CALIFORNIA High-Speed Rail Authority

SIGNATURE/APPROVAL SHEET

TO: Bill Casey

FROM: Mathias Prakesch

SUBJECT: Approval of 2024 Business Plan 50-Year Lifecycle Capital Cost Model Documentation

DESCRIPTION OF ENCLOSED DOCUMENT(S): 2024 Business Plan 50-Year Lifecycle Capital Cost Model Documentation

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California High-Speed Rail Authority

2024 Business Plan

Technical Supporting Document

50-Year Lifecycle Capital Cost Model Documentation

Rev 1.0 (Draft)

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CALIFORNIA
High-Speed Rail Authority

Prepared by

DB

for the Authority

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TO: Bill Casey

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SUBJECT: Approval of 2024 Business Plan 50-Year Lifecycle Capital Cost Model Documentation

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ACRONYMS AND ABBREVIATIONS

Abbreviation	Description
Authority	California High-Speed Rail Authority
EIB	European Investment Bank
ETO	Early Train Operator
FRA	Federal Railroad Administration
O&M	Operations and Maintenance
UIC	International Union of Railways
YOE	Year of Expenditure

1 INTRODUCTION

1.1 The California High-Speed Rail Authority System

The California High-Speed Rail Authority (Authority) is responsible for planning, designing, building and operating the first high-speed rail system in the nation. High-speed rail will connect culturally and economically diverse communities, contribute to economic development and increase job growth and mobility—all in an environmentally sustainable manner. With the completion of Phase 1, the system will run from San Francisco to the Los Angeles basin in under three hours at speeds capable of over 200 miles per hour. The system will eventually extend to Sacramento and San Diego, totaling 800 miles with up to 24 stations.

1.2 Background

In 2019, there was a transition in responsibility from the Rail Planning and Delivery Group to Operations for select supporting documents of the Business Plan. As a result, the Early Train Operator (ETO) has assumed the responsibility of updating the 50-Year Lifecycle Capital Cost Model for the subsequent Business Plans and Project Update Reports. The team reviewed the methodology, service assumptions, and consulted with subject matter experts to compile and review the capital expenditure inputs and technical data to run the 50-Year Lifecycle Capital Cost Model. Furthermore, the team reviewed and updated the model framework to show the lifecycle costs for both system phases (Silicon Valley to Central Valley and Phase 1), as described in the sections that follow.

2 PURPOSE OF THE MODEL

This Technical Supporting Document outlines the definition, methodologies, inputs and assumptions used for the model. The purpose of the model is to develop an estimate that forecasts the 50-year lifecycle costs for the infrastructure and assets of California's high-speed rail system. The model presents the lifecycle costs in two ways:

- Constant dollars—Estimates are provided in June 2023 dollars.
- Year-of-expenditure (YOE) dollars—Estimates can be inflated to YOE dollars, using 2023 dollars as a baseline and construction cost indices as documented in the 2024 Business Plan Capital Cost Basis of Estimate Report.

2.1 Model Framework

The team used the framework from the previous lifecycle cost methodology to make refinements to the model. The team developed a refined approach to the cost model, creating an agile model capable of reflecting changes in rehabilitation and replacement assumptions quickly. Even so, the model remains consistent, using a framework based on a similar process produced by maintenance, renewal and improvement of rail transport infrastructure to reduce economic and environmental impacts (MAINLINE), which is part of the European Union-funded research program on a variety of topics, to analyze lifecycle cost estimates. MAINLINE's methodology is documented in Proposed Methodology for a Life Cycle Assessment Tool and aims to capture all costs involved throughout the life of an asset: construction, operation, maintenance and end-of-life. As previously mentioned, operation and maintenance costs are modeled/forecasted in the Operations and Maintenance Cost Model Documentation and only added as a total sum in the framework of the model.

2.1.1 Track Cost

The International Union of Railways (UIC) International Benchmarking of Track Cost compares track costs between different projects. UIC conducted a benchmarking exercise using 12 Western-European, 5 US-Class I and 4 selected East-Asian Railways. The main objectives of the exercise were to compare the cost of investment and maintenance and identify and analyze individual cost drivers. The results of the benchmarking exercise include:

- Major track and catenary renewal are as expensive as new construction of track and catenary.
- Slab track and subgrade works are important cost-drivers for track.
- Slab track has lower maintenance cost, but due to special roadbed and civil engineering, the impact of its cost is more pronounced than superstructure cost alone.
- Renewal costs from the study participants are broken down as follows:
  - Overhead: 15%
  - Labor: 12%
  - Material: 22%
  - Machinery: 3%
  - Miscellaneous: 2%
  - Contractors (External): 46%

However, the Lifecycle Capital Cost Model does not break out costs into these categories.

2.1.2 Asset Lifecycles

Lifecycle estimates align with best practices where guidance is available. UIC and the European Investment Bank (EIB) provide the following guidance for the maintenance of high-speed line components in Table 1. Asset lifecycles were subsequently adjusted based on industry expertise in the United Kingdom. Certain assets such as tunnels have a 100 year design-life, and thus are not subject to lifecycle activity during the model's 50-year forecast period.

Table 1 Lifecycle Requirements Comparison

Asset	UIC Lifecycle (years)	EIB Lifecycle (years)	2024 Model (years)
Track Structure (e.g., tunnels, viaducts, etc.)	0	80-100	100[1]
Concrete Ties	40	40	50
Slab Track	60	0	>50
Fastenings	40	0	40
Ballast	35	20	50[2]
Overhead Contact System Piles and Portals	40	0	[3]
Signaling Systems	15	0	30[4]
Vehicles	0	15-25	30
Access Facilities: Structural elements	0	10-50	100

Notes:

1 Higher Reliability, Availability, Maintainability and Safety targets are being applied to California's greenfield application, combined with relatively light usage of the track structure, ties and ballast is anticipated to lead to useful lifecycles beyond those found in older European systems.

2 Ballast is assumed to have two rehabilitation cycles (i.e., mid-life cleanings) instead of one (the first cycle starting at year 16 of the asset's lifecycle and the second starting at year 33), helping extend the anticipated lifecycle to 50 years.

3 The overhead contact system is assumed to have an indefinite lifecycle because continuously replaced as part of maintenance activities.

4 Rehabilitation for signaling systems is assumed to occur every 15 years and includes uninterruptable power supply battery replacement and commercial off-the-shelf and other hardware replacement. Since component parts are replaced often (as reflected in the rehabilitation portion of the Communications and Signaling estimates), the entire system can be maintained in place for a longer period.

3 UPDATES TO THE MODEL SINCE THE 2018 BUSINESS PLAN

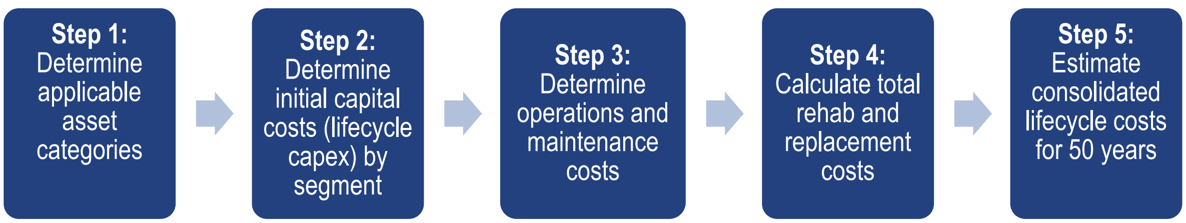
3.1 Forecasting and Costing Methodology for the Lifecycle Capital Cost Model

Lifecycle costing methodology used in the 2024 Business Plan compiles all expenditures that the Authority will incur in the system over the lifespan of 50 years, including initial capital investments, operations, maintenance and specific costs to rehabilitating and replacing those investments over the 50-year timespan. The ETO team applied this definition to update the methodology behind the 2020 Lifecycle Capital Cost Model and has used it since then.

In the 2018 Lifecycle Capital Cost Model, the methodology was based on providing a “cash flow” representation and estimate of the cash out required for rehabilitation and replacement for a timespan of 30 years.

The new 50-year lifecycle cost estimation includes a consolidated expenditures view by year, including the operations and maintenance costs in addition to the rehabilitating and replacement expenditures. See Figure 1 below:

Figure 1 Steps in Lifecycle Capital Cost Model



3.2 Updated Service Plan Assumptions

Assumptions were made for the model run to reflect the current alignment and phasing assumptions of the project, as documented in the 2024 Business Plan. The planned alignment stretches from San Francisco to Anaheim once Phase 1 begins. In the 2024 cost model all 3 building blocks, namely the interim Central Valley service, Silicon Valley to Central Valley increment, and Phase 1 increment are modeled phases. An incremental approach was used in our model to be able to react flexibly to changes in the timeline. Previously, Silicon Valley to Central Valley and Phase 1 were the phases modeled.

Table 2 Station Scenarios for Silicon Valley to Central Valley and Phase 1

Stations in Use in Model	2020 BP Scenario for Silicon Valley to Central Valley	2020 BP Scenario for Phase 1	2024 BP Scenario for Silicon Valley to Central Valley	2024 BP Scenario for Phase 1
Transbay Center	No	Yes	No	Yes
4th & Townsend	No	Yes	No	Yes
4th & King	Yes	No	Yes	No
Millbrae	Yes	Yes	Yes	Yes
San Jose	Yes	Yes	Yes	Yes
Gilroy	Yes	Yes	Yes	Yes
Merced	Yes	Yes	Yes	Yes
Madera[1]	Yes	Yes	Yes	Yes
Fresno	Yes	Yes	Yes	Yes
Kings Tulare	Yes	Yes	Yes	Yes
Bakersfield	Yes	Yes	Yes	Yes
Palmdale	No	Yes	No	Yes
Burbank Airport High-Speed Rail	No	Yes	No	Yes
Los Angeles Union Station	No	Yes	No	Yes
Fullerton	No	Yes	No	No
Anaheim	No	Yes	No	Yes

Notes:

1 Environmentally cleared and funded by others.

3.3 Fleet Size Assumptions

Fleet size numbers were adjusted to reflect new service assumptions in the 2024 Business Plan and to match those used in the operations and maintenance (O&M) cost forecast for the 2024 Business Plan. More information on fleet size numbers can be found in Section 7.9.

4 GENERAL ASSUMPTIONS

The following assumptions were derived from the previous 2018 Lifecycle Capital Cost Model, and new assumptions were made where applicable for the updates across the entire model:

1. Assets were analyzed at the second level of the Federal Rail Administration (FRA) standard cost categories (referred to as “asset classes”) for capital projects/programs.
2. The rehabilitation and replacement costs of these new second-level categories are calculated independently then added together to generate the original second-level rehabilitation and replacement costs.
3. Each asset class has an initial capital cost associated with a phase (Silicon Valley to Central Valley/Phase 1)
4. California High-Speed Rail asset classes and initial capital costs were pulled directly from the capital cost model for the 2024 Business Plan. Initial capital costs were provided at the second level, matching asset class lifecycle assumptions which are also at the second level.
5. The base year for model cost estimates is 2023; meaning real costs are reported in 2023 dollars.
6. Model outputs are designed to reflect both real (year 2023) and nominal (year of expenditure) dollars. Costs in nominal dollars will increase (or decrease) from costs in real dollars depending on the variable inflation rate, assigned by the model user. If the inflation rate is set to zero, then the real and nominal costs will be the same.
7. Capital costs are assumed to include all labor, materials and contractor costs associated with the asset’s construction and subsequent rehabilitation or replacement.
8. Assets are procured as close as possible to specifications.
9. The O&M cost model estimates are designed to allow for all costs necessary to maintain a state of good repair through adequate preventive maintenance. Thus, the capital rehabilitation and replacement model assumes that preventive maintenance will occur on schedule, so the effects of deferred maintenance are not considered.
10. Rehabilitation and replacement costs are assumed to be spread over one or more years (this is a model input). Rehabilitation and replacement “spread” refers to the number of years over which rehabilitation and replacement costs are incurred. The spread is designed to allow for rehabilitation and replacement programs that last more than one year.
11. Rehabilitation and replacement costs are cyclical and spread evenly before and after the target year for odd-numbered spreads. For even-numbered spreads that cannot be split in half to be before and after the target year, the spread is weighted backwards (e.g., two years before target year, one year after for a four-year spread). In some cases, the spread is irregular and is entered as a row input (see #17 below).
12. Rehabilitation and replacement cycles will not overlap (i.e., if an asset is being replaced in a given time period, then rehabilitation will not occur in that time period).
13. Rehabilitation and replacement costs are reported as a percentage of the initial capital cost of an asset class (whether for all components of an asset class or individual components, depending on the initial capital cost estimate format per asset category). This was done to reflect only the portions of assets that will be rehabilitated or replaced throughout the 50-year timeframe, unless otherwise noted.

14. Model inputs are based on industry standards and experience of existing systems when applicable; sources were documented accordingly.
15. Rehabilitation and replacement inputs are reported using the two approaches below:
16. For rehabilitation and replacement costs that follow a standard, cyclical pattern, costs are entered directly into the input sheet. For example, when an asset is replaced every 20 years, and costs are spread over 3 years.
17. For rehabilitation and replacement costs that do not follow a standard, cyclical or consistent pattern, costs are entered as row inputs, as a percentage of the initial capital cost. For example, when an asset is rehabilitated in year 10 with a spread of 2 years, and again in year 25 with a spread of 4 years.
18. Asset classes/categories are entered by year of the asset's operation. Year one is represented one year after start of operations.
19. The evaluation period refers to the 50-year timeframe.
20. An unallocated contingency of 5 percent has been applied to each second-level asset category. The total unallocated contingency for all second-level asset categories is included as a separate first-level cost category ("90 Unallocated Contingency").
21. Allocated contingency (11 to 31 percent based on the capital cost model) has also been applied to each second-level asset category and is included in each second-level category's cost estimate. For a list of allocated contingency rates applied to lifecycle costs, please see Section 7.11.2.
22. An allowance for professional services of 10 percent of total costs has been applied to the following asset cost categories: 10 Track and Track Structures; 20 Stations, Terminals, Intermodal; 30 Support Facilities, Yards, Shops and Administration Buildings; and 40 Sitework, Right-of-Way, Land and Existing Improvements, and 20 percent of total costs has been applied to 50 Communications and Signaling and 60 Electric Traction.[1] Professional services costs are not applicable to 70 Vehicles. The total professional services costs for all second level asset categories are included as a separate first-level cost category (80 Professional Services). For a breakdown of the components of the professional services, see Section 7.10 of this Technical Supporting Document.

The following sections describe in detail the assumptions and estimation methods for each asset category of the high-speed rail system.

[1] No costs were included for category 40 Sitework, Right-of-Way, Land and Existing Improvements, since rehabilitation and replacement are not anticipated during the 50-year timeframe. However, the 10 percent allowance for professional services was still applied to this category in the event the lifecycle information is updated.

5 INITIAL CAPITAL COSTS

Categories and initial capital investments costs used in this model are coming from the Authority's Detailed Capital Cost Budget, divided in 2 stages: Silicon Valley to Central Valley and Phase 1. For the purposes of evaluation, the lifecycle costs of the Central Valley interim stage are consolidated within the Silicon Valley to Central Valley stage. The team can run future iterations (if required) with the Central Valley Lifecycle costs independently.

6 OPERATIONS AND MAINTENANCE COSTS

The associated expenditures come from the Operations and Maintenance Costs Model Documentation Technical Supporting Document. The O&M costs were also divided in two stages: Silicon Valley to Central Valley and Phase 1. For the purposes of this evaluation, the lifecycle cost of the Central Valley is consolidated within the Silicon Valley to Central Valley stage. The ETO team can run future iterations (if required) with the Central Valley lifecycle costs independently.

7 REHABILITATION AND REPLACEMENT COSTS METHODOLOGY

The same methodology used in the 2018 Business Plan was applied for the 2024 Rehabilitation and Replacement Cost Model; however, the assumptions were reviewed and instead of separating by segment, the initial capital costs were separated by stage (Silicon Valley to Central Valley and Phase 1) to show the incremental change.

This methodology does not include an accrual-based method, where the cost of rehabilitating and replacing the asset would be distributed evenly across its lifespan. Instead, in consultation with the Authority, it is assumed that the Authority will have the means to cover the costs for rehabilitation and replacement in the year in which it occurs (including the years of spread according to the assumptions listed in the asset category sections below).

The timeline for the cost model was set at 50 years. Costs occurring after 50 years were not considered for this exercise, neither were the costs of decommissioning system parts after the end of their lifecycle. This approach differs from the 2018 Lifecycle Capital Cost Model, which forecasted costs until 2060 (30 years).

7.1 Allocated Contingency Rate Assumptions

For the purpose of the 2024 Business Plan, the same allocated contingency rates for rehabilitation and replacement activities and previous contingency rates used for the initial capital cost estimates were used in the model to maintain a conservative approach. The allocated contingency rates can be found in Section 7.11.2.

7.2 Other Model Components and Input Assumptions

All other model components and assumptions were found to be in line with current industry best practices and the current status and design scope of the California High-Speed Rail System, as verified by industry subject matter experts. To maintain a conservative approach in line with the previous iteration of the 2018 Business Plan, the following model components were kept in the 2024 Business Plan:

- Rehabilitation spread (number of years over which rehabilitation costs are spread)
- Replacement cycle
- Replacement cost (reported as a percentage of the initial capital cost)
- Replacement spread (number of years over which replacement costs are spread)

The inputs and assumptions for this base scenario were compiled based on assets' design lives, international and domestic experience with the rehabilitation and replacement of the specific system components, and industry best practices with regard to asset management. Please reference the sections below for more information on the assumptions made for each of the asset categories.

7.3 Track Structures and Track

Since the 2018 Business Plan, for category 10 assets, there has been an update to the assumptions. Previously, there was not an assumption for the cost category 10.16, Track: Switch Heaters (with power and control). In the 2024 Business Plan, the capital expenditure figures were updated by the Authority assuming a total allocated cost of $20,366,742 for Silicon Valley to Central Valley increment, and no additional cost for Phase 1 increment (for cost line item 10.16). To be consistent with the other capital cost budget line-item categories, we assumed the same rehabilitation and replacement assumptions as cost category 10.14, Track: Special track work (switches, turnouts, insulated joints) and updated in the Table 3 below. Additionally, there was not previously an assumption for 10.04 Track Structure: Culverts and drainage structures; therefore, the same assumptions for asset category 10.05-10.07 for track structures was applied (70-year rehabilitation and 100-year replacement interval).

Industry subject matter experts reviewed each of the rehabilitation and replacement assumptions previously used for the 2018 Business Plan and found them to be consistent with current industry best practices.

7.3.1 Model Input Assumptions

Table 3 Track Structures and Track Inputs

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
10.01	Track Structure: Viaduct	70 years	70	N/A	N/A	100 years	100	N/A	N/A
10.02	Track Structure: Major/movable bridge	70 years	70	N/A	N/A	100 years	100	N/A	N/A
10.04	Track Structure: Culverts and drainage structures	70 years	70	N/A	N/A	100 years	100	N/A	N/A
10.05	Track Structure: Cut and fill (>4' height/depth)	70 years	70	N/A	N/A	100 years	100	N/A	N/A
10.06	Track Structure: At grade (grading and subgrade stabilization)	70 years	70	N/A	N/A	100 years	100	N/A	N/A
10.07	Track Structure: Tunnel	70 years	70	N/A	N/A	100 years	100	N/A	N/A
10.08	Track Structure: Retaining walls and systems	70 years	70	N/A	N/A	100 years	100	N/A	N/A

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
10.09	Track New Construction: Conventional ballasted	At full life (see below)	See below	See below	See below	50 years	50	See below	See below
10.09A	Ditching and Drainage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10.09B	Ballast	Years 16 and 33, 6% of initial capital cost of all 10.09 components, spread over 5 years (years16-21, 33-38)	16 and 33	6	5	50 years, 35% of initial capital cost of all 10.09 components, spread over 10 years	50	35	10
10.09C	Ties	N/A	N/A	N/A	N/A	50 years, 20% of initial capital cost of all 10.09 components, spread over 10 years	50	20	10
10.09D	Rail	N/A	N/A	N/A	N/A	50 years, 36% of initial capital cost of all 10.09 components, spread over 10 years	50	36	10
10.10	Track New Construction: Non-ballasted	At full life (see below)	See below	See below	See below	>50 years	50	See below	See below
10.10A	Ditching and Drainage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10.10B	Track Fasteners	N/A	N/A	N/A	N/A	50 years, 25% of initial capital cost of all 10.10 components, spread over 30 years	50	25	30

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
10.10C	Rail	N/A	N/A	N/A	N/A	50 years, 25% of initial capital cost of all 10.10 components, spread over 10 years	50	25	10
10.14	Track: Special track work (switches, turnouts, insulated joints)—crossovers, each	See below	See below	See below	See below	See below	See below	See below	See below
10.14A	Turnouts	25 years, 30% of initial capital cost of 10.14A, spread over 10 years	25	30	10	50 years, 100% of initial capital cost of 10.14 A, spread over 20 years	50	100	20
10.14B	Crossovers	50 years, 30% of initial capital cost of 10.14B, spread over 10 years	50	30	10	100 years, 100% of initial capital cost of 10.14B	100	100	1
10.14C	Switch Heaters	Already included in 10.14A and 10.14B	N/A	N/A	N/A	Already included in 10.14A and B	N/A	N/A	N/A
10.16	Switch Heaters (with power and control)	25 years, 30% of initial capital cost, spread over 10 years	25	30	10	50 years, 100% of initial capital cost, spread over 20 years	50	100	20

7.4 Stations, Terminals, Intermodal

No assumptions or asset class structures have changed since the 2018 Business Plan for category 20 assets.

Industry subject matter experts reviewed each of the rehabilitation and replacement assumptions previously used for the 2018 Business Plan and found them to be consistent with current industry best practices.

7.4.1 Assumptions and Model Inputs

Table 4 Stations, Terminals, Intermodal Inputs

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
20.01	Station Buildings: Intercity passengers and rail	See below	See below	See below	See below	See below	See below	See below	See below
20.01A	Station Structure	N/A	N/A	N/A	N/A	> 100 years, and costs 15% of initial capital cost, spread over 5 years	100	15	5
20.01B	Station Envelope	Every 50 years, costs 4% of initial capital cost, done the same year	50	4	1	Every 100 years, costs 15% of initial capital cost, and spread over 5 years	100	15	5
20.01C	Station Interior Construction and Finishes	N/A	N/A	N/A	N/A	Every 50 years, costs 10% of initial capital cost, and spread over 5 years	50	10	5
20.01D	Station Mechanical System	Every 35 years, costs 10% of initial capital cost, and spread over 30 years	35	10	30	Every 100 years	100	100	1
20.01E	Station Elements: Landscape and utilities	N/A	N/A	N/A	N/A	Every 50 years, costs 15% of initial capital cost, and spread over 5 years	50	15	5
20.02	Station Buildings: Joint use (commuter rail, intercity bus)	See below	See below	See below	See below	See below	See below	See below	See below

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
20.02A	Station Structure	N/A	N/A	N/A	N/A	> 100 years, and costs 15% of initial capital cost, spread over 5 years	100	15	5
20.02B	Station Envelope	Every 50 years, costs 4% of initial capital cost, done the same year	50	4	1	Every 100 years, costs 15% of initial capital cost, and spread over 5 years	100	15	5
20.02C	Station Interior Construction and Finishes	N/A	N/A	N/A	N/A	Every 50 years, costs 10% of initial capital cost, and spread over 5 years	50	10	5
20.02D	Station Mechanical Electrical System	Every 35 years, costs 10% of initial capital cost, and spread over 30 years	35	10	30	Every 100 years	100	100	1
20.02E	Station Elements: Landscape and utilities	N/A	N/A	N/A	N/A	Every 100 years, costs 15% of initial capital cost, and spread over 5 years	100	15	5
20.06	Pedestrian/Bike Access and Accommodation, Landscaping, Parking Lots	Every 35 years, and costs 30% of initial capital cost, spread over 2 years	35	30	2	Every 100 years, 100% of initial cost of 20.06, spread over 2 years	100	100	2

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
20.07	Automobile, Bus, Van Accessways Including Roads	Every 35 years, and costs 30% of initial capital cost of 20.07, spread over 2 years	35	30	2	Every 100 years, 100% of initial cost of 20.07, spread over 2 years	100	100	2

7.5 Facilities, Yards, Shops and Administration Buildings

No assumptions or asset class structures have changed since the 2018 Business Plan for category 30 assets.

Industry subject matter experts reviewed each of the rehabilitation and replacement assumptions previously used for the 2018 Business Plan and found them to be consistent with current industry best practices.

7.5.1 Assumptions and Model Inputs

Table 5 Support Facilities, Yards, Shops and Administration Buildings Inputs

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
30.02	Light Maintenance Facilities	See below	See below	See below	See below	See below	See below	See below	See below
30.02A	Structure	Every 50 years, and costs 10% of initial capital cost of all 30.02 components, spread over 5 years	50	10	5	Every 100 years, costs 35% of initial capital cost of all 30.02 components, spread over 5 years	100	35	5
30.02B	Interior Construction and Finishes	Every 35 years, and costs 15% of initial capital cost of all 30.02 components, spread over 30 years	35	15	30	Every 100 years	100	100	1

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
30.02C	Interior Construction and Finishes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30.02D	Interior Construction and Finishes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30.02E	Interior Construction and Finishes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30.02F	Drop Tables	30 years, 4% of initial capital cost of all 30.02 components, spread over 4 years	30	4	4	N/A	N/A	N/A	N/A
30.02G	Overhead Cranes	30 years, 4% of initial capital cost of all 30.02 components, spread over 4 years	30	4	4	N/A	N/A	N/A	N/A
30.02H	Toilet Evac. System	20 years, 10% of initial capital cost of all 30.02 components, spread over 4 years	20	10	4	N/A	N/A	N/A	N/A
30.02I	Auto Wheel Inspection System	20 years, 6% of initial capital cost of all 30.02 components, spread over 4 years	20	6	4	N/A	N/A	N/A	N/A
30.02J	Auto Trainset Carwash	30 years, 15% of initial capital cost of all 30.02 components, spread over 4 years	30	15	4	N/A	N/A	N/A	N/A

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
30.02K	Water Recycling Plant	30 years, 20% of initial capital cost of all 30.02 components, spread over 4 years	30	20	4	N/A	N/A	N/A	N/A
30.02L	Pantograph Repair Platform	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30.02M	Undercar Vehicle Inspection System	20 years, 6% of Initial capital cost of all 30.02 components, spread over 4 years	20	6	4	N/A	N/A	N/A	N/A
30.02N	Interior Construction and Finishes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30.03	Heavy Maintenance Facilities	See below	See below	See below	See below	See below	See below	See below	See below
30.03A	Structure	Every 50 years, and costs 10% of initial capital cost of 30.03, spread over 5 years	50	10	5	Every 100 years, costs 35% of initial capital cost of all 30.03 components, spread over 5 years	100	35	5
30.03B	Interior Construction and Finishes	Every 35 years, and costs 15% of initial capital cost, spread over 30 years	35	15	30	Every 100 years	100	100	1
30.03C	Track	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30.03D	Inspection Pits/Drainage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
30.03E	Overhead Contact System Catenary	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30.03F	Drop Tables	Every 30 years, 2% of initial capital costs of all 30.03 components, spread over 4 years	30	2	4	N/A	N/A	N/A	N/A
30.03G	Wheel Lathe	Every 30 years, 2% of initial capital costs of all 30.03 components, spread over 4 years	30	2	4	N/A	N/A	N/A	N/A
30.03H	Overhead Cranes	Every 30 years, 2% of initial capital costs of all 30.03 components, spread over 4 years	30	2	4	N/A	N/A	N/A	N/A
30.03I	Toilet Evac Systems	Every 20 years, 3% of initial capital costs of all 30.03 components, spread over 4 years	20	3	4	N/A	N/A	N/A	N/A
30.03J	Auto Wheel Inspection System	Every 20 years, 3% of initial capital costs of all 30.03 components, spread over 4 years	20	3	4	N/A	N/A	N/A	N/A

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
30.03K	Auto Trainset Car Wash	Every 30 years, 3% of initial capital costs of all 30.03 components, spread over 4 years	30	3	4	N/A	N/A	N/A	N/A
30.03L	Pantograph Repair Platform	Every 20 years, 1% of initial capital costs of all 30.03 components, spread over 4 years	20	1	4	N/A	N/A	N/A	N/A
30.03M	Water Recycling Plant	Every 30 years, 4% of initial capital costs of all 30.03 components, spread over 4 years	30	4	4	N/A	N/A	N/A	N/A
30.03N	Undercar Vehicle Inspection System	Every 20 years, 2% of initial capital costs of all 30.03 components, spread over 4 years	20	2	4	N/A	N/A	N/A	N/A
30.03O	Paint Shop Complete	Every 20 years, 4% of initial capital costs of all 30.03 components, spread over 4 years	20	4	4	N/A	N/A	N/A	N/A

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
30.03P	Trainset Lifting System	Every 30 years, 7% of initial capital costs of all 30.03 components, spread over 4 years	30	7	4	N/A	N/A	N/A	N/A
30.03Q	Bogie Turntable System	Every 20 years, 2% of initial capital costs of all 30.03 components, spread over 4 years	20	2	4	N/A	N/A	N/A	N/A
30.03R	Bogie Wash Systems	Every 20 years, 1% of initial capital costs of all 30.03 components, spread over 4 years	20	1	4	N/A	N/A	N/A	N/A
30.03S	Shop Cranes	Every 20 years, 4% of initial capital costs of all 30.03 components, spread over 4 years	20	4	4	N/A	N/A	N/A	N/A
30.03T	Wheel Press	Every 20 years, 3% of initial capital costs of all 30.03 components, spread over 4 years	20	3	4	N/A	N/A	N/A	N/A

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
30.04	Storage or Maintenance-of-way Building/ Bases	See below	See below	See below	See below	See below	See below	See below	See below
30.04A	Structure	Every 50 years, and costs 10% of initial capital cost, spread over 5 years	50	10	5	Every 100 years, costs 35% of initial capital cost, spread over 5 years	100	35	5
30.04B	Interior Construction and Finishes	Every 35 years, and costs 15% of initial capital cost, spread over 30 years	35	15	30	Every 100 years	100	100	1
30.04C	Track	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30.04D	Inspection Pits/Drainage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30.04E	Overhead Contact System Catenary/ Cranes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30.05	Yard Track	See below	See below	See below	See below	See below	See below	See below	See below
30.05A	Track Rehab, Ballast and Surface	N/A	N/A	N/A	N/A	>50 years	N/A	N/A	N/A
30.05B	Yard Turnouts/ Crossovers	N/A	N/A	N/A	N/A	Every 20 years, 41% of initial capital cost of all 30.05 components, spread over 5 years	20	41	5

7.6 Sitework, Right-of-Way, Land and Existing Improvements

No assumptions have changed since the 2018 Business Plan, as category 40 assets are not rehabilitated or replaced during the 50-year timeframe.

7.6.1 Assumptions and Model Inputs

There are no assumptions for asset class 40: Sitework, Right of Way, Land and Existing Improvements listed in the 2018 50-Year Lifecycle Capital Cost Model Documentation that transfer into our Lifecycle Capital Cost Model. In the detailed Capital Cost Budget, the Authority only considers the following two items:

- 40.05 Site Structure Including Retaining Walls, Sound Walls
- 40.08 Highway/Pedestrian Overpass/Grade Separation

Assets in 40.05 Site Structure Including Retaining Walls, Sound Walls are designed for 100 years, and no rehabilitation or replacement is anticipated during the 50-year timeframe. It is assumed that inspections and repairs are a part of O&M costs. These assumptions are consistent with the 2018 50-Year Lifecycle Capital Cost Model Documentation.

40.08 Highway/Pedestrian Overpass/Grade Separation falls under the assumption that cost categories 40.01 – 40.04 and 40.06 – 40.09 have been excluded since they are not applicable to capital rehabilitation and replacement, consistent with the 2018 50-Year Lifecycle Capital Cost Model Documentation.

7.7 Communications and Signaling

Since the 2018 Business Plan, for category 50 assets, there has been an update to the assumptions. Previously, there was no estimate for the cost category 50.03, On-board Signaling Equipment. In the 2024 Business Plan, the capital expenditure figures were updated by the Authority assuming a total allocated cost of $1,051,988 for Phase 1 (for cost line item 50.03). To be consistent with the other capital cost budget line-item categories, we assumed the same rehabilitation and replacement assumptions as cost category 50.04, Traffic Control and Dispatching Systems and updated in the Table 6 below.

Industry subject matter experts reviewed each of the rehabilitation and replacement assumptions previously used for the 2018 Business Plan and found them to be consistent with current industry best practices.

7.7.1 Assumptions and Model Inputs

Table 6 Communications and Signaling Inputs

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
50.01	Wayside Signaling Equipment	Every 15 years, 20% of initial capital cost of 50.01, spread over 3 years	15	20	3	Every 30 years, 80% of initial capital cost of 50.01, spread over 5 years	30	80	5
50.03	On-board Signaling Equipment	Every 15 years, 3% of initial capital cost of 50.04, spread over 15 years	15	3	15	Every 25 years, 100% of initial capital cost of 50.04, spread over 1 year	25	100	1

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
50.04	Traffic Control and Dispatching Systems	Every 15 years, 3% of initial capital cost of 50.04, spread over 15 years	15	3	15	Every 25 years, 100% of initial capital cost of 50.04, spread over 1 year	25	100	1
50.05	Communica-tions	See below	See below	See below	See below	See below	See below	See below	See below
50.05A	Shelters, Cabinets, Towers, Ductbanks, Manholes, Fiber Optic, Heating, Ventilation and Air Conditioning, Radiax	Every 10 years, 3% of initial capital cost of 50.05, spread over 5 years (years 10-14, 20-24, 40-44)	10	3	5	Every 30 years, 10% of initial capital cost of 50.05, spread over 5 years	30	10	5
50.05B	Wide Area Networking, Networked Storage, etc.	N/A	N/A	N/A	N/A	Every 10 years, 15% of initial capital cost of all 50.05 components, spread over 2 years (years 10-11, 20-21, 30-31, 40-41, 50-51)	10	15	2
50.05C	Radio Systems (Operations Radio System, Broadband Radio System)	Every 10 years, 1% of initial capital cost of 50.05 components, spread over 5 years (years 10-14, 20-24 and 40-44)	10	1	5	Every 30 years, 5% of initial capital cost of 50.05 components, spread over 5 years (years 30-34)	30	5	5

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
50.05D	Application Systems: Closed circuit TV, fixed asset software, electronic access control systems, intrusion detection system, passenger address and communication system, etc.	Every 10 years, 1% of initial capital cost of all 50.05 components, spread over 5 years (years 10-14, 20-24, 40-44)	10	1	5	Every 30 years, 4% of initial capital cost of all 50.05 components, spread over 5 years (years 30-34)	30	4	5
50.06	Grade Crossing Protection	Every 20 years, costs 30% of initial capital cost, and spread over 10 years	20	30	10	Every 30 years, costs 90% of initial capital cost, and spread over 10 years	30	90	10
50.07	Hazard Detectors/Pro-tection	Every 15 years, costs 20% of initial capital cost, and spread over 3 years	15	20	3	Every 30 years, costs 80% of initial capital cost, and spread over 5 years	30	80	5

7.8 Electric Traction

No assumptions or asset class structures have changed since the 2018 Business Plan for category 60 assets.

Industry subject matter experts reviewed each of the rehabilitation and replacement assumptions previously used for the 2018 Business Plan and found them to be consistent with current industry best practices.

7.8.1 Assumptions and Model Inputs

Table 7 Electric Traction Inputs

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
60.02	Traction Power Supply: Substations	Every 25 years, 20% of initial capital cost of 60.02, spread over 15 years	25	20	15	Every 50 years, 25% of 60.02, spread 20 years from the 51st year	50 (51)	25	20
60.03	Traction Power Distribution: Catenary and third rail	Every 30 years, 30% of initial capital cost of 60.03, spread over 10 years	30	30	10	Every 60 years, 61% of initial capital cost for overhead catenary system - catenary assembles, spread over 20 years from the 61st year	60 (61)	61	20
60.04	Traction Power Control	Every 25 years, costs 20% of initial capital cost, and spread over 15 years	25	20	15	Every 50 years, costs 25% of initial capital cost, and spread over 20 years from 51st year	50 (51)	25	20

7.9 Vehicles

No assumptions or asset class structures have changed since the 2018 Business Plan for category 70 assets.

Industry subject matter experts reviewed each of the rehabilitation and replacement assumptions previously used for the 2018 Business Plan and found them to be consistent with current industry best practices.

7.9.1 Assumptions and Model Inputs

Table 8 Vehicle Inputs

No.	Asset Type	2024 Rehabilitation Assumptions	2024 Rehab. Years	2024 Rehab. %	2024 Rehab. Spread (years)	2024 Replacement Assumptions	2024 Replace. Years	2024 Replace. %	2024 Replace. Spread (years)
70.02	Vehicle Acquisition: Electric multiple unit	Every 15 years, and costs 75% of initial capital costs	15	75	1	Every 30 years, and costs 100% of initial capital cost, spread over 5 years	30	100	5
70.06	Vehicle Acquisition: Maintenance of way vehicles	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
70.07	Vehicle Acquisition: Non-railroad support vehicles	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

7.9.2 Assumption Changes Since the 2018 Business Plan

- Each trainset costs $52,000,000 (in 2017 dollars) in the 2018 Business Plan.
- Each trainset costs $54,366,325 (in 2019 dollars) in the 2020 Business Plan.
- Each trainset costs $44,679,947 (in 2023 dollars) in the 2024 Business Plan.
- The 2018 Business Plan introduced mid-life overhauls for each trainset, which will occur every 15 years and will cost 75 percent of the initial capital cost of each train set; these assumptions remain in the 2024 Business Plan.

7.9.3 Unit Quantities

The following unit quantities apply to 70.02 Vehicle Acquisition: Electric multiple unit:

- 17 sets for Silicon Valley to Central Valley line (San Francisco to Bakersfield)
- 58 total sets for Phase 1 (San Francisco to Anaheim)

Table 9 outlines the number of trainsets per group.

Table 9 Potential Rolling Stock Delivery Schedule

Silicon Valley to Central Valley	Year	No. of Trainsets	Phase 1	Year	No. of Trainsets
Available from Central Valley Segment service	0	6	Available from Silicon Valley to Central Valley service	0	17
Before operations	-3	3	Before operations	-4	6
Before operations	-2	4	Before operations	-3	10
Before operations	-1	4	Before operations	-2	10
Start of operations	0	0	Before operations	-1	10
No data	0	0	Start of operations	0	5
	Total	**17**		**Total**	**58**

7.10 Professional Services

Category 80 Professional Services includes all professional, technical and management services related to the design and construction of infrastructure (categories 10-60) during the preliminary engineering, final design and construction phases of the project/program (as applicable). These services include environmental work, design, engineering and architectural services, specialty services such as safety or security analyses, value engineering, risk assessment, cost estimating, scheduling, ridership modeling and analyses, auditing, legal services, administration and management, etc., by agency staff or outside consultants.[2]

Table 10 shows the professional cost allowances as percentages of construction costs, adjusted from category 80 in the capital cost model to reflect only those costs that would be relevant for capital rehabilitation and replacement. The percentages assumed in the 2024 Business Plan are consistent with those assumed in the 2018 Business Plan.

Table 10 Professional Services Cost Allowances for Categories 10, 20, 30 and 40

Group	Cost Allowances for Categories 10, 20, 30 and 40	Percentage of Construction Costs
Program Management	PM costs will not include the environmental approval process or oversight of planning development.	1.0%
Final Design	Level of design and planning will be less than for a new facility provided there is no upgrading of components in the rehabs/renewals.	4.0%[1]
Construction Management	Field oversight of all replacement work is assumed (no self-certification).	5.0%
Agency Costs	No agency permits or approvals would be required for rehabs/renewals.	0.0%

[2] As defined by the FRA Standard Cost Categories for Capital Projects: https://www.transit.dot.gov/funding/grant-programs/capital-investments/core-capacity-scc-workbook. However, not all of these categories would apply to the rehabilitation or replacement of assets.

Group	Cost Allowances for Categories 10, 20, 30 and 40	Percentage of Construction Costs
N/A	N/A	**10.0%[2]**

Notes:
1 Only applicable to categories 10-40. Final design for categories 50-60 is 20 percent, 15 percent for system engineering and 5 percent for integration, testing and commissioning.
2 The total professional services allocation for categories 50-60 is 26 percent.

Final design for categories 50 and 60 is assumed to be 20 percent consisting of 15 percent for system engineering and 5 percent for integration, testing and commissioning. A higher amount of integration and coordination is needed for high-tech components of the California High-Speed Rail System. These are consistent with inputs for the capital cost model.

7.11 Contingency

The model contains two sets of contingencies: (1) unallocated contingency to account for unknowns that may arise in the rehabilitation and replacement of system assets; and (2) allocated contingency to account for known risks, uncertainties and unknowns associated with individual cost categories.

7.11.1 Unallocated Contingency

Unallocated contingency was set at 5 percent of costs before contingency. This is the same as the unallocated contingency applied in the capital cost estimates and the operations and maintenance cost estimates and is designed to account for unknowns that cannot be anticipated.

7.11.2 Allocated Contingency

Allocated contingency percentages ranging from 11 percent to 31 percent were applied to account for unknowns, risk and uncertainties specific to each asset category. The range for allocated contingencies mirrors the percentages applied to the capital cost estimate in the 2018 Business Plan. The allocated contingency percentages are presented in Table 11. Stations and support facilities were given allocated contingency rates of 20 percent to 21 percent to reflect the current level of design (these rates will be revisited once stations and support facilities are at a higher level of design definition).[3]

Table 11 Allocated Contingency Percentages by Cost Category

No.	FRA Standard Cost Categories for Capital Projects/Programs	Allocated Contingency %
10	Track Structures and Track	N/A
10.01	Track Structure: Viaduct (includes culverts and drainage)	20
10.02	Track Structure: Major/movable bridge	20
10.05	Track Structure: Cut and fill (> 4’ height/depth)	25
10.06	Track Structure: At-grade (grading and subgrade stabilization)	19
10.07	Track Structure: Tunnel	31
10.08	Track Structure: Retaining walls and system	20
10.09	Track New Construction: Conventional ballasted	11

[3] Rolling stock allocated contingencies are included in the initial capital cost estimate for each vehicle.

No.	FRA Standard Cost Categories for Capital Projects/Programs	Allocated Contingency %
10.10	Track New Construction: Non-ballasted	11
10.14	Track-Special Track Work (switches, turnout, insulated joints)	11
20	Stations, Terminals, Intermodal	N/A
20.01	Station Buildings: Intercity passenger rail only	21
20.02	Station Buildings: Joint use (commuter rail, intercity bus)	21
20.06	Pedestrian/Bike Access and Accommodation, Landscaping, Parking Lots	21
20.07	Automobile, Bus, Van Accessways Including Roads	21
30	Support Facilities, Yards, Shops, and Administration Buildings	N/A
30.02	Light Maintenance Facility	21
30.03	Heavy Maintenance Facility	21
30.04	Storage or Maintenance-of-way Building/Bases	21
30.05	Yard and Yard Track	20
40	Sitework Right-of-Way, Land, and Existing Improvements	N/A
40.05	Site Structures Including Retaining Walls, Sound Walls	21
50	Communications and Signaling	N/A
50.01	Wayside Signaling Equipment	11
50.04	Traffic Controls and Dispatching Systems	11
50.05	Communications	11
50.06	Grade Crossing Protection	11
50.07	Hazard Detectors	11
60	Electric Traction	N/A
60.02	Traction Power Supply: Substations	11
60.03	Traction Power Distribution: Catenary and third rail	11
60.04	Traction power control	11

7.11.3 Monte Carlo Risk Analysis

Monte Carlo simulations are part of a broad class of computational algorithms that rely on repeated random sampling to determine the range of possible outcomes along with the probability of different cost, schedule, revenue or other outcomes. Monte Carlo simulations are used in a variety of ways for the California High-Speed Rail Program to determine possible cost, schedule or revenue outcomes when uncertainty and risk are incorporated into the underlying models.

For the lifecycle cost risk analysis, the Authority employed Monte Carlo simulations as part of a top-down or “Reference-Class” analysis. “Risk” here is defined simply as variance from planned or expected costs. While reference class analysis cannot provide the granularity of a traditional bottom-up approach that is most useful from an internal management standpoint, the results of the reference-class analysis are based on actual project outcomes and are not dependent on the quality or comprehensiveness of internal risk identification or assessment efforts. In a top-down analysis, the algorithm works much the same way and is used for the same purposes, but instead of individual schedule activities or costs, it uses actual outcomes from similar projects to determine the probability of certain outcomes, for example, that a particular revenue projection will be met or costs will be below a certain target.

The results of a traditional or bottom-up risk analysis approach are typically captured in a risk register. As recommended in Department of Transportation Inspector General guidance and elsewhere, the risk register is eminently useful for systematizing and documenting the identification, assessment and mitigation of individual risks. For this reason, it is a key tool in California High-Speed Rail System risk management efforts as described in the Authority's Risk Management Plan. The risk register and underlying bottom-up approach does, however, have potentially significant limitations with regard to the accurate quantification of risk exposure, which also contributes to the decision to use a top-down approach. Chief of these is that the degree to which such an effort captures the actual risk exposure is dependent on the ability of participants to comprehensively identify and then accurately quantify the impact of said risks.

To a greater or lesser extent, a bottom-up analysis is also affected by certain modeling decisions such as correlation between individual risks—the actualization of some affects the likelihood and impact of others, sometimes making them more likely and/or expensive, sometimes less. For the vast majority of project risks, there is no objective means for determining the appropriate correlation factor. Additionally, to be complete, this methodology also requires a determination of the dollar value of any identified schedule impacts, which in turn requires a significant amount of foresight regarding not just what risks may strike a project but also when. The extent to which these activities are carried out by project personnel and/or stakeholders also introduces the potential for optimism bias. For Business Plan/Project Update Report purposes, as opposed to internal tracking and risk management purposes, the key objective of the risk analysis was and is to develop an accurate, objective measure of the risk exposure as measured by the potential variance between actual (eventual) and estimated costs together with the probability of a given variance. Given the relative weaknesses of a bottom-up approach for such a determination, this risk analysis employs a reference-class methodology to quantify the risk exposure associated with Lifecycle costs.

In reference-class analysis, the algorithm is given a set of outcomes from other, similar projects and then uses these in a Monte Carlo simulation to, in a sense, work backwards to determine a probability distribution that would lead to the given set of outcomes. From this resulting distribution, we can determine how likely a outcome is for this project based on the outcomes of other similar projects. This is akin to asking a number of people who live in your town how long it takes them to drive to another town. From this sample, you could develop a general idea of what's a reasonable amount of time to allot for your trip and what is not. The Monte Carlo simulation simply allows for much more specific predictions, e.g., there is a 75 percent chance that your trip will take between 41 and 57 minutes or there is a 2 percent chance that your trip will take longer than 80 minutes.

Unlike the reference-class analysis done for O&M costs, there were no direct cases comparing projected versus actual lifecycle costs on high-speed rail systems from which to derive risk exposure curves since many systems have not reached the ends of their assets' useful lives and where they have, the assets are not always comparable. To develop a risk exposure curve for lifecycle costs, the Authority first developed distributions believed to bracket the area describing lifecycle cost risk exposure. Three risk exposure curves were developed for this purpose:

1. The O&M curve, based on six reference cases comparing planned versus actual costs, as a percentage.

2. Rail capital expenditure curve without outliers, based on 54 of an original 58 rail projects with the two best and two worst cases excluded from the data set.[4]
3. Rail capital expenditure curve with outliers, based on 58 rail projects.

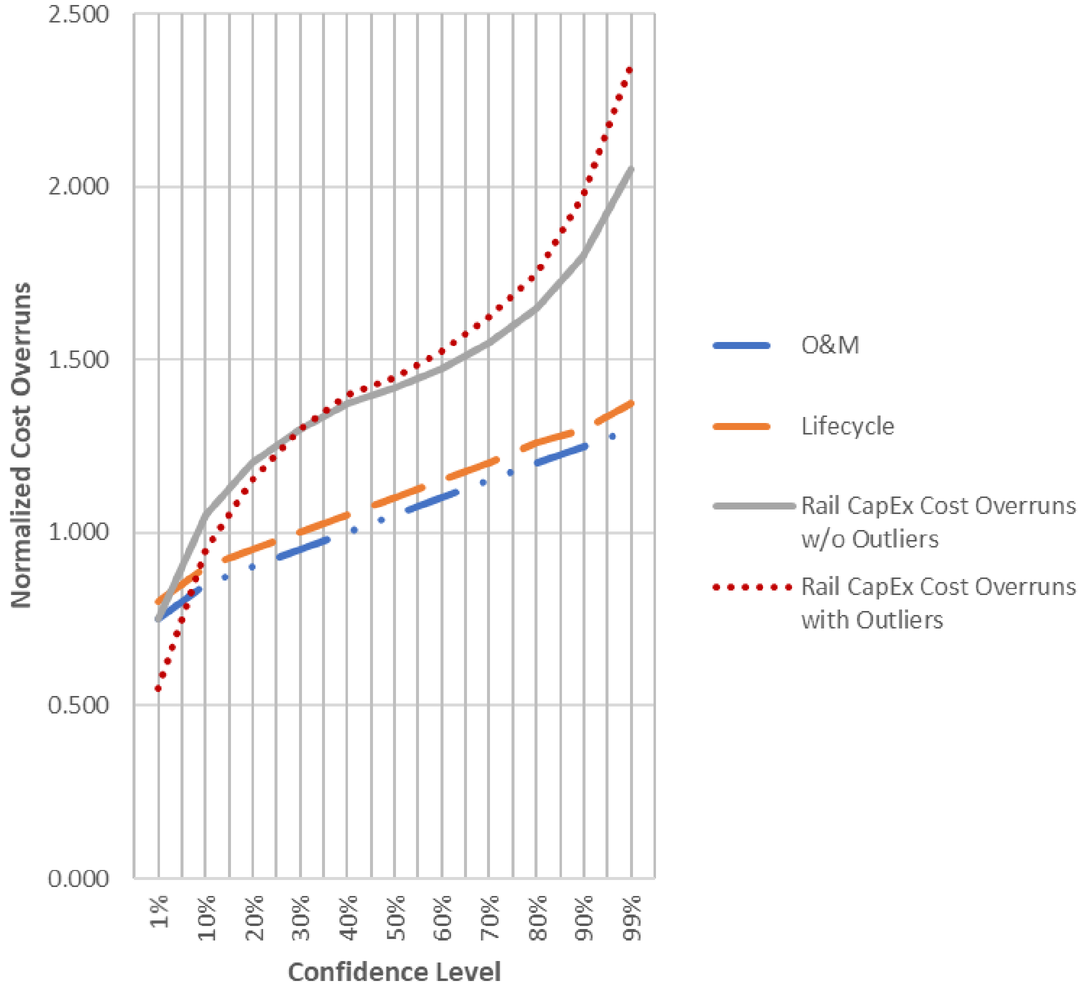
The determination of the O&M and both rail capital expenditure risk curves employed the actual project outcomes in Monte Carlo simulations to develop probabilistic estimates of cost under- or overruns, and the results were normalized for comparison with one another. Using these three curves, the ultimate specification of an appropriate lifecycle cost risk exposure curve was based on three premises:

1. There is greater risk/uncertainty in lifecycle cost than in O&M due to lack of data on high-speed rail systems, larger time interval between when costs are estimated and when they are realized and because current lifecycle costs are largely based on current capital cost estimates.
2. There is a less risk/uncertainty in lifecycle costs than that indicated by rail capital expenditure risk curves and underlying project outcomes, because the largest drivers of cost overruns in capital expenditure (e.g., time to achieve political consensus, acquisition of right-of-way, stakeholder issues) are largely or completely resolved by the time lifecycle costs are realized.
3. While underlying work is essentially a series of capital expenditures, the risk profile and parameterization more closely match that of O&M.

The resulting lifecycle risk exposure curve has the same risk profile as O&M but exhibits higher normalized costs at every confidence level than O&M (see Figure 2). Conversely, at confidence levels of approximately 8 percent or higher, the rail capital cost estimate risk exposure is greater and significantly greater at confidence levels above 20 percent, than lifecycle. In percentage terms, it is anticipated that there will be greater variance between estimated and actual lifecycle costs than there will be for O&M, but significantly less than that indicated by rail capital expenditure reference cases. For comparison, the median (50th percentile) results for O&M, lifecycle, rail capital cost estimate without outliers and rail capital cost estimate were 1.038, 1.094, 1.407 and 1.450, indicating median cost overruns of 3.8 percent, 9.4 percent, 40.7 percent and 45 percent, respectively.

[4] These cases were collected and presented in Megaprojects and Risk: An Anatomy of Ambition by Bent Flyvbjerg, Nils Bruzelius and Werner Rothengatter, 2003 by Cambridge University Press.

Figure 2 Risk Exposure: Illustrative Operations and Maintenance, Lifecycle and Capital Expenditure Curves



The resulting parameterization for the lifecycle cost risk exposure was:

- Minimum: 0.70*lifecycle with contingency or 70 percent of lifecycle cost estimate with contingency.
- Most Likely: Lifecycle cost estimate with contingency +10.7 percent.
- Maximum: Medium cost scenario with contingency + 41.28 percent.

For comparison, the equivalent parameters, in percentage terms, applied to the medium O&M cost with contingency were 86%/+0%/+34% (Min/ML/Max). Consistent with the premises outlined above, there is greater risk of actual lifecycle costs exceeding estimates than actual O&M costs exceeding estimates. Graphically, this is indicated by the normalized lifecycle cost curve being greater (above) the normalized

O&M curve at every confidence level. Also, consistent with the premises outlined above, both exhibit much less variance than the capital expenditure cases.

This exposure curve, applied to the individual estimates by year and phase, served as the input to Monte Carlo simulation(s). Individual simulations were run for each year of each phase, San Francisco to Bakersfield and Phase 1 increment as well as for each year of “All” (combined San Francisco to Bakersfield and Phase 1 increment), based on the risk-adjusted cost estimates for those years and phases. Note that for analysis of “All,” estimates for San Francisco to Bakersfield and Phase 1 Increment were summed first, and then parameterization and Monte Carlo analysis were applied to this total.

The analysis purposefully avoids statistical correlation from year-to-year for the following two reasons:

- Rehabilitation and replacement costs will eventually be assumed through several individual procurement contracts that are not correlated with each other. Application of, for example, a year-to-year correlation, would suggest that these contracts have some fixed relationship to one another of greater or lesser strength. While there may be some exogenous factors that would affect all the individual contracts making up the total lifecycle cost in the same way, other factors are likely to affect different components in different ways. As a result, individual contracts making up total lifecycle costs may exhibit negative correlation with one another at some times, positive correlation with others or at different times, or no correlation at all. Absent a supportable and quantifiable relationship between the individual components, application of such a relationship to the overall lifecycle costs could not be justified.
- In an event that any rehabilitation or replacement costs must be deferred, it would be possible for one year of total lifecycle costs to be lower than expected (the year of deferral) and the following year to be higher than expected (when deferrals may need to be addressed). In this case, the correlation would be negative. However, without any deferral, lifecycle costs may also exhibit positive correlation. For example, if rehabbing an elevator proved higher than anticipated in general, it would likely be equally as high in year 1 of its rehab as year 2. In the absence of clear correlation, it was determined to avoid year-to-year correlation overall.

8 CLOSING REMARKS

The team ran the model to obtain different lifecycle cost views: Cumulative through 2060 (in 2023 dollars and YOE), cumulative through 2082 (in 2023 dollars and YOE).

- Table 12 shows the cumulative 50-year rehabilitation and replacement costs (including professional services, allocated contingency, unallocated contingency and risk contingency) view for Silicon Valley to Central Valley Line in 2023 dollars
- Table 13 shows the cumulative 50-year rehabilitation and replacement costs (including professional services, allocated contingency, unallocated contingency and risk contingency) view for Phase 1 increment in 2023 dollars
- Table 14 shows the cumulative 50-year rehabilitation and replacement costs (including professional services, allocated contingency, unallocated contingency and risk contingency) view for Silicon Valley to Central Valley Line through Phase 1 in 2023 dollars.
- Table 15 shows the cumulative 50-year rehabilitation and replacement costs (including professional services, allocated contingency, unallocated contingency and risk contingency) view for Silicon Valley to Central Valley Line in YOE dollars.
- Table 16 shows the cumulative 50-year rehabilitation and replacement costs (including professional services, allocated contingency, unallocated contingency and risk contingency) view for Phase 1 increment in YOE dollars.
- Table 17 shows the cumulative 50-year rehabilitation and replacement costs (including professional services, allocated contingency, unallocated contingency and risk contingency) view for Silicon Valley to Central Valley Line through Phase 1 increment in YOE dollars.
- Table 18 shows the cumulative 50-year O&M costs view for Silicon Valley to Central Valley Line in 2023 dollars.
- Table 19 shows the cumulative 50-year O&M costs view for Phase 1 Increment in 2023 dollars.
- Table 20 shows the cumulative 50-year O&M costs view for Silicon Valley to Central Valley Line through Phase 1 in 2023 dollars.
- Table 21 shows the cumulative 50-year O&M costs view for Silicon Valley to Central Valley Line in YOE dollars.
- Table 22 shows the cumulative 50-year O&M costs view for Phase 1 increment in YOE dollars.
- Table 23 shows the cumulative 50-year O&M costs view for Silicon Valley to Central Valley Line through Phase 1 in YOE dollars.

Each of the tables presents a high, medium and low lifecycle cost forecast, following the top-down Monte Carlo simulation approach described in Section 7.

Table 12 Cumulative Rehabilitation and Replacement Costs: Silicon Valley to Central Valley Line (in millions of 2023 dollars)

Lifecycle Cost Range	50-Year Span
High Lifecycle Cost	10,575
Medium Lifecycle Cost	9,709
Low Lifecycle Cost	8,807

Table 13 Cumulative Rehabilitation and Replacement Costs: Phase 1 Increment (in millions of 2023 dollars)

Lifecycle Cost Range	50-Year Span
High Lifecycle Cost	8,801
Medium Lifecycle Cost	8,080
Low Lifecycle Cost	7,329

Table 14 Cumulative Rehabilitation and Replacement Costs: Silicon Valley to Central Valley Line Through Phase 1 (in millions of dollars)

Lifecycle Cost Range	50-Year Span
High Lifecycle Cost	19,375
Medium Lifecycle Cost	17,789
Low Lifecycle Cost	16,136

Table 15 Cumulative Rehabilitation and Replacement Costs: Silicon Valley to Central Valley Line (in millions of YOE dollars)

Lifecycle Cost Range	50-Year Span
High Lifecycle Cost	26,183
Medium Lifecycle Cost	24,040
Low Lifecycle Cost	21,806

Table 16 Cumulative Rehabilitation and Replacement Costs: Phase 1 Increment (in millions of YOE dollars)

Lifecycle Cost Range	50-Year Span
High Lifecycle Cost	21,192
Medium Lifecycle Cost	19,457
Low Lifecycle Cost	17,649

Table 17 Cumulative Rehabilitation and Replacement Costs: Silicon Valley to Central Valley Line Through Phase 1 (in millions of YOE dollars)

Lifecycle Cost Range	50-Year Span
High Lifecycle Cost	47,375
Medium Lifecycle Cost	43,497
Low Lifecycle Cost	39,455

Table 18 Cumulative Operations and Maintenance Costs: Silicon Valley to Central Valley Line (in millions of dollars)

O&M Cost Range	50-Year Span
High O&M Cost	33,234
Medium O&M Cost	30,378
Low O&M Cost	29,211

Table 19 Cumulative Operations and Maintenance Costs: Phase 1 Increment (in millions of dollars)

O&M Cost Range	50-Year Span
High O&M Cost	35,042
Medium O&M Cost	32,036
Low O&M Cost	30,851

Table 20 Cumulative Operations and Maintenance Costs: Phase 1 Increment (in millions of dollars)

O&M Cost Range	50-Year Span
High O&M Cost	68,276
Medium O&M Cost	62,414
Low O&M Cost	60,062

Table 21 Cumulative Operations and Maintenance Costs: Silicon Valley to Central Valley Line (in millions of YOE dollars)

Lifecycle Cost Range	50-Year Span
High O&M Cost	71,293
Medium O&M Cost	65,167
Low O&M Cost	62,663

Table 22 Cumulative Operations and Maintenance Costs: Phase 1 Increment (in millions of YOE dollars)

Lifecycle Cost Range	50-Year Span
High O&M Cost	75,205
Medium O&M Cost	68,754
Low O&M Cost	66,210

Table 23 Cumulative Operations and Maintenance Costs: Silicon Valley to Central Valley Line Through Phase 1 (in millions of YOE dollars)

Lifecycle Cost Range	50-Year Span
High O&M Cost	146,498
Medium O&M Cost	133,921
Low O&M Cost	128,872

In a future iteration of the Business Plan or the Project Update Report, the ETO foresees a complete redesign of the Lifecycle Capital Cost Model, capable of presenting the costs in both accrual and cashflow views. In a future update, the team would like to do extensive research on the international assumptions for capital asset replacement and rehabilitation lifespans from similar scale high-speed rail projects. Furthermore, the team sees a potential to reconsider the approach regarding the Monte Carlo risk analysis. Rather than continue the top-down approach, the team would like to present the findings of implementing a bottom-up approach, which would allow for simulations run on each cost variable. Finally, the team recommends extending the lifecycle cost estimate from 50 years to over 100 years to capture several asset categories that have replacement cycles further out than the 50 years.