Guidehouse

Transportation Electrification Proactive Planning: Corridor Disaggregation Methodology

DRAFT FOR PUBLIC COMMENT

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List of Acronyms and Terminology

- AADT: Average annual daily traffic derived from the Federal Highway Administration's Freight Analysis Framework, Version 5, and trip data. Average annual daily traffic is the number of vehicles that travel across a corridor segment on an average day.
- Charger: Electric vehicle supply equipment used to charge electric vehicle batteries, which may consist of one or many ports.
- Corridor Disaggregation Methodology: The methodology by which public DC charging load for LD and MDHD EVs is allocated to specific corridor segments throughout major corridors in California.
- Corridor Segment: A section of a major arterial and collector road, interstate highway, collector/distributor lane or controlled access highway no longer than 3 miles in length that varies in traffic volume from adjacent sections of the same major arterial and collector road, interstate highway, collector/distributor lane or controlled access highway and exists in a single utility territory
- CTC: California Transportation Commission
- DAC: Disadvantaged Community, as designated by CalEnviroScreen. Disadvantaged Communities refer to areas throughout California which are most impacted by a combination of economic, health and environmental indicators.
- DCFC: Direct current fast charging infrastructure for electric vehicles
- EV: Electric vehicle
- FAF 5: Federal Highway Administration's Freight Analysis Framework, Version 5, providing estimates of US freight flows
- I&A: CPUC's Transportation Electrification Proactive Planning Modeling Inputs and Assumptions
- IEPR: Integrated Energy Policy Report
- IOU: Investor-Owned Utility
- L2: Level 2 charging infrastructure for electric vehicles, operating anywhere from 3 kW to 19 kW of AC power
- LD: Light duty [vehicle]
- MDHD: Medium and heavy duty [vehicle]
- Non-attainment area (NAA): [Ozone] Nonattainment areas, EPA terminology for areas that do not meet the national primary or secondary ambient air quality for a national ambient air quality standard (NAAQS)
- O/D: Origin/destination, typically used in reference to vehicle trip data that provides insights into where a vehicle began its trip and where a vehicle completed its trip
- Port: The component of a charger that is physically connected to an electric vehicle to provide energy to the vehicle.
- POU: Publicly owned utilities

- SOC: State of charge, measured as the current energy in an electric vehicle's battery divided by the total battery capacity. The SOC is used to indicate how much energy an electric vehicle has left in its battery.
- TE: Transportation Electrification
- TOU: Time of use, used in reference to electric rates that have different costs of electricity based on the time of day the energy is pulled from the grid.
- VGI: Vehicle-grid-integration; any method of altering the time, charging level, or location at which grid-connected electric vehicles charge or discharge in a manner that optimizes interaction with the electric grid
- VMT: Vehicle Miles Traveled

1. Introduction

The adoption of battery electric vehicle (BEV) technology in the California market is rapidly extending beyond light-duty (LD) vehicles. Meeting the energy demand and transportation needs of medium- and heavy-duty (MDHD) electric vehicles will require public charging infrastructure. Transportation electrification (TE) infrastructure planning must account for increased load impacts to California's electric system from the emerging MDHD BEV population as the market develops.

To support this infrastructure planning, the California Public Utility Commission (CPUC) has engaged Guidehouse Inc. to develop a Corridor Disaggregation Methodology (CDM). The **purpose** of this methodology is to inform targeted grid planning by estimating public charging demand for LD and MDHD BEVs, and depot charging demand for MDHD BEVs within one mile of 150 major California corridors at a granular level. The **objective** of this document is to outline the **Corridor Disaggregation Methodology (CDM)** which leverages the TEPP Modeling Input and Assumptions (TEPP Modeling I&A). The CDM can be used by the California Energy Commission (CEC) as part of its approach to disaggregating the load from its Integrated Energy Policy Report (IEPR) energy demand forecast. The CDM brings together I&A including charging assumptions and geospatial input data for various corridors within the state of California to identify demand for charging on a corridor segment basis.

1.1 Overview of Corridor Disaggregation Methodology

The CDM intends to identify expected TE load associated with public LD and MDHD BEV charging and MDHD BEV depot charging along 150 California highway corridors, leveraging the TEPP Modeling I&A. The output of the CDM is a disaggregation of TE charging demand **through 2045 for each corridor segment** (see Sections 1.2, Section 2.1 through 2.5).

The CDM will leverage the TEPP Modeling I&A for data inputs and assumptions. This includes integrating trip data and charging behavior insights to accurately model how much energy will be required to support BEVs, where BEV charging is likely to take place, and what BEV charging load can be expected for all hours of an average day across California's highway corridors.

The CDM will identify load associated with 150 major arterial and collector roads, interstate highways, collector/distributor lanes and controlled access highways in California split into corridor segments. Each **corridor segment** will be defined as a section of a major arterial and collector road, interstate highway, collector/distributor lane or controlled access highway that varies in traffic volume from adjacent sections of the same major arterial and collector road, interstate highway, collector/distributor lane or controlled access highway and exists in a single utility territory.

1.2 Approach to BEV Load Calculation

This section describes the approach to calculating BEV charging load used in the CDM.

1.2.1 BEV Charging Load

BEV charging load is the hourly load, in megawatts (MW), that BEVs are expected to use for charging. The first step in determining BEV charging load will be to calculate the cumulative energy required for BEVs to traverse all corridor segments associated with a trip. The cumulative BEV energy requirement is the sum of the BEV energy requirement (see Appendix A) associated with each corridor segment a vehicle passes through while driving from an 'Origin A' to a 'Destination B.' This cumulative energy requirement will be determined by integrating trip data from the TEPP Modeling I&A to establish corridors on which BEVs will travel. See Appendices A through C for more details on the cumulative energy requirement calculation.

After the cumulative energy requirement is calculated, charging behavior will be integrated to model *where* charging is occurring along highway corridors and *when* it is likely to occur at hourly intervals. Charging behavior assumptions will be informed by the TEPP Modeling I&A.

To establish *where* charging is likely to occur, the CDM identifies the BEV energy requirement associated with each corridor segment, which will be the cumulative energy requirement used by a BEV while traveling from its origin to the corridor segment where it will charge. To establish *when* during the day charging will happen, the CDM will determine the hourly load for a given corridor segment by allocating the corridor's daily BEV energy requirement to each hour of the day based on a normalized load shape.

Table 1-1 provides parameters that will be used to define charging behavior in the CDM.

Table 1-1. Parameters Associated with Charging Behavior

Charging Behavior Parameter	Associated Assumption	Description
Starting Vehicle State-of-Charge (SOC)	Charging Location	BEV minimum SOC when beginning trip
En-Route Vehicle SOC	Charging Location	BEV minimum SOC integrated with calculated SOC along trip that identifies where vehicles will need to charge
Presence of Rest Stops	Charging Location	Rest stops as potential locations of future BEV public charging infrastructure signifying convenient and known stopping locations

Charging Behavior Parameter	Associated Assumption	Description
Presence of Truck Stops	Charging Location	Truck stops as potential locations of MDHD BEV public charging infrastructure signifying convenient and known stopping locations
Presence of Existing/Planned Infrastructure	Charging Location	Existing infrastructure identifying where BEV charging behavior may occur through convenience
Proximity to Fleet Depots	Charging Location	Depots in close proximity to corridor segments, which may indicate a reduced need for public charging infrastructure
Local BEV Traffic Volume	Charging Location	Areas of high BEV traffic volume, which may indicate ideal locations for charging infrastructure rollout
Trip Destinations	Charging Location	Corridor segment a trip concludes, which may align with where a vehicle charges based on fleet owners' preference towards charging vehicles at the end of trips as opposed to en route
Home Charging Access	Charging Location	Home charging access represents how prevalent the option to charge at a BEV owner's residence is, and limited access to home charging will lead to increased charging at other locations, e.g., public charging
Price Signals	Charging Time	Economic incentives, such as off-peak electricity costs, to shift the time of BEV charging
Load Management	Charging Time	May include active and passive managed charging, as implemented through Vehicle-Grid-Integration (VGI)

Table 1-2 outlines the charging use case and charging technology combinations included in the vehicle-per-charger ratios.

Table 1-2. Charging Use Cases and Technologies

Charging use case	Charging technology	Description
HD Corridor (intercity)	DCFC	Public charging of HD long-haul BEVs using Direct Current Faster Chargers (DCFC)
HD Depot	DCFC	Private charging of HD BEV fleets, excluding long-haul BEVs, using DCFC
MDHD Hub (regional)	DCFC	Public charging of MDHD BEVs that serve local or regional routes using DCFC
HD Long-Haul Depot	DCFC	Private charging of HD long-haul BEV fleets using DCFC
MD Depot	DCFC	Private charging of MD BEV fleets using DCFC
MD Depot	L2	Private charging of MD BEV fleet using Level 2 (L2) chargers
LD BEV Depot	DCFC	Private charging of LD BEV fleets using DCFC
LD BEV Depot	L2	Private charging of LD BEV fleets using L2 chargers
LD Public	DCFC	Public charging of individually owned LD BEVs using DCFC chargers
LD Public	L2	Public charging of individually owned LD BEVs using L2 chargers

1.3 Scope of Analysis

The CDM will focus analysis on 150 major arterial and collector roads, interstate highways, collector/distributor lanes and controlled access highways across California, broken into corridor segments.

The 150 roads and highways represent all major arterial and collector roads, interstate highways, collector/distributor lanes and controlled access highways across California identified in the FAF 5 data. The roads and highways are either 50 miles or more[1] in length, included as part of the 34 priority corridors defined by CTC's SB 671 Clean Freight Corridor Assessment, or included in the National Zero-Emission Freight Corridor Strategy that was released in March 2024.

Corridor segments were determined based on the existing segmentation of roads in the Federal Highway Administration's Freight Analysis Framework, Version 5 (FAF 5). Further segmentation was conducted to reduce any segment to no greater than three miles in length, and split any segment that overlapped utility service territories into territory-unique segments. For example, if a segment in the FAF 5 data was five miles in length, the CDM would split that segment into two segments of 2.5 miles in length. If a segment crossed from PG&E's service territory into SCE's service territory, the CDM would split that segment into two segments, with one exclusively in PG&E's service territory and one exclusively in SCE's service territory.

[1] 50-mile minimum length specified in CTC's SB 671 Clean Freight Corridor Assessment

1.4 Data and Inputs

The CDM will incorporate several data sets as inputs, which are provided through the TEPP Modeling I&A. The data and inputs can be grouped into three categories that support certain aspects of the CDM:

- **Geospatial data**, used to associate characteristics to corridor segments
- **Electric vehicle and EVSE characteristics**, used to determine where BEVs are traveling and the energy associated with those trips
- **Charging behavior**, used to determine where BEVs are likely to charge along California's major highway corridors and when BEVs are likely to charge during an average day

Data granularity is a critical feature for both BEV characteristics and charging behavior. The CDM breaks out electric vehicle data by vehicle use case, duty, ownership, year, and census tract. Charging behavior data and load shapes are broken out by charging use case, vehicle use case, duty, ownership and charging technology.

Table 1-3, Table 1-4, and Table 1-5 outline the data that are used to inform the CDM. The TEPP Modeling I&A Report provides more details about the data and its assumptions.

Table 1-3. Geospatial Data for CDM

Data/Input	Description
California Counties	Geographic information system (GIS) shapefiles for county borders; this will allow for targeting of corridor segments within a certain county and understand vehicle trips, charging infrastructure, and grid impacts associated with that geographical area.
Freight Analysis Framework (FAF) 5 Model Highway Network (California's Highway Corridors)	FAF 5 geodatabase that includes all roads in the National Highway System and the National Highway Freight Network, showing traffic flows by corridor segment at five-mile increments; this will allow for identification of a comprehensive road network in California and the travel patterns of MDHD BEVs along those roads.
IOU/POU Service Areas	GIS shapefiles for IOU and POU service areas; this will allow for identification of corridor segments associated with specific IOUs and POUs.
Disadvantaged Communities (DAC)	California Office of Environmental Health Hazard Assessment's (OEHAA) CalEnviroScreen locations; this shapefile will allow for identification of corridor segments in close proximity to DACs and attempt to increase electrification in those areas to reduce negative health impacts from transportation pollution.

Data/Input	Description
PM2.5 and Ozone Non-Attainment Areas (NAA)	NAA geographic layers that will be used to associate corridor segments with non-attainment areas, or any areas that do not meet (or that contribute to ambient air quality in nearby areas that do not meet) the national primary or secondary ambient air quality standards for National Ambient Air Quality (NAAQ).
Planned & Existing Public Charging Infrastructure	AFDC-provided geographic spatial layers that identifies where planned and currently existing public charging infrastructures will be or is located; this includes the number of ports, associated charging power, and accessibility (public/private), and will be used to current nodes in the charging network and identification of gaps for optimal charging locations.
Truck Stops	Geographic layer from Find my fuels that identifies the location of major California truck stops; this will be used to provide insights into where electric semis may recharge at public stations along transportation corridors.
Rest Stops	Geographic layer from Caltrans that will be used to identify locations of California rest stops, and that has the potential to offer insights into where passenger BEVs may recharge at public stations along transportation corridors.
Fleet Depots	Geographic layer currently only available through private sector vendors that identifies the location of major California fleet depots. This offers improved accuracy in fleet domicile locations and offers better precision in determining where public charging infrastructure should be located to facilitate fleet routes.

Table 1-4. BEV Characteristics for CDM

Data/Input	Description
BEV Population	Used to determine what percent of traffic associated with a corridor segment is attributable to BEVs
Origin/Destination Data	Used to determine where BEV trips are beginning and ending
Trip Route Data	Used to determine what corridors are used for BEV trips
Annual Average Daily Trips	Used to both verify accuracy of trip route data and develop weights for route likelihood
BEV Battery Capacity	Used to establish BEV range and BEV state-of-charge along trips
BEV Efficiency	Used to determine energy required to traverse corridor segments and impact on BEV state-of-charge
Public Charging %	Used to determine what percent of BEV load will be charged using public charging infrastructure
Vehicle per Charger Ratio	Used to determine the number of charging ports needed to support BEV charging, based on the number of BEVs

Table 1-5. Charging Behavior for CDM

Data/Input	Description

Vehicle Start SOC	Used to determine the SOC of a BEV as it begins its trip
Likelihood to Charge by SOC	Used to determine the probability that a BEV charges given its current SOC
Likelihood to Charge by Trip Details	Used to determine the probability that a BEV charges given where a trip ends or a trips length
Public Charging %	Used to determine what percent of BEV load will be charged using public charging infrastructure
BEV Charging Load Shape	Used to determine at what hours during an average day BEVs are charging (BEV hourly load)

1.5 Document Contents

The remainder of this document is organized as follows:

- **Section 2: CDM Implementation** describes the components and functionality of the CDM.
- **Section 3: Potential Future Refinements** outlines the suggested future enhancements to the CDM as it continues to evolve over time.
- **Section 4: Key Considerations** outlines some of the limitations with the currently best available data.

2. CDM Implementation

Corridor Disaggregation Methodology Implementation

The purpose of the CDM is to estimate public charging demand for LD and MDHD BEVs, and depot charging demand for MDHD BEVs within one mile of 150 major California corridors at a granular level. The CDM builds on work conducted by the California Transportation Commission (CTC), which was mandated by Senate Bill 671 to conduct a Clean Freight Corridor Efficiency Assessment to identify road networks and major arterial corridors that will require charging infrastructure to support zero-emission (ZEV) MDHD vehicles.

This section provides a detailed description of the **CDM**. This process begins by segmenting California's highway corridors and assigning characteristics to each corridor segment. This will determine the energy requirement associated with BEVs traversing each corridor segment.

Once the corridor segments and associated energy requirements for BEVs traversing the segment have been established, trip data will help determine the most likely routes of travel and the cumulative BEV energy requirement for trips passing along each route. Charging behavior data will then help identify **where** along the routes and corridors charging is most likely to occur, and **when** charging will occur during an average day. **Where** charging is likely to occur establishes the amount of energy needed to charge BEVs at each corridor segment. **When** charging is likely to occur, represented by load shapes, establishes the hourly BEV load.

Figure 2-1. CDM Output Calculation Process

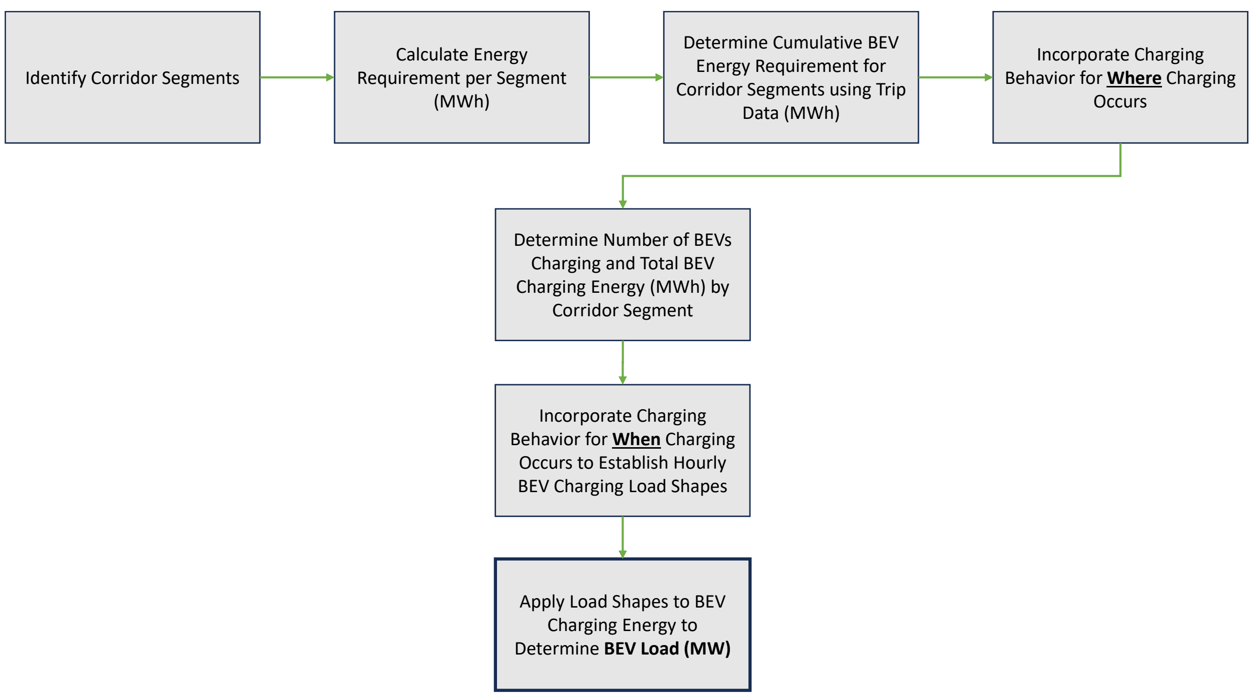
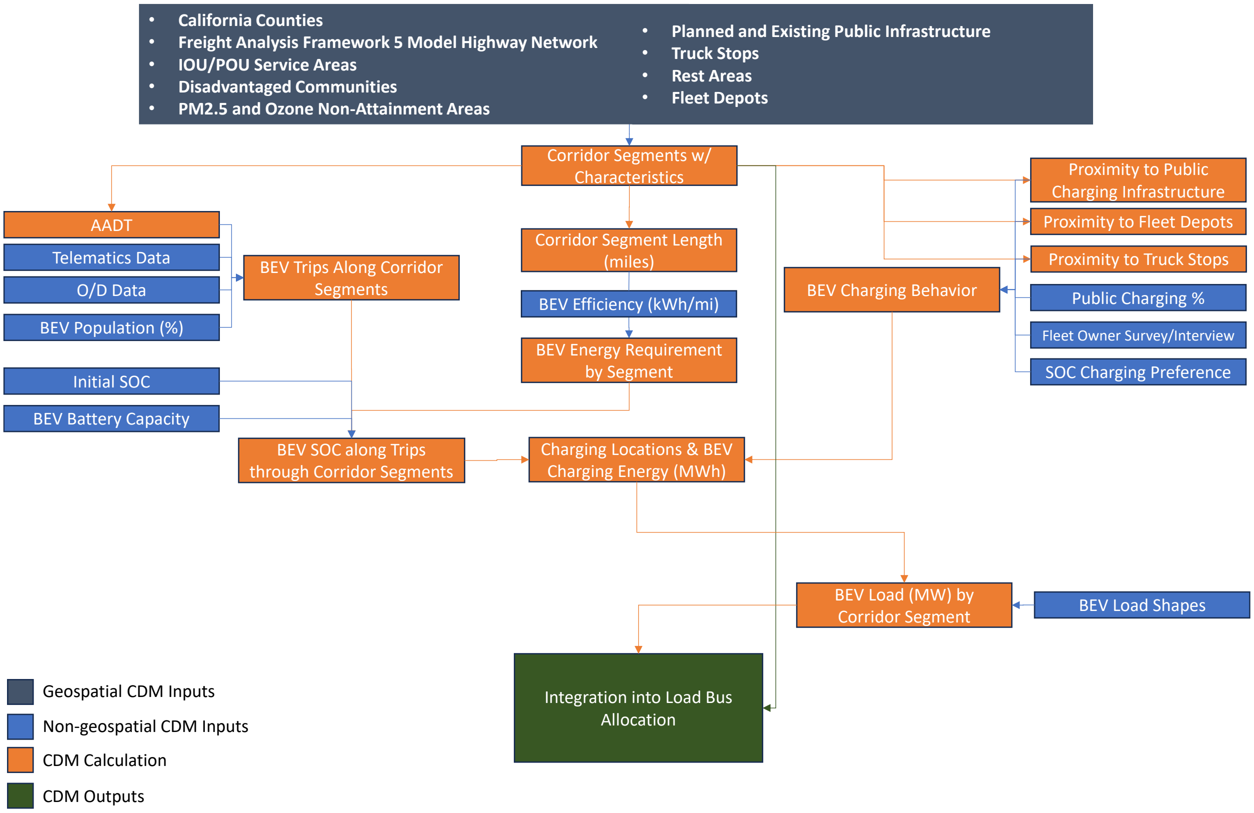


Figure 2-2 provides a **logic model** of the CDM inputs, calculations, and outputs, which would include a BEV load disaggregation through 2045.

Figure 2-2. CDM Logic Model[2]



[2] IOU/POU: investor-owned utilities, publicly owned utilities
AADT: average annual daily traffic; see Section 2.3 for details
O/D: origin-destination; see Section 2.3 for details
SOC: state of charge; see Table 1.1 in Section 1.2 for details

2.1 Corridor Segmentation and Characteristic Assignment

The road network used for the CDM consists of 150 major arterial and collector roads, interstate highways, collector/distributor lanes and controlled access highways in California that are at least 50 miles in length, have been identified as one of the 34 priority corridors by CTC's SB 671 Clean Freight Corridor Assessment or are included in the National Zero-Emission Freight Corridor Strategy. Figure 2-3 is a map of all highways considered as part of the CDM. A full list of the 150 roads included in the CDM is captured in Appendix F.

Figure 2-3. California Highways in CDM

These 150 highways are split into smaller segments based on changes in traffic volume as reported by FAF 5. The corridor segments defined in the CDM will further split the highway segments based on utility territory boundaries so that no single segment exists within two utility territories. The results will be unique segments of the 150 highways that vary in traffic volume from adjacent sections of the same highway and exist within a single utility's territory. Appendix E provides an illustration of this process.

Each corridor segment will be assigned characteristics. Table 2-1 describes the list of characteristics that are assigned to corridor segments.

Table 2-1. Corridor Segment Characteristics

Corridor Segment Characteristic	Description	Purpose
BEV Load (MW)	The forecasted annual load associated with a corridor segment	BEV load will provide insights into the load capacity needed to support BEV charging
Minimum Corridor Segment Length (Miles)	Minimum threshold for corridor segment length	Allows for targeting of corridor segments above a specific length
Minimum Vehicle Volume (Average Annual Daily Trips)	Minimum threshold for average annual daily trips, as proxy for vehicle volume, associated with corridor segment	Allows for targeting of corridor segments with high total vehicle traffic
Minimum BEV Vehicle Volume (Average Annual Daily Trips)	Minimum threshold for average BEV annual daily trips, as proxy for BEV volume, associated with corridor segment	Allows for targeting of corridor segments with high BEV traffic
IOU/POU	IOU or POU service territory through which the corridor segment passes	Allows for targeting of corridor segments within a specific IOU or POU service territory
County	County through which the corridor segment passes	Allows for targeting of corridor segments within a specific California county
DAC Status	Whether a corridor segment falls within a DAC area	Allows for targeting of corridor segments that serve disadvantaged communities
Road Class Description	Classification of corridor segment	Allows for specification of the types of roads to be included, e.g., highway, freeway
Road Name	Name of corridor segment	Allows for specification of the roads to be included, e.g., highway, freeway
Existing and Planned BEV Charging Infrastructure	Corridor segments that have existing and planned BEV charging infrastructure within a 1-mile width	BEV charging infrastructure may provide insights on both where charging is likely to happen if there is a high density of infrastructure or where gaps in charging networks exist
Truck Stops	Corridor segments that have truck stops within a 1-mile width	Truck stops may provide insights into where public charging may occur, as truck stops may be natural locations for public MDHD charging
Rest Stops	Corridor segments that have rest stops within a 1-mile width	Rest stops may provide insights into where public charging may occur, as rest stops may be natural locations for public LD charging
Fleet Depots	Corridor segments that have fleet depots within a 1-mile width	Fleet depots may provide insights into where private MDHD charging may occur

For the corridor segment characteristics that are not forecasted or calculated based on a forecast, underlying data will be provided through the TEPP Modeling I&A and associated with corridor segments using geoprocessing such as joins and intersections in ArcGIS. For those characteristics that are based on forecasts, such as BEV load and BEV charging infrastructure, they will be determined and assigned to corridor segments through the methodology described in Sections 2.2 through 0.

Most corridor segment characteristics can be determined based on whether the corridor segment intersects with the characteristic. For example, IOU/POU is determined based on whether the corridor segment is in a certain IOU/POU's service territory. Other characteristics, such as existing/planned infrastructure and fleet depots, may not fall directly on a corridor segment. For characteristics that may not fall directly on a corridor segment, the CDM will determine the associated segment by identifying whether the characteristic, such as the existing and planned infrastructure, and truck stops, are within a 1-mile width[3] of the corridor.

2.2 Corridor Energy Requirement Calculation

The BEV energy requirement associated with each corridor segment is calculated once the corridor segmentation is completed (see Appendix A). The BEV energy requirement for each segment represents the kilowatt hours (kWh) of energy a BEV needs to traverse a given corridor segment. For each corridor segment, this metric will be determined for both an individual BEV trip and for all BEV trips in a given year. Table 2-2 identifies the required inputs for calculating a corridor segment's BEV load.

Table 2-2. Inputs for Corridor Segment BEV Load Calculation

Input	Description
Corridor Segment Length	Each corridor segment's length in miles
Trips along Corridor	The number of trips taken along each corridor segment
BEV Population	The percent of trips along each corridor segment attributable to BEVs, broken out by year and vehicle use case
BEV Efficiency	The efficiency of the BEVs (kWh/mi), broken out by year and vehicle use case

The per trip BEV energy requirement for a given corridor segment will be calculated by multiplying the corridor segment's length by the BEV efficiency. The BEV efficiency will be broken out by vehicle duty, vehicle use case, and vehicle year. Each corridor segment will have multiple per trip BEV energy requirements that vary across these three fields (see Appendix A for equation).

The annual BEV energy requirement for a given corridor segment will be calculated by scaling up the per trip BEV energy requirement for each vehicle use case/duty combination for each year by the number of annual trips taken for each vehicle use case/duty combination for each year (see Appendix A for equation).

[3] The 1-mile width refers to an aerial buffer measured 1-mile adjacent to the corridor with the intent to include existing and planned charging infrastructure. This is not meant to be measured as a distance driven on roads.

2.3 Integration of Trip Data and Cumulative BEV Energy Requirement

Trip data will be integrated into the CDM to determine the number of daily trips taken along corridor segments, broken out by various BEV duties and vehicle use cases (e.g., long-haul truck, short-haul truck, delivery truck, passenger cars). This process begins with identifying a trip's origin and destination and then determining which corridors the BEVs are using to reach their destination.

Depending on the available data, this analysis may be as simple as integrating route analysis information from the Origin and Destination (O/D) data itself. If route analysis data is not available, weights will be established instead for the likelihood of a BEV using a specific corridor segment given a trip starting at Origin A and ending at Destination B. These weights will be determined by combining route analysis to determine the best route from location A to location B and average annual daily traffic data (AADT) along applicable corridors. The best route can be defined as either the fastest route in terms of travel time or the shortest route in terms of miles. Figure 2-4 outlines this approach, and an example calculation is provided in Appendix B.

Figure 2-4. Route Likelihood Calculation

Determine Trip Count	Determine Routes	Determine BEV AADT by Routes	Determine Route Weight	Determine Trips by Route
Use O/D data to determine number of EV trips from Origin A to Destination B	Visual inspection of corridors connecting Origin A to Destination B Route Analysis to identify Top 3 – 5 best routes from Origin A to Destination B	Use AADT from FAF 5 to determine how many trips are taken along each route Apply local BEV population percent to AADT by route to determine BEV AADT by route	Sum all BEV AADT by route to get total AADT from Origin A to Destination B Divide BEV AADT by route for each route by total BEV AADT to calculate route weight	Apply Route Weight to Trip Counts to calculate how many trips from Origin A to Destination B use each route

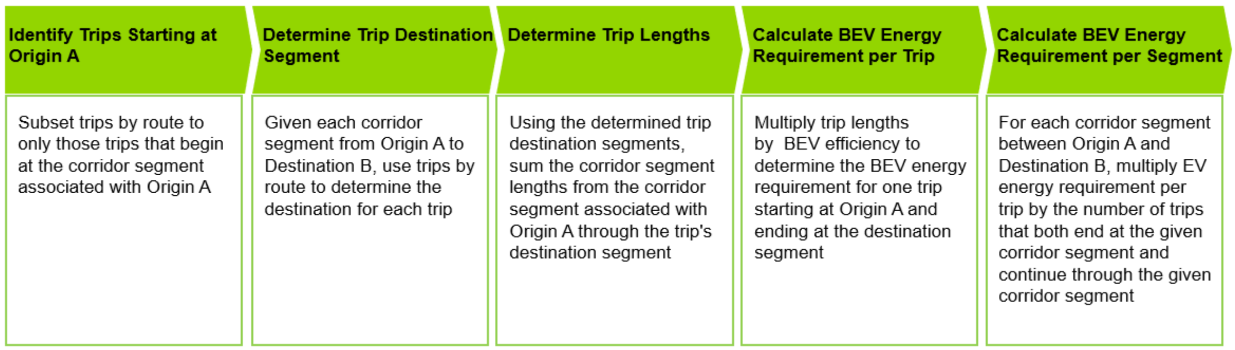
Once trip routes and the number of trips along a corridor by vehicle use case have been established, the annual BEV energy requirement associated with a corridor will be calculated, as described in Section 2.2. Additionally, having determined trip routes, the CDM will determine the cumulative BEV energy requirement for a given BEV trip at a given corridor segment.

The cumulative BEV energy requirement for a trip is a central datapoint for forecasting BEV load at corridors segments. As a BEV traverses a corridor segment, it will expend some amount of energy, which is calculated as the per trip BEV energy requirement for a corridor segment in Section 2.2. A BEV trip from Origin A to Destination B will consist of traversing a number of corridor segments, expending energy as it travels through each corridor segment. A trip's cumulative BEV energy requirement is the sum of the per trip BEV energy requirement for a corridor segment for each corridor segment the vehicle traverses while traveling from Origin A to Destination B.

Scaling up the cumulative BEV energy requirement for a single trip through a corridor segment to all trips will determine the cumulative BEV energy requirement for a corridor segment. This value represents the total energy expended by all BEVs as they drive from their origin to the given corridor segment. For the CDM, the cumulative BEV energy requirement for a corridor segment represents the total amount of energy BEVs would need to recharge their batteries assuming they have not recharged since leaving their origin.

Error! Reference source not found. outlines the approach for calculating the Cumulative BEV energy requirement for a trip and for a corridor segment, and an example calculation is provided in Appendix C.

Figure 2-5. Cumulative BEV Energy Requirement Calculation



2.4 BEV Load Calculation through Integration of Charging Behavior

The work described in Sections 2.2 and 2.3 establish how much energy BEVs are using for public and depot charging and along which corridor segments. The integration of charging behavior serves to establish both where charging is likely to occur and when during an average day charging is likely to happen. By determining where charging is likely to occur, the CDM can identify which corridor segments will have high levels of BEV charging. By determining when charging is likely to occur, the CDM can calculate the hourly load associated with BEV charging at a given corridor segment. See Appendix D for formulas summarizing the BEV load calculation.

2.4.1 Where Charging is Likely to Occur

Section 2.3 describes the process of determining the amount of energy BEVs need to recharge their battery at a given corridor segment, defined as the cumulative BEV energy requirement for a corridor segment. The cumulative BEV energy requirement for a corridor segment only represents the potential amount of BEV charging at that corridor segment – not all the energy BEVs need at a corridor segment will be recaptured through charging at that corridor segment. The CDM will integrate assumptions from the TEPP Modeling I&A on where charging is likely to occur to determine the energy associated with BEV charging (MWh) at each corridor segment.

The CDM will determine where charging is likely to occur using a probabilistic model that uses the cumulative BEV energy requirement for corridor segments to calculate vehicle state of charge (SOC) along trips and integrate the likelihood of charging at any given SOC. The output of the probabilistic model will establish weights that are applied to the cumulative BEV energy requirement for corridor segments that determine the energy associated with BEV charging at a given corridor segment. The CDM will provide a perspective on where BEV charging will be the heaviest, assuming charging infrastructure can be rolled out at any given corridor segment.

The probability curve associated with the likelihood of charging at any given SOC will be based on the TEPP Modeling I&A, which will include surveys and interviews with MDHD fleet owners and operators to address unique uncertainties associated with MDHD BEV charging. These assumptions vary based on vehicle use cases, duties and ownership models and will capture the nuances across vehicle charging use cases and duty cycles. The TEPP Modeling I&A will be used to establish more targeted scenarios that do not assume charging infrastructure is available at all corridor segments (e.g., scenarios where charging only occurs at a specific SOC).

In addition to vehicle SOC, the location of existing or planned BEV charging infrastructure may indicate where charging is likely to happen. The CDM will integrate geospatial inputs from the TEPP Modeling I&A based on existing and planned EVSE to establish where infrastructure will be deployed. Truck stop and rest stop location data will also be integrated into the CDM, as these locations may serve as suitable locations for future BEV infrastructure rollout out.

Table 2-3 outlines BEV charging assumptions the CDM will incorporate from the TEPP Modeling I&A.

Table 2-3. Assumptions on Where a BEV Will Charge

Assumptions on Where a BEV Will Charge	Applicable Vehicle Duty and Ownership	Description
Minimum SOC before Charging	All Duties	The target lowest state of charge a BEV should reach before drivers are recommended to recharge their battery
Minimum Allowed SOC	All Duties	The minimum SOC a vehicle can reach and still be recommended to **not** charge
Minimum SOC at Trip Start	All Duties	The lowest state of charge a BEV can have when beginning a trip
End of Trip vs On Route Charging	All Fleet-owned Duties	Whether MDHD BEVs target charging at the end of their trip, or charge on route
Use of Public Infrastructure	All Duties	Whether BEVs use public infrastructure to charge or rely solely on depot/home charging

Lastly, the CDM will identify infrastructure locations derived from network optimization analysis, which determines the mathematically optimal sites where BEV charging infrastructure can be deployed using AADT, vehicle miles traveled (VMT) and BEV population over time to define BEV charging demand for a given objective function (such as maximize network coverage). The analysis identifies point locations that capture BEV charging demand, which is ideal for estimating future charging sites, charging gaps, and network adequacy.

2.4.2 When Charging is Likely to Occur

The previous sections described the process for determining how much BEV charging will occur at each corridor segment. To convert that into BEV load forecasted through 2045, the CDM will distribute the energy associated with BEV charging at each corridor for an average weekday and weekend to each hour of the day using normalized load shapes.

The energy associated with BEV charging at each corridor segment is broken out by vehicle use case and duty. Using assumptions from the TEPP Modeling I&A, each vehicle use case and duty's energy associated with BEV charging will be allocated to applicable charger technologies (e.g., L2 and DCFC charging stations). The normalized load shapes will also account for this level of granularity in energy associated with BEV charging, and each hourly load will be calculated for each vehicle use case/duty/charging technology combination. These load shapes will then be combined to create a final hourly BEV load profile for each corridor segment.

The baseline load shapes used in the CDM will be provided through the TEPP Modeling I&A. The load shapes are aligned with the 2024 IEPR 8760 load shapes, aggregated to the average weekday and weekend for each month and cross-walked to TEPP Modeling I&A charging use cases, with the exception of Hub and Long-Haul Depot. Hub and Long-Haul Depot load shapes were not available in the 2024 IEPR, and are sourced from NREL data.2.4

2.5 CDM Outputs

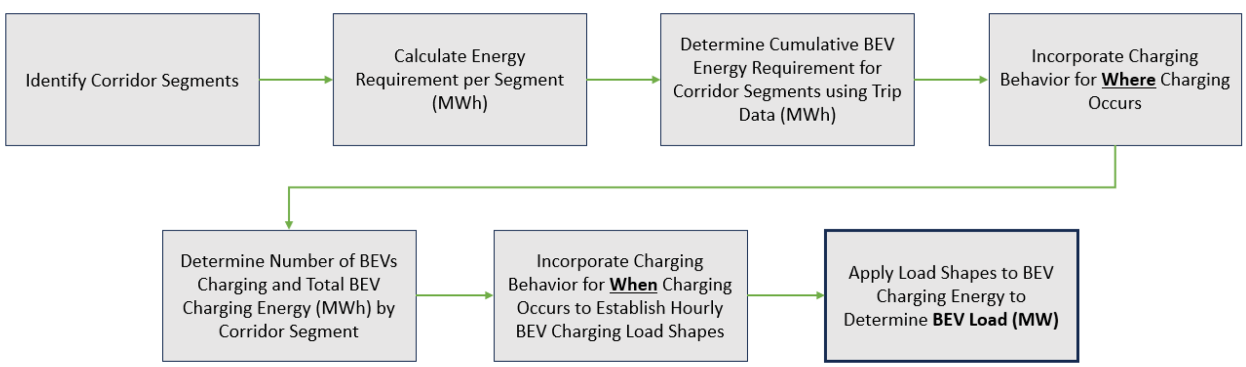
Section 1.3 describes the key metric the CDM will determine for each corridor segment. This metric is intended to provide a comprehensive perspective on all details associated with BEV charging at each corridor segment, with the key metrics related to the BEV load forecast through 2045, described through Section 2 being BEV Load (MW).

2.5.1 BEV Load (MW)

BEV Load (MW) is the hourly load associated with BEV charging at a specific charging segment for an average day. BEV Load establishes how much electric load for each hour of an average day will be needed to support BEV charging at a given corridor segment and can be used to identify the peak BEV charging load.

This metric will be derived from determining the cumulative BEV charging requirement at each corridor segment to support public LD and MDHD BEV charging and MDHD BEV depot charging, then establishing which segments charging will occur based on charging behavior assumptions described in Sections 2.1 through 2.4. Once the CDM calculates the cumulative BEV charging requirement for the corridor segments where charging will occur for the average daily, charging behavior associated with when charging will occur, based on BEV load shapes, will determine what the hourly BEV charging load is at each corridor segment, as described in Section 2.4.2. This metric represents the key output for BEV Load.

Figure 2-6. Calculation of BEV Load (MW)



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2.6 Integration with CEC Load Bus Allocation

CDM represents a refinement of the CEC current process of allocating public DC charging load to load buses. The CEC disaggregates the load forecast to bus bars. Since the CDM offers the bottom-up forecast, the CEC will replace the public DC charging load in the disaggregated load forecast with the CDM outputs. This process will require the CEC to isolate public DC charging load from the overall EV charging load in the load bus allocation. A key consideration in integrating the CDM with the CEC's load bus allocation is ensuring that the total EV charging load is trued up so as to avoid any double counting.

The CDM provides granular data on the location of public EV charging load well suited for association with IOU substations. The challenge is ensuring that accurate geospatial and power flow data on a substation's footprint is available. Accurate, mutually exclusive substation footprints, provided by the IOUs, would reduce the processes of allocating corridor segment load to substations to a geospatial analysis.

Summary of CEC Load Bus Allocation Proposed Steps:

1. CEC isolates public DC charging load forecast from the overall EV charging load

2. CDM provides the geospatial load at the point of need.

3. Using utility grid data, the CDM identified load is mapped to the grid asset and subsequently to the bus bar.

4. The bus bar CDM allocated load is used in place of the isolated public DC charging load.

3. Potential Future Refinements

This section outlines future refinements that could be made to the CDM in the future.

3.1 Integration of Additional Road Networks

The CDM will identify load associated with 150 major arterial and collector roads, interstate highways, collector/distributor lanes, and controlled access highways in California, identified by whether they are at least 35 miles in length or included in the 34 priority corridors identified by SB 671. The tool is intended to highlight corridor segments along these highways where high-volume BEV charging is most likely to occur.

California's comprehensive road network consists of many additional roads, including common roads, evacuation routes, and scenic byways, which are not captured in the scope for the initial CDM. These roads are not expected to contain the same levels of traffic as the corridors incorporated into the CDM, but BEV charging may still occur on these roads and contribute to the overall BEV load in California.

Future versions of the CDM could look to integrate additional roads to capture a more comprehensive perspective on BEV load on California's corridors.

3.2 Integration of Light Duty Residential and Workplace Charging

The CDM as described in Section 2 will model public charging for LD and MDHD BEVs, and depot charging for LD and MDHD fleets, along California's highways. Future versions of the CDM could expand beyond the major highway systems to also include residential and workplace charging, providing a more comprehensive picture of BEV charging. This would incorporate private versus public charging assumptions from the TEPP Modeling I&A and charging behavior assumptions associated with the private charging use case and vehicle use cases.

3.3 Integration of Additional Vehicle Types (e.g., Off-road)

The CDM forecasts BEV load on California's highways for on-road vehicles, which are expected to represent the majority of BEV charging in the near- term. Off-road vehicles such as agricultural equipment, airport ground support equipment, port cargo handling equipment, and forklifts could be incorporated into future versions of the CDM.

3.4 Data Updates and Refinements

The CDM will leverage inputs and assumptions from the TEPP Modeling I&A. As the BEV market is still early in its maturity curve, particularly for MDHD BEVs, these inputs and assumptions could be updated over time, with input from stakeholders, through the CEC's IEPR process.

Examples of inputs that could be updated over time include:

- Updates to the vehicle adoption forecast, including forecasts based on various policy scenarios
- Additions to vehicle use cases to capture nuances in duty-cycle, efficiency and charging behavior
- Updates to trip data
- Refinements to charging behavior as MDHD BEV fleet owners develop an improved understanding of how they will use BEVs
- Refinements to the associations across BEV energy and specific fleet depots
- Updates to load shapes, including load shapes for scenarios that emphasize managed charging

Updates to the TEPP Modeling I&A would drive future versions of the CDM.

4. Key Considerations

The following section highlights key considerations around the underlying data, and assumptions for the CDM.

4.1 Corridor Definition

Geospatially, a corridor is defined as a linear stretch of road associated with major arterial and collector roads, interstate highways, collector/distributor lanes, and controlled access highways. Any characteristic assigned to the corridor segments contain or intersect the corridor segment. For example, the IOU/POU associated with a corridor segment is determined by where the linear stretch of road is located.

Certain characteristics the CDM will assign to corridor segments may fall outside of the linear segment. For example, existing and planned charging infrastructure or fleet depots may not fall precisely on a road segment defining the corridor. The CDM will associate such infrastructure or fleet depots with a specific corridor to provide insights on charging behavior.

To fully characterize corridor segments , existing and planned charging infrastructure will be identified, including truck stops that fall within a 1-mile width of the corridor. Finally, all other characteristics of a corridor segment that may not contain or intersect a specific corridor segment will be assigned to the nearest corridor segment within a 1-mile width.

Once completed, the forecast underlying the CDM will be transmitted to the IOUs, who will map corridor segments to distribution substations using their knowledge of the substation’s electrical footprint. The IOUs will then aggregate loads from distribution substations to transmission substations.

4.2 Fleet Depot Data

The use of fleet depot data in the CDM will provide insights into charging behavior and BEV load for any corridor segment containing the depot within its footprint. Clusters of fleet depots along certain corridor segments may indicate a high BEV load associated with charging at depots but also limited demand for public charging infrastructure, as charging would likely occur at the depot.

A key challenge with the integration of fleet depot data is establishing depot-level granularity for associated BEV load. Knowing where depots are located only supports the functionality to identify corridor segments with fleet depots but does not provide insights into which BEVs are domiciled at each depot, a detail needed to calculate BEV load at the depot-level.

Additional assumptions and heuristics still need to be developed to accurately allocate a percentage of BEV load to specific depots themselves, and alignment on the validity of these assumptions will be required.

While this challenge is significant, it is important to include fleet depot data to provide a more complete perspective on BEV charging along California’s highway corridors. Any limitation will be caveated, and refinements can be made in future versions of the CDM.

4.3 Charging Behavior Assumptions for Medium- and Heavy-Duty BEVs

While surveys, interviews, and market research are key inputs into charging behavior assumptions, the MDHD BEV market is still in its nascency. Insights from fleet owners and operators will be based on preliminary expectations on BEV duty-cycles and have a high likelihood of changing as MDHD BEV adoption continues to mature. Assumptions on charging behavior applied to the CDM will be limited by this overall uncertainty.

While charging behavior assumptions integrated into the CDM provide guidance on where charging will likely take place, they need to be caveated with the degree of uncertainty associated with the MDHD BEV segment.

4.4 Charging Behavior Assumptions for Public Charging

Load shapes used in the CDM are not explicitly designed to capture shifts in charging behavior associated with price signals, load management, and flexible load. The load shapes are aligned with the 2024 IEPR or are based on NREL data, and are intended to reflect charging behavior based on charging convenience. Alternative perspectives on when charging is likely to occur when influenced by load management does affect the broader BEV charging ecosystem, especially in the private charging domain, but are not currently included in the CDM as they have limited impacts on public charging.

Since the CDM focuses primarily on public charging along California's main corridors, managed charging through price signals or VGI are unlikely to have significant impacts on the time and manner of charging.

Appendix A. BEV Energy Requirement Formulas

CDM per trip BEV energy requirement across a given corridor segment:

Equation 1. CDM BEV energy for individual trip

$$L_c * e_{v,y}$$

where:

- L_c the corridor segment length in miles
- $e_{v,y}$ the BEV efficiency in kWh/mile for vehicle use case v in year y

CDM annual BEV energy requirement associated with a corridor segment:

Equation 2. CDM annual BEV energy for corridor segment

$$\sum_{v} \left(AADT_C * L_C \quad * e_{v,y} * 365 \right) P_{v,C}$$

where:

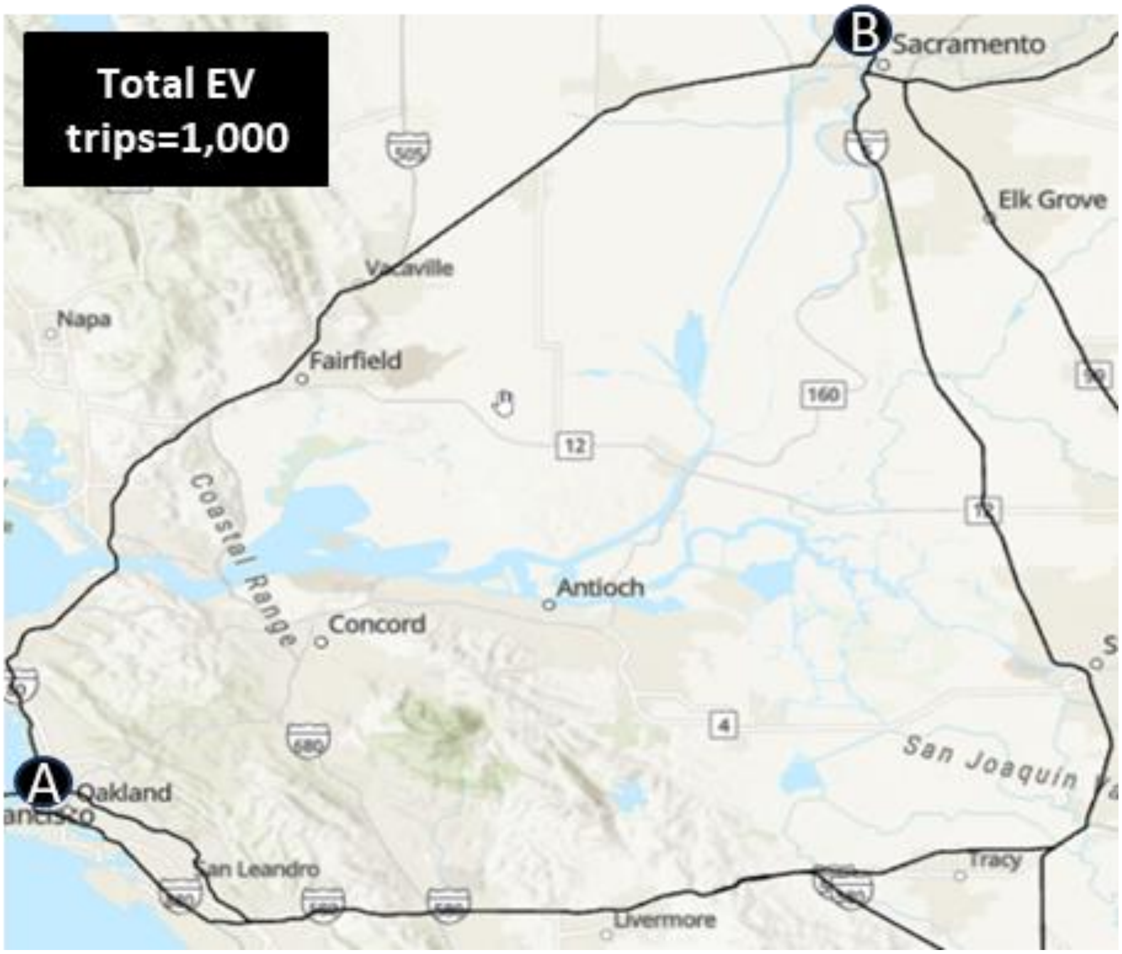
- $AADT_c$ the annual average daily traffic along a corridor segment C
- L_c the corridor segment C length in miles
- $e_{v,y}$ the BEV efficiency in kWh/mile for vehicle use case v in year y
- $P_{v,C}$ the percent of AADT taken by BEVs of use case v on corridor segment C

Appendix B. Route Likelihood Calculation Example

The following is an example of how route likelihood weights will be calculated, as described in Section 2.3. Values in this example are for demonstrative purposes only and are not actuals.

Step 1: Determine the number of BEV trips from Oakland (Origin A) to Sacramento (Destination B) using O/D data provided by the TEPP Modeling I&A.

Figure B-1. Route Likelihood Step 1 Example: Number of Trips

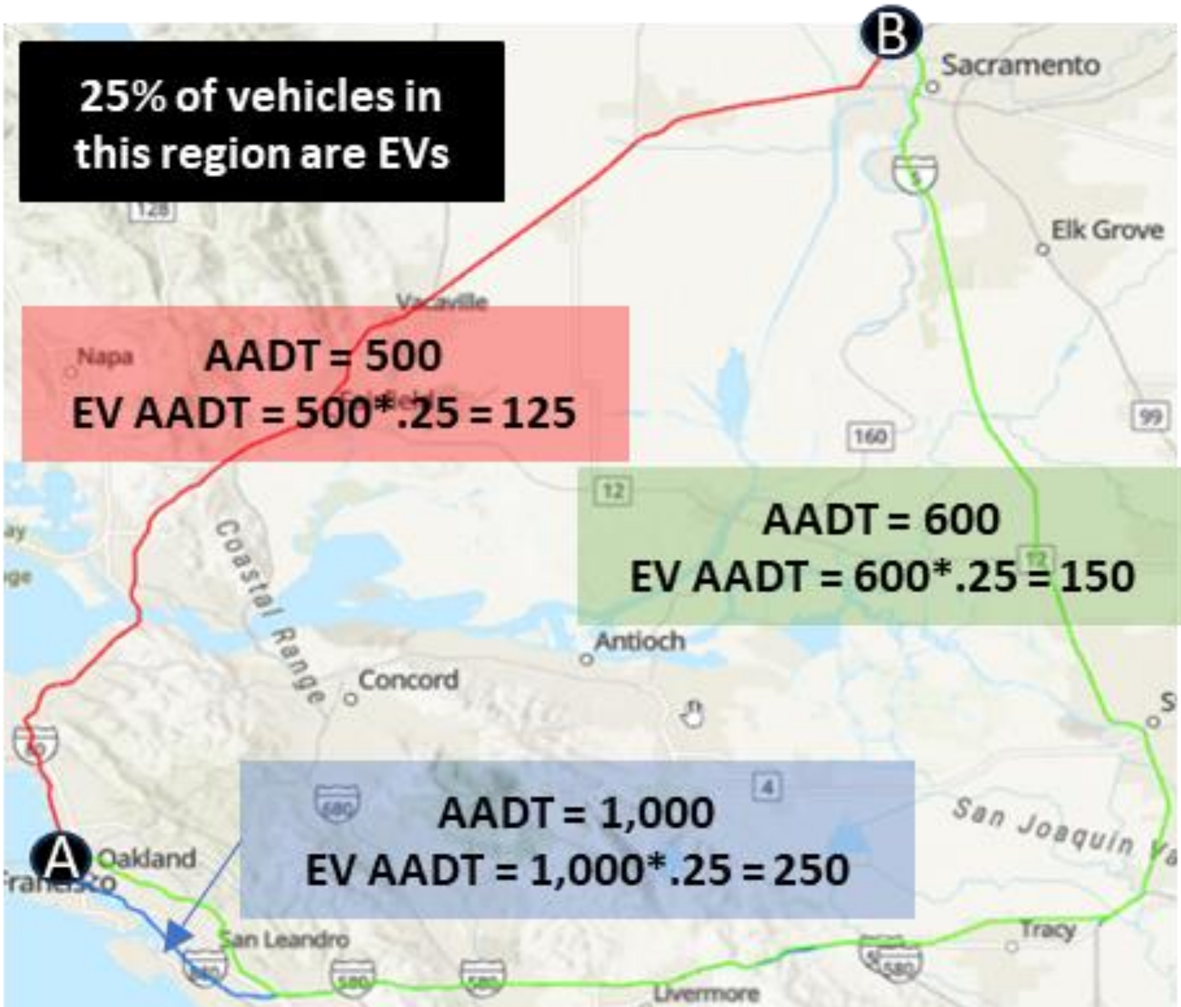


Step 2: Identify the routes from Oakland (Origin A) to Sacramento (Destination B) via visual inspection and/or route analysis.

Figure B-2. Route Likelihood Step 2 Example: Identify Routes

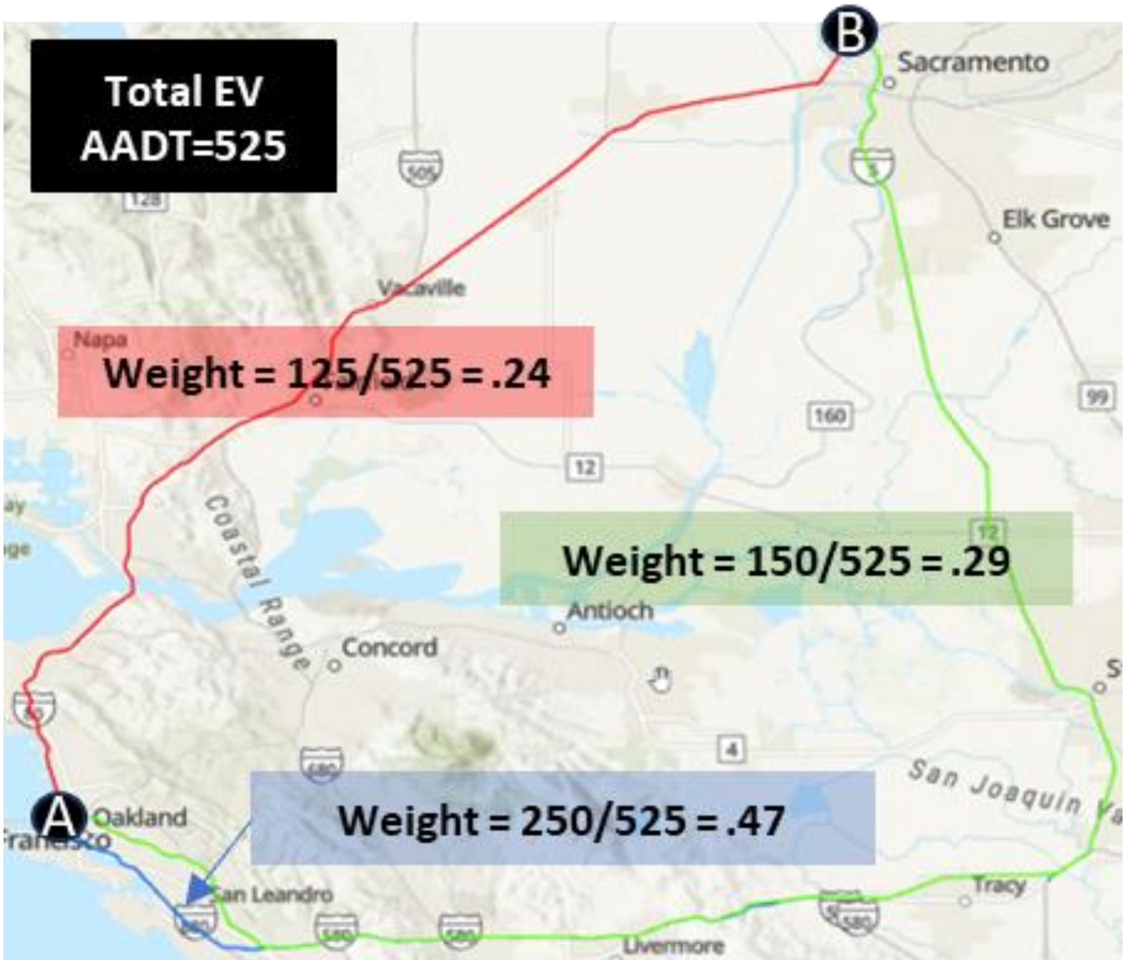
Step 3: Using AADT data associated with each route and BEV population data provided by the TEPP Modeling I&A, calculate the AADT associated with BEVs for each route.

Figure B-3. Route Likelihood Step 3 Example: Calculate AADT



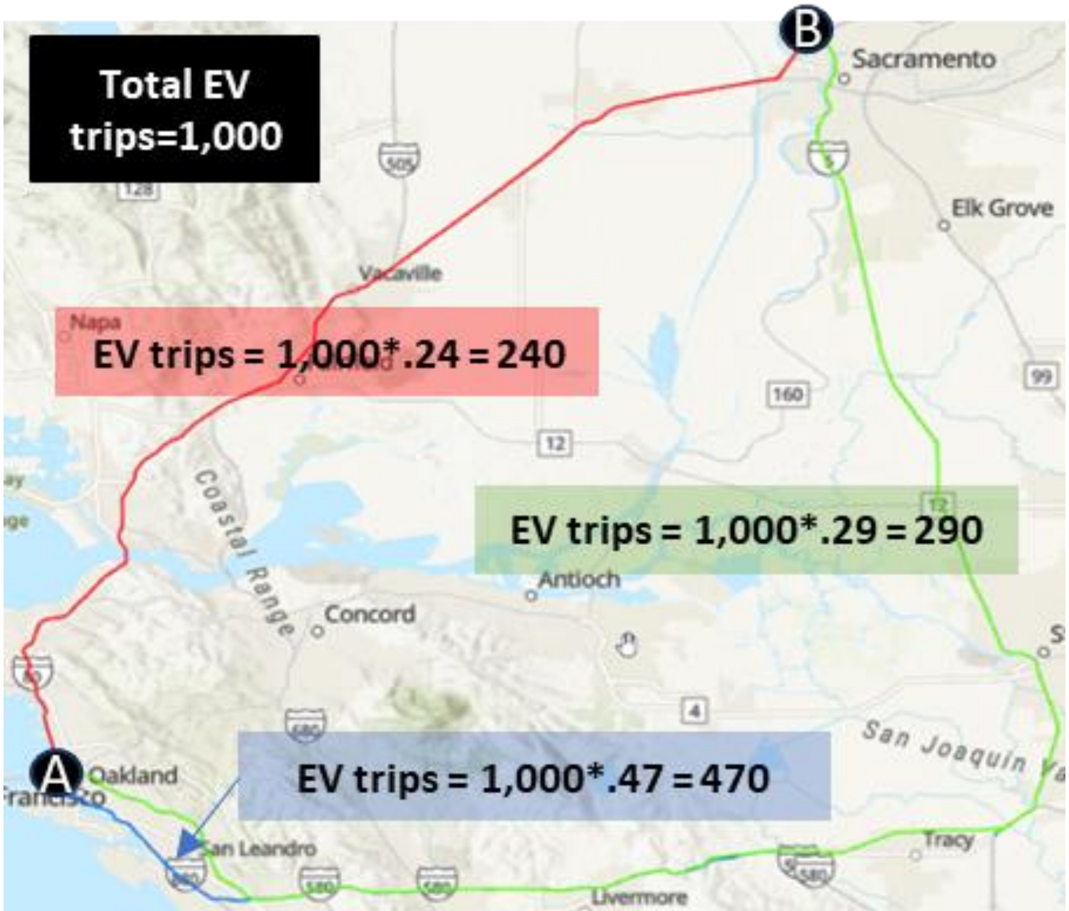
Step 4: Divide each route's BEV AADT by the total number of BEV AADT associated with all routes to determine each route's weight.

Figure B-4. Route Likelihood Step 4 Example: Determine Route Weight



Step 5: Multiply the number of BEV trips from Oakland (Origin A) to Sacramento (Destination B) by each route's weight to determine the number of BEV trips associated with each route.

Figure B-5. Route Likelihood Step 5 Example: Determine Number of Trips per Route



Appendix C. Cumulative BEV Energy Requirement Calculation Example

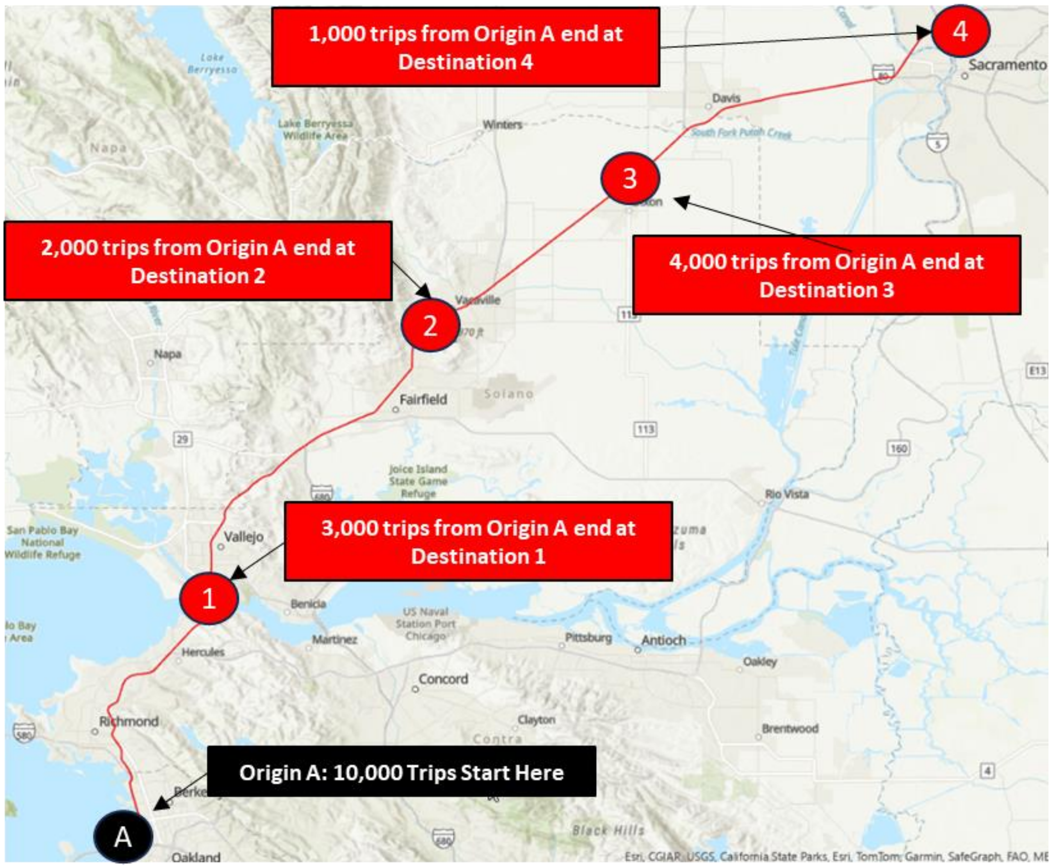
The following is an example of how the cumulative BEV energy requirement will be calculated, described in Section 2.3. Values in this example are for demonstrative purposes only and are not actuals.

Step 1: Using O/D data provided through the TEPP Modeling I&A, determine the number of trips that start at Oakland (Origin A).

Figure C-1. Cumulative Energy Step 1 Example: Number of Trips

Step 2: Using O/D data provided through the TEPP Modeling I&A, for those trips that start at Oakland (Origin A), determine at what corridor segment those trips end.

Figure C-2. Cumulative Energy Step 2 Example: Identify Destination Corridor Segments

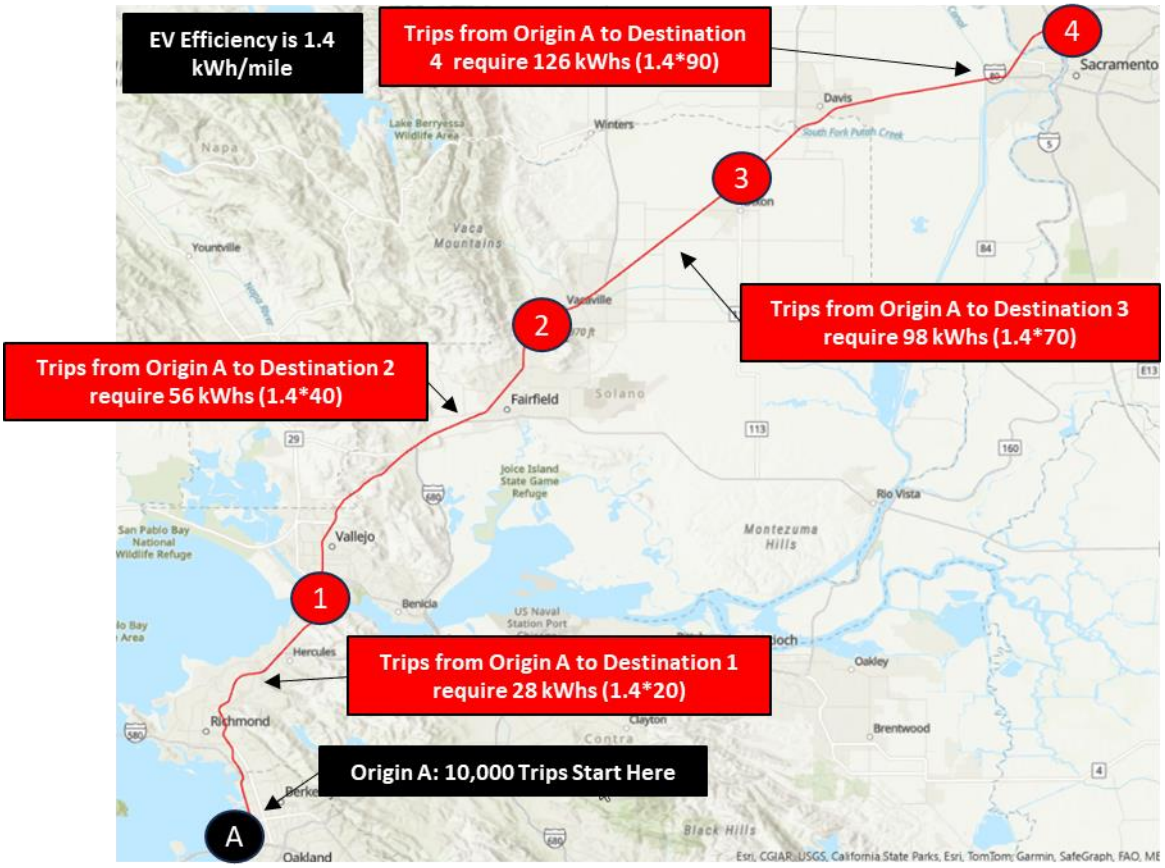


Step 3: Determine the length of each trip that passes through each corridor segment using data on California's highways provided through the TEPP Modeling I&A.

Figure C-3. Cumulative Energy Step 3 Example: Determine Length of Trip

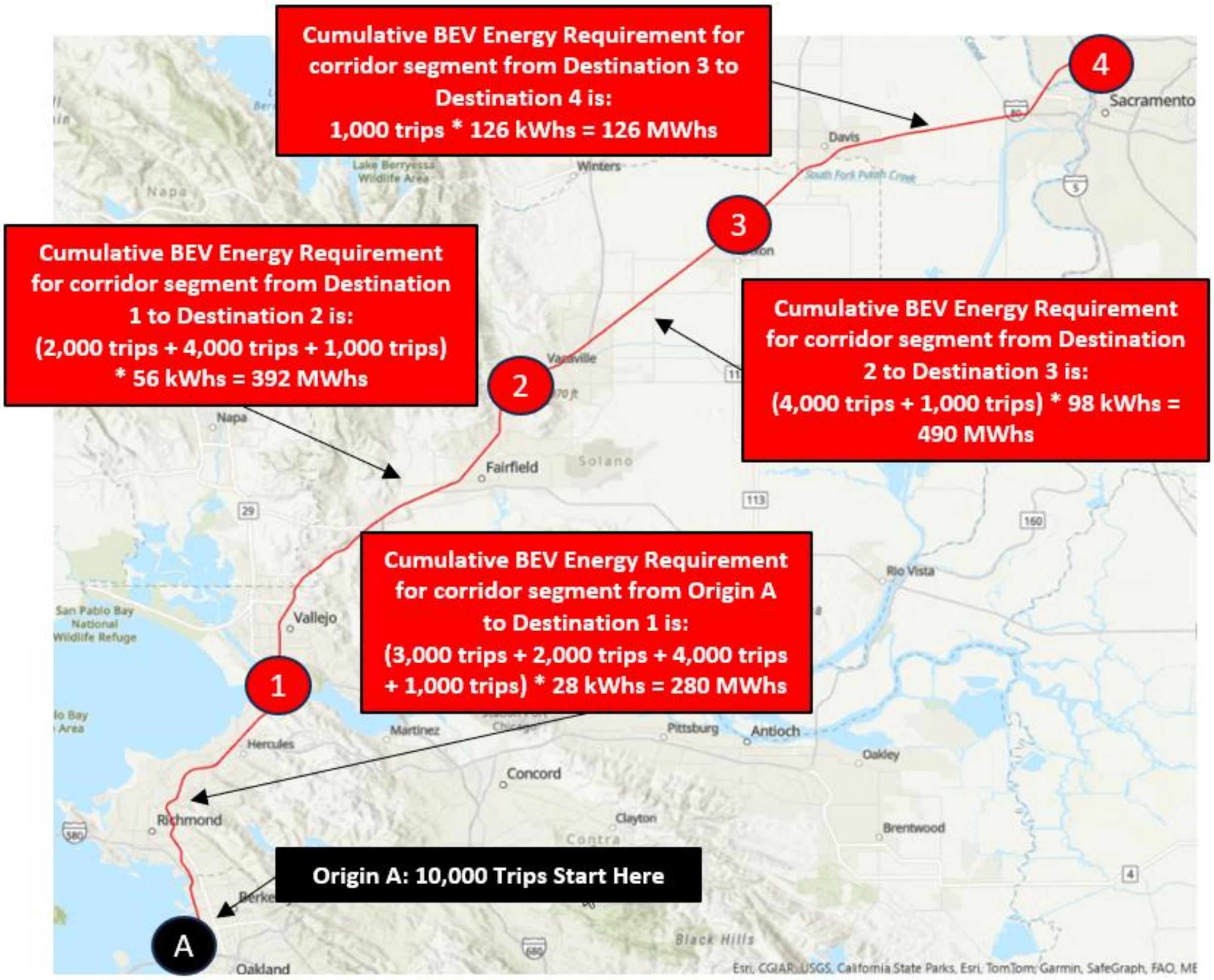
Step 4: Determine the per trip BEV energy requirement associated with each trip identified in Step 3 by multiplying each trip's length by BEV efficiency, provided through the TEPP Modeling I&A.

Figure C-4. Cumulative Energy Step 4 Example: Determine Trip BEV Energy Requirement



Step 5: For each corridor segment, sum the per trip BEV energy requirement for each trip that either passes through the corridor segment or concludes at the corridor segment. The resulting value is the cumulative BEV energy requirement for a corridor segment and represents the amount of energy BEVs would need to charge at that corridor segment to return to the SOC at the beginning of their trip (at Oakland, Origin A).

Figure C-5. Cumulative Energy Step 5 Example: Determine Cumulative BEV Energy Value



Appendix D. BEV Load (MW) Formula

CDM BEV hourly load for a given corridor segment at a given hour:

Equation 3. CDM BEV load for corridor segment

$$\sum_{u} E_u * P_{u,h}$$

where:

- E_u the average daily energy associated with charging for vehicle use case u at a given corridor segment
- $P_{u,h}$ the percent of charging of vehicle use case u that occurs at hour h of an average day

Appendix E. Corridor Segmentation Example

The following is an example of how the CDM will segment the FAF 5 corridors for inclusion in the CDM, as described in Section 2.1.

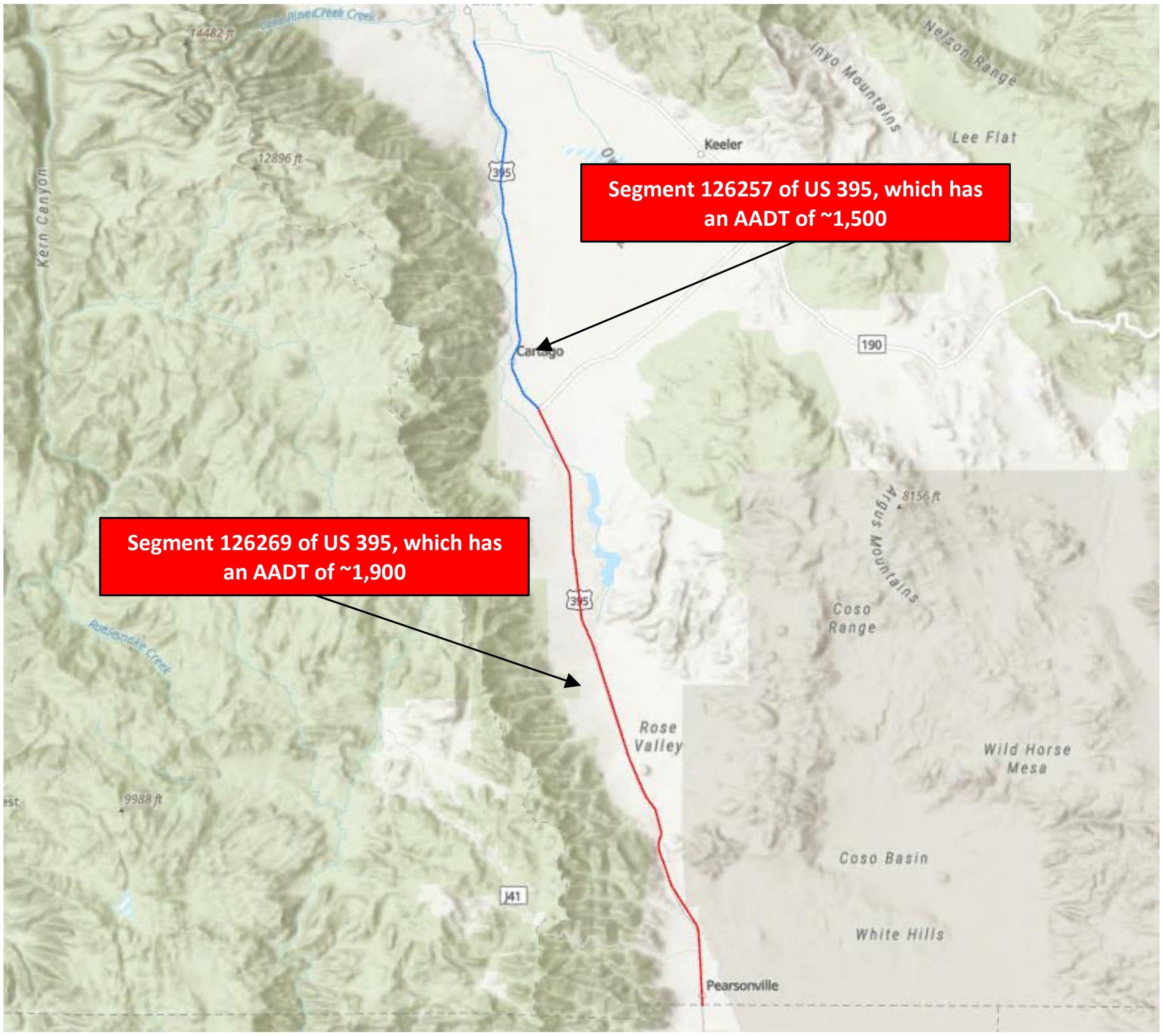
Step 1: Identify the 150 major arterial and collector roads, interstate highways, collector/distributor lanes and controlled access highways across California from the Federal Highway Administration's Freight Analysis Framework, Version 5 (FAF 5) data that are either 50 miles or more[4] in length or included as part of the 34 priority corridors defined by CTC's SB 671 Clean Freight Corridor Assessment.

Figure E-1. Interstate Highway in FAF 5 to be Included in CDM

[4] 50-mile minimum length specified in CTC's SB 671 Clean Freight Corridor Assessment

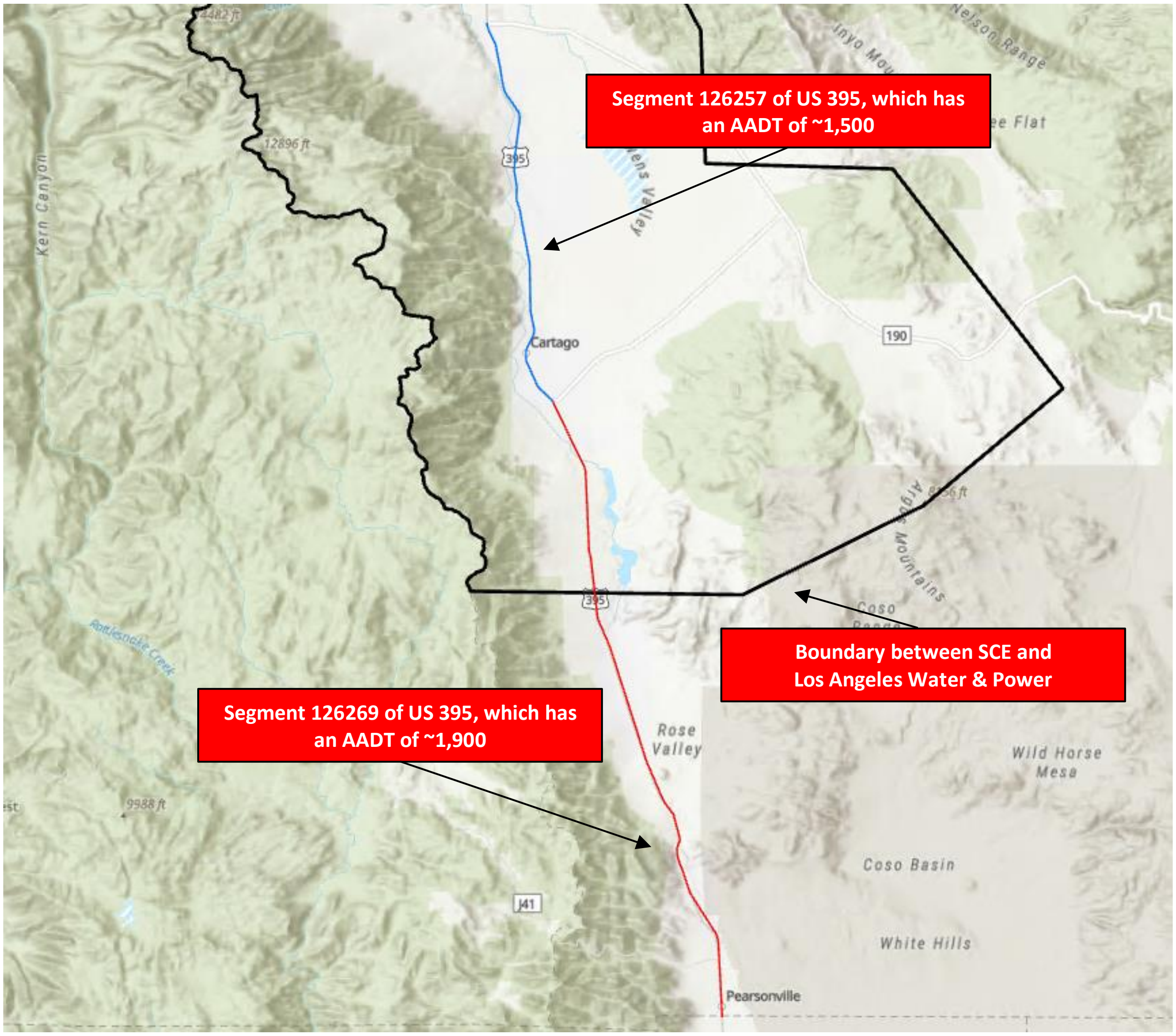
Step 2: Identify FAF 5's existing segmentation of roads based on variation in traffic volume.

Figure E-2. Segments of US 395 from FAF 5 based on Traffic Volume



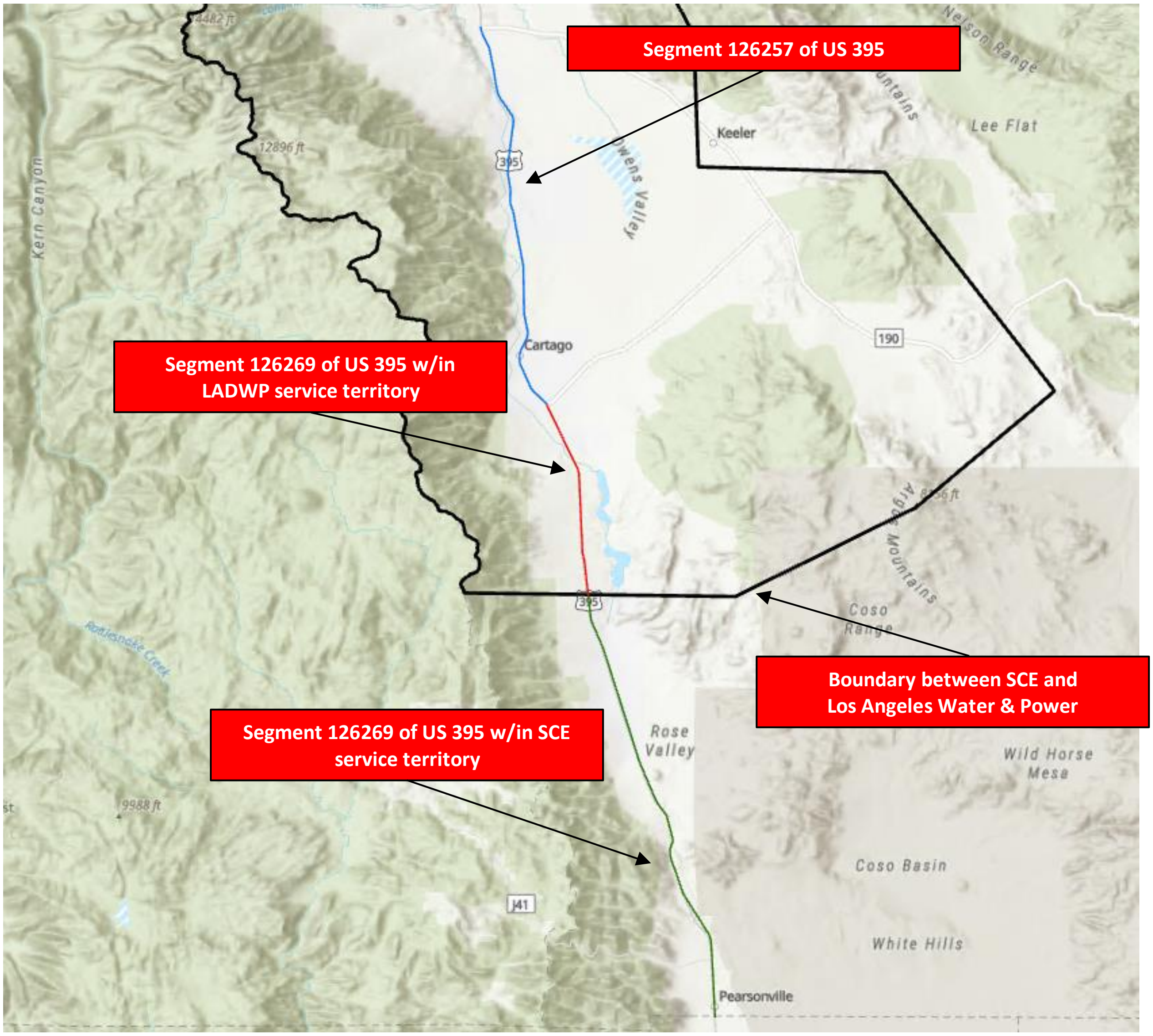
Step 3: Incorporate IOU/POU service territory boundaries.

Figure E-3. Segments of US 395 with SCE and LADWP Boundary



Step 4: Split Segment 126269 based on IOU/POU service territory boundaries.

Figure E-4. Segments of US 395 split based on Traffic Volume and IOU/POU Service Territory



Appendix F. Roads Included in CDM

Table F-1. Roads Included in the CDM

Road Names				
Death Valley Rd	SR 1	SR 16	SR 3	SR 76
I 10	SR 101 P	SR 160	SR 32	SR 78
I 105	SR 103	SR 162	SR 33	SR 79
I 110	SR 104	SR 165	SR 35	SR 84
I 15	SR 108	SR 166	SR 36	SR 85
I 170	SR 11	SR 168	SR 37	SR 86
I 205	SR 110	SR 17	SR 38	SR 88
I 210	SR 111	SR 170	SR 4	SR 89
I 215	SR 113	SR 175	SR 41	SR 905
I 238	SR 116	SR 178	SR 43	SR 91
I 280	SR 118	SR 18	SR 44	SR 92
I 380	SR 119	SR 180	SR 45	SR 94
I 40	SR 12	SR 190	SR 46	SR 96
I 405	SR 120	SR 198	SR 47	SR 98
I 5	SR 125	SR 2	SR 49	SR 99
I 505	SR 126	SR 20	SR 52	US 101
I 580	SR 127	SR 201	SR 55	US 199
I 605	SR 128	SR 210	SR 57	US 395
I 680	SR 132	SR 22	SR 58	US 50
I 710	SR 134	SR 223	SR 60	US 6
I 780	SR 138	SR 23	SR 62	US 95
I 8	SR 139	SR 241	SR 63	US 97
I 80	SR 14	SR 245	SR 65	Old Bakersfield Highway- San Bernadino County
I 805	SR 140	SR 246	SR 67	Pomerado Road- San Diego County
I 880	SR 145	SR 247	SR 7	Laurel Street- San Diego County
I 980	SR 15	SR 25	SR 70	Grape Street- San Diego County

Road Names				
Jolon Rd	SR 150	SR 26	SR 71	Hawthorne Street- San Diego County
National Trails Hwy	SR 152	SR 269	SR 710	Cesar Chavez Street- San Francisco County
North Hwy	SR 154	SR 29	SR 73	Roth Road- San Joaquin County
Sierra Hwy	SR 155	SR 299	SR 74	Las Posas Road- Ventura County

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