to the San Diego region's share of the State's EV targets under EO B-16-12 and B-48-18. Once finalized, the forecasted population and daily VMT for the San Diego region can be input into the calculator for each milestone year. To calculate the per-capita CO_2 reductions associated with the EV off-model calculations, total daily reductions from both programs are divided by SANDAG's forecasted population. To evaluate how SANDAG's EV programs would help achieve the State's EV targets, SANDAG's total EV population and eVMT under both EV programs are compared to SANDAG's LDV population and VMT, respectively, for each milestone year.

SANDAG EV OFF-MODEL METHODOLOGY

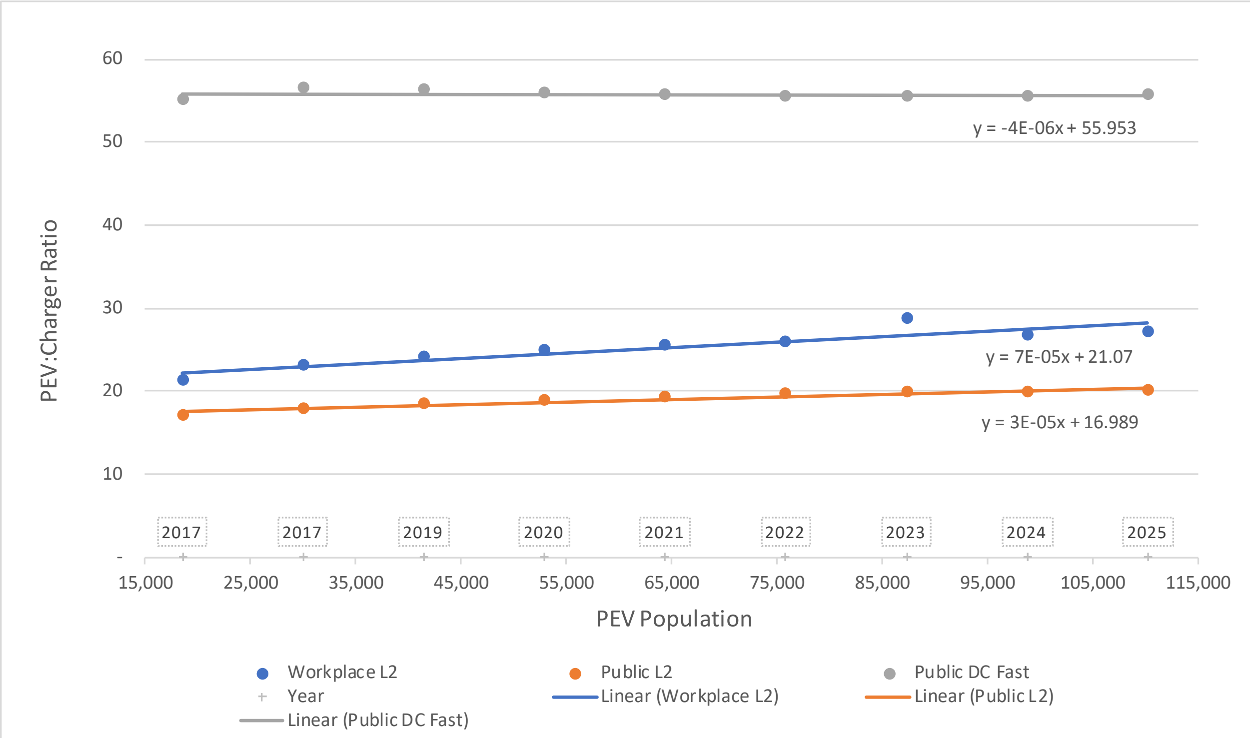
SANDAG's EV off-model calculator quantifies the CO_2 reductions attributable to SANDAG's EV programs that go beyond the reductions that would occur under current State legislation. The calculator quantifies CO_2 reductions associated with implementation of the RECP and VIP for the milestone years 2020, 2025, 2030, 2035, and 2050. These years have been selected primarily to be consistent with the milestone years set in AB 32, SB 32, and SB 375. The tool allows the user to adjust program targets (e.g., number of chargers or vehicles incentivized) and other assumptions to calculate the CO_2 reductions relative to a BAU forecast. The BAU forecast of PEV and eVMT growth is based on historical vehicle sales data and assumed regulatory compliance with the State's ZEV mandate, as modeled in EMFAC2017. Descriptions of how the BAU forecast was calculated for BEVs and PHEVs are shown on pages 11 and 16, respectively. This approach allows CO_2 reductions to be separated out for only SANDAG's programs rather than both State and SANDAG actions.

Both the RECP and VIP calculators use the same assumptions for vehicle emission factors of offset gasoline LDVs and average miles travelled per day per vehicle by vehicle type. For offset gasoline LDVs, emission factors were modeled in EMFAC2017 for the SANDAG region for each milestone year. The EMFAC2017 web database was used to obtain the emission factors, in contrast with the desktop version of EMFAC that includes the post-processed SB 375 analysis option. The SB 375 analysis option in EMFAC is typically used to determine the emissions reductions associated with VMT reductions in future years under a given transportation plan, so that MPOs do not rely on increasing vehicle efficiencies to meet the regional SB 375 CO_2 reduction targets. However, for the purposes of assigning CO_2 reductions to the proposed EV programs, it is more conservative to compare to more efficient gasoline vehicles that have lower emission factors than to compare to gasoline vehicles that have higher emission factors that would have been assumed under the SB 375 analysis option.

Regional Electric Vehicle Charger Program

Under the RECP, SANDAG would continue to expand the public EV charging infrastructure in the San Diego region to support and incentivize the growing PEV population in the region. Chargers alone do not reduce CO_2 emissions. However, the public EV charging infrastructure allows for the PEV population to grow by making it easier and more convenient for PEV drivers to charge their vehicles. The relationship between the charging infrastructure and the PEV population and travel behavior has been a primary study focus for several research groups, including various universities, national laboratories, and state agencies. However, until recently, this research has been limited to the behavior of early PEV adopters.

As the State prepares for greater adoption of PEVs to fulfill its climate goals, SANDAG's RECP calculator utilizes CEC's recent EVI-Pro modeling to account for travel and charging behavior that is more representative of mainstream drivers in the San Diego region (CEC 2018:1). The PEV-to-charger ratios from CEC's EVI-Pro modeling was used to estimate the number of chargers needed to support a given PEV population, accounting for San Diego-specific estimates of the PEV fleet mix, access to home charging, and other factors. The resulting PEV-to-charger ratios characterize the demand for various charger types for a given PEV population and is the basis for both the CO_2 reduction and cost estimates related to the RECP. Based on CEC's results, Ascent calculated a ratio of one charger for approximately every 17 to 56 PEVs, depending on the targeted PEV population and type of charger. Charger types include workplace Level 2, public Level 2, and public DC Fast Chargers. The relationship between PEV population and charger demand by charger type for the San Diego region is shown in Figure 1.



Note: Adapted from CEC's results from EVI-Pro for the San Diego Region, consistent with results in "California Plug-In Electric Vehicle Infrastructure Projections: 2017-2025 Future Infrastructure Needs for Reaching the State's Zero Emission-Vehicle Deployment Goals." (CEC 2018). [1]

Figure 1 PEV-to-Charger Ratio vs. PEV Population for the San Diego Region (2017-2025)

Figure 1 shows the PEV-to-charger ratios between the 2017 and 2025 PEV population in the San Diego region, as assumed in CEC's EVI-Pro modeling. These ratios vary depending on the type of charger and are primarily used to calculate the number of chargers by type needed in the region under the RECP (see Equation 3). This figure also shows that, for 2025, CEC estimates that SANDAG's fair share of PEVs to meet the 2025 goals under EO B-16-12 is 110,227 PEVs. In contrast, EMFAC2017 forecasts that the SANDAG region would have 61,378 PEVs by 2025, almost half of the State's 2025 target. Ascent assumes that the linear trend between 2017 and 2025 would continue past 2025. As such, the equations shown in Figure 1 are used to calculate the number of workplace and public Level 2 and public DC Fast Chargers needed to support a given PEV population, as used in Equation 3. SANDAG's goal under the RECP is to meet the charger demand under a selected PEV population scenario.

CO_2 reductions from implementation of the RECP are based on the effect of the additional chargers on BEV and PHEV travel activity, assumed to offset equivalent gasoline LDV VMT. The RECP affects BEV and PHEV activity differently because charging behavior differs between BEV and PHEV drivers. While BEV drivers may experience range anxiety due to a limited presence of chargers, all miles associated with BEV driving are electric and BEVs are assumed to primarily charge at home (See Figure 2). On the other hand,

[1] EVI-Pro should not be confused with EVI-Pro Lite, a simplified version of EVI-Pro, was not used in this analysis (AFDC 2018). Although EVI-Pro Lite is a publicly available version of EVI-Pro, it does not include many of the assumptions embedded in CEC's California-specific runs. In comparisons between EVI-Pro and EVI-Pro Lite, the latter substantially underestimates the number of DC Fast Chargers in the San Diego region. EVI-Pro Lite also requires the user to input the PEV fleet mix and level of access to home charging, whereas CEC already uses data specific to the San Diego region to support those assumptions.

PHEV drivers have the option of travelling further using gasoline after their electric-only range has been exhausted and a nearby charger is unavailable (It should be noted that no diesel PHEVs are currently on the market). However, the increased availability of chargers could allow PHEV drivers to extend their electric-only range, resulting in a greater percentage of eVMT across all miles driven in a PHEV.

Equations 1 through 3 are used to calculate the CO_2 reductions from BEVs and PHEVs under the RECP for a given milestone year. (Note that SANDAG's EV off-model calculator allows users to adjust all variables, though defaults are provided and explained herein.)

$$E_{RECP} = \left(E_{BEV_{RECP}} + E_{PHEV_{RECP}}\right) * \frac{I_{SANDAG\_RECP}}{I_{SANDAG\_RECP} + I_{Non-SANDAG\_Chargers}} \qquad (Equation\ 1)$$

Where:

E_{RECP} = Emissions reductions associated with implementation of RECP (MT CO_2)

E_{BEV_RECP} = Emissions reductions associated with BEVs under the RECP (MT CO_2)

E_{PHEV_RECP} = Emissions reductions associated with PHEVs under the RECP (MT CO_2)

I_{SANDAG} = Average incentive per chargers under the RECP offered by SANDAG (Dollars)

$I_{Non\text{-}SANDAG\_Chargers}$ = Average incentives per charger totaled across all non-SANDAG programs in the SANDAG region (Dollars)

To attribute the reductions to the RECP, specifically, an additional adjustment is made based on the proportion of the RECP incentives to all incentives offered on a per-charger basis.

<u>BEV CO_2 Reductions</u>

CO_2 reductions from BEVs are based on the difference between emissions from charging associated with the eVMT provided to BEVs under the RECP compared to the eVMT from BEVs anticipated by EMFAC. Any additional eVMT from the RECP is assumed to offset equivalent gasoline LDV VMT. Thus, for a given milestone year, BEV emission reductions from the RECP are based on Equation 2.

$$E_{BEV_{RECP}} = \frac{\left(VMT_{BEV_{RECP}} - VMT_{BEV_{BAU}}\right) * (EF_{Gas})}{10^6 \frac{g}{MT}} \qquad (Equation\ 2)$$

Where:

E_{BEV_RECP} = Emissions reductions from additional BEV eVMT from chargers operating under the RECP scenario compared to the BAU forecasts (MT CO_2)

VMT_{BEV_RECP} = eVMT associated with the electricity provided by chargers to BEVs under the RECP (mi/day)

VMT_{BEV_BAU} = eVMT associated with all BEV VMT under the BAU forecast (mi/day)

EF_{Gas} = Emissions factor per mile associated with gasoline LDVs in the SANDAG region, as modeled in EMFAC2017 (g CO_2/mi). Based on the four EMFAC vehicle categories included in the model's SB 375 analysis option (passenger cars [LDA], light duty trucks with an estimated total weight less than 3,750 pounds [LDT1], light duty trucks with an estimated total weight less between 3,751 and 5,750 pounds [LDT2], and medium duty trucks [MDV]).

VMT_{BEV_RECP} is the eVMT provided to BEVs by all chargers in the SANDAG region including those associated with RECP that would have been installed after 2019. VMT_{BEV_BAU} is the product of the BEV population and the average daily VMT per EV, based on EMFAC2017 results that were adjusted by the difference between SANDAG VMT forecasts and EMFAC VMT forecasts. These and other adjustments were made to EMFAC results because EMFAC2017 does not output EV populations by PEV type and because EMFAC VMT forecasts were not developed based on locally-specific data, as SANDAG VMT forecasts are. The following adjustments were made to EMFAC results to estimate the BAU BEV forecasts:

1. Based forecasts on 2018 BEV populations for San Diego County taken from DMV vehicle registration data,

2. Forecasted the 2018 BEV population into the future years by using EMFAC's assumed growth in LDVs and the assumed proportion of new vehicles that must be ZEVs under the state's ZEV mandate, and

3. Applied an adjustment factor based on the ratio between the SANDAG regional VMT forecast with EMFAC2017's VMT forecast to population and daily VMT per vehicle (CARB 2015, Department of Motor Vehicles [DMV] 2018).

These adjustments were made because EMFAC2017 uses historical vehicle populations through calendar year 2016 and regulation-based EV projections for years after 2016. Thus, projections were calibrated based on actual 2018 vehicle populations. The SANDAG regional VMT forecasts are considered a variable in this off-model calculator and are not shown here due to the current development of SANDAG's travel demand model as part of the 2019 RTP/SCS. The assumptions behind EMFAC's growth forecasts for ZEVs are shown in Table 1 for each ZEV type.

VMT_{BEV_RECP} is calculated from the total number of chargers, active charging time for BEVs per charger, and EV fuel economy as shown in Equation 3.

$$VMT_{BEV_{RECP}} = \sum_{i=Charger\ Type}^{n} \frac{C_i * H_{i_{BEV}} * P_i * \eta_{charger}}{FE_{EV}} \qquad (Equation\ 3)$$

Where:

VMT_{BEV_RECP} = eVMT associated with the electricity provided by chargers to BEVs under the RECP

i = charger type (e.g., Level 2 or DC Fast Charger)

C_i = Cumulative number of chargers by type installed under RECP (chargers).

H_{i_BEV} = Active hours charged by charger type, per charger, per day associated with BEVs (hours/charger)

P_i = Power rating of charger type (e.g., 6.6 kW for Level 2 chargers or between 55 and 105 kW for DC Fast Chargers)

$\eta_{charger}$ = Charger efficiency (i.e., electricity delivered by the charger divided by the electricity drawn from the electricity grid by the charger)

FE_{EV} = Fuel economy of electric vehicles (kWh/mi) (e.g., 0.225 kWh/mi)

Table 1 Zero Emission Vehicle Forecast Assumptions

	PHEV	BEV	FCEV
DMV 2018 Population in San Diego County[1]	11,216	14,960	135
Sectors	Required Percent of New LDV Sales that Must be ZEVs in EMFAC2017[2]		
Model Year	PHEV	BEV	FCEV
2019	1.86%	0.54%	5.44%
2020	3.26%	0.98%	8.59%
2021	4.82%	1.52%	11.34%
2022	5.25%	2.54%	11.93%
2023	6.01%	3.05%	13.00%
2024	6.70%	3.56%	13.98%
2025 through 2050	7.32%	4.06%	14.89%
Sectors	Calculated Year-over-Year Percent Growth in ZEV Population in San Diego County assumed in EMFAC2017		
Model Year	PHEV	BEV	FCEV
2019	20%	6%	167%
2020	28%	11%	141%
2021	30%	15%	104%
2022	26%	14%	69%
2023	23%	14%	50%
2024	20%	13%	40%
2025	18%	12%	36%
2026	16%	10%	27%
2027	13%	9%	21%
2028	12%	9%	17%
2029	10%	8%	15%
2030 through 2050	3-9%	2-7%	3-12%

Notes: EMFAC2017 uses the same future ZEV sales requirements as assumed in EMFAC 2014.

EMFAC = EMission FACtor model; ZEV = zero emission vehicle; SANDAG = San Diego Association of Governments; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; FCEV = fuel cell electric vehicle.

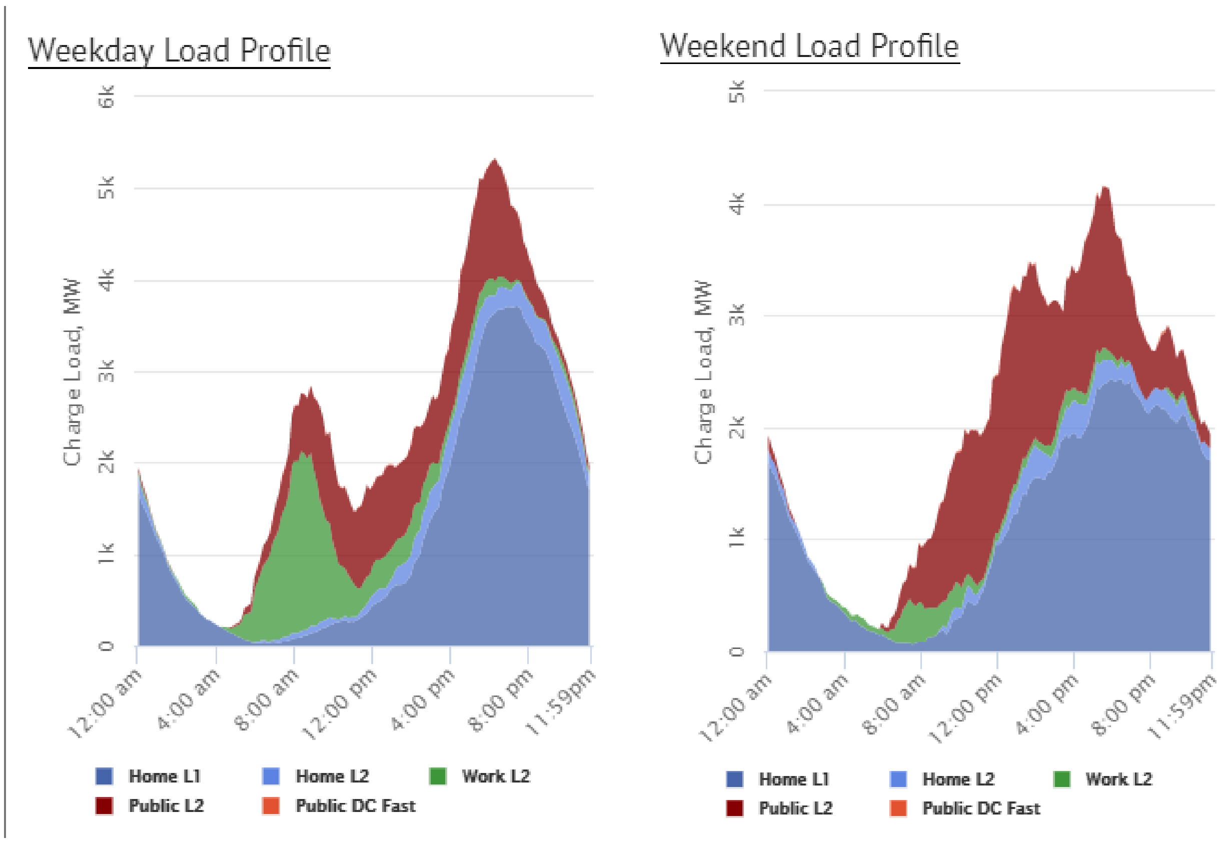
[1] DMV 2018

[2] CARB 2015: Table 3.3-7

Source: CARB 2015: Table 3.3-7, DMV 2018

C_i is calculated from the charger-to-PEV ratio from EVI-Pro (See Figure 1). The active charging referred to in H_i is distinct from charging time, because a car may still be plugged in but not actively charging as the attached car may have completed or stopped charging. For H_i, the default charging activity is shown in at the bottom of Table 3 where workplace chargers are estimated to actively charge BEVs for 0.6 hours and PHEVs for 2.2 hours per charger, across multiple vehicles over the course of an average day. Values in Table 3 were calculated from load profiles by charger type, as shown in Figure 2. These charging times are consistent with the understanding that PHEVs would need to charge more frequently due to their smaller range compared to BEVs. P_i, $\eta_{charger}$, and FE_{EV} assumptions are consistent with those used in CEC's EVI-Pro runs statewide. CEC assumed a charger efficiency of 90 percent in its analysis for all charger types (CEC 2018:25). Charger efficiency is understood here as the electricity delivered by the charger divided by the electricity drawn from the electricity grid by the charger.

The default H_i values given above are calculated from charger load results from CEC's EVI-Pro runs for the SANDAG region (NREL 2018b). The charger load results show how much power, in MW, is drawn from each charger destination type (e.g., public level 2, workplace level 2, and public DC fast charger) over a 24-hour period, as shown in Figure 2. These results varied by the day of the week. Weekday and weekend loads were combined to provide average daily loads.



Source: NREL 2018a. Note that Public DC Fast charger loads are imperceptible in this figure due to very small loads in comparison to other charger types.

Figure 2 **Weekend and Weekday Power Load by Charger Destination Type over a 24-hour Period for SANDAG in 2025**

The area under the curve by each charger type is equal to the daily electricity demand for all chargers in the SANDAG region in 2025, under CEC's target scenario in their 2018 infrastructure report (CEC 2018). Dividing the total energy delivered (in MWh) by the average charger power rating (in kW) gives the average hours charged by charger type. Ascent further disaggregated the charging hours by PEV type using the charger demand profile by PEV type assumed in CEC's modeling (CEC 2018: Figure 4.5). This methodology to calculate the charging hours was recommended by CEC (Bedir, Pers. Comm., 2018). See Table 3 for the resulting calculated active daily charging hours by PEV type and charger type based on the data shown in Figure 2. It was assumed that the 2025 charging behavior by charger type would stay constant from 2020 through 2050. CEC's EVI-Pro analysis did not have similar data available for years other than 2025.

PHEV CO_2 Reductions

For CO_2 reductions from PHEVs, the approach differs from the BEV calculations because the chargers affect the overall electric UF of PHEVs. Depending on the charger assumptions, the chargers would increase the amount of eVMT provided to PHEVs. Dividing the eVMT provided by the chargers by the PHEV VMT assumed in EMFAC would result in a higher UF relative to EMFAC defaults, potentially beyond the maximum UF for PHEVS. The maximum UF for PHEVs, assuming access to charging is widely available, is 80 percent according to a 2017 NREL study and the San Diego 2025 PEV fleet mix [NREL 2017: Figure 26]. MTC used this approach of comparing UFs to assign CO_2 reductions to the MTC's RECP and estimated a UF of 80 percent with additional chargers.

However, PHEV UF assumed under the RECP is inextricably connected with the assumptions used to estimate reductions from the VIP. This is because the VIP has the potential to increase overall PHEV VMT by increasing the number of PHEVs in the region. This affects the calculation of the PHEV UF under the RECP because the UF is calculated by dividing PHEV eVMT provided under the RECP by the total PHEV VMT. Thus, the calculations are set up to avoid double counting reductions from PHEVs from the two programs. This approach is detailed in Equations 4 through 7.

$$E_{PHEV_{RECP}} = E_{PHEV_{BAU}} - E_{PHEV_{SANDAG}} - E_{PHEV_{VIP}} \qquad (Equation\ 4)$$

Where:

E_{PHEV_RECP} = Emissions reductions associated with PHEVs under the RECP (MT CO_2)

E_{PHEV_BAU} = Emissions from PHEVs and Gasoline LDVs in the BAU forecast (MT CO_2)

E_{PHEV_SANDAG} = Emissions from PHEVs that would occur under the RECP and VIP (MT CO_2)

E_{PHEV_VIP} = Emissions reductions from PHEVs that would occur under the VIP only (MT CO_2)

The overall PHEV daily VMT, regardless of fuel types, is assumed to be equal for both E_{PHEV_BAU} and E_{PHEV_SANDAG}. E_{PHEV_VIP} is calculated in Equation 10. The PHEV-related VMT (VMT_{PHEV_SANDAG}) under both programs is assumed to be equal to the product of 1) the total number of PHEVs anticipated under the VIP (incentivized and existing) and 2) average daily VMT per gasoline LDV assumed in the BAU forecast. The PHEV population target under the VIP needs to be greater than or equal to the BAU forecasts to achieve applicable reductions. The VIP CO_2 reductions from PHEVs are subtracted from the total in Equation 4 to avoid double counting.

Equation 5 describes how E_{PHEV_BAU} is calculated.

$$E_{PHEV_{BAU}} = \frac{\left(VMT_{PHEV_{VIP}} - \left[VMT_{PHEV_{BAU}} * UF_{EMFAC}\right]\right) * EF_{Gas}}{10^6 \frac{g}{MT}} \qquad (Equation\ 5)$$

Where:

E_{PHEV_BAU} = BAU-forecasted emissions from PHEVs and Gasoline LDVs (MT CO_2)

VMT_{PHEV_VIP} = Daily VMT associated with entire PHEVs population under the VIP (mi/day)

VMT_{PHEV_BAU} = BAU-forecasted daily VMT associated with all PHEVs (mi/day)

UF_{EMFAC} = Default PHEV Utility Factor assumed in EMFAC2017 (%).

EF_{Gas} = Emissions factor per mile associated with gasoline LDVs in the SANDAG region, as modeled in EMFAC2017 (g CO_2/mi). Based on EMFAC vehicle categories LDA, LDT1, LDT2, and MDV.

VMT_{PHEV_VIP} is the product of the total PHEV population under VIP and the average daily miles per gasoline LDV, as modeled in EMFAC2017. VMT_{PHEV_BAU} is calculated by multiplying the PHEV population and the average daily gasoline VMT per LDV, based on EMFAC2017 results that were adjusted by the difference between SANDAG VMT forecasts and EMFAC VMT forecasts. As with the approach for BEVs, these and other adjustments were made to EMFAC results because EMFAC2017 does not output EV populations by PEV type and because EMFAC VMT forecasts were not developed based on locally-specific data, as SANDAG VMT forecasts are. The following adjustments were made to EMFAC results to estimate the business-as-usual PHEV forecasts:

1. Based forecasts on 2018 PHEV populations for San Diego County taken from DMV vehicle registration data,

2. Forecasted the 2018 PHEV population into the future years by using EMFAC's assumed growth in LDVs and the assumed proportion of new vehicles that must be ZEVs under the state's ZEV mandate, and

3. Applied an adjustment factor based on the ratio between the SANDAG regional VMT forecast with EMFAC2017's VMT forecast to both the PHEV population and daily VMT per vehicle (CARB 2015, DMV 2018).

As with the approach for BEVs, these adjustments were made because EMFAC2017 uses historical vehicle populations through calendar year 2016 and regulation-based EV projections for years after 2016. Thus, projections were calibrated based on actual 2018 vehicle populations. The SANDAG regional VMT forecasts are considered a variable in this off-model calculator and are not shown here due to the current development of SANDAG's travel demand model as part of the 2019 RTP/SCS. EMFAC's ZEV forecast assumptions are shown in Table 1.

UF_{EMFAC} was based on data obtained directed from CARB. CARB provided PHEV UF assumptions for each model year (MY) starting with MY 2018. Prior to MY 2018, EMFAC assumes all PHEVs have a UF of 40 percent, which was the assumption used in MTC's EV off-model calculator. For EMFAC2017, however, CARB increased the UF assumptions for future model years to account for increasing electric range of available PHEVs (Long, pers. comm., 2018b). EMFAC2017 UF assumptions by model year are summarized in Table 2. These assumptions were applied to the PHEV population mix in EMFAC to calculate a weighted average UF_{EMFAC} that accounts for the different UFs across model years for a given calendar year.

Table 2 EMFAC2017 PHEV Utility Factor Assumptions

Model Year	PHEV UF
Pre-2018	40%
2018	46%
2019	47%
2020	48%
2021	50%
2022	55%
2023	56%
2024	58%
2025 though 2050	59%

Notes: UF assumptions apply statewide. EMFAC = EMission FACtor model; PHEV = plug-in hybrid electric vehicle; UF = utility factor.

Source: Long, pers. comm., 2018b

Equation 6 describes how E_{PHEV_RECP} is calculated.

$$E_{PHEV_{SANDAG}} = \frac{\left(VMT_{PHEV_{VIP}} - [1 - UF_{RECP}]\right) * EF_{Gas} + VMT_{PHEV_{VIP}} * UF_{RECP} * EF_{EV}}{10^6 \frac{g}{MT}} \qquad (Equation\ 6)$$

Where:

E_{PHEV_SANDAG} = Emissions from PHEVs as anticipated under 2019 Regional Plan scenarios with the implementation of the off-model programs (MT CO_2)

VMT_{PHEV_VIP} = Daily VMT associated with PHEVs under the VIP (mi/day)

UF_{RECP} = PHEV utility factor associated with charger scenario under the RECP. Limited to be between UF_{EMFAC} and a maximum of 80 percent. (%)

EF_{Gas} = Emissions factor per mile associated with gasoline LDVs in the SANDAG region, as modeled in EMFAC2017 (g CO_2/mi). Based on EMFAC vehicle categories LDA, LDT1, LDT2, and MDV.

EF_{EV} = FE_{EV} * EF_E (g CO_2/mi) (See Equation 2)

UF_{RECP} is the calculated PHEV UF associated with the charging scenario under the RECP, as shown in Equation 7.

$$UF_{RECP} = \frac{eVMT_{PHEV_{RECP}}}{VMT_{PHEV_{VIP}}} \qquad (Equation\ 7)$$

Where,

$eVMT_{PHEV\_RECP}$ = eVMT associated with the electricity provided by chargers to PHEVs under the RECP

VMT_{PHEV_VIP} = Daily VMT associated with PHEVs under the VIP (mi/day)

$eVMT_{PHEV\_RECP}$ is the eVMT provided to PHEVs by all chargers in the SANDAG region including those associated with RECP. $eVMT_{PHEV\_RECP}$ is calculated identically to Equation 3, with the exception of H_i. In the case of PHEVs, H_{i_PHEV} refers to the active hours charged by charger type per charger per day associated with PHEVs. To simplify model assumptions, the H_i for both BEVs and PHEVs were assumed to be constant for all milestone years based on charger load assumptions used in CEC's EVI-Pro analysis for 2025 for the San Diego region.

Tables 3 and 4 show the assumptions and calculation of the active charging hours (H_i) for BEVs and PHEVs by non-residential charger type based on the CEC's EVI-Pro charger load profile, which is based on data behind Figure 2. Table 3 shows the charger load profile that CEC's EVI-Pro model quantified for the San Diego region in 2025 broken out by PEV and charger type. Table 4 shows the estimated charging behavior (i.e., hours of charge per day per PEV by charger type and day of the week) based on the data in Table 3. The average daily charging patterns by PEV are used as the active charging hours (H_i) applied in Equation 3 to calculate the VMT anticipated from each PEV type under the RECP.

Note that fuel cell electric vehicles (FCEV) were not included in the RECP calculations because FCEVs are assumed to only be fueled via hydrogen fueling stations and are not assumed to have on-board batteries that can be charged separately from the hydrogen fuel cell.

Table 3 CEC EVI-Pro Charging Behavior Results for 2025 in the San Diego Region

Metric	Unit	Workplace L2	Public L2	Public DC Fast	Total
EVI-Pro Charger Load Results[4]	Number of Chargers[1]	4,051	5,485	1,981	11,517
	MWh/weekday[2]	86	79	53	218
	MWh/weekend[2]	21	106	125	252
	BEV kW[3]	6.6	6.6	105	N/A
	PHEV kW[3]	4.9	4.9	-	N/A
Percent of Demand Associated with BEVs by Charger Type	%[5]	27	6	100	N/A
Percent of Demand Associated with PHEVs by Charger Type	%[5]	73	94	0	N/A
BEVs per charger by type	Vehicles[6]	11	8	22	4
PHEVs per charger by type	Vehicles[6]	16	12	33	6

Notes: Values may not sum due to rounding. DC = direct current; CEC = California Energy Commission; MWh = megawatt-hours; BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle; L2 = Level 2 charger, kW = kilowatt; PEV = plug-in electric vehicle

[1] NREL 2018b

[2] Bedir, Pers. Comm., 2018

[3] CEC 2018: Table 4.1

[4] CEC assumed a charger efficiency of 90% across all chargers and PEV combinations (CEC 2018: 25)

[5] CEC 2018: Figure 4.5

[6] Calculated by dividing the number of chargers by the 2025 BEV or PHEV population based on a total population of 110,227 and apportioned based on the calibrated EMFAC population forecast for BEVs and PHEVs in 2025.

Table 4 Calculated Active Charger Load and Hours per Charger by PEV in 2025 in the San Diego Region[1]

Metric	Day	Workplace L2	Public L2	Public DC Fast	Total
kWh delivered to ALL BEVs per day per charger	Weekday	5	1	24	30
	Weekend	0	0	6	6
	Average	4	1	19	23
kWh delivered to ALL PHEVs per day per charger	Weekday	14	12	0	26
	Weekend	3	16	0	20
	Average	11	13	0	24
Active Charging Hours for ALL BEVs per day per charger (H_{i_BEV})[2]	Weekday	0.8	0.1	0.2	1
	Weekend	0.0	0.0	0.1	0.1
	Average	0.6	0.1	0.2	1
Active Charging Hours for ALL PHEVs per day per charger (H_{i_PHEV})[3]	Weekday	2.9	2.5	0	5
	Weekend	0.7	3.3	0	4
	Average	2.2	2.7	0	5

Notes: Values may not sum due to rounding. DC = direct current; MWh = megawatt-hours; BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle; L2 = Level 2 charger, kWh = kilowatt-hours; PEV = plug-in electric vehicle

[1] For each charger type, active charging hours by PEV equals the product of daily MWh, efficiency, and percent demand by PEV type divided by the number of chargers based on data shown in Table 3.

[2] The average daily results should be used to represent the H_{i_BEV} variable shown in Equation 3.

[3] The average daily results should be used to represent the H_{i_PHEV} variable based on Equation 3.

Vehicle Incentive Program

Under the VIP, SANDAG would offer incentives for drivers to replace older gasoline passenger vehicles with equivalent PEVs. While SANDAG could consider incentivizing fuel-cell electric vehicles (FCEVs) in addition to PEVs, this calculator only accounts for reductions associated with incentives for PEVs due to the relatively small FCEV population forecast and limited amount of existing infrastructure (see Table 1). The VIP would increase the share of PEVs among the LDA fleet in the San Diego region. It is assumed that the VIP would not increase or decrease overall VMT in the San Diego region anticipated under 2019 Regional Plan.

The CO_2 reductions associated with the VIP are essentially a comparison of the new eVMT that would occur from the additional BEVs and PHEVs incentivized under the program beyond the BAU forecast. To account for reductions attributed to non-SANDAG incentives, an additional adjustment is made based on the proportion of the VIP incentives to all incentives offered on a per-vehicle basis. The calculation of CO_2 reductions from VIP are reflected in Equations 8 through 10. Similar to Equation 1, the emissions reductions from VIP are the sum of the emissions reductions from BEVs and PHEVs under the program.

$$E_{VIP} = \left(E_{BEV_{VIP}} + E_{PHEV_{VIP}}\right) * \frac{I_{SANDAG\_VIP}}{I_{SANDAG\_VIP} + I_{Non-SANDAG\_ZEV}} \qquad (Equation\ 8)$$

Where:

E_{VIP} = Emissions reductions associated with implementation of VIP (MT CO_2)

E_{BEV_VIP} = Emissions reductions associated with BEVs under the VIP (MT CO_2)

E_{PHEV_VIP} = Emissions reductions associated with PHEVs under the VIP (MT CO_2)

I_{SANDAG} = Average incentive per ZEV under the VIP offered by SANDAG (Dollars)

$I_{Non\text{-}SANDAG\_Chargers}$ = Average incentive per ZEV totaled across all non-SANDAG programs in the SANDAG region (Dollars)

<u>BEV CO_2 Reductions</u>

CO_2 reductions from BEVs are based on the difference between emissions from charging associated with the eVMT of the BEVs incentivized under the VIP compared to the eVMT from BEV anticipated by EMFAC. Any additional eVMT from the VIP is assumed to offset equivalent gasoline LDV VMT. Similar to Equation 2, BEV emission reductions from the VIP are based on the following equation.

$$E_{BEV_{VBIP}} = \frac{\left(VMT_{BEV_{VIP}} - VMT_{BEV_{BAU}}\right) * EF_{Gas}}{10^6 \frac{g}{MT}} \qquad (Equation\ 9)$$

Where:

E_{BEV_VIP} = Emissions reductions from the BEV population under VIP compared to the BAU forecast (MT CO_2)

VMT_{BEV_VIP} = eVMT associated with all BEVs including those incentivized under the VIP (mi/day)

VMT_{BEV_BAU} = eVMT associated will all BEV VMT under the BAU forecast (mi/day)

EF_{Gas} = Emissions factor per mile associated with gasoline LDVs in the SANDAG region, as modeled in EMFAC2017 (g CO_2/mi). Based on EMFAC vehicle categories LDA, LDT1, LDT2, and MDV.

Because both Equations 2 and 9 calculate reductions relative to EMFAC-forecasted VMT, BEV emissions reductions from VIP (E_{BEV_VIP}) are assumed to be independent of the BEV reductions from RECP (E_{BEV_RECP}). VMT_{BEV_VIP} is the product of the targeted BEV population under VIP and the average daily miles per vehicle for EVs as modeled in EMFAC2017 and adjusted based on the difference between SANDAG and EMFAC VMT forecasts. VMT_{BEV_BAU} and EF_{Gas} are the same values used in Equation 2.

<u>PHEV CO_2 Reductions</u>

For emission reductions from PHEVs, the approach is similar to Equation 6 with an added complication behind the UF assumption.

$$E_{PHEV_{VIP}} = \frac{\left(VMT_{PHEV_{VIP}} * [1 - UF_{VIP}]\right) * EF_{Gas}}{10^6 \frac{g}{MT}} \qquad (Equation\ 10)$$

Where:

E_{PHEV_VIP} = Emissions from PHEVs as anticipated under the VIP (MT CO_2)

VMT_{PHEV_VIP} = Daily VMT associated with PHEVs under the VIP (mi/day)

UF_{VIP} = PHEV utility factor assumed for VIP (%)

EF_{Gas} = Emissions factor per mile associated with gasoline LDVs in the SANDAG region, as modeled in EMFAC2017 (g CO_2/mi). Based on EMFAC vehicle categories LDA, LDT1, LDT2, and MDV.

VMT_{PHEV_VIP} is the product of the targeted PHEV population under VIP and the average daily miles per vehicle for gasoline LDVs as modeled in EMFAC2017 and adjusted based on the difference between SANDAG and EMFAC VMT forecasts. To be conservative and to avoid circular arguments, UF_{VIP} is assumed to be equal to the UF assumed under EMFAC2017 (UF_{EMFAC}).

Incentive Costs

To estimate the cumulative incentive program costs to SANDAG, the user can input SANDAG's incentive costs per charger or vehicle and percent-based administrative costs (e.g., five percent of all vehicle incentives) for each milestone year. For the RECP, the user can choose SANDAG's average incentive cost per workplace charger, public L2 charger, and public DC Fast Charger. For the VIP, the user can choose SANDAG's average incentive cost per BEV and PHEV. The total cost of each program would be based on the per-unit incentives multiplied by the associated new chargers or PEV populations as of 2018, as calculated from the EV off-model calculator for each milestone year. The calculated costs are cumulative, because the tool calculates the cumulative number of new chargers and PEVs as of 2018 associated with the RECP and VIP. Thus, the input costs per unit should reflect the average cost across all new chargers or vehicle incentivized since 2018.

Results

[TO BE ADDED ONCE SANDAG SELECTS SCENARIO]

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Personal Communications

Bedir, Kadir. Air Pollution Specialist. California Energy Commission, Sacramento, CA. July 6, 2018. – call with Brenda Hom of Ascent Environmental regarding questions on how to estimate charging hours associated with different PEVs and charger destination types.

Long, Jeffrey. Staff Air Pollution Specialist. Mobile Source Analysis Branch, Air Quality Planning and Science Division, California Air Resources Board, El Monte, CA. June 25, 2018a – email to Brenda Hom of Ascent Environmental with a breakdown of the ZEV population by ZEV type and model year through 2017 for the month of October 2016 in the SANDAG region, as modeled in EMFAC2017;

June 8, 2018b – email to Brenda Hom of Ascent Environmental with the assumed utility factor for PHEVs in EMFAC2017 by model year.