California Air Resources Board

Quantification Methodology for the California High-Speed Rail Authority High-Speed Rail Project

California Climate Investments Greenhouse Gas Reduction Fund

FINAL
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Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating greenhouse gas (GHG) emission reductions; strengthening the economy; improving public health and the environment; and providing benefits to residents of disadvantaged communities, low-income communities, and low-income households, collectively referred to as "priority populations." Where applicable and to the extent feasible, California Climate Investments must maximize economic, environmental, and public health co-benefits to the State.

The California Air Resources Board (CARB) is responsible for providing guidance on estimating the net GHG emission reductions and co-benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefit calculator tools. CARB develops these methodologies and tools based on the project types eligible for funding by each administering agency, as reflected in the program expenditure records available at: http://www.arb.ca.gov/cci-expenditurerecords.

The California High-Speed Rail Authority (CHSRA or Authority) is responsible for planning, designing, building, and operating California's high-speed rail (HSR) system. Provision 10 of Item 2665-306-6043 of Senate Bill (SB) 1029 (Committee on Budget, Chapter 152, Statutes of 2012) directs the Authority to analyze the GHG impacts of the HSR system. Additionally, the Authority is required by Public Utilities Code Sec. 185033 to prepare, publish, adopt, and submit a business plan to the California Legislature every two years. The Authority's business plan is an overarching policy document used to inform the Legislature, the public, and stakeholders of the project's implementation and assist the Legislature in making policy decisions regarding the HSR system.

For the CHSRA HSR Project, CARB staff developed this Quantification Methodology to summarize the quantification approach used to estimate the net GHG emission reductions and air pollutant emission co-benefits from operation of the HSR system (Section B) and outline the process for tracking and reporting GHG and other benefits (Section C). This Quantification Methodology summarizes the approach developed by the Authority and used to estimate net emission reductions associated with transportation mode shifts from low-occupancy vehicles and airplanes to the lower-emitting HSR system during HSR system operation. In accordance with the California Environmental Quality Act (CEQA) and the National Environmental Policy Act (NEPA), the Authority prepared an Environmental Impact Report/Environmental Impact Statement (EIR/EIS).[i] The EIR/EIS considers the comprehensive nature and scope of the proposed HSR system; this Quantification Methodology only considers the evaluation of the net emission reductions associated with the operation of the HSR system.

For GGRF reporting purposes for the Annual Report to the Legislature (Annual Report),[ii] the Authority will report to CARB the total net GHG emission reductions and air pollutant

emission co-benefits estimated using the approach and methods outlined in this Quantification Methodology. If any of the methods or equations used in the estimation of GHG emission reductions and air pollutant emission co-benefits are updated, CARB, in consultation with the Authority, will review and update this Quantification Methodology, as necessary. Any changes to the approach or methods, and resulting changes to estimates, may not be captured in the Annual Report until this Quantification Methodology has been updated.

California High-Speed Rail Project

The goal of the HSR system is to connect San Francisco and the Los Angeles Basin and eventually extend to Sacramento and San Diego, totaling 800 miles with up to 24 stations. The HSR system reduces GHG and air pollutant emissions by:

- Shifting travel from cars and airplanes to the HSR system;
- Operating the HSR system on 100 percent renewable energy;
- Implementing a multi-faceted tree planting program; and
- Mitigating emissions from the construction phase through strict, binding requirements on construction contractors.

Business Plan and Ridership Forecasts

The Authority is required to prepare, publish, adopt, and submit a business plan to the California Legislature every two years. Each business plan summarizes the progress made over the past two years, including updates to available funding and financing, ridership forecasts, and risk management information. The business plans are available on the Authority website at: http://www.hsr.ca.gov/.

The Authority updates ridership forecasts for the business plan every two years using the business plan model (BPM). These forecasts are produced by the Authority in consultation with the Ridership Technical Advisory Panel (RTAP) and the Authority's Peer Review Group (PRG). Ridership model forecasts are also reviewed by the United States (U.S.) Government Accountability Office (GAO) and an independent financial advisory firm specializing in infrastructure projects.[iii]

Sustainability Report

In addition to the business plan, the Authority publishes an annual sustainability report that provides a summary of the program's performance and progress—including information on business and management, energy, natural resources, sustainable infrastructure, and communities. The reports are available on the Authority website at: http://www.hsr.ca.gov/Programs/Green_Practices/index.html.

Methodology Development

CARB, in consultation with the Authority, developed this Quantification Methodology consistent with the guiding implementation principles of California Climate Investments, including ensuring transparency and accountability.[iv] This Quantification Methodology summarizes the approach used by the Authority to estimate the GHG emission reductions and air pollutant emission co-benefits for HSR operations over a 50-year period. The Authority developed the approach[v] used to estimate outcomes and to track results of the HSR system. This Quantification Methodology summarizes the ridership model, methods, and emission factors used in the Authority's approach and associated with:

- Mode shift from low-occupancy auto vehicle miles traveled (VMT) to the HSR system;
- Mode shift from air travel to the HSR system; and
- 100 percent shift from higher-emitting energy sources and petroleum-based fuels to cleaner renewable energy sources for rail operations.

While data and inputs are continually updated by the Authority, the methods and equations used in the Authority's approach have not undergone substantial changes for several years. These methods and equations are provided in greater detail in Appendix A of this document. CARB staff have determined the approach used by the Authority is reasonable for estimating GHG emission reductions and air pollutant emission co-benefits associated with operation of the HSR system.

Updates

Updates to the methods, models, and reports on the HSR system are presented by the Authority in each subsequent business plan and supporting document, as applicable. The Authority updates the BPM as needed to incorporate more recent input data, new variables, and adjustments, among others. If any of the methods or equations used in the estimation of GHG emission reductions and air pollutant emission co-benefits are updated, CARB, in consultation with the Authority, will review and update this Quantification Methodology, as necessary.

Program Assistance

Stakeholders should use the following resources for additional questions and comments:

- Questions on this document should be sent to GGRFProgram@arb.ca.gov.
- For more information on CARB's efforts to support implementation of GGRF investments, see: https://www.arb.ca.gov/auctionproceeds.
- Questions pertaining to HSR should be sent to info@hsr.ca.gov.

Section B. Quantification Methodology

Overview

This section describes the methods used by the Authority to estimate the net GHG emission reductions and air pollutant emission co-benefits from operation of the HSR system. The estimated net GHG emission reduction and air pollutant emission co-benefits result from reductions in auto VMT and air travel, as estimated by the BPM, as well as emissions generated from energy production to operate and maintain the HSR system. This Quantification Methodology summarizes the Authority's approach used to estimate the net emission reductions associated with:

- Mode shift from low-occupancy auto VMT to the HSR system;
- Mode shift from air travel to the HSR system; and
- 100 percent shift from higher-emitting energy sources and petroleum-based fuels to cleaner renewable energy sources for rail operations.

Methods and equations used for estimating the net GHG emission reductions and air pollutant emission co-benefits from the HSR system are provided in Appendix A. In general, the net emission reductions are estimated using the following approaches in Table 1.

Table 1. General Approach to Quantification

Total Emission Reductions
$$Total\ Emission\ Reductions = Emission\ Reductions_{Auto\ VMT} + Emission\ Reductions_{Air\ Travel}$$
Net Emission Reductions
$$Net\ Emission\ Reductions = Total\ Emission\ Reductions - Emissions_{Energy\ Use}$$

NOTE: GHG emissions for site preparation, upstream[1] emissions from materials, or any mitigation activities (e.g., sequestration from tree planting) are not included in Authority's net GHG emission reduction estimate, nor were they evaluated by CARB staff for the purposes of this Quantification Methodology.

[1] "Upstream" is used in the context of life cycle assessment, and pertains to feedstock materials and energy associated with the production, processing, and delivery of infrastructure materials.

Tools

The Authority's approach to estimate the net GHG emission reductions and air pollutant emission co-benefits from operation of the HSR system relied on project-specific outputs from the latest version of the BPM and CARB Mobile Source Emission Factor Model (EMFAC).[2]

The Authority used the BPM to produce ridership and revenue forecasts for different service options of the HSR system. The BPM is a travel demand model that incorporates HSR and all other long-distance travel mode network assumptions, socioeconomic data, and travel behavior and preference data, among other inputs, to project ridership and revenue for each forecast year. The BPM has been enhanced and developed over the past 15+ years and incorporates the latest industry best practices, data, surveys, and methodologies. It has been reviewed and approved by several independent parties, including the International Union of Railways. A more detailed overview of the methods applied in the BPM is located in Appendix B of this document; the full model documentation can be found on the Authority website at: http://hsr.ca.gov/About/ridership_and_revenue.html.

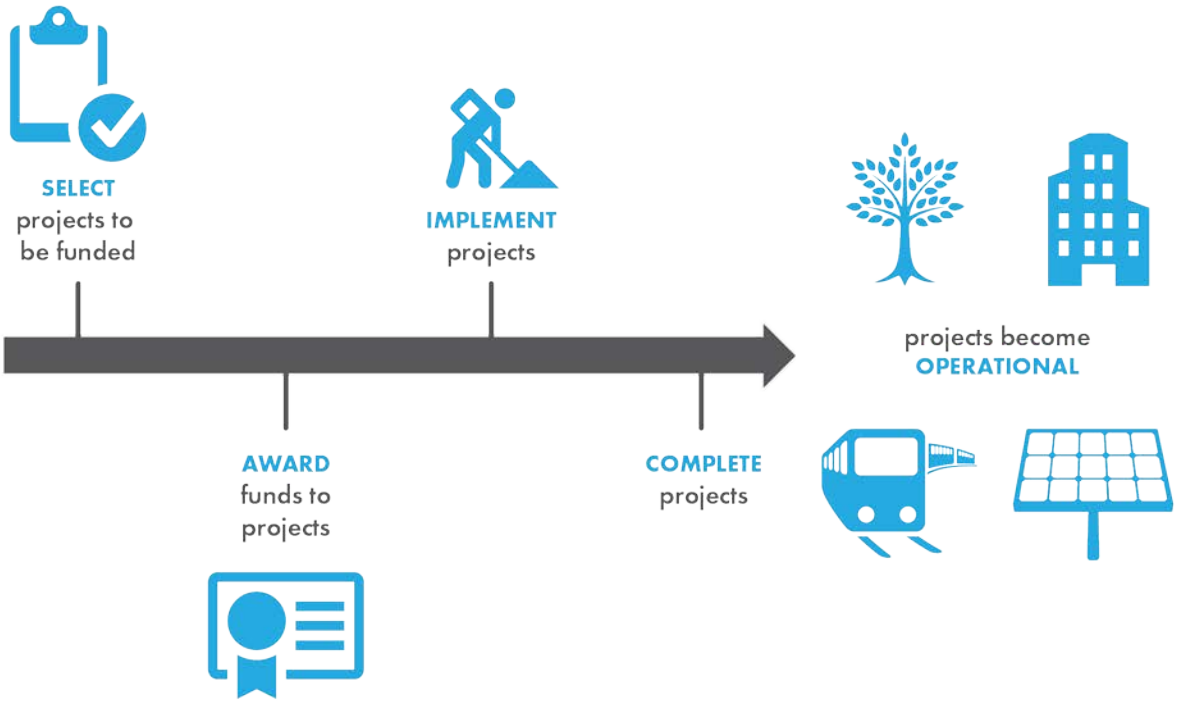
The Authority used EMFAC to develop vehicle emission factors for estimating GHG emission reduction and air pollutant emission co-benefits. EMFAC is used statewide, subject to regular updates to incorporate new information, and available free of charge to anyone with internet access. EMFAC can be accessed at: https://www.arb.ca.gov/msei/msei.htm.

[2] The Authority uses the latest available version of the EMFAC model that has been approved by the U.S. Environmental Protection Agency.

Section C. Reporting after Funding Award

Accountability and transparency are essential elements for all California Climate Investments. All administering agencies are required to track project implementation and report on the benefits of those investments. CARB develops tracking and reporting guidance for California Climate Investments. The reporting process and requirements are found in CARB's Funding Guidelines for Agencies that Administer California Climate Investments (Funding Guidelines).[3]

The Authority will submit periodic reports to CARB. The specific data that need to be reported depend on the project type and the stage of project implementation at the time of reporting. Initially, administering agencies must report basic project information and expected benefits. As projects are implemented, administering agencies provide additional information on project status, benefits, and results. When projects are completed, administering agencies submit project closeout reports. The Authority will report on project outcomes upon reaching a specified milestone and being considered "operational." Reporting templates which contain detailed reporting requirements that are specific to each project type and cover all stages of reporting are available at: www.arb.ca.gov/cci-resources.



[3] CARB released Draft Revised Funding Guidelines in April 2018. These Draft Revised Funding Guidelines are subject to change based on public input and Board direction. While the draft provides an indication of what is currently required, administering agencies must incorporate all provisions reflected in the Draft Revised Funding Guidelines and subsequent Board approved Funding Guidelines.

The Authority is required to collect and compile project data, including the net GHG emission reductions estimated using the methods summarized in this Quantification Methodology, co-benefits, and information on benefits to priority populations.[4] Reported information will be used to demonstrate how the Administration is achieving or exceeding the statutory objectives for California Climate Investments. The Authority has the obligation to provide, or provide access to, data and information on project outcomes and to meet requirements within CARB's Funding Guidelines.

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[i] California High Speed Rail Authority. Addendum/Errata to Final Program EIR/EIS for the Bay Area to Central Valley Portion of the California HST System. June 2008. Available at: http://www.hsr.ca.gov/docs/programs/bay_area_eir/BayCValley2008_EIR_fin_adn3errata.pdf.

[ii] Available at: www.arb.ca.gov/cci-annualreport.

[iii] California High-Speed Rail Authority. Ridership and Revenue Forecasting. Available at: http://www.hsr.ca.gov/About/ridership_and_revenue.html.

[iv] California Air Resources Board. Funding Guidelines for Agencies that Administer California Climate Investments. Available at: www.arb.ca.gov/cci-fundingguidelines.

[v] California High Speed Rail Authority. Contribution of the High-Speed Rail Program to Reducing California's Greenhouse Gas Emission Levels. June 2013. Available at: http://www.hsr.ca.gov/docs/programs/green_practices/HSR_Reducing_CA_GHG_Emissions_2013.pdf.

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[4] Priority populations include residents of: (1) census tracts identified as disadvantaged by the California Environmental Protection Agency per SB 535; (2) census tracts identified as low-income per Assembly Bill (AB) 1550; or (3) a low-income household per AB 1550. Detailed information is provided in CARB's Funding Guidelines.

Appendix A. Equations Supporting Emission Estimates

A. Emission Reduction Estimates from Auto Mode Shift

The Authority estimated the emission reductions that result from the mode shift of low-occupancy vehicles to the HSR system using the reduction in statewide auto VMT from the BPM and auto emission factors from EMFAC.[1] The emission reduction estimates from auto VMT reductions are calculated using Equation 1.

Equation 1: Emission Reductions from Auto Mode Shift

$$Emission\ Reductions_{Auto\ VMT} = \sum_{i}^{i+50} [Annual\ VMT_{BPM}\ x\ EF_{Auto}]_i$$

Where,

			Units
$Emission\ Reductions_{Auto\ VMT}$	=	Total emission reductions from reduced auto VMT	MT CO_2; or lbs
i	=	The operation year (over a 50-year quantification period)	Year
$Annual\ VMT_{BPM}$	=	Reduced annual auto VMT, as calculated from the BPM	Miles
EF_{Auto}	=	Weighted annual auto emission factor, using Equation 2	MT CO_2/mile; or lbs/mile

The BPM forecasts statewide long-distance travel behavior, including long-distance travel by low-occupancy vehicles, in build and no-build scenarios expressed annually over a 50-year quantification period. Annual VMT reductions are calculated by subtracting total VMT in the HSR-build scenario from total VMT in the no-build scenario.

[1] The Authority uses the latest available version of the EMFAC model that has been approved by the U.S. Environmental Protection Agency.

The Authority developed the annual auto emission factors using a weighted average by VMT for gasoline and diesel fuel types using Equation 2.

Equation 2: Annual Auto Emission Factor

$$EF_{Auto} = \sum_{i}^{i+50} \left[\frac{(VMT * E_{RUNEX} * CF)_{LDA} + (VMT * E_{RUNEX} * CF)_{LDT1} + (VMT * E_{RUNEX} * CF)_{LDT2}}{Total\ VMT} \right]_i$$

Where,			Units
EF_{Auto}	=	Weighted annual auto emission factor	MT CO_2/mile; or lbs/mile
i	=	The operation year (over a 50-year quantification period)	Year
VMT	=	Vehicle miles traveled by speed, vehicle and fuel type	Miles
E_{RUNEX}	=	Emission rate by speed, vehicle, and fuel type[2]	MT CO_2/mile; or lbs/mile
CF	=	Correction factor[3]	%

EMFAC provides emission factors in two modes: stabilized running mode (RUNEX) and start mode (STREX). For carbon dioxide (CO_2), RUNEX provides tailpipe emission rates for the vehicle after it has reached optimal running temperature, while STREX provides emission rates for the vehicle during the first 100 seconds of operation after the engine has been started, when engine and/or catalyst may not have achieved their optimal operating temperature range. Additionally, EMFAC categorizes passenger vehicles as light-duty autos (LDA), light-duty trucks (LDT1 and LDT2), and medium-duty vehicles (MDV).

The Authority developed annual statewide emission factors using RUNEX CO_2 emission rates for LDA, LDT1 and LDT2. The Authority excluded STREX emission rates and the MDV category from the analysis. The exclusion of the STREX emission rates and the MDV category results in an underestimate of the emission factor developed for autos. EMFAC currently does not project emission rates beyond 2050; therefore, the developed emission factors used in the analysis remain constant at the 2050 emission rate for years beyond 2050.

Emission factors were converted from GHG emissions to carbon dioxide equivalents (CO_2e) by dividing by a factor of 0.985.[i]

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[2] Emission rates are multiplied by 10^{-6} to convert grams to metric tons (MT) and 2.2046×10^{-3} to convert grams to pounds (lbs).

[3] The Authority applied a correction factor to the RUNEX emission rates to account for the projected future saturation of zero-emissions vehicles in the California vehicle fleet. The correction factor was developed using percentage of electric VMT divided by total VMT using EMFAC.

B. Emission Reduction Estimates from Airplane Travel Mode Shift

The Authority estimated the emission reductions that result from the mode shift of air trips to the HSR system based on the reduction in statewide air travel from the BPM and emission factors from CARB's Inventory for California Airplanes – 2016 Edition.[ii] The emission reduction estimates from air travel reductions are calculated using Equation 3.

Equation 3: GHG Emission Reductions from Airplane Mode Shift

$$Emission\ Reductions_{Air\ Travel} = \sum_{i}^{i+50} [(Annual\ Air\ Trips_{BPM}/Passengers)\ x\ EF_{Plane}]_i$$

Where,			Units
$Emission\ Reductions_{Air\ Travel}$	=	Total emission reductions from reduced air travel	MT CO_2; or lbs
i	=	The operation year (over a 50-year quantification period)	Year
$Annual\ Air\ Trips_{BPM}$	=	Annual air-passengers diverted to the HSR system, as calculated from the BPM	Passengers
$Passengers$	=	Number of passengers (for year i through i + 50), as calculated from the BPM	Passengers/flight
EF_{Plane}	=	Emission factor for airplane trips from CARB's Inventory for California Airplanes[4]	MT CO_2/flight; or lbs/flight

Similar to auto VMT reductions, air trip reductions are estimated from BPM forecasts of air trips in build and no-build scenarios expressed annually over a 50-year quantification period. 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.

[4] Emission factors are multiplied by 10^{-6} to convert grams to metric tons (MT) and 2.2046×10^{-3} to convert grams to pounds (lbs).

C. Emission Estimates from Energy Usage

The Authority estimated the emissions from the operation and maintenance of the HSR system using the amount of energy needed annually to operate and maintain the HSR system, and the emission factors for the production of renewable energy used to operate the HSR system. The emissions associated with the operation of the HSR system are calculated using Equation 4.

Equation 4: Emissions from Energy Usage

$$Emissions_{Energy} = \sum_{i}^{i+50} [Annual\ Energy_{BPM}\ x\ EF_{Renewable}]_i$$

Where,			Units
$Emissions_{Energy}$	=	Total emissions from energy to operate the HSR system	MT CO_2; or lbs
i	=	The operation year (over a 50-year quantification period)	Year
$Annual\ Energy_{BPM}$	=	Annual energy required to operate the HSR system, as calculated from the BPM	GWh
$EF_{Renewable}$	=	Emission factor for renewable energy[5]	MT CO_2/GWh; or lbs/GWh

Emission factors for renewable energy were taken from the 2013 Climate Registry Default Emission Factors[iii] and the Geothermal Energy Association 2012 Report, Geothermal Energy and Greenhouse Gas Emissions.[iv]

The estimated energy needed annually to operate and maintain the HSR system includes energy for maintenance facilities, station facilities, revenue train-miles, and non-revenue train-miles (deadheading). The Authority has committed to operating the system on a mix of renewable energy.[v] While there are several different methods that can be used to determine net-zero operations, the Authority's basic concept is that it will procure and produce enough new renewable energy to supply to the electric grid to compensate for any non-renewable energy loads used to operate the HSR system. The net use of energy from the grid will equal the net supply of renewable energy supplied to the grid.

[5] Emission factors are multiplied by 10^{-6} to convert grams to metric tons (MT) and 2.2046×10^{-3} to convert grams to pounds (lbs).

D. Net Emission Reduction Estimates

The net emission reductions for the HSR system, which is equal to the sum of each of the emission reductions minus the sum of emissions (calculated from Equations 1 to 4), is calculated using Equation 5.

Equation 5: Net Emission Reductions

$$Net\ Emission\ Reductions = \sum Emission\ Reductions_{Auto\ VMT} + \sum Emission\ Reductions_{Air\ Travel} - \sum Emissions_{Energy}$$

Appendix B. BPM Ridership and Revenue Model

The Authority has been developing and enhancing their travel demand forecast tools for over 15 years. Each business plan and supporting document produced by the Authority use the BPM for all travel demand forecasting. The BPM incorporates HSR and all other long-distance travel mode network assumptions, socioeconomic data, and travel behavior and preference data, among other inputs, to project ridership and revenue for each forecast year over the 50-year quantification period of the HSR system.

The Authority consults with the RTAP and the U.S. GAO to identify improvements needed for the BPM. The RTAP is a panel of international experts in travel demand forecasting that provided external review and feedback throughout the development of ridership and revenue forecasting. The GAO is the audit institution for the U.S. federal government, and provides independent and nonpartisan audit, evaluation, and investigative services. The ridership model forecasts are also reviewed by an independent financial advisory firm specializing in infrastructure projects.

The BPM is updated as needed to incorporate more recent input data, new variables that better reflect travel behavior, and adjustments to transit access network and station locations, among others.

Model Overview

The BPM forecasts statewide long-distance travel in a given year for various model scenarios. Long-distance trips are defined as more than 50 miles from the traveler's origin to their destination; only travel within California is captured. Distances are estimated using Geographic Information System (GIS) to calculate the straight-line distance between geocoded origin and destination locations. The following travel is not included in the BPM:

- Non-home-based travel occurring more than 50 miles from home;
- Trips by visitors to California;
- Trips with one end outside of California; and
- Short-distance trips (defined as trips less than 50 miles in length).

The long-distance model estimates trip frequency, destination choice, access/egress, and main mode choice stratified by trip purpose. Trip purposes include:

- **Business** – Includes all business travel to locations other than a traveler's normal place of work.
- **Commute** – Includes all travel to a person's regular place of work. Note that a person might work from home three or more days per week, but travel to an assigned office more than 50 miles from their home one or two days per week; such travel is included in the commute category.

- **Recreation** – Includes all trips made for recreation, vacations, leisure, or entertainment.
- **Other** – Includes all trips made for other purposes, such as school, visiting friends or relatives, medical, personal business, weddings, and funerals.

The long-distance trip frequency estimates account for induced travel resulting from improved accessibility due to the HSR system. Likewise, the destination choice estimates account for induced HSR corridor travel resulting from diversion from other corridors.

Risk Analysis

As part of the travel demand forecasting, the Authority develops a list of potential risks that could impact ridership and revenue. The Authority then identifies risk variables that could be adjusted within the BPM to reflect the upside and downside of the individual risks listed. Sensitivity analysis on each risk variable is performed to select the risk variables with the greatest potential impact on ridership and revenue forecasts. These risk variables include:

- Business, commute, recreation, and other HSR mode constants;
- Business, commute, recreation, and other trip frequency constants;
- Auto operating costs;
- HSR fares;
- HSR frequency of service;
- Coefficient on transit access/egress time/auto distance variable;
- Availability and frequency of service of conventional rail and HSR feeder buses;
- Airfares;
- Number and distribution of households throughout the State;
- Auto travel time;
- Penalties for exceptionally long access or egress trips;
- Induced travel; and
- Visitor travel.

For each of the risk variables, a range (i.e., minimum, most likely, and maximum) and probability distribution is assigned to describe the associated uncertainty. Range and distribution values for each risk variable are developed from available research and analysis. Based on the ranges for each risk variable, Monte Carlo simulations[6] are used to project a range of ridership and revenue forecasts with a probability of each forecast occurring. The risk variables included vary based on the forecast year being analyzed.

[6] Monte Carlo simulations involve repeated runs of an analytical model with inputs randomly drawn from a range of possible values in order to quantify the probability of a potential outcome.

Model Runs

The BPM is fully run several times for each operating plan and forecast year. Data from these runs are used in linear regression models to approximate relationships between the BPM revenue and ridership, and model inputs and variables. Monte Carlo simulations provide distributions of a range of HSR ridership and revenue forecasts, and the relative impact of each risk factor. Overall, these distributions show the projected high, medium, and low ridership forecasts, as presented in the Authority's business plans and supporting document.

Technical memos, findings, and recommendations from the RTAP, as well as information on ridership and revenue estimates, the BPM, and model documentation, are available on the Authority's Ridership and Revenue Forecasting webpage at: http://hsr.ca.gov/About/ridership_and_revenue.html.

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[i] United State Environmental Protection Agency. Available at: https://www.nrc.gov/docs/ML1320/ML13205A377.pdf.

[ii] California Air Resources Board. California 2000-2014 GHG Emission Inventory: Technical Support Document. 2016 Edition. September 2016. Available at: https://www.arb.ca.gov/cc/inventory/doc/methods_00-14/ghg_inventory_00-14_technical_support_document.pdf.

[iii] The Climate Registry. Available at: https://www.theclimateregistry.org/.

[iv] Geothermal Energy Association. Geothermal Energy and Greenhouse Gas Emissions. November 2012. Available at: http://geo-energy.org/reports/GeothermalGreenhouseEmissionsNov2012GEA_web.pdf.

[v] California High Speed Rail Authority. High-Speed Rail Operations & Renewable Energy. Available at: https://www.hsr.ca.gov/Programs/Green_Practices/operations.html.