APPENDIX 3.2-B: VEHICLE MILES TRAVELED FORECASTING

CALIFORNIA High-Speed Rail Authority

Memorandum

DATE: January 22, 2020

TO: Memo to File

FROM: John Helsel, Travel Demand Forecasting for the RDP 2017-2019

SUBJECT: Further Background on Cambridge Systematics Explanation of Ridership Forecasts

Cambridge Systematics, Inc. (CS) developed the ridership and revenue forecasting model used to support the 2016 Business Plan. This model was named the Business Plan Model – Version 3 (BPM-V3) and is documented separately. The BPM-V3 was also used to estimate changes in vehicle miles traveled (VMT) for the California High-Speed Rail Authority (the Authority) to support various environmental planning efforts. CS documented its efforts in the main document which this memo accompanies.[1]

The CS ridership, revenue, and VMT forecasts were used as the core input to produce year-by-year estimates by the Rail Delivery Partner (RDP) for use by the Authority. This memo documents the reason and methodology for the process by which the CS inputs were used to create the year-by-year estimates.

Application of CS Forecasts

The CS forecasts for the 2016 Business Plan formed the basis for the forecasts of ridership, revenue, and VMT used by the Authority but had to be aligned with the required application in business plan and environmental analysis as follows:

- The Business Plan cash flow analysis and environmental planning groups required annual forecasts for every year between the start of operations and 2060 (while CS forecasts were developed only for three individual years and not for every year between the start of operations and 2060); and,
- The Business Plan cash flow analysis and environmental planning groups required a set of reasonable ramp-up assumptions to account for the introduction of new services (the BPM-V3 model assumes a steady-state system). These ramp-up assumptions reflect the reality that transit systems experience a transition over their initial operation as new riders begin to incorporate the system into their travel planning. This is especially likely to be true with HSR because it will be a new mode for most travelers and not merely an extension of an existing system.

The BPM-V3, like most travel demand models, delivers forecasts for a single typical day, which are then annualized to estimate annual travel behavior. Each forecast requires socioeconomic, land use, and transportation network data for the year of the forecast. Each forecast also requires processing time of about a week on a high performance computer. It is unreasonable to produce individual year forecasts when the only input changes are the baseline socioeconomic, land use, and transportation network data. Instead, the RDP directed CS to provide forecasts for three model years and then interpolated forecasts for the years not explicitly modeled.

[1] Cambridge Systematics. October 4, 2019. *California High Speed Rail Environmental Analysis: Method for Forecasting Vehicle-Miles of Travel Reductions*.

Methodology for Transition from CS Single-Year Forecasts to Multi-Year Forecasts

The methodology to estimate vehicle miles traveled (VMT) from the ridership model was driven by the methodology to estimate overall ridership. These two efforts were tied together in order to make the year-by-year estimates as consistent and theoretically coherent as possible. Thus, this section will discuss both the original estimates for ridership and then highlight to additional effort to derive forecasts for VMT.

In 2016, CS provided forecasts for three years (2025, 2029, and 2040).[2] Since the 2016 Business Plan forecasts were developed, the Authority has adopted its 2018 Business Plan, which was accompanied by updated forecasts. The 2016 and 2018 Business Plan ridership forecasts were developed using the same travel forecasting model; the forecasts differ due to changes in the model's inputs, including the high-speed rail service plan, demographic forecasts, estimates of automobile operating costs and travel times, and airfares.

Forecasts of the Valley-to-Valley line (San Francisco to Bakersfield) were provided for its first and last years of operation (when Phase 1 would come online): 2025 and 2029. Forecasts for the Phase 1 line (San Francisco to Anaheim) were provided for its first year of operation and a reasonable out year for forecasts: 2029 and 2040.

To develop the ridership and revenues series shown in the Business Plan[3], the RDP took the forecasts for Valley-to-Valley and Phase 1 and developed a compound annual growth rate (CAGR) for the two systems between the modeled years. These were calculated to be 0.10% for Valley-to-Valley and 1.33% for Phase 1. Ridership growth after 2040 was assumed to be 1% annually through 2060. This series represented the steady state for ridership on the system without accounting for the ramp-up of introducing new services.

However, it is well documented that it takes time for riders to reach these steady state behaviors and so ramp-up factors were applied to ensure that the Authority would report reasonably conservative forecasts during initial operation. The full set of assumptions for the ridership ramp-up are reported in the 2016 Business Plan, but are repeated here for completeness. The RDP used a 5-year ramp-up cycle (40%, 55%, 70%, 85%, and 100%). From 2025-2028, this series was applied in a straightforward manner. From 2029 to 2034, when Phase 1 was introduced, the ramp-up applied only to the difference in ridership between Valley-to-Valley and Phase 1. In other words, the ridership that used the system during Valley-to-Valley operation was assumed to continue to use the system without alteration, but the additional ridership from the larger system was incremental.

Importantly, the RDP did not estimate any differentials in which markets would be affected during the ramp-up periods. The ramp-up cuts were applied to the headline system-wide ridership and revenue values and assumed to apply evenly.[4]

The forecasted VMT and vehicle hours traveled (VHT) *reductions* (relative to the No Build scenario without high-speed rail service) were adjusted to be consistent with this methodology. First, CS provided Build and No Build VMT and VHT totals and by county for each scenario as well as the reduction in VMT

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[2] A full description of the assumptions and modeling efforts for the 2016 Business Plan can be found in the Technical Memo attached to that plan on the Authority's website: https://hsr.ca.gov/docs/about/business_plans/2016_Business_Plan_Ridersihp_Revenue_Forecast.pdf.

[3] See Exhibit 7.1 to Exhibit 7.10 in the Business Plan: https://hsr.ca.gov/docs/about/business_plans/2016_BusinessPlan.pdf.

[4] The BPM-V3 was developed to estimate steady-state travel conditions. Ramp-up periods vary depending on ridership markets, competitive situation and existing ridership experience. While it was reasonable to use the steady-state condition as an upper bound of ridership, it was not well suited to the task of determining how particular sectors might react during the ramp up period. For instance, it may be that people living in San Jose will immediately begin using the system to travel to San Francisco because it is very similar to existing Caltrain service. And it may come to pass that people living in Bakersfield will be slightly slower to adopt HSR because it would be a much newer mode. The model did not have any data to support such differentiated approaches and the magnitude of ramp-up and so the decision was made to just apply the ramp up percentage evenly across all ridership markets and geographies.

and VHT (i.e., the difference between the Build and No Build scenarios).[5,6] Second, the reduction in VMT and VHT was modeled using the CAGR developed for overall ridership and the No Build VMT and VHT were increased using a CAGR between the No Build scenarios (and assumed to grow at 1% post 2040). Again, no attempt was made to identify any differences in trip-making patterns during the ramp-up period so all VMT/VHT estimates were factored at the same rate. Finally, the Build VMT was then re-derived as the difference between the No Build and the reduction. Because the reductions were streamed using the ridership CAGR rather than developing a VMT reduction specific CAGR, it is not surprising that the estimate slightly differed from the CS forecast, especially by 2040.[7]

Conclusion

The RDP has produced numerous forecasts of ridership, revenue, and environmental impacts in support of the Authority's mission to deliver high speed rail to California. These forecasts begin with the Authority's service plans for trip times and frequency, are evaluated in the BPM-V3 to find a steady state forecast for several future years, and then interpolated according to the methodology outlined in this memo to meet the needs of the Authority's stakeholders. These interpolations are conservative adjustments to the raw model outputs and represent a reasonable compromise between the BPM-V3's technical limitations and the Authority's business planning needs.

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[5] It should be noted that the structure of the travel model provides a forecast for the *change* in VMT/VHT, but does not explicitly provide a forecast for total statewide no build or build VMT/VHT. The BPM-V3 is a long-distance trip model that forecasts all trips longer than 50 miles and shorter trips only in Los Angeles and the San Francisco Bay Area. This has caused some confusion when reporting county wide VMT/VHT where some counties are modeled in the short distance trip model and others are only modeled in the long-distance trip model. The full details of the BPM-V3 short and long distance models can be found in the model documentation: https://hsr.ca.gov/docs/about/ridership/CHSR_Ridership_and_Revenue_Model_BP_Model_V3_Model_Doc.pdf

[6] The raw CS data is found in tables 2.7 and 2.8 in the memo cited in Footnote 1.

[7] The medium case 2040 annual statewide total estimated VMT reductions produced as a result of using the same CAGR used for the ridership series resulted in a reported savings of 4.767 billion VMT reduced. The medium 2040 annual statewide VMT reductions estimated as a direct output of the BPM-V3 were 4.785 billion VMT reduced. Thus, the methodology adopted by the RDP understated the project's impact by 0.35% compared to the VMT seen in the raw model output.

California High-Speed Rail Environmental Analysis

Method for Forecasting Vehicle-Miles of Travel Reductions

prepared for

DB Engineering & Consulting USA Inc. for the California High-Speed Rail Authority

prepared by

Cambridge Systematics, Inc.

January 20, 2020

www.camsys.com

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prepared by

Cambridge Systematics, Inc.
1801 Broadway, Suite 1100
Denver, CO 80202

date

January 20, 2020

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1.0 Travel Modeling Approach

Since 2007, Cambridge Systematics (CS) has been supporting the California High-Speed Rail Authority (Authority) by producing ridership and revenue forecasts for different high-speed rail (HSR) service options. CS developed the "Version 1" model, which was estimated and calibrated using data from the 2000-2001 California Household Travel Survey (CSHTS) and stated-preference (SP) survey data from a revealed preference/stated preference (RP/SP) survey conducted in 2005 for the express purpose of HSR ridership and revenue forecasting.[1] The Version 1 model was used to support alternatives analyses and project-level environmental work.

In preparation for the 2012 Business Plan, CS updated the Version 1 model based on a new trip frequency survey of long-distance travel made by California residents and recalibrated it to 2008 conditions. The enhancements culminated in ridership and revenue model runs used to support the California High-Speed Rail 2012 Business Plan.[2]

In 2012 and 2013, CS made additional enhancements to the ridership and revenue model to accommodate the evolving forecasting needs of the Authority, including the 2014 Business Plan. The enhanced model, known as the Version 2 ridership and revenue model, represented a major overhaul of all model components and incorporated new and reanalyzed data from the 2012-2013 CSHTS and the 2005 SP and revealed preference (RP) data. The enhancements to the Version 2 model incorporated the recommendations of the Authority's Ridership Technical Advisory Panel (RTAP) and considered comments from the Authority's Peer Review Group (PRG) and the Government Accountability Office's report. In addition to the ridership and revenue model enhancements, CS developed a risk analysis approach to estimate uncertainty in the forecasts and prepare and present ridership and revenue forecasts.

Since application of the Version 2 model in the 2014 Business Plan, CS updated the model to the current Business Plan Model-Version 3 (BPM-V3)[3]. During the development of the 2014 Business Plan, CS completed a new 2013-2014 RP/SP survey that was incorporated into the BPM-V3 model.[4] The BPM-V3 was estimated using data from the 2013-2014 RP/SP survey in addition to the 2005 RP/SP survey and the 2012-2013 CSHTS data. Additionally, the model includes an adjustment to explicitly divide auto costs by an assumed average auto occupancy of 2.5 for those who travel in groups.

Finally, based on model applications using the Version 2 model, CS identified a tendency of the model to forecast trips with long access and/or egress times, coupled with relatively short trips on the main mode. This tendency did not show up in the model calibration or validation since most observed trips on conventional rail (CVR) were relatively short and, conversely, most trips by air were relatively long. Since

1 Cambridge Systematics, Inc., *Bay Area/California High-Speed Rail Ridership and Revenue Forecasting Study: Interregional Model System Development*, prepared for Metropolitan Transportation Commission and the California High-Speed Rail Authority, August 2006.

2 Cambridge Systematics, Inc., *California High-Speed Rail 2012 Business Plan, Ridership, and Revenue Forecasting, Final Technical Memorandum*, prepared for Parsons Brinckerhoff for the California High-Speed Rail Authority, April 12, 2012.

3 Cambridge Systematics, Inc., *California High-Speed Rail Ridership and Revenue Model, Business Plan Model-Version 3 Model Documentation, Final Report*, prepared for the California High-Speed Rail Authority, February 17, 2016.

4 Cambridge Systematics, Inc., Corey, Canapary and Galanis Research, and Kevin F. Tierney, *California High-Speed Rail 2013-2014 Traveler Survey – Survey Documentation*, prepared for the California High-Speed Rail Authority, February 2015.

HSR provided competitive service for the full range of distances, trips by HSR were more likely affected by the long access-egress/short main mode issue and, thus, the issue was not identified until model application.

In response, CS made enhancements to the BPM-V3 by including four new variables in the mode choice utility functions: auto access time, non-auto access time, auto egress time, and non-auto egress time with each being divided by total auto distance. These variables appear in the access and egress utility components of the mode choice model. The BPM-V3 model was used to produce forecasts of total ridership and revenue primarily for 2016 business planning purposes.

1.1 Approach for VMT and GHG Calculation

1.1.1 2016 Business Plan Ridership Modeling

CS used the BPM-V3 to develop ridership and revenue forecasts[5] for two main phases of the project as specified by the Authority:

1. Silicon Valley to Central Valley (VtoV) – San Jose to a station north of Bakersfield opening in year 2025.
2. Phase 1: San Francisco and Merced to Los Angeles and Anaheim opening in 2029 and an out-year of 2040.

Ridership and revenue forecasts were prepared for the opening year for each implementation step and a Phase 1 out year. The 2016 Business Plan lays out an implementation strategy that starts with the Silicon Valley to Central Valley line. The 2040 forecast reflects ridership on a mature system that would at the time have more than 10 years of operating history.

As noted, the BPM-V3 was used to forecast ridership and revenue for the 2016 Business Plan. The BPM-V3 is a detailed travel model for long distance trips greater than or equal to 50 miles in length made within California on an average day. Four model components are used to estimate the travel:

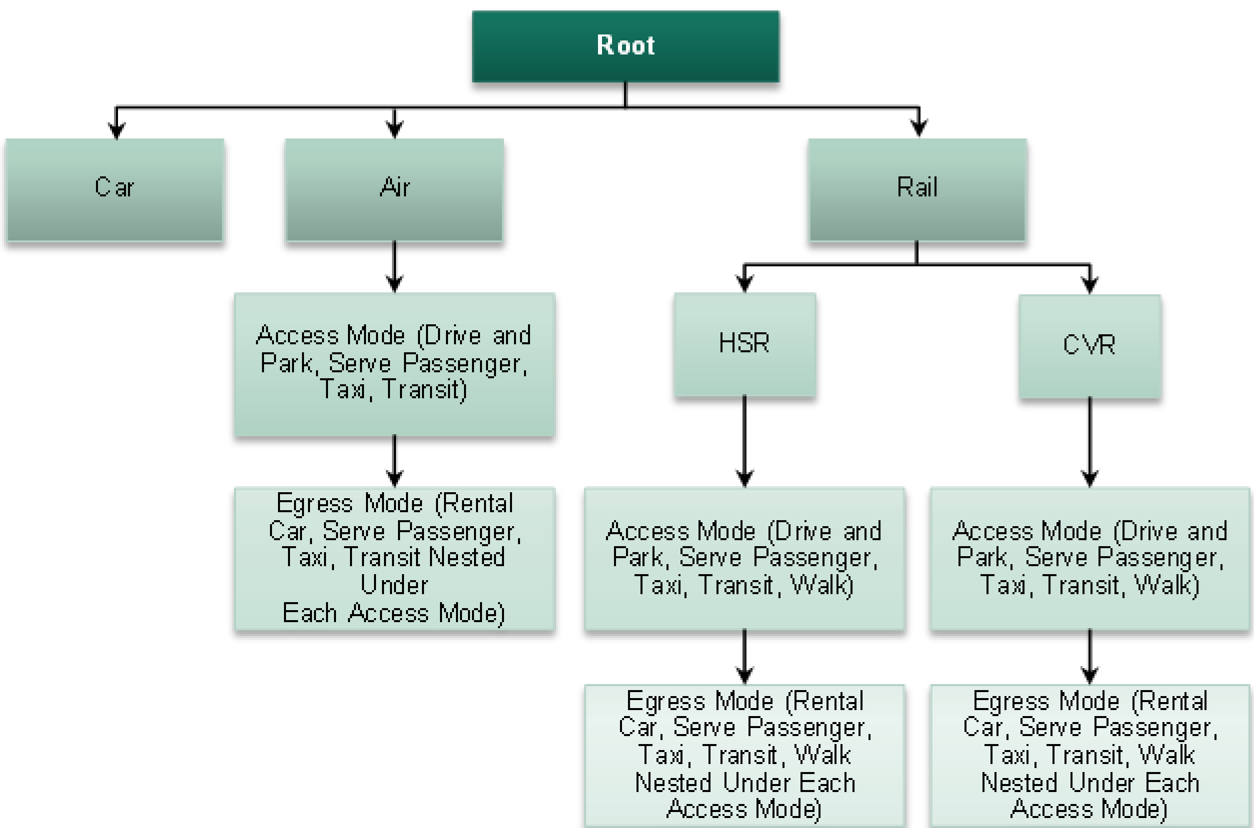
- Trip frequency choice – the choice of making either zero or one long distance trip (e.g., home to work) by residents of California
- Trip destination choice – given that a long-distance trip is being made, what is the destination of that trip from the trip-makers' home locations
- Main mode choice – given a long-distance trip from a trip-makers' home to a specified destination, what mode is used for the travel: auto, air, conventional rail, or high-speed rail
- Access/egress mode choice – given a long distance trip by air, conventional rail, or high-speed rail, what are the access and egress modes used to get to and from the airports or rail stations used for the travel: drive and park (from home to departure airport/station), rental car (from arrival airport/station to destination), dropped off/picked up by auto, or transit.

[5] Detailed ridership and revenue forecast assumptions and results for the 2016 Business Plan are documented in: https://www.hsr.ca.gov/docs/about/business_plans/2016_Business_Plan_Ridersihp_Revenue_Forecast.pdf.

The final model component steps are crucial in understanding forecasts performed using the BPM-V3. Figure 1.1 shows the model structure for the joint mode choice and access/egress choice model. In the figure, "Root" represents trips made by individuals with common household characteristics for (see Section 1.2.2) for a specific TAZ to TAZ interchange. Information regarding the travel options for the interchange, including egress from the best destination station or airport and access to the best origin station or airport for each of the main public transportation modes (air, CVR, and HSR) feeds up through the modeling process and is considered along with the travel characteristics for the main modes. Based on the information, the joint model is used to estimate the probabilities of auto, air, and rail travel for the long-distance trips, then under rail, the probabilities of using CVR or HSR, and then under each of the main modes the probabilities of using each of the available access and egress modes. The number of long distance trips for the individuals making the trips are multiplied by the probabilities to estimate trips by each of the main modes and access/egress modes.

The key is that improvements to travel characteristics for access to or egress from a main mode or changes to the travel characteristics for a main mode proportionally affects the competing modes. Thus, the introduction of HSR for an interchange will proportionally divert travel from both auto and air to rail (the rail travel characteristics are based on both the HSR and CVR characteristics). Further, the rail trips will split between HSR and CVR based on the quality of service and other characteristics afforded by those modes.

Figure 1.1 Nesting Structure for Joint Main Mode – Access/Egress Mode Model



Source: Cambridge Systematics

The long-distance person-trips are modeled for each of four trip purposes:

- Business – trips made from home to another location on an infrequent basis for work-related purposes
- Commute – trips made from home to another location on a regular basis for work
- Recreation – trips made from home to another location for recreational purposes
- Other – trips made from home to another location for personal business purposes (e.g. doctor, visit, etc.)

Note that all trips are modeled from home to non-home locations. This standard modeling practice is designated as modeling trips in "production-attraction" format. Trips from the non-home location to the home location are modeled as being made in the home to non-home direction. This convention allows for the consideration of household characteristics of trip-makers at their home (production) zone.

The BPM-V3 also includes intraregional models for the San Francisco Metropolitan Transportation Commission (MTC) and Southern California Association of Governments (SCAG) regions since high-speed rail may be an option for trips within those regions. Short-distance trips (less than 50 miles in length) that take place within the SCAG or MTC regions are modeled with separate intraregional mode choice models. Although these trips are not a major market for HSR, they are evaluated to get a more complete picture of travel within the state that may be attracted to and served by the HSR system. Both the SCAG and MTC intraregional mode choice models are based on a refined version of the MTC BAYCAST model. The models use static trip tables adopted from the SCAG and MTC regional models.[6] In addition, the models use transportation level of service (LOS) characteristics and household characteristics developed specifically for the HSR model system. During application, the models are run for all trips (both less than and greater than 50 miles in length), and then the long-distance trips (greater than or equal to 50 miles in length) are removed from the results (since they are modeled using the BPM-V3 long distance travel model). Thus, the model results presented in this section encompass all trip lengths without duplication.

1.1.2 Risk Analysis

A detailed, eight-step risk analysis approach was employed to forecast a range of revenue and ridership forecasts for the 2016 Business Plan as shown in Figure 1.2 below.[7] The process was used to forecast the probabilities of achieving different levels of ridership and revenue for the system based on the variation of specified risk factors that would affect future travel. The risk factors included calibrated model parameters as well as variation in input assumptions as shown in Table 1.1.

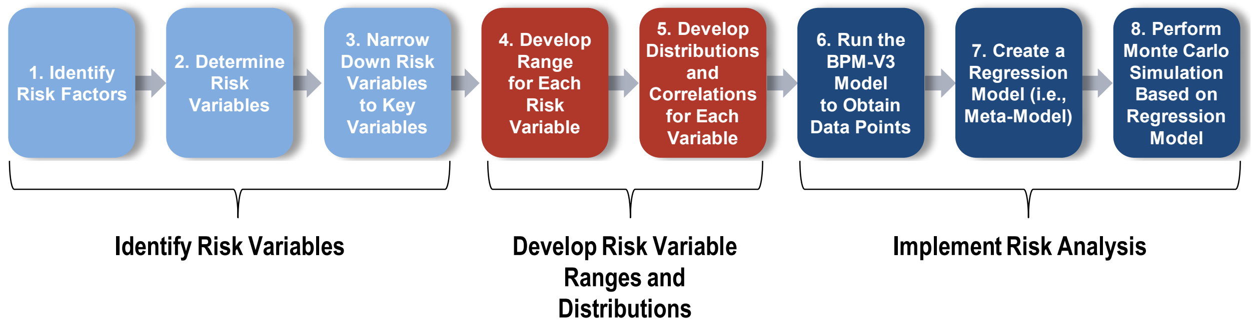
The key to the risk analysis approach was the development of simplified meta-models based on the specified risk factors that reasonably reproduced the results of the BPM-V3. The BPM-V3, which takes hours of computer time for each forecast, was run 59 times for each forecast year varying the risk factors. The resulting forecasts formed the inputs necessary for the development of linear regression-based models of the BPM-V3 forecasts that could be run in fractions of a second on a computer. This approach made it possible

[6] Southern California Association of Governments, *SCAG Regional Travel Demand Model and 2008 Model Validation*, June 2012; and Metropolitan Transportation Commission, *Travel Model Development: Calibration and Validation*, May 2012.

[7] See the 2016 Business Plan documentation for additional details regarding the risk analysis.

to produce 50,000 forecasts of ridership and revenue for each forecast year using Monte Carlo simulation procedures varying the input risk variables.

Figure 1.2 Risk Analysis Approach



Source: Cambridge Systematics.

Table 1.1 Risk Factors Considered by Forecast Year

Risk Variable	2025	2029	2040
HSR mode choice constant	x	x	x
Business/Commute and Recreation/Other trip frequency constants	x	x	x
Auto operating cost	x	x	x
HSR fares	x	x	x
HSR frequency of service	x	x	x
Availability and frequency of service of CVR and HSR bus connections to HSR termini	x		
Coefficient on transit access and egress TIME/AUTO DISTANCE variable	x	x	
Airfares		x	
Number and distribution of households throughout the state			x
Auto travel time			x

Source: Cambridge Systematics.

For business planning purposes, the 25th percentile forecast of HSR revenue was used; and for environmental analyses, the 75th percentile of HSR ridership was used. Since the risk analysis procedures produced only the HSR ridership or revenue forecasts, a separate, full, BPM-V3 forecast was performed with input values and assumptions set to reproduce the 75th percentile HSR ridership forecast. Estimation of 75th percentile VMT and VHT were based on this special forecast.

1.1.3 Modeling Process for Ridership and Differences in VMT

Two travel forecasts are produced for each forecast year in order to estimate differences in travel by each mode:

- a no-build forecast without the HSR system, and
- a build forecast with the HSR system.

The transportation systems and levels of service for auto, air, and CVR are assumed to be the same for the no-build and build forecasts.

Each of the model runs produces person trip tables for auto, air, CVR, and HSR for each of the four trip purposes. The BPM-V3 does not include a traffic assignment process since its primary focus was the forecast of HSR ridership and revenue. The California Statewide Travel Demand Model (CSTDM) does include a roadway network and traffic assignment process.[8] The BPM-V3 forecasts of person trips made by auto were, thus, processed using CSTDM forecast results to convert the auto person trips in the 50 or more mile range to auto vehicle trips. These were combined with CSTDM forecasts of auto vehicle trips less than 50 miles in length, commercial vehicle trips, and auto trips to, from, or through California and assigned to the CSTDM roadway network to produce VMT and VHT forecasts. Finally, since the BPM-V3 intraregional modeling procedures for the MTC and SCAG regions produced auto vehicle trips that can be assigned to the more detailed roadway networks in those regions, the intraregional VMT and VHT for those regions were used to replace the results of the CSTDM forecasts.

Detailed Procedures for Producing Differences in VMT

The BPM-V3 outputs auto person trips by four purposes – business, commute, recreation, and other. The CSTDM assignment process requires auto vehicle trips for the four different time periods – AM, midday, PM and off-peak for each of three different modes – single occupant vehicles (SOV), two occupant vehicles (HOV2), and three or more occupant vehicles (HOV3+). The following process was used to convert the BPM-V3 forecasts of auto person trips by purpose to vehicle trips by occupancy:

- BPM-V3 forecasts of auto person trips for business, commute, recreation, and other trip purposes were aggregated at the TAZ to TAZ level and then converted from production-attraction format to origin-destination format;
- The BPM-V3 auto person trips were split into short-distance (SD) trips greater than or equal to 50 miles and less than 100 miles and long-distance (LD) trips greater than or equal to 100 miles. The 100-mile cutoff distance was based on the CSTDM criterion of using straight line distance. The two trip tables were then converted from BPM-V3 zone system to CSTDM zone system based on proportion of area overlap;
- The total auto person trips were then split into person trips for the three different occupancy levels by the four time periods based on forecast CSTDM county to county proportions for each of the 12 combinations of person trips by vehicle occupancy by time of day. This step was performed for both for SD and LD trips.
- The person trips were then converted to vehicle trips by dividing the person trips by the occupancy level and summing the resulting vehicle trips. The CSTDM uses an HOV3+ occupancy rate of 3.6 persons per vehicle.
- CSTDM SD trips less than 50 miles (straight line distance) were added to the BPM-V3 SD trip table produce a full set of SD trips between 0-100 miles in length.

[8] Auto travel times used for the BPM-V3 are obtained from CSTDM forecasts.

- The resulting SD and LD vehicle trips were combined with commercial and external vehicle trips obtained from the CSTDM forecast for the appropriate year.

The resulting trip tables were then assigned for each of the four different time periods, and the resulting VMT on each link for each time of day was aggregated to produce statewide VMT estimate.

The above process was performed for both the no-build and 75th percentile BPM-V3 forecasts and the differences between the forecasts were calculated.

1.1.4 Process to Estimate Differences in Air Travel and Air Service Needs

As noted in Section 1.1.1, the introduction of HSR will divert trips from auto, air, and CVR. Those diverted trips can be consistently and deterministically forecast by comparing the differences in forecast trips by mode between the build and no-build alternatives.

The determination of changes in air service needs are more difficult to estimate since the amount of air service provided by carriers is based on their individual responses to HSR and other factors. Based on the structure of the BPM-V3, air trip interchanges can be assigned to origin and destination airports.[9] The average daily air passenger trips were multiplied by 365 to estimate annual intra-California air passenger trips. Each airport was assigned to one of six regions: San Francisco Bay Area, Sacramento Valley, San Diego, San Joaquin Valley, Southern California, and the Remainder of the state. The forecast no-build and modeled annual air trips were aggregated into tables of trips from airport region to airport region.

Annual passenger and flight data between California airports updated in May 2015 by the US Bureau of Transportation Statistics (BTS) were used to determine load factors for flights from each of the six regions. The detail of the BTS data allowed for the calculation of different load factors for flights internal to California and flights destined to locations outside of California.

The forecast airport region to airport region trips were then divided by the BTS derived load factor for the departure airport region to determine the number of annual flights required to serve the passenger loads based on load factors estimated from 2015 passenger and flight data. The reduction was then the estimated flights for the no-build forecast minus the estimated flights for the build forecast.

Flight reductions computed using the above approach represent what might be expected in the future. However, airline response to changes in air passengers due to the introduction of HSR might be different.

1.1.5 Greenhouse Gas Emissions Modeling

Authority analysts evaluated on-road vehicle emissions using average daily VMT estimates and associated average daily speed estimates for each affected county. Analysts estimated emission factors using the emission factors using the California Air Resources Board (CARB) emission factor program, EMission FACtors 2014 (EMFAC2014), which accounts for existing regulations that would reduce emissions, such as the Pavley Clean Car Standards. Parameters were set in the program for each individual county to reflect conditions within each county and statewide parameters to reflect travel through each county. The analysis was conducted for the following modeling years:

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[9] Air passenger trips are in production-attraction format. Thus, the trips from airport A to airport B actually represent both the outbound and return trips to locations served by airport A.

- Existing (Year 2015)
- Opening Year (Year 2029)
- Horizon Year (Year 2040)

To determine overall pollutant burdens generated by on-road vehicles, analysts multiplied the estimated VMT by the applicable pollutant's emission factors, which are based on speed, vehicle mix, and analysis year.

Air-passenger trip reductions are the number of passengers that shift from air travel to the HSR system. Air-passenger trips are used to estimate the number of airplane flights reduced which results in airline fuel use reductions. Airplane flights removed are based on a full airplane cycle, including taxi/idle, take-off, climbing, cruise, decent, and landing. Emission factors are provided by airplane type and for each component of the full airplane cycle. The source of emissions factors for airplane flights include the Federal Aviation Administration's Aviation Environmental Design Tool (AEDT) and the California Air Resources Board (California 2000-2014 GHG Emission Inventory: Technical Support Document, 2016 Edition. September 2016).

1.2 Growth Forecasts

As documented in Section 1.1, the BPM-V3 is a choice model with four distinct steps: trip frequency choice, trip destination choice, main mode choice, and access/egress mode choice. The primary keys to growth in travel are the growth in the number of households and the amount of employment within California coupled with changes in accessibility afforded by the HSR system. This information directly impacts the total numbers of trips forecast through the trip frequency model and the distribution of those trips within the state.

1.2.1 Population, Household, and Employment Forecasts

Forecasts of future population, households, and employment in California used as input to the BPM-V3 were based on county-level socioeconomic estimates and forecasts from many sources, including:

- **Federal agencies:** U.S. Census Bureau;
- **State agencies:** California Department of Finance (DOF) and the California Employment Development Department (EDD);
- **MPOs:** Metropolitan Transportation Commission (MTC), Sacramento Area Council of Governments (SACOG), San Diego Association of Governments (SANDAG), Southern California Association of Governments (SCAG), and the San Joaquin Valley MPOs;
- **Third Parties within California:** input data for the CSTDM, California Economic Forecast Project (CEF), Center for Continuing Study of the California Economy, University of California Los Angeles (UCLA – Anderson School), and University of Southern California (Price School).
- **Third Parties outside California:** Moody Analytics and Woods & Poole, Inc.

The data and forecasts from the various agencies were critically evaluated and processed to produce county-level forecasts of population, households, and employment throughout the state. Information from the MPOs was used to disaggregate the forecasts to TAZs.

1.2.2 Growth in Trips Forecast by the Trip Frequency Model

The trip frequency choice model forecasts the choice of making either zero or one long distance trip greater than 50 miles by residents of California. The models produce the probabilities of a single person in each household type in a TAZ making one travel-alone long-distance trip and one travel-in-group long-distance trip on a given day. Household types are stratified by four household size groups (1, 2, 3, or 4+), three income groups (low, medium, or high income), three auto ownership groups (0, 1, or 2+ autos), and three number of workers groups (0, 1, or 2+ workers) to produce the numbers of households by each of 99 different household types for each TAZ.[10] The forecasts produce the probabilities of making either a production-attraction trip or the return attraction-production trip. The resulting probabilities represent the trips per person for each household type. The trips per person were multiplied by the household size and, then, by the number of households in the specific household size group to estimate the total person trips "generated." Thus, the growth in total forecast trips for any forecast year is directly related to the growth in the numbers of households by household type.

The forecast of future trips is also directly related to change in accessibility in the state. As roadways become more congested and travel times increase, accessibility decreases and, thus, long distance trips also decrease. Likewise, if the aggregate accessibility from a TAZ to all other TAZs increases due to good HSR connections, long distance trips from that TAZ will increase. When comparing a build alternative to a no-build alternative, an increase in total trip making for the build alternative can be considered one component of induced travel.

1.2.3 Growth in Corridor-Level Trips Forecast by the Destination Choice Model

The total numbers of trips produced by household in each TAZ are determined using the Trip Frequency model. However, based on changes in the accessibility for each TAZ to TAZ interchange, trips from a TAZ may be diverted from less accessible destination TAZs to more accessible destination TAZs. Thus, in comparison to a no-build alternative, trips between TAZs in well-served corridors may increase, compensating for decreases in trips in less well-served corridors. This change in trips due to accessibility constitutes as second component of induced travel.

1.3 Transportation Network

1.3.1 HSR Network Assumptions for the Different Horizon Years

The business case evaluation assumes that the high-speed rail project will open in phases, from 2025 through 2029, as described below.

Silicon Valley to Central Valley Line–Open in 2025

The Silicon Valley to Central Valley line is planned to begin service in 2025, characterized by:

- A north terminal at San Jose and a south terminal at a station north of Bakersfield (Figure 1.3);

[10] 4×3×3×3=108 household strata. However, nine illogical strata where number of workers per household are greater than the household size are removed.

- Dedicated coach services will be provided between the Fresno station and the Sacramento region, as well as between the line's southern terminus and locations in the Los Angeles Basin (LA Basin);
- Connections with Amtrak at Fresno to the Bay Area and Sacramento would be coordinated; and
- Potential extensions to the Silicon Valley to Central Valley phase would extend high-speed rail service from San Jose to San Francisco in the north and from the assumed southern terminus to Bakersfield.

Figure 1.3 Silicon Valley to Central Valley Line

Phase 1

Scheduled to start operations in 2029, Phase 1 completes the high-speed rail system from a north terminal at San Francisco to the south terminal at Anaheim (Figure 1.4), with these characteristics:

- High-speed rail service will operate on Caltrain tracks from San Jose to San Francisco, meaning that congestion on the corridor is taken into account for assumed travel time;
- Dedicated coach services would be provided from Merced to Sacramento;
- Connections with Amtrak at Merced to the Bay Area and Sacramento would be coordinated; and
- Connections with Metrolink feeder service at Los Angeles Union Station (LAUS) to LA Basin destinations would be coordinated.

Figure 1.4 Phase 1–Open in 2029

High-Speed Rail Service Plan Assumptions

High-speed rail fares for all 2016 Business Plan scenarios were identical to those in the 2014 Business Plan escalated from 2013 dollars to 2015 dollars. The fares are based on the formula below, with an $89 maximum in 2015 dollars:

- $32.26 + $0.1994 per mile (in 2015 dollars) for interregional fares;
- $23.94 + $0.1662 per mile (in 2015 dollars) for intraregional fares for the SCAG region; and
- $15.51 + $0.1330 per mile (in 2015 dollars) for intraregional fares for MTC and SANDAG regions.

Service assumptions varied by scenario. The details of the service frequencies are described in Table 1.2.

Table 1.2 High-Speed Rail Service Plan Assumptions by Scenario

Business Plan Scenario	North Terminus	South Terminus	High-Speed Rail Service Summary[a]	Dedicated Peak Bus Coach Connections[b]		Conventional Rail Connections
				North Terminus	South Terminus	
Silicon Valley to Central Valley Line	San Jose	North of Bakersfield	• 2 peak TPH from San Jose and North of Bakersfield (1 in off-peak)	• 2 peak BPH from Fresno and Sacramento (1 in off-peak)	• 2 BPH from North of Bakersfield and LAUS (1 in off-peak) • 2 BPH from North of Bakersfield and West LA (1 in off-peak) • 2 BPH from North of Bakersfield and Santa Anita (1 in off-peak)	• Coordinated service with Amtrak at Fresno
Silicon Valley to Central Valley Line Extension	San Francisco	Bakersfield	• 2 peak TPH from San Francisco and Bakersfield (1 in off-peak)	• 2 peak BPH from Fresno and Sacramento (1 in off-peak)	• 2 BPH from Bakersfield and LAUS (1 in off-peak) • 2 BPH from Bakersfield and West LA (1 in off-peak) • 2 BPH from Bakersfield and Santa Anita (1 in off-peak)	• Coordinated service with Amtrak at Fresno
Phase 1	San Francisco and Merced	Los Angeles and Anaheim	• 2 peak TPH from San Francisco and Los Angeles (3 in off-peak) • 2 peak TPH from San Francisco and Anaheim (1 in off-peak) • 2 peak TPH from San Jose and Los Angeles (0 in off-peak) • 1 peak TPH from Merced and Los Angeles (0 in off-peak) • 1 peak TPH from Merced and Anaheim (same in off-peak)	• 2 BPH from Sacramento and Merced (1 in off-peak)	None	• Coordinated service with Amtrak at Merced • Metrolink connections at LAUS

[a] TPH – Trains per Hour
[b] BPH - Buses per Hour

1.3.2 Assumed roadway improvements

The highway network assumptions were the same as those used for the CSTDM for each respective forecast year.[11] CS averaged AM and PM peak congested travel times derived from the CSTDM for use when peak travel times were needed in the mode choice model. Similarly, CS averaged midday and off-peak congested speeds for when off-peak travel times were needed. Auto terminal times representing the average time to access one's vehicle at each end of the trip were added to the congested travel time to get the total congested travel time skim. Terminal times were based on the area type and assessed at both the origin and destination of the trip. When the CSTDM forecast years did not match the 2016 Business Plan forecast years, the travel times for the modeled forecast years were determined by interpolating between the closest CSTDM forecast years.

Auto costs (besides operating costs) comprise tolls and parking costs. Toll costs were imported from networks developed for the CSTDM. Tolls corresponding to single-occupancy vehicles were assumed in the auto skims. Peak and off-peak tolls were averaged where costs differed. The parking costs developed for the 2010 base year scenario were used for all future year scenarios.

Automobile Operating Cost

Auto operating costs for the 2016 Business Plan were developed based on information regarding gasoline prices from the U.S. Energy Information Administration's (EIA) 2011 Annual Energy Outlook (AEO) coupled with projected motor gasoline prices in California based on the 2013 AEO, which extends through 2040. This procedure was consistent with the methodology used for the 2014 Business Plan. The forecasts for fuel efficiency were based on the adopted Corporate Average Fuel Economy (CAFE) standards for light-duty vehicles for model year 2012 to 2016, as well as fuel economy projections based on the 2013 AEO forecasts, which included the adopted fuel efficiency standards for model year 2017 through model year 2025. The auto operating costs used for the different forecast years are summarized in Table 1.3.

Table 1.3 Auto Operating Costs in 2015 Dollars

Forecast Year	Range (Cents per Mile)
2025	26
2029	26
2040	24

Source: Cambridge Systematics, Inc.

1.3.3 Aviation Network Assumptions

Air service assumptions for forecast years were based on the latest air service patterns in the California Corridor markets.[12] The past decade of U.S. Department of Transportation (DOT) data on airline service and fare levels were used to provide information on the economic factors affecting airline responses to changes

[11] For more information regarding the CSTDM model development and assumptions, see the documentation provided on the California DOT (Caltrans) web site: http://www.dot.ca.gov/hq/tsip/otfa/cstdm/cstdm_documentation.html.

[12] Forecasts were produced by Aviation System Consulting, LLC (ASC), a California-based expert firm.

in competition and capacity, and helped determine scenarios of potential airline competitive response to the introduction of high-speed rail service.

The baseline assumption for air fares and assumed headways for all forecast years was that air fares would remain consistent with average fares and frequency of service that were used in the 2014 Business Plan. Table 1.4 provides base airfares and headways between select major airports.

Table 1.4 Air Service Assumptions

Origin Airport	Destination Airport	Assumed Airfare (2015 Dollars)	Assumed Headway (Minutes)
Burbank	San Francisco	$115	480.0
Burbank	Sacramento	$112	150.0
Los Angeles	San Diego	$237	32.0
Los Angeles	San Francisco	$100	23.0
Oakland	San Diego	$111	46.0
Oakland	Los Angeles	$111	44.0
Sacramento	Burbank	$112	150.0
Sacramento	San Francisco	$299	141.0
San Francisco	San Diego	$96	28.0
San Francisco	Burbank	$115	480.0

Source: Aviation System Consulting.

1.3.4 Conventional Passenger Rail Service Assumptions

CVR service, including travel times, frequency of service, and stations served, were updated to reflect the latest conditions and forecasts from the 2013 California State Rail Plan (CSRP),[13] MPO forecasts, and the CSTDM. The largest service changes from 2016 conditions include increased conventional rail service on the Altamont Corridor Express and the San Joaquins to connect with HSR, and increased service between San Diego and Los Angeles via connected Coaster and Metrolink service. In the Silicon Valley to Central Valley scenarios, the enhanced San Joaquin trains were assumed to connect from Sacramento and Oakland to HSR at Fresno. In Phase 1, that connection was assumed to be at Merced. The sources for CVR service are summarized in Table 4.2 and operating frequencies are summarized in Table 4.3. Fare assumptions for all CVR lines were consistent with on-line published fares from 2011. Consistent with previous assumptions, the peak period was assumed to be three hours during each of the AM and PM peak periods, and 10 hours for the off-peak period.

[13] 2013 California State Rail Plan, May 2013. Available at: http://californiastaterailplan.dot.ca.gov/.

Table 1.5 Source of CVR Operating Plan Forecasts

Source of Forecast	CVR Operators
California State Rail Plan	Amtrak San Joaquin Capitol Corridor Pacific Surfliner Altamont Corridor Express Caltrain Coaster MetroRail
MPO Plans	BART SMART Metrolink
California Statewide Transportation Demand Model	Muni LRT VTA LRT Sacramento LRT SANDAG LRT Sprinter

Table 1.6 CVR Operating Plan Service Frequencies

	2025 / 2029-2040[a]
Caltrain	
Gilroy – San Jose	11 / 11
Tamien/San Jose – San Francisco (4th and King/SF Transbay)	68 / 68
Capitol Corridor Route	
Auburn – Oakland	2 / 2
Sacramento – Oakland	3 / 3
Sacramento – San Jose	11 / 11
San Joaquin Route	
Sacramento – Merced connection to high-speed rail via San Joaquin Route	10 / 10
Sacramento – Bakersfield via San Joaquin Route	- / -
Oakland – Bakersfield via San Joaquin Route	- / -
Oakland – Merced connection to high-speed rail via San Joaquin Route	10 / 10
Stockton – Merced connection to high-speed rail via San Joaquin Route	1 / 1
Merced – Bakersfield via San Joaquin Route	6 / 6
Ace Route	
San Jose – Stockton via ACE Route	4 / 4
San Jose – Merced connection to high-speed rail via ACE and Union Pacific Railroad (UPRR) Route	2 / 2
San Jose – Merced connection to high-speed rail via ACE and BNSF Railway (BNSF) Route	4 / 4
Pacific Surfliner	
San Luis Obispo – Los Angeles	2 / 2
Goleta – Los Angeles	3 / 3
Los Angeles – San Diego	18 / 18
Metrolink (Ventura and Orange County Lines) and COASTER	
East Ventura[p] – Los Angeles	20 / 20
Los Angeles – Irvine/Laguna Niguel	5 / 5
Los Angeles – Oceanside	2 / 2
Los Angeles – San Diego (Metrolink COASTER "through" commuter service)	5 / 5
Riverside – San Diego (Metrolink-COASTER "through" commuter service)	0 / 2
Oceanside – San Diego	17 / 17
Metrolink – Other Lines	
Antelope Valley Line (LAUS – Palmdale)	19 / 19
San Bernardino Line (LAUS – San Bernardino)	23 / 23
Riverside Line (LAUS – Riverside)	6 / 6
91/Perris Valley Line (LAUS – Riverside-Perris)	7 / 7
Burbank Airport Line (LAUS – Burbank Airport)	7 / 7
IEOC (San Bernardino-Riverside-Irvine-Laguna Niguel/Mission Viejo)	10 / 10
OC Intracounty Line (Fullerton – Laguna Niguel/Mission Viejo)	5 / 5

Source: Cambridge Systematics, Inc.

[a] This column denotes the number of conventional passenger rail trains per day in each direction for the Silicon Valley to Central Valley lines in 2025 and for Phase 1 between 2029 and 2040.

2.0 Summary of Estimates

2.1 75th Percentile Travel Forecasts

2.1.1 Trips by Mode

2025 Results

Table 2.1 summarizes the annual trips by mode for the no-build and build alternatives for major markets in California in 2025. The results are raw model output and do not account for ramp-up. Table 2.2 summarizes the diversion of trips to HSR from other modes along with the induced long-distance travel. There are no forecast short distance changes in ridership in the MTC and SCAG regions for 2025 since the Silicon Valley to Central Valley HSR system does not serve those regions.

2029 Results

Table 2.3 summarizes the annual trips by mode for the no-build and build alternatives for major markets in California in 2025. The results are raw model output and do not account for ramp-up.

Table 2.4 summarizes the diversion of trips to HSR from other modes along with the induced long-distance travel. The short distance trip model for the MTC and SCAG regions was not rerun for the 2029 75th percentile no-build scenario. No-build trips by mode for 2029 were estimated by prorating the short distance HSR trips to the auto and CVR modes.

2040 Results

Table 2.5 summarizes the annual trips by mode for the no-build and build alternatives for major markets in California in 2025. The results are raw model output and do not account for ramp-up.

Table 2.6 summarizes the diversion of trips to HSR from other modes along with the induced long-distance travel. The short distance trip model for the MTC and SCAG regions was not rerun for the 2040 75th percentile no-build scenario. No-build trips by mode for 2040 were estimated by prorating the short distance HSR trips to the auto and CVR modes.

Table 2.1 2025 Annual Trips (in Millions) – No-Build and Silicon Valley to Central Valley Alternatives
75th Percentile Forecast

Market		Ridership – No Build Alternative					Ridership – Silicon Valley to Central Valley Alternative				
		Auto	Air	HSR	CVR	Total	Auto	Air	HSR	CVR	Total
SACOG	SACOG	3.5	-	-	0.0	3.5	3.5	-	-	0.0	3.5
SACOG	SANDAG	0.6	0.4	-	0.0	1.0	0.6	0.4	0.0	0.0	1.0
SACOG	MTC	54.7	0.0	-	1.6	56.3	54.7	0.0	0.0	1.6	56.3
SACOG	SCAG	5.2	1.7	-	0.0	6.9	5.0	1.6	0.3	0.0	7.0
SACOG	San Joaquin Valley	13.3	0.0	-	0.1	13.4	13.1	0.0	0.2	0.1	13.4
SACOG	Other Regions	16.7	0.0	-	0.0	16.8	16.6	0.0	0.1	0.0	16.8
SANDAG	SANDAG	1.0	-	-	0.0	1.0	1.0	-	-	0.0	1.0
SANDAG	MTC	2.0	1.4	-	0.0	3.4	1.9	1.3	0.2	0.0	3.4
SANDAG	SCAG	110.6	0.3	-	3.2	114.1	110.5	0.3	-	3.2	114.0
SANDAG	San Joaquin Valley	3.0	0.2	-	0.0	3.2	2.9	0.2	0.1	0.0	3.2
SANDAG	Other Regions	2.4	0.3	-	0.0	2.7	2.4	0.2	0.0	0.0	2.7
MTC	MTC	34.9	0.0	-	1.0	35.9	34.6	0.0	0.3	0.9	35.9
MTC	SCAG	14.3	5.6	-	0.1	19.9	13.1	4.7	2.2	0.1	20.1
MTC	San Joaquin Valley	39.8	0.3	-	0.5	40.6	37.4	0.2	2.7	0.5	40.8
MTC	Other Regions	44.9	0.0	-	0.5	45.4	43.8	0.0	1.2	0.4	45.4
SCAG	SCAG	153.0	0.0	-	1.9	154.9	153.0	0.0	-	1.9	154.9
SCAG	San Joaquin Valley	31.3	0.4	-	0.9	32.6	30.5	0.4	0.8	0.9	32.6
SCAG	Other Regions	28.5	0.8	-	0.3	29.6	28.1	0.7	0.5	0.3	29.6
San Joaquin Valley	San Joaquin Valley	21.1	0.0	-	0.3	21.4	20.1	0.0	1.1	0.2	21.5
San Joaquin Valley	Other Regions	24.1	0.0	-	0.1	24.3	23.4	0.0	0.7	0.1	24.3
Other Regions	Other Regions	20.1	0.0	-	0.0	20.1	19.9	0.0	0.2	0.0	20.1
Long-Distance Total		624.8	11.6	-	10.6	646.9	616.2	10.2	10.6	10.3	647.4
MTC (< 50 miles)	MTC (< 50 miles)	8,406.6	-	-	15.4	8,422.0	8,406.6	-	-	15.4	8,422.0
SCAG (< 50 miles)	SCAG (< 50 miles)	18,655.0	-	-	13.9	18,668.9	18,655.0	-	-	13.9	18,668.9
Short-Distance Total[1]		**27,061.7**	-	-	**29.2**	**27,090.9**	**27,061.7**	**-**	**-**	**29.2**	**27,090.9**
Total		**27,686.5**	**11.6**	-	**39.8**	**27,737.8**	**27,677.9**	**10.2**	**10.6**	**39.6**	**27,738.3**

[1] With the exception of the SCAG and MTC regions, only long distance trips (trips made to locations 50 or more miles from a traveler's home) are shown in the table. In the SCAG and MTC regions, separate summaries of intraregional trips made to locations less than 50 miles from the travelers' homes are also shown. Only short-distance auto, HSR, and CVR modes are shown in this table.

Source: Cambridge Systematics

Table 2.2 2025 Annual Trips (in Millions) and Shares of Trips Diverted from Each Mode to HSR
75th Percentile Forecast

Market		HSR Ridership Diverted from Each Mode				Percentage of HSR Ridership Diverted from Each Mode			
		Auto	Air	CVR	Induced	Auto	Air	CVR	Induced
SACOG	SACOG	-	-	-	-	0%	0%	0%	0%
SACOG	SANDAG	0.0	0.0	-	0.0	39%	52%	0%	9%
SACOG	MTC	0.0	-	0.0	-	96%	0%	4%	0%
SACOG	SCAG	0.2	0.1	0.0	0.0	54%	40%	1%	5%
SACOG	San Joaquin Valley	0.2	0.0	0.0	0.0	93%	2%	3%	1%
SACOG	Other Regions	0.1	0.0	0.0	0.0	94%	1%	2%	3%
SANDAG	SANDAG	-	-	-	-	0%	0%	0%	0%
SANDAG	MTC	0.1	0.1	-	0.0	39%	55%	0%	6%
SANDAG	SCAG	-	-	-	-	0%	0%	0%	0%
SANDAG	San Joaquin Valley	0.1	0.0	0.0	0.0	81%	14%	2%	4%
SANDAG	Other Regions	0.0	0.0	-	0.0	62%	36%	0%	3%
MTC	MTC	0.3	-	0.0	0.0	88%	0%	11%	1%
MTC	SCAG	1.1	0.9	0.0	0.1	51%	42%	1%	7%
MTC	San Joaquin Valley	2.4	0.0	0.1	0.2	90%	1%	3%	7%
MTC	Other Regions	1.1	0.0	0.0	0.0	92%	0%	3%	4%
SCAG	SCAG	-	-	-	-	0%	0%	0%	0%
SCAG	San Joaquin Valley	0.7	0.1	0.0	0.0	88%	7%	2%	3%
SCAG	Other Regions	0.4	0.1	0.0	0.0	78%	17%	0%	5%
San Joaquin Valley	San Joaquin Valley	1.0	-	0.0	0.0	93%	0%	4%	4%
San Joaquin Valley	Other Regions	0.7	0.0	0.0	0.0	96%	0%	1%	3%
Other Regions	Other Regions	0.1	-	-	0.0	97%	0%	0%	3%
Long-Distance Total		8.6	1.4	0.2	0.5	80%	13%	2%	5%
MTC (< 50 miles)	MTC (< 50 miles)	-	-	-	-	-	-	-	-
SCAG (< 50 miles)	SCAG (< 50 miles)	-	-	-	-	-	-	-	-
Short-Distance Total		-	-	-	-	-	-	-	-
Total		8.6	1.4	0.2	0.5	80%	13%	2%	5%

Source: Cambridge Systematics

Table 2.3 2029 Annual Trips (in Millions) – No-Build and Phase 1 Alternatives
75th Percentile Forecast

Market		Ridership – No Build Alternative					Ridership – Silicon Valley to Central Valley Alternative				
		Auto	Air	HSR	CVR	Total	Auto	Air	HSR	CVR	Total
SACOG	SACOG	4.1	-	-	0.0	4.2	4.1	-	-	0.0	4.1
SACOG	SANDAG	0.8	0.5	-	0.0	1.3	0.8	0.4	0.2	0.0	1.3
SACOG	MTC	66.6	0.0	-	2.0	68.6	65.7	0.0	0.9	2.0	68.6
SACOG	SCAG	6.8	1.7	-	0.0	8.5	5.9	1.3	1.4	0.0	8.6
SACOG	San Joaquin Valley	15.8	0.0	-	0.1	16.0	15.5	0.0	0.3	0.1	16.0
SACOG	Other Regions	20.3	0.0	-	0.0	20.3	20.1	0.0	0.2	0.0	20.3
SANDAG	SANDAG	1.3	-	-	0.0	1.3	1.3	-	-	0.0	1.3
SANDAG	MTC	2.6	1.5	-	0.0	4.1	2.1	1.0	1.1	0.0	4.2
SANDAG	SCAG	131.8	0.2	-	4.0	136.0	128.7	0.2	3.5	3.7	136.1
SANDAG	San Joaquin Valley	3.6	0.2	-	0.0	3.8	3.1	0.1	0.6	0.0	3.9
SANDAG	Other Regions	2.9	0.3	-	0.0	3.2	2.7	0.2	0.3	0.0	3.2
MTC	MTC	41.1	-	-	1.1	42.2	38.7	-	2.7	0.9	42.3
MTC	SCAG	17.8	5.5	-	0.1	23.4	13.1	3.1	7.8	0.0	24.0
MTC	San Joaquin Valley	46.5	0.2	-	0.5	47.3	41.7	0.2	5.2	0.5	47.6
MTC	Other Regions	51.7	0.0	-	0.6	52.4	48.9	0.0	3.0	0.5	52.5
SCAG	SCAG	182.3	0.0	-	2.3	184.7	174.5	0.0	8.2	2.1	184.9
SCAG	San Joaquin Valley	36.8	0.4	-	1.0	38.2	30.5	0.2	7.2	0.6	38.5
SCAG	Other Regions	32.9	0.7	-	0.3	33.9	31.2	0.5	2.1	0.3	34.0
San Joaquin Valley	San Joaquin Valley	25.1	0.0	-	0.2	25.3	22.7	0.0	2.5	0.2	25.4
San Joaquin Valley	Other Regions	27.4	0.0	-	0.1	27.5	26.3	0.0	1.0	0.1	27.5
Other Regions	Other Regions	23.1	0.0	-	0.0	23.1	22.9	0.0	0.2	0.0	23.1
Long-Distance Total		741.5	11.2	-	12.6	765.3	700.5	7.4	48.3	11.1	767.3
MTC (< 50 miles)	MTC (< 50 miles)	8,675.9	-	-	17.2	8,693.1	8,675.5	-	0.4	17.2	8,693.1
SCAG (< 50 miles)	SCAG (< 50 miles)	19,060.0	-	-	13.7	19,073.7	19,059.9	-	0.1	13.7	19,073.7
Short-Distance Total[1,2]		27,735.9	-	-	30.9	27,766.8	27,735.4	-	0.5	30.9	27,766.8
Total		28,477.4	11.2	0.0	43.5	28,532.2	28,435.9	7.4	48.9	42.0	28,534.2

[1] With the exception of the SCAG and MTC regions, only long distance trips (trips made to locations 50 or more miles from a traveler's home) are shown in the table. In the SCAG and MTC regions, separate summaries of intraregional trips made to locations less than 50 miles from the travelers' homes are also shown. Only short-distance auto, HSR, and CVR modes are shown in this table.

[2] The short distance trip model for the MTC and SCAG regions was not rerun for the 2029 75th percentile no-build scenario. No-build trips by mode for 2029 were estimated by prorating the short distance HSR trips to the auto and CVR modes.

Source: Cambridge Systematics

Table 2.4 2029 Annual Trips (in Millions) and Shares of Trips Diverted from Each Mode to HSR
75th Percentile Forecast

Market		HSR Ridership Diverted from Each Mode				Percentage of HSR Ridership Diverted from Each Mode			
		Auto	Air	CVR	Induced	Auto	Air	CVR	Induced
SACOG	SACOG	-	-	-	-	0%	0%	0%	0%
SACOG	SANDAG	0.1	0.1	0.0	0.0	51%	42%	1%	6%
SACOG	MTC	0.9	0.0	0.0	-	96%	0%	4%	0%
SACOG	SCAG	0.9	0.4	0.0	0.1	64%	29%	0%	6%
SACOG	San Joaquin Valley	0.3	0.0	0.0	-	97%	1%	2%	0%
SACOG	Other Regions	0.2	0.0	0.0	-	98%	1%	2%	0%
SANDAG	SANDAG	-	-	-	-	0%	0%	0%	0%
SANDAG	MTC	0.5	0.4	0.0	0.1	50%	42%	0%	7%
SANDAG	SCAG	3.2	0.0	0.3	0.0	89%	1%	9%	1%
SANDAG	San Joaquin Valley	0.5	0.0	0.0	0.0	86%	7%	2%	5%
SANDAG	Other Regions	0.2	0.1	0.0	0.0	74%	19%	1%	6%
MTC	MTC	2.4	-	0.2	0.1	90%	0%	6%	4%
MTC	SCAG	4.7	2.4	0.0	0.6	61%	30%	1%	8%
MTC	San Joaquin Valley	4.8	0.1	0.1	0.3	92%	1%	2%	5%
MTC	Other Regions	2.8	0.0	0.1	0.1	93%	0%	4%	3%
SCAG	SCAG	7.8	0.0	0.2	0.2	95%	0%	3%	2%
SCAG	San Joaquin Valley	6.3	0.1	0.4	0.4	88%	2%	5%	5%
SCAG	Other Regions	1.8	0.2	0.0	0.1	86%	9%	1%	4%
San Joaquin Valley	San Joaquin Valley	2.3	0.0	0.1	0.1	94%	0%	3%	3%
San Joaquin Valley	Other Regions	1.1	0.0	0.0	-	99%	0%	1%	0%
Other Regions	Other Regions	0.2	0.0	0.0	-	99%	1%	1%	0%
Long-Distance Total		41.0	3.8	1.5	2.0	85%	8%	3%	4%
MTC (< 50 miles)	MTC (< 50 miles)	0.4	-	-	-	100%	-	-	-
SCAG (< 50 miles)	SCAG (< 50 miles)	0.1	-	-	-	100%	-	-	-
Short-Distance Total		0.5	-	-	-	100%	-	-	-
Total		41.5	3.8	1.5	2.0	85%	8%	3%	4%

Source: Cambridge Systematics

Table 2.5 2040 Annual Trips (in Millions) – No-Build and Phase 1 Alternatives

75th Percentile Forecast

Market		Ridership – No Build Alternative					Ridership – Silicon Valley to Central Valley Alternative				
		Auto	Air	HSR	CVR	Total	Auto	Air	HSR	CVR	Total
SACOG	SACOG	4.5	-	-	0.0	4.5	4.5	-	-	0.0	4.5
SACOG	SANDAG	0.8	0.7	-	0.0	1.5	0.8	0.6	0.1	0.0	1.5
SACOG	MTC	76.1	0.0	-	2.4	78.6	74.9	0.0	1.3	2.4	78.5
SACOG	SCAG	7.0	2.6	-	0.0	9.6	6.3	2.1	1.3	0.0	9.7
SACOG	San Joaquin Valley	23.9	0.1	-	0.2	24.2	23.5	0.0	0.4	0.2	24.2
SACOG	Other Regions	25.5	0.0	-	0.1	25.6	25.3	0.0	0.2	0.0	25.6
SANDAG	SANDAG	1.5	-	-	0.0	1.5	1.5	-	-	0.0	1.5
SANDAG	MTC	2.5	2.0	-	0.0	4.6	2.1	1.6	0.9	0.0	4.6
SANDAG	SCAG	146.0	0.5	-	4.5	151.0	140.2	0.4	4.1	4.0	148.7
SANDAG	San Joaquin Valley	5.0	0.3	-	0.1	5.4	4.3	0.2	0.8	0.1	5.4
SANDAG	Other Regions	3.1	0.4	-	0.0	3.6	2.9	0.3	0.2	0.0	3.5
MTC	MTC	44.6	0.0	-	0.9	45.5	41.8	0.0	3.1	0.8	45.6
MTC	SCAG	17.6	7.6	-	0.1	25.3	13.8	4.9	7.1	0.1	25.9
MTC	San Joaquin Valley	67.2	0.5	-	0.9	68.6	61.3	0.3	6.5	0.8	68.9
MTC	Other Regions	58.8	0.1	-	0.7	59.6	55.6	0.1	3.4	0.5	59.6
SCAG	SCAG	206.6	0.0	-	2.7	209.4	198.7	0.0	9.0	2.4	210.1
SCAG	San Joaquin Valley	50.5	0.8	-	1.3	52.6	43.4	0.5	8.2	0.9	53.0
SCAG	Other Regions	33.9	1.2	-	0.3	35.4	32.4	1.0	1.9	0.3	35.5
San Joaquin Valley	San Joaquin Valley	43.5	0.0	-	0.4	43.9	40.2	0.0	3.5	0.3	44.0
San Joaquin Valley	Other Regions	39.0	0.0	-	0.1	39.2	37.8	0.0	1.2	0.1	39.1
Other Regions	Other Regions	31.3	0.0	-	0.0	31.3	31.0	0.0	0.2	0.0	31.3
Long-Distance Total		889.0	16.9	-	14.8	920.7	842.3	12.2	53.5	12.8	920.8
MTC (< 50 miles)	MTC (< 50 miles)	9,217.8	-	-	19.3	9,237.1	9,217.3	-	0.5	19.3	9,237.1
SCAG (< 50 miles)	SCAG (< 50 miles)	20,028.5	-	-	13.3	20,041.9	20,028.4	-	0.1	13.3	20,041.9
Short-Distance Total[1,2]		29,246.3	-	-	32.7	29,279.0	29,245.7	-	0.6	32.7	29,279.0
Total		30,135.3	16.9	-	47.5	30,199.7	30,088.0	12.2	54.1	45.5	30,199.8

[1] With the exception of the SCAG and MTC regions, only long distance trips (trips made to locations 50 or more miles from a traveler's home) are shown in the table. In the SCAG and MTC regions, separate summaries of intraregional trips made to locations less than 50 miles from the travelers' homes are also shown. Only short-distance auto, HSR, and CVR modes are shown in this table.

[2] The short distance trip model for the MTC and SCAG regions was not rerun for the 2040 75th percentile no-build scenario. No-build trips by mode for 2040 were estimated by prorating the short distance HSR trips to the auto and CVR modes.

Source: Cambridge Systematics

Table 2.6 2040 Annual Trips (in Millions) and Shares of Trips Diverted from Each Mode to HSR
75th Percentile Forecast

Market		HSR Ridership Diverted from Each Mode				Percentage of HSR Ridership Diverted from Each Mode			
		Auto	Air	CVR	Induced	Auto	Air	CVR	Induced
SACOG	SACOG	-	-	-	-	0%	0%	0%	0%
SACOG	SANDAG	0.1	0.1	0.0	-	48%	51%	1%	0%
SACOG	MTC	1.2	0.0	0.1	-	93%	0%	7%	0%
SACOG	SCAG	0.7	0.5	0.0	0.1	54%	38%	0%	7%
SACOG	San Joaquin Valley	0.4	0.0	0.0	-	95%	2%	3%	0%
SACOG	Other Regions	0.2	0.0	0.0	-	97%	1%	2%	0%
SANDAG	SANDAG	-	-	-	-	0%	0%	0%	0%
SANDAG	MTC	0.4	0.5	0.0	-	45%	54%	0%	0%
SANDAG	SCAG	5.8	0.1	0.5	-	91%	1%	8%	0%
SANDAG	San Joaquin Valley	0.7	0.1	0.0	-	88%	9%	3%	0%
SANDAG	Other Regions	0.2	0.1	0.0	-	74%	25%	2%	0%
MTC	MTC	2.8	-	0.1	0.1	91%	0%	5%	4%
MTC	SCAG	3.7	2.7	0.0	0.6	52%	39%	1%	9%
MTC	San Joaquin Valley	5.9	0.1	0.1	0.3	91%	2%	2%	5%
MTC	Other Regions	3.2	0.0	0.1	0.1	93%	0%	4%	3%
SCAG	SCAG	8.0	0.0	0.3	0.7	89%	0%	3%	8%
SCAG	San Joaquin Valley	7.0	0.2	0.4	0.5	86%	3%	5%	6%
SCAG	Other Regions	1.5	0.3	0.0	0.1	78%	13%	1%	7%
San Joaquin Valley	San Joaquin Valley	3.3	0.0	0.1	0.1	94%	0%	3%	3%
San Joaquin Valley	Other Regions	1.2	0.0	0.0	-	99%	0%	1%	0%
Other Regions	Other Regions	0.2	0.0	0.0	-	99%	0%	1%	0%
Long-Distance Total		46.7	4.7	2.0	0.1	87%	9%	4%	0%
MTC (< 50 miles)	MTC (< 50 miles)	0.5	-	-	-	100%	-	-	-
SCAG (< 50 miles)	SCAG (< 50 miles)	0.1	-	-	-	100%	-	-	-
Short-Distance Total		0.6	-	-	-	100%	-	-	-
Total		47.3	4.7	2.0	0.1	87%	9%	4%	0%

Source: Cambridge Systematics

2.2 Changes in VMT

Table 2.7 and Table 2.8 summarize the assigned annual VMT in billions of miles and daily VMT in thousands of miles, respectively, for the three forecast years using the procedures outlined in Section 1.1.3. The modeling procedures used to forecast the assigned VMT are based on the underlying assumptions that the HSR system is operating in a steady state situation for the entire year.

Table 2.7 Annual Auto VMT in Billions of Miles

Summary	2025	2029	2040
Modeled Intraregional Assignment Results			
No-Build VMT	159.458	162.234	171.921
Build Alternative VMT	159.458	162.229	171.916
Change in VMT Due to HSR	0.000	-0.005	-0.005
Modeled Interregional Raw Assignment Results			
No-Build VMT	60.368	67.501	73.727
Build Alternative VMT	58.978	61.795	66.461
Change in VMT Due to HSR	-1.390	-5.706	-7.266
Modeled Total Raw Assignment Results			
No-Build VMT	219.826	229.735	245.648
Build Alternative VMT	218.436	224.024	238.377
Change in VMT Due to HSR	-1.390	-5.711	-7.271

Source: Cambridge Systematics

Table 2.8 Daily Auto VMT in Thousands of Miles

Summary	2025	2029	2040
Modeled Intraregional Assignment Results			
No-Build VMT	476,179	484,506	513,406
Build Alternative VMT	476,179	484,491	513,390
Change in VMT Due to HSR	0	-15	-15
Modeled Interregional Raw Assignment Results			
No-Build VMT	157,612	188,871	739,135
Build Alternative VMT	153,661	173,346	722,884
Change in VMT Due to HSR	-3,951	-15,525	-16,250
Modeled Total Raw Assignment Results			
No-Build VMT	633,791	673,377	1,252,541
Build Alternative VMT	629,840	657,837	1,236,275
Change in VMT Due to HSR	-3,951	-15,540	-16,266

Source: Cambridge Systematics

2.3 Avoided Air Trips

Section 2.1.1 summarized the diversion of air passenger trips to HSR for the three forecast years. The procedures outlined in Section 1.1.4 were used to estimate the changes in required annual flights assuming airlines maintain the same passenger load factors achieved in 2015. Table 2.9 summarizes the results.

Table 2.9 Potential Annual Flight Reductions Due to Diversion of Air Trips to HSR

Scenario and Interchange	2025	2029	2040
No-Build			
Bay Area	97,058	93,895	137,732
Sacramento Valley	33,845	33,917	54,461
San Diego	31,976	31,714	48,483
San Joaquin Valley	3,544	2,553	6,097
Southern California	112,316	107,443	162,667
Rest of State	4,532	3,720	7,219
Total	283,270	273,240	416,659
Build			
Bay Area	91,700	71,250	95,616
Sacramento Valley	32,930	29,623	46,034
San Diego	31,299	27,574	39,468
San Joaquin Valley	3,106	1,409	4,698
Southern California	106,284	82,707	117,437
Rest of State	4,300	3,036	6,252
Total	269,620	215,599	309,505
Flight Reductions			
Bay Area	(5,358)	(22,644)	(42,116)
Sacramento Valley	(915)	(4,294)	(8,428)
San Diego	(677)	(4,140)	(9,015)
San Joaquin Valley	(438)	(1,143)	(1,399)
Southern California	(6,031)	(24,736)	(45,230)
Rest of State	(232)	(684)	(967)
Total	(13,651)	(57,641)	(107,154)

2.4 Input to GHG analysis

Statewide VMT and Air-passenger trip reductions, calculated by the methodology discussed in 1.1.5 and expressed as metric tons of carbon dioxide equivalent, are combined and presented as the total GHG emissions avoided due to mode shift to high-speed rail service.

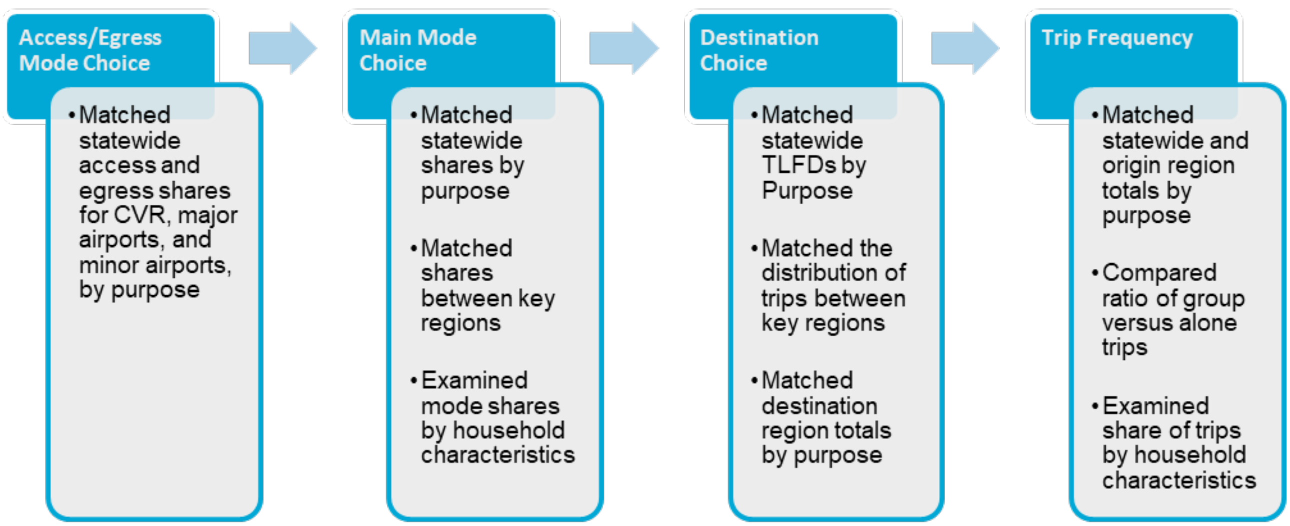
3.0 Model Calibration/Quality Control

3.1 BPM-V3 Calibration

The BPM-V3, including trip frequency, destination choice, main mode choice, and access/egress mode choice, was calibrated to reproduce estimates of long-distance travel patterns of California travelers.[14] The observed data were based on an expansion of the 2012-2013 CSHTS Daily Diary and Long-Distance survey data to match the socioeconomic characteristics of the 2010 California population.

Since the model components pass logsum information "up" through the modeling process and trip information "down" through the process, the individual model components had to be calibrated in an iterative fashion. The initial step was calibration of the access/egress portion of the mode choice model followed by, and sometimes simultaneously with, the main mode portion of the mode choice model. Once calibration targets were reached for access/egress and main mode choice models, destination choice was calibrated, followed by trip frequency. The process was repeated, since individual adjustments to one model could affect others. Figure 3-1 illustrates this iterative process used for calibration and targets for each model.

Figure 3-1 Calibration Process



Source: Cambridge Systematics.

3.2 Quality Control Measures

Ridership and revenue forecasts were based on information regarding the HSR service provided by the Rail Delivery Partners (RDP) and the Authority. Other input data were developed by CS such as auto, air, and CVR services and socioeconomic forecasts were reviewed with the RDP and Authority for reasonableness prior to being used in the BPM-V3. An internal quality control process was used to ensure that the correct data files were used for each run of the BPM-V3 and that the resulting forecasts were reasonable in comparison to other forecasts produced using the BPM-V3.

[14] Full details of the model calibration and validation process can be found in the BPM-V3 model documentation: https://www.hsr.ca.gov/docs/about/ridership/CHSR_Ridership_and_Revenue_Model_BP_Model_V3_Model_Doc.pdf

3.3 Peer Review Process

A formal Peer Review Panel (PRP) provided advice on the development, calibration, and validation of the BPM-V3. The following panelists comprised the PRP:

- Frank S. Koppelman, PhD, Professor Emeritus of Civil Engineering, Northwestern University (chair)
- Kay W. Axhausen, Dr.Ing., Professor, Institute for Transport Planning and Systems, ETH Zurich (Swiss Federal Institute of Technology Zurich)
- Eric Miller, PhD, Professor, Department of Civil Engineering, University of Toronto
- David Ory, PhD, Principal Planner/Analyst, Metropolitan Transportation Commission
- Kenneth A. Small, PhD, Professor Emeritus, Department of Economics, University of California-Irvine

The PRP was re-designated the Ridership Technical Advisory Panel (RTAP) in 2014 with the new designation stemming from the Authority's reliance on the PRP for advice rather than just reviews of completed work.

As stated in the 2016 Business Plan:[15]

> In their review of the forecasts and methodologies for this 2016 Business Plan, the Ridership Technical Advisory Panel (RTAP), a group of international experts in travel demand forecasting, stated that:
>
> > *"The review confirmed the Panel's previously expressed belief that the [Business Plan Model – Version 3] BPM-V3 model is suitable for use in business planning"*
> >
> > *"The Panel reviewed the Authority's design for a risk analysis for the 2016 Business Plan, as well as preliminary results on the likely range of ridership and revenue. This risk assessment is of high quality, more advanced than usual practice based on the Panel's experience, and highlights those uncertain factors that have a strong bearing on the results."*

The 2016 Business Plan ridership and revenue forecasts were also reviewed by Project Finance Advisory Limited (PFAL). In their memorandum to the Authority, PFAL stated:[16]

> *"We consider the CS forecasting model to be of good quality and can provide it with a clean bill of health in terms of its design and functionality. We have identified a number of areas where we consider the produced forecasts to be optimistic and also a number where we consider the forecasts to be pessimistic."*

[15] California High-Speed Rail Authority, *Connecting and Transforming California, 2016 Business Plan*, May 1, 2016, page 84.

[16] Memorandum from PFAL to Boris Lipkin, Deputy Director of Business, Analytics and Commercial Implementation, California High Speed Rail Authority, Re: HSR14-65 Draft Memo on Ridership and Revenue for Valley to Valley Line of the California High-Speed Rail System, dated December 5, 2016.

4.0 Uncertainty/Limitation

4.1 Focus on Differences in VMT Balances

"It's hard to make predictions, especially about the future." Yogi Berra and others

The ridership and revenue forecasts are based on myriad predictions regarding the future including population, households and structure of those households, employment, the transportation system, travel costs, and traveler behavior. The potential for variation of some of the input variables has been rigorously taken into account through the formal risk analysis procedures documented in Section 1.1.2.

While there can be variation in the absolute magnitude of the ridership and revenue forecasts, some of the variation is reduced when alternatives are compared. The BPM-V3 is a deterministic model: If the same input assumptions are used for two different model runs, the same ridership and revenue forecasts will result. When two forecasts are compared, many of the inputs are the same. For the no-build and build forecasts, the only difference in the BPM-V3 inputs was the representation of the HSR system. As a result, there can be increased confidence in the veracity of the forecast differences.

4.2 Model Limitations

The BPM-V3, like any travel model, is based on a limited number of variables. While the BPM-V3 has been calibrated to reasonably reproduce travel for a base year, much of the "unexplained" variation in travel is "explained" through calibrated model constants. The constants account for unknown input variables that affect travel. In effect, the constants assume that the impacts of those unknown variables do not change over time.

The information and results presented in this technical memorandum are estimates and projections that involve subjective judgments, and may differ materially from the actual future ridership and revenue. This technical memorandum is not intended, nor shall it be construed, to constitute a guarantee, promise, or representation of any particular outcome(s) or result(s). Further, the material presented in this technical memorandum is provided solely for the Authority's planning purposes and should not be used for any other purpose.

4.3 Relevance for GHG estimation

The GHG analysis, as described earlier, was based on the calculation of VMT multiplied by an applicable pollutant's emission factor. Although the emission factors also consider vehicle speed, vehicle mix, and analysis year, the resultant GHG emission burdens are directly related to the VMT estimates. Since these VMT estimates are derived from the ridership and revenue forecasts, any limitations with regards to the certainty of the future ridership and revenue estimates also apply to the resultant GHG estimates. As such, the GHG estimates may differ from the actual future GHG emissions of the roadway network.