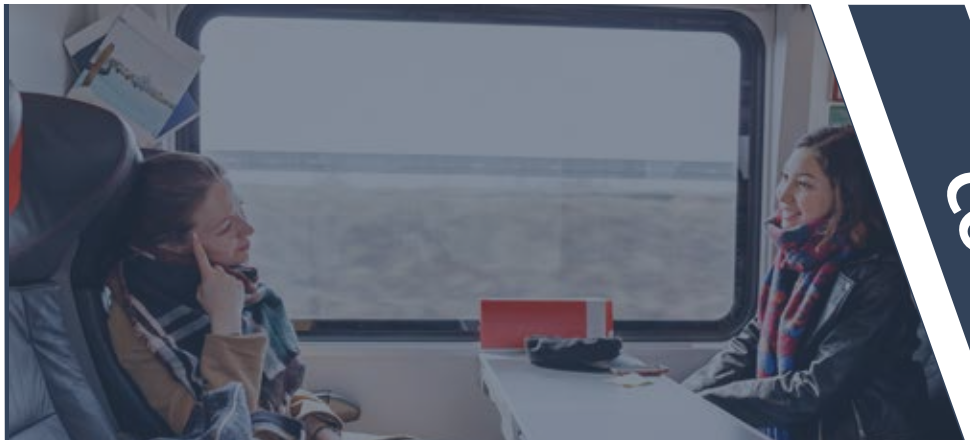
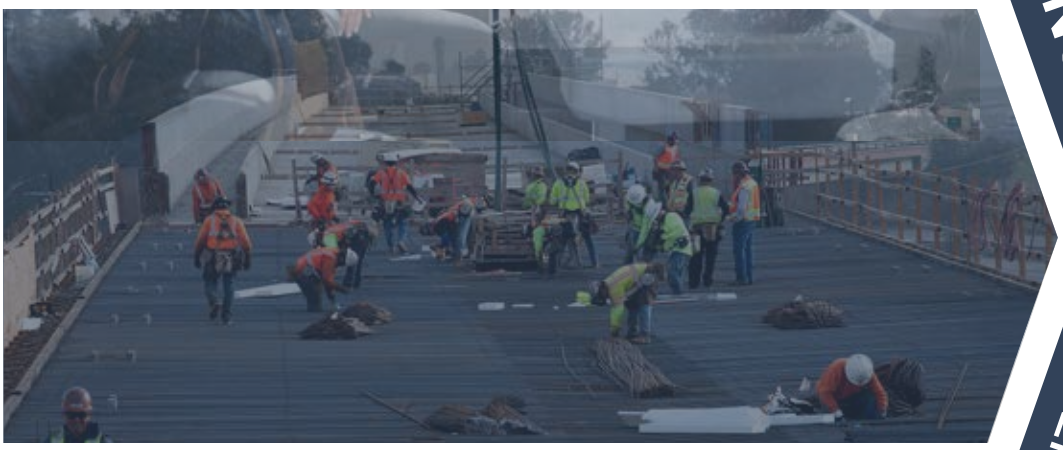
2018 Business Plan: Technical Supporting Document

50-Year Life Cycle Capital Cost Model Documentation

June 1, 2018





CONNECTING CALIFORNIA

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CALIFORNIA High-Speed Rail Authority

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Prepared by WSP

for the Authority

CALIFORNIA High-Speed Rail Authority

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Description of Enclosed Document(s): 2018 Business Plan 50-Year Lifecycle Capital Cost Model Documentation

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ACRONYMS AND ABBREVIATIONS

BART	Bay Area Rapid Transit
FRA	Federal Railroad Administration
HMF	Heavy Maintenance Facility
HVAC	Heating, Ventilation and Air Conditioning
O&M	Operations and Maintenance
UIC	International Union of Railways
USDOT	United States Department of Transportation
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 California's mega-regions, contribute to economic development and a cleaner environment, create jobs and preserve agricultural and protected lands. By 2033, 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 Model Scope

This Technical Supporting Document outlines the inputs, assumptions and methodologies used to develop an Excel-based spreadsheet model that forecasts the 50-year capital rehabilitation and replacement costs for the infrastructure and assets of California's high-speed rail system.

2 PURPOSE OF THE MODEL

The purpose of the model is to develop a capital replacement estimate that forecasts the 50-year capital rehabilitation and replacement costs for the infrastructure and assets of California's high-speed rail system. The Excel-based spreadsheet model presents the rehabilitation and replacement costs in two ways:

- Constant dollars—Estimates are provided in December 2017 dollars
- Year-of-expenditure dollars—Estimates can be inflated to year-of-expenditure dollars, using 2017 dollars as a baseline and construction cost indices as documented in the *2018 Business Plan Capital Cost Basis of Estimate Report*

The team worked closely with subject matter experts for various system components to compile the technical data and refined *2016 Business Plan* system and service assumptions to reflect the *2018 Business Plan* system and service assumptions. The model results are an early stage forecast and represent an order of magnitude cost estimate, based on industry standards, guidelines, experience and expertise.

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3 UPDATES TO THE MODEL SINCE THE *2016 BUSINESS PLAN*

The *2018 Business Plan* lifecycle model for the California High-Speed Rail system is a comprehensive Excel-based spreadsheet tool capable of forecasting 50-year capital rehabilitation and replacement costs for the Authority infrastructure and related assets. The model and its underlying logic and assumptions have been verified by industry experts with extensive rail asset management experience, and were found to be consistent with both the project's current level of design and industry best practice.

This Technical Supporting Document contains development information, methodology and assumptions related to the *2018 Business Plan* lifecycle model, which builds on the structure, foundation, and framework of the *2016 Business Plan* lifecycle model. The 2016 model was re-validated by industry subject matter experts and only minor adjustments were made to support the *2018 Business Plan*. These changes are summarized in the following sections, with more details contained throughout this Technical Supporting Document.

3.1 Updated Geographic Train Stop Segments

Stop segments in the model were updated to reflect the current alignment and phasing assumptions of the project, as documented in the *2018 Business Plan* and in Table 3 of Section 4.2.2. The planned alignment stretches from San Francisco to Anaheim once Phase 1 begins in 2033.

3.2 New Lifecycle Capital Cost Categories

A major driver of lifecycle costs is the initial capital cost estimate of assets subject to lifecycle activity, as many rehabilitation and replacement assumptions pivot off this total. As was the case in the *2016 Business Plan*, the lifecycle capital cost estimate or the capital cost estimate anticipated to require rehabilitation and replacement that will be assumed by the Authority for the *2018 Business Plan* model was provided in a lump-sum format by second-level FRA Standard Cost Category.

Table 1 New Replacement/Rehabilitation Assumptions Since the *2016 Business Plan*[1]

Asset Type	2018 Rehabilitation Assumptions	2018 Replacement Assumptions
Within 20.01 Station Buildings: Intercity passengers and rail		
20.01 B Station Envelope	Every 50 years, costs 4% of initial capital cost, done the same year	Every 100 years, costs 15% of initial capital cost, and spread over 5 years
20.01 C Station Interior Construction and Finishes	—	Every 50 years, costs 10% of initial capital cost, and spread over 5 years
20.01 D Station Mechanical System	Every 35 years, costs 10% of initial capital cost, and spread over 30 years	Every 100 years

[1] Assumptions include no overlapping between Rehabilitation and Replacement cycles.

Asset Type	2018 Rehabilitation Assumptions	2018 Replacement Assumptions
20.01 E Station Elements – Landscape and Utilities	—	Every 50 years, costs 15% of initial capital cost, and spread over 5 years
Within 20.02 Station buildings: Joint use (commuter rail, intercity bus)		
20.02 B Station Envelope	Every 50 years, costs 4% of initial capital cost, done the same year	Every 100 years, costs 15% of initial capital cost, and spread over 5 years
20.02 C Station Interior Construction and Finishes	—	Every 50 years, costs 10% of initial capital cost, and spread over 5 years
20.02 D Station Mechanical Electrical System	Every 35 years, costs 10% of initial capital cost, and spread over 30 years	Every 100 years
20.02 E Station Elements – Landscape and Utilities	—	Every 100 years, costs 15% of initial capital cost, and spread over 5 years
50.04 Traffic Control Dispatching Systems	Every 15 years, costs 3% of initial capital cost, and spread over 15 years	Every 25 years, costs 100% of initial capital cost, and done the same year
50.06 Grade Crossing Protection[2]	Every 20 years, costs 30% of initial capital cost, and spread over 10 years	Every 30 years, costs 90% of initial capital cost, and spread over 10 years
50.07 Hazard Protection	Every 15 years, costs 20% of initial capital cost, and spread over 3 years	Every 30 years, costs 80% of initial capital cost, and spread over 5 years
60.04 Traction power control	Every 25 years, costs 20% of initial capital cost, and spread over 15 years	Every 50 years, costs 25% of initial capital cost, and spread over 20 years from 51st year

3.3 Refined Lifecycle Assumptions

A number of lifecycle assumptions for select asset categories were refined to reflect new industry best practices and a more evolved design of the project. This review of inputs was undertaken by industry subject matter experts. A full list of refined and revised inputs can be found in Table 2, with more information found in later sections of this Technical Supporting Document.

[2] Costs include upgrades to existing grade crossings, to allow for higher speed and more frequent trains. Costs also include rehabilitation and replacement of grade crossings owned by the Authority

Table 2 Revised Assumptions since the *2016 Business Plan*[3]

Column Head	2016 Rehabilitation Assumption	2018 Rehabilitation Assumption	2016 Replacement Assumption	2018 Replacement Assumption
20.01 A Station Structure	—	—	Every 100 years, and costs 27% of initial capital cost, spread over 30 years	> 100 years, and costs 15% of initial capital cost
20.02 A Station Structure	—	—	Every 100 years, and costs 27% of initial capital cost, spread over 30 years	> 100 years, and costs 15% of initial capital cost
20.06 Pedestrian/bike access and accommodation, landscaping, parking lots	Every 10 years, and costs 30% of initial capital cost	Every 35 years, and costs 30% of initial capital cost	Every 50 years	Every 100 years
20.07 Automobile, bus, van accessways including roads	Every 10 years, and costs 30% of initial capital cost	Every 35 years, and costs 30% of initial capital cost	Every 50 years	Every 100 years
30.02 A Structure (30.02 A Roof in the *2016 Business Plan*)	Every 20 years, and costs 5% of initial capital cost, spread over 4 years	Every 50 years, and costs 10% of initial capital cost, spread over 5 years	—	Costs 35% of initial capital cost
30.02 B Interior Construction and Finishes (30.02 B Exterior in the *2016 Business Plan*)	Every 30 years, and costs 5% of initial capital cost, spread over 4 years	Every 35 years, and costs 15% of initial capital cost, spread over 30 years	—	Every 100 years
30.02 C Track	Every 20 years	—	—	—
30.02 D Inspection pits/drainage	Every 20 years	—	—	—
30.02 E Overhead Contact System catenary	Every 30 years	—	—	—
30.02 L Pantograph Repair Platform	Every 20 years	—	—	—
30.03 A Structure (30.02 A Roof in the *2016 Business Plan*)	Every 20 years, and costs 5% of initial capital cost, spread over 4 years	Every 50 years, and costs 10% of initial capital cost, spread over 5 years	—	Costs 35% of initial capital cost
30.03 B Interior Construction and Finishes (30.02 B Exterior in the *2016 Business Plan*)	Every 30 years, and costs 3% of initial capital cost, spread over 4 years	Every 35 years, and costs 15% of initial capital cost, spread over 30 years	—	Every 100 years

[3] Assumptions include no overlapping between Rehabilitation and Replacement cycles.

Column Head	2016 Rehabilitation Assumption	2018 Rehabilitation Assumption	2016 Replacement Assumption	2018 Replacement Assumption
30.03 C Track	Every 20 years	—	—	—
30.03 D Inspection pits/drainage	Every 20 years	—	—	—
30.03 E Overhead Contact System catenary	Every 30 years	—	—	—
30.04 A Structure (30.02 A Roof in the *2016 Business Plan*)	Every 20 years, and costs 5% of initial capital cost, spread over 4 years	Every 50 years, and costs 10% of initial capital cost, spread over 5 years	—	Costs 35% of initial capital cost
30.04 B Interior Construction and Finishes (30.02 B Exterior in the *2016 Business Plan*)	Every 30 years, and costs 5% of initial capital cost, spread over 4 years	Every 35 years, and costs 15% of initial capital cost, spread over 30 years	—	Every 100 years
30.04 C Track	Every 20 years	—	—	—
30.04 D Inspection pits/drainage	Every 20 years	—	—	—
30.04 E Overhead Contact System catenary	Every 30 years	—	—	—
70.02 Vehicle acquisition: Electric multiple unit	—	Every 15 years, and costs 75% of initial capital costs	—	Every 30 years, and costs 100% of initial capital cost, spread over five years

Also, the following second level categories were listed from the *2016 Business Plan*, and are not listed in the *2018 Business Plan*.

- Within 20.01 Station buildings: Intercity passenger rail only
    - 20.01 B Station architecture (finishes, glazing, roofing, etc.)
    - 20.01 C Station mechanical ductwork and piping (plumbing, fire protection)
    - 20.01 D Station mechanical HVAC (plumbing, fire protection)
    - 20.01 E Station electrical, lighting
    - 20.01 F Station site elements
    - 20.01 G Escalators – Trusses (replacement only)
    - 20.01 H Escalators – Moving parts
    - 20.01 I Elevators
- Within 20.02 Station buildings: Joint use (commuter rail, intercity bus)
    - 20.02 B Station architecture (finishes, glazing, roofing, etc.)
    - 20.02 C Station mechanical ductwork and piping (plumbing, fire protection)
    - 20.02 D Station mechanical HVAC (plumbing, fire protection)
    - 20.02 E Station electrical, lighting
    - 20.02 F Station site elements
    - 20.02 G Escalators – Trusses (replacement only)
    - 20.02 H Escalators – Moving parts
    - 20.02 I Elevators

The new approach of category 20 Stations brought for the *2018 Business Plan* is more precise, and the related assumptions remain conservative in nature. Please read Sections 3.2 and 8 for more details.

3.4 Updated Allocated Contingency Rates

New contingency rates for rehabilitation and replacement activities were used in the model to match the new contingency rates used for the initial capital cost estimate in the *2018 Business Plan*. Previously in 2016, the allocated contingency range was 12-20%. The range now used is 11-31%, depending on the type of asset. More information on the new allocated contingency rates can be found in Section 15.2.[4]

3.5 Increased Fleet Size

Fleet size numbers were adjusted to reflect new service assumptions in the *2018 Business Plan* and to match those used in the Operations and Maintenance (O&M) cost forecast for the *2018 Business Plan*. More information on fleet size numbers can be found in Section 13.2.

3.6 Other Model Components and 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.

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

4 FORECASTING AND COSTING METHODOLOGY

The cost estimates include all the resources and activities needed to perform the rehabilitation and replacement of the assets in the high-speed rail system that will be necessary in its first 50 years of operation. The inputs and assumptions are compiled based on assets' design lives, international and domestic experience with the rehabilitation and replacement of system components, and industry best practices with regard to asset management. These inputs and assumptions have been reviewed since the *2016 Business Plan* and modified where necessary. System and service level assumptions also impact rehabilitation and replacement costs and have been updated to reflect assumptions applied in the *2018 Business Plan*. Various procurement options and contracting arrangements under review were also considered in the development of model assumptions.

4.1 Model Components

The 50-year capital rehabilitation and replacement model consists of two major components:

1. **Asset rehabilitation costs** refer to significant investments (that go beyond routine maintenance) associated with achieving a state of good repair during the first 50 years of operations. Rehabilitation activities include part upgrades, tie replacements, major upkeep projects, etc.
2. **Asset replacement costs** refer to the costs to replace an asset or major asset components in full during the first 50 years of operations.

The costs are calculated by route segment, based on lifecycle inputs for each asset category to allow for the analysis to adapt to phasing and implementation assumptions. Allocated contingency, professional services and unallocated contingency are then added to the costs to produce the 50-year capital rehabilitation and replacement forecast (Figure 1).

Figure 1 Capital Rehabilitation and Replacement Model Components

Rehabilitation and replacement costs were calculated based on lifecycle activity requirements provided by each asset class specialist, as described below.

4.2 Capital Rehabilitation & Replacement Costs 50-Year Forecasting Methodology

The team took the following steps (Figure 2) to develop a 50-year forecast of rehabilitation and replacement costs.

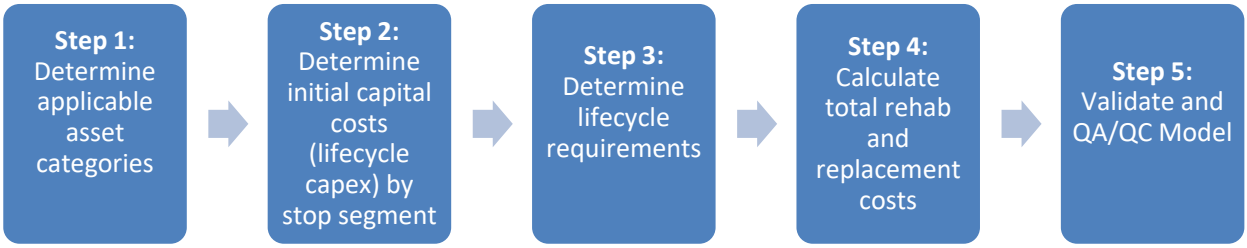

Figure 2 Development of Rehabilitation and Replacement Costs

4.2.1 Step 1: Determine applicable asset categories

In step 1, the team worked with the engineering and capital cost estimating teams to identify the second level Federal Railroad Administration (FRA) standard cost categories that are part of the system's design (and corresponding initial capital costs) from within the first level categories as follows:

- *10 Track structures and track*—includes bridges, tunnels, viaducts, and conventional ballasted and non-ballasted track
- *20 Stations, terminals and intermodal*—includes station buildings, accessways and parking lots
- *30 Support facilities, Yards, Shops, and Administration Buildings*—includes light maintenance facility, heavy maintenance facility, storage/maintenance of way building, and yard and track
- *40 Sitework, Right-of-Way, Land, and Existing Improvements*—includes retaining walls and sound walls
- *50 Communications and signaling*—includes wayside signaling equipment and communications
- *60 Electric traction*—includes traction power supply and distribution
- *70 Vehicles*—includes revenue vehicles, non-revenue vehicles and spare parts

The capital cost team extracted those cost categories that were part of the estimate prepared for the *2018 Business Plan*. Only the initial capital costs of assets subject to lifecycle activity were inputted into the lifecycle cost model. Certain cost categories, such as one-time capital expenditures for assets to be owned by external entities such as the Caltrain corridor, the SF Downtown Rail Extension (DTX) and LA Union Station LINK, were excluded from the initial capital costs used for the 2018 lifecycle model.

4.2.2 Step 2: Determine initial capital costs by segment

In step 2, the team identified the initial capital costs (in 2017 dollars) by stop segment for the corresponding asset categories identified in step 1. These inputs were extracted from the capital cost estimate model prepared for the *2018 Business Plan*. Table 3 lists the capital cost estimate geographic segments of the system and their start dates, as presented in the *2018 Business Plan*.

Table 3 System Geographic Segments as Proposed in the *2018 Business Plan*

Geographic Segments	Valley-to-Valley Line Anticipated Opening Year
San Francisco to San Jose	2029[5]
San Jose to Gilroy	2029
Gilroy to Carlucci Road	2029
Carlucci Road to Madera	2029
Wye Leg 1	2033
Wye Leg 2	2033
Merced to Wye Legs	2033
Madera to North of Bakersfield	2029
North of Bakersfield to Bakersfield	2029
Bakersfield to Palmdale	2033
Palmdale to Burbank	2033
Burbank to Los Angeles Union Station	2033
Los Angeles Union Station to Anaheim	2033

4.2.3 Step 3: Determine lifecycle requirements

In step 3, the team worked with each asset class specialist, to conduct the necessary analysis and research to develop the lifecycle requirements for each asset category identified in step 1. The information that was developed for each asset class included:

- Design life
- Rehabilitation timing (when rehabilitation occurs during the asset's lifecycle)
- Rehabilitation cost (reported as a percentage of the initial capital cost)
- 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)

[5] Does not assume the full investment from San Francisco to San Jose.

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.

4.2.4 Step 4: Calculate total rehabilitation and replacement costs

In step 4, the initial capital costs of each asset category (as provided by the capital cost estimating team) was then used to calculate rehabilitation and replacement costs for each stop segment, based on the lifecycle requirements for each asset category that were collected in step 3. The evaluation period for each stop segment begins at the start of the anticipated opening year for that segment of the system. The approaches used to calculate these costs are summarized in more detail in the next section.

The sum of all costs for rehabilitation and replacement in each year for each stop segment is the total capital rehabilitation and replacement cost, which is calculated in both 2017 dollars or in nominal Year of Expenditure (YOE) dollars. A variable inflation rate can be assigned by the model user to calculate costs in year-of-expenditure dollars.

Rehabilitation and replacement costs that will occur beyond the 50-year timeframe were not included in the estimate.

4.2.5 Step 5: Validate model

In step 5, the team worked with the asset class specialists to thoroughly review the model framework and calculations for validity and confirm that model inputs and results are within a reasonable order of magnitude. In addition, subject matter experts reviewed all assumption changes since the *2016 Business Plan*, as outlined in Section 3. A thorough QA/QC process was conducted on the model to assure calculations were being made correctly, model inputs/assumptions were logically consistent, and the model updates produced conceptually sound results.

4.3 Model Functionality

The model functionality includes the following:

- **Inputs**—The model easily allows for changes to the asset classes' rehabilitation costs, rehabilitation timing and spread, replacement costs, replacement timing and spread, and number of units in each geographic segment. However, the model does not easily allow for any changes to the asset class hierarchy.
- **Scenario testing**—The model was developed to handle scenario testing related to the timing of when assets come online in each stop segment and the timing, cost, and spread of replacement.
- **Transparency**—The model was developed to transparently present which methodologies are used for each asset class and all associated data sources. The model also allows for changes to forecasting approaches. Specific approaches are discussed in further detail in the next section.
- **Outputs**—The model generates tables and graphs that summarize the 50-year lifecycle costs in real and inflated dollars, annual and total costs, costs by asset categories, rehabilitation versus replacement costs, etc.

5 LITERATURE REVIEW

5.1 Model Framework

The framework to develop the lifecycle cost estimate methodology is based on established research and practice; the team conducted a literature review prior to the development of the model to extract any relevant guidance for the development of the model. This model uses 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. This model excludes operation and maintenance costs but extracts the relevant philosophy from MAINLINE's methodology to develop a process to analyze lifecycle costs:

- Asset type and classification needs to be defined for the evaluation process.
- Lifecycle costs include the initial cost to acquire and install assets and the cost of ownership throughout the lifecycle, as a result of asset degradation.
- Calculating total costs requires consideration for system operations and any other key parameters necessary for a lifecycle cost analysis.
- Maintenance and rehabilitation are needed to keep an asset in safe condition or to extend its service life; corrective maintenance/rehabilitation work is necessary when a structure is considered to be structurally inadequate (e.g., major concrete repairs, replacements of structural elements, etc.).
- Replacement is necessary when the structure is considered to be functionally obsolete.

5.2 Track Cost

The International Union of Railways (UIC)'s *International Benchmarking of Track Cost* compares track cost between different projects. UIC conducted a benchmarking exercise using twelve Western-European, five US-Class I and four 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 is 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 on 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 2018 lifecycle model does not breakout costs into these categories so it is difficult to make an "apples to apples" comparison.

5.3 Asset Lifecycles

Lifecycle estimates align with best practice where guidance is available. The International Union of Railways (UIC) and the European Investment Bank (EIB) provide the following guidance for the Maintenance of high-speed lines components outlined in Table 4. 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 4 Lifecycle Requirements Comparison

Asset	UIC Lifecycle (years)	EIB Lifecycle (years)	2018 Model (years)
Track Structure (e.g., tunnels, viaducts, etc.)	—	80-100	100[6]
Concrete Ties	40	40	50[6]
Slab Track	60	—	>50
Fastenings	40	—	40
Ballast	35	20	50[6,7]
Overhead Contact System Piles and Portals	40	—	—[8]
Signaling Systems	15	—	30[9]
Vehicles	—	15-25	30
Access Facilities: Structural Elements	—	10-50	100

[6] Higher RAMS 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.

[7] 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.

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

[9] 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.

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6 UNIVERSAL ASSUMPTIONS

The following assumptions are applicable across the entire model:

1. Assets were analyzed at the second level of the FRA standard cost categories (referred to as "asset classes") for capital projects/programs.[10]
2. In some cases, new second level categories were defined to enable a rational lifecycle analysis of pertinent costs when the lifecycle variables were derived at levels that were different from the standard cost categories. These new second level categories are demarcated with a letter (e.g., *20.02 A Station Structure*).
3. 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.
4. Each asset class has an initial capital cost that can vary by geographical segment of the California High-Speed Rail line. It is assumed that the geographical segment will be associated with a phase, which will provide each asset class' start date (this is necessary for calculating the asset's rehabilitation and replacement timing).
5. California High-Speed Rail asset classes and initial capital costs were pulled directly from the capital cost model for the *2018 Business Plan*. Initial capital costs were provided at the second level, matching asset class lifecycle assumptions which are also at the second level.
6. The base year for model cost estimates is 2017; meaning real costs are reported in 2017 dollars.
7. Model outputs are designed to reflect both real (year 2017) 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.
8. Capital costs are assumed to include all labor, materials, and contractor costs associated with the asset's construction and subsequent rehabilitation or replacement.
9. Assets are procured as close as possible to specifications.

[10] The first level of Federal Railroad Administration standard cost categories is, for example, 10: Track structures and track. The second level is, for example, *10.01: Track structures: Viaduct*. The third level would be, for example, *10.01.122: Elevated structures—1 track (30' average pier height)*. There are a number of codes consisting of "NC" followed by three digits; these would be considered as part of the third level.

10. 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.
11. 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.
12. 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., 2 years before target year, 1 year after for a 4-year spread). In some cases, the spread is irregular and is entered as a row input (see 17.b below).
13. 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).
14. 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.
15. Model inputs are based on industry standards and experience of existing systems when applicable; sources were documented accordingly.
16. Rehabilitation and replacement inputs are reported using the two approaches below:
    a. 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 three years.
    b. 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.
17. Row inputs are entered by year of the asset's operation. If a given stop segment's operations begin in 2030, that year represents "year 1" for rehabilitation and replacement purposes.
18. The Evaluation Period refers to the 50-year timeframe, spanning from 2029-2078.

19. An unallocated contingency of 5% 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").

20. Allocated contingency (11 to 31% 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 15.2.

21. An allowance for professional services of 10% of total costs has been applied to 1*0 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% of total costs has been applied to *50 Communications and Signaling* and *60 Electric Traction*.[11] 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 14, of this Technical Supporting Document.

22. Two additional segments have been included in the model as placeholders in the event new stop segments are added (or existing stop segments are split into shorter segments).

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

[11] No costs were included for *40 Sitework, Right-of-Way, Land, and Existing Improvements* since rehabilitation and replacement is 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.

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7 TRACK STRUCTURES AND TRACK

Category *10 Track Structures and Track* includes the following asset classes:

- *10.01 Track structure: Viaduct (includes culverts and drainage)*
- *10.02 Track structure: Major/Movable Bridge*
- *10.05 Track structure: Cut and fill (>4' height/depth)*
- *10.06 Track structure: At-grade (grading and subgrade stabilization)*
- *10.07 Track structure: Tunnel*
- *10.08 Track structure: Retaining walls and systems*
- *10.09 Track new construction: Conventional ballasted*
    - *10.09 A Ditching and drainage*
    - *10.09 B Ballast*
    - *10.09 C Ties*
    - *10.09 D Rail*
- *10.10 Track new construction: Non-ballasted*
    - *10.10 A Ditching and drainage*
    - *10.10 B Track fasteners*
    - *10.10 C Rail*
- *10.14 Track: Special track work (switches, turnouts, insulated joints)*
    - *10.14 A Turnouts*
    - *10.14 B Crossovers*
    - *10.14 C Switch heaters*

7.1 Assumptions and Model Inputs

The following assumptions were made for category *10 Track Structures and Track*:

- New first and second level categories were defined to refine the lifecycle analysis of pertaining costs.
- Asset categories *10.01 Track structure: Viaduct (including culverts and drainage)*, *10.02 Track structure: Major/Movable bridge*, *10.05 Track structure: Cut and fill (> 4' height/depth)*, *10.06 Track structure: At-grade (grading and subgrade stabilization)*, *10.07 Track structure: Tunnel*, and

10.08 Track structure: Retaining walls and systems have a design life of 100 years and will not have any rehabilitation or replacement costs during the 50-year timeframe.

- The rehabilitation of joints and bearings are included as part of regular operations and maintenance costs and are not included as part of rehabilitation costs for *10.01 Track structure: Viaduct (including culverts and drainage)* and *10.02 Track structure: Major/Movable bridge*
- No wheel-rail interface issues were assumed in the model to reflect the high degree of technical compatibility for all system elements

10.09 Track Structure Conventional ballasted

- Track structure has a lifecycle greater than 50 years, but track components will need to be rehabilitated and/or replaced within the 50-year timeframe
    - *10.09 A Ditching and drainage*
        - Ditching and drainage is considered an O&M activity and is not included as part of capital costs
    - *10.09 B Ballast*
        - Rehabilitation will occur during years 16 and 33 of the asset's lifecycle
        - The first rehabilitation cycle will occur during years 16-21 and the second cycle will occur during years 33-38
        - Rehabilitation will cost 6 percent of the initial capital cost of all 10.09 components
        - Replacement will occur every 50 years and is spread over 10 years
        - Replacement will cost 35 percent of the initial capital cost of all 10.09 components
        - Ballast replacement will ideally coincide with the timing of rail renewal
    - *10.09 C Ties (replacement only)*
        - No rehabilitation is anticipated during the 50-year timeframe
        - Replacement will occur every 50 years
        - Replacement will cost 20 percent of the initial capital cost of all 10.09 components and is spread over 10 years
        - Concrete ties are imputed to have a 50-year life expectancy. The extremely light vehicle weights should also lengthen the span of ties owing to less stress.
    - *10.09 D Rail (replacement only)*

        - No rehabilitation is anticipated during the 50-year timeframe
        - Lifecycle is 50 years
        - Replacement will cost 36 percent and is spread over 10 years of the initial capital cost of all 10.09 components
- The Authority will not be responsible for the rehabilitation and replacement of ballasted freight track and ballasted track relocation; the costs for these asset classes are not included in this analysis/report
- Estimates are based on high-speed rail experience in France, Germany, and conventional American and British railroad operations

10.10 Track new construction: Non-ballasted

- Track structure has a lifecycle of greater than 50 years, but track components will need to be rehabilitated and/or replaced within 50-year timeframe (see below)
    - *10.10 A Ditching and drainage*
        - Ditching and drainage is considered an O&M activity and is not included as part of capital costs
    - *10.10 B Track fasteners (replacement only)*
        - No rehabilitation is anticipated during the 50-year timeframe
        - Replacement will occur every 50 years
        - Replacement will cost 25 percent of the initial capital cost of all 10.10 components and is spread over 30 years
    - *10.10 C Rail (replacement only)*
        - No rehabilitation is anticipated during 50-year timeframe
        - Lifecycle is 50 years
        - Replacement will cost 25 percent of the initial capital cost of all 10.10 components and is spread over 10 years
- Estimates are based on high-speed rail experience in France, Germany, Taiwan, and conventional American and British railroad operations

10.14 Track: Special track work (switches, turnouts, insulated joints)

- *10.14 A Turnouts*
    - Rehabilitation will occur every 25 years

  - Rehabilitation will cost 30 percent of the initial capital cost for this individual asset category and is spread over 10 years
  - Replacement will occur every 50 years
  - Replacement will cost 100 percent of the initial capital cost for turnouts per stop segment and is spread over 20 years
- *10.14 B Crossovers*
  - Rehabilitation will occur every 50 years
  - Rehabilitation will cost 30 percent of the initial capital cost for this individual asset category and is spread over 10 years
  - Replacement will occur every 100 years and cost 100 percent of the initial capital cost for crossovers per stop segment
- *10.14 C Switch heaters*
  - In the event switch heaters are used, costs will be accounted for as a percentage of the initial capital cost of 10.14 A and 10.14 B
- Estimates are based on high-speed rail experience in France, Germany, Taiwan, and conventional American and British railroad operations

Model inputs are presented in Table 5.

Table 5 Track and Track Structure Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
10.01	Track structure: Viaduct	—	100	—	—	70	—	—
10.02	Track structure: Major/movable bridge	—	100	—	—	70	—	—
10.05	Track structure: Cut and fill (>4' height/depth)	—	100	—	—	70	—	—
10.06	Track structure: At-grade (grading and subgrade stabilization)	—	100	—	—	70	—	—
10.07	Track structure: Tunnel	—	100	—	—	70	—	—
10.08	Track structure: Retaining walls and systems	—	100	—	—	70	—	—
10.09	Track new construction: Conventional ballasted	—	>50	see below	see below	at full life	see below	see below
A	Ditching and drainage	—	—	—	—	—	—	—
B	Ballast	—	50	10	35% of initial capital cost of all 10.09 components	Year 16 and Year 33	First cycle between years 16-21, second cycle between 33-38	6% of initial capital cost of all 10.09 components

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
C	Ties	—	50	10	20% of initial capital cost of all 10.09 components	—	—	—
D	Rail	—	50	10	36% of initial capital cost of all 10.09 components	—	—	—
10.10	Track new construction: Non-ballasted	see below	>50	see below	see below	at full life	see below	see below
A	Ditching and drainage	lump sum	—	—	—	—	—	—
B	Track fasteners	lump sum	50	30	25% of initial capital cost of all 10.10 components	—	—	—
C	Rail	lump sum	50	10	25% of initial capital cost of all 10.10 components	—	—	—
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
A	Turnouts	lump sum	50	20	100 % of initial capital cost of 10.14 A	25	10	30% of initial capital cost of 10.14 A

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
B	Crossovers	lump sum	100	—	100 % of initial capital cost of 10.14 B	50	10	30% of initial capital cost of 10.14 B
C	Switch heaters	lump sum	Included in 10.14 A and B	Included in 10.14 A and B	Included in 10.14 A and B	—	—	Included in 10.14 A and B

7.2 Assumption Changes since the *2016 Business Plan*

No assumptions have changed since the 2*016 Business Plan* for category 10 assets.

Industry subject matter experts reviewed all other station assumptions and inputs previously used for the *2016 Business Plan* and found them to be consistent with current industry best practices.

8 STATIONS, TERMINALS, INTERMODAL

Category *20 Stations, Terminals, Intermodal* includes the following asset classes:

- *20.01 Station buildings: Intercity passenger rail only*
    - *20.01 A Station Structure*
    - *20.01 B Station Envelope*
    - *20.01 C Station Interior Construction and Finishes*
    - *20.01 D Station Mechanical Electrical System*
    - *20.01 E Station Elements – Landscape and Utilities*
- *20.02 Station buildings: Joint use (commuter rail, intercity bus)*
    - *20.02 A Station Structure*
    - *20.02 B Station Envelope*
    - *20.02 C Station Interior Construction and Finishes*
    - *20.02 D Station Mechanical Electrical System*
    - *20.02 E Station Elements – Landscape and Utilities*
- *20.06 Pedestrian / bike access and accommodation, landscaping parking lots*
- *20.07 Automobile, bus, van accessways including roads*

8.1 Assumptions and Model Inputs

The following assumptions were made to *20 Stations, Terminals and Intermodal*:

20.01 Station buildings: Intercity passenger rail only

- The following sub-classes were defined to enable a rational lifecycle analysis of pertaining costs:
    - *A Station Structure (15 percent of initial capital cost of 20.01)*
    - *B Station Envelope (15 percent of initial capital cost of 20.01)*
    - *C Station Interior Construction and Finishes (10 percent of initial capital cost of 20.01)*
    - *D Station Mechanical Electrical System (45 percent of initial capital cost of 20.01)*
    - *E Station Elements – Landscape and Utilities (15 percent of initial capital cost of 20.01)*
- Lifecycle estimates are based on California High-Speed Train Project Technical Memorandum 1.1.2, references from Bay Area Rapid Transit (BART), Caltrain, Metrolink, the French high-speed rail system, Channel Tunnel Rail Link – UK, and the sources listed below

20.01 A Station Structure

- No rehabilitation is anticipated during the 50-year timeframe
- Replacement will occur after 100 years
- Replacement will cost 15 percent of the initial capital cost for all 20.01 components, spread over 5 years

20.01 B Station Envelope

- Rehabilitation of Station Envelope will occur every 50 years
- Rehabilitation will cost 4 percent of the initial capital cost of all 20.01 components, and will be done within a year
- Replacement will occur every 100 years
- Replacement will cost 15 percent of the initial capital cost of all 20.01 components, spread over 5 years
- Lifecycle estimates are based on BART

20.01 C Station Interior Construction and Finishes

- No rehabilitation is anticipated during the 50-year timeframe
- Replacement will occur every 50 years
- Replacement will cost 10 percent of the initial capital cost of all 20.01 components, spread over 5 years
- Lifecycle estimates are based on relevant experience with applicable transit stations

20.01 D Station Mechanical Electrical System

- Rehabilitation of Station Mechanical Electrical System will occur every 35 years
- Rehabilitation will cost 10 percent of the initial capital cost of all 20.01 components, spread over 30 years
- Replacement will occur every 100 years
- Lifecycle estimates are based on relevant experience with applicable transit stations

20.01 E Station Elements – Landscape and Utilities

- No rehabilitation is anticipated during the 50-year timeframe
- Replacement will occur every 50 years

- Replacement will cost 15 percent of the initial capital cost of all 20.01 components, spread over 5 years
- Lifecycle estimates are based on BART experience with relevant station examples

20.02 Station buildings: Joint Use (Commuter rail, intercity bus)

- The following sub-classes were defined to enable a rational lifecycle analysis of pertaining costs:
    - *A Station Structure (15 percent of initial capital cost of 20.02)*
    - *B Station Envelope (15 percent of initial capital cost of 20.02)*
    - *C Station Interior Construction and Finishes (10 percent of initial capital cost of 20.02)*
    - *D Station Mechanical Electrical System (45 percent of initial capital cost of 20.02)*
    - *E Station Elements – Landscape and Utilities (15 percent of initial capital cost of 20.02)*
- Station modernization programs for *20.02 Station buildings: Joint Use (Commuter rail, intercity bus*) should be a continuous rotation after 20 years of operations
- Lifecycle estimates are based on Technical Memorandum 1.1.2, references from BART, Caltrain, Metrolink, the French high-speed rail system, Channel Tunnel Rail Link (UK) and additional sources listed below

20.02 A Station structure

- No rehabilitation is anticipated during the 50-year timeframe
- Replacement will occur after 100 years
- Replacement will cost 15 percent of the initial capital cost for all 20.02 components, spread over 5 years

20.02 B Station Envelope

- Rehabilitation of Station Envelope will occur every 50 years
- Rehabilitation will cost 4 percent of the initial capital cost, and will be done within a year
- Replacement will occur every 100 years
- Replacement will cost 15 percent of the initial capital cost of all 2*0.02 components, spread over 5 years*
- Lifecycle estimates are based on BART

20.02 C Station Interior Construction and Finishes

- No rehabilitation is anticipated during the 50-year timeframe

- Replacement will occur every 50 years
- Replacement will cost 10 percent of the initial capital cost of all 20.02 components, spread over 5 years
- Rehabilitation will include equipment and fixtures
- Lifecycle estimates are based on relevant experience with applicable transit stations

20.02 D Station Electrical System

- Rehabilitation of Station Electrical System will occur every 35 years
- Rehabilitation will cost 10 percent of the initial capital cost of all 20.02 components, spread over 30 years
- Lifecycle estimate is 100 years

20.02 E Station Elements – Landscape and Utilities

- No rehabilitation is anticipated during the 50-year timeframe
- Replacement will occur every 100 years
- Replacement will cost 15 percent of the initial capital cost of all 20.02 components, spread over 5 years
- Lifecycle estimates are based on relevant experience with applicable transit stations

20.06 Pedestrian / bike access and accommodation, landscaping, parking lots

- Rehabilitation of Pedestrian / bike access and accommodation, landscaping, parking lots will occur every 35 years
- Rehabilitation will cost 30 percent of the initial capital cost of all 20.06 components, spread over 2 years
- Replacement will occur every 100 years
- Replacement will cost 100 percent of the initial capital cost of all 20.06 components, spread over 2 years
- Lifecycle estimates are based on California High-Speed Train Project Technical Memorandum 1.1.2 and Caltrain and Caltrans

20.07 Automobile, bus, van accessways including roads

- Rehabilitation of Automobile, bus, van accessways including roads will occur every 35 years

- Rehabilitation will cost 30 percent of the initial capital cost of all 20.07 components, spread over 2 years
- Replacement will occur every 100 years
- Replacement will cost 100 percent of the initial capital cost of all 20.07 components, spread over 2 years
- Lifecycle estimates are based on California High-Speed Train Project Technical Memorandum 1.1.2 and Caltrain and Caltrans

Model inputs are presented in Table 6.

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Table 6 Stations, Terminals, Intermodal Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
20.01	Station buildings: Intercity passenger rail only, including:	lump sum	see below	see below	see below	see below	see below	see below
A	Station structure	lump sum	> 100	5	15% of initial capital cost of all 20.01	—	—	—
B	Station Envelope	lump sum	100	5	15% of initial capital cost of all 20.01 components	50	1	4% of initial capital cost of all 20.01 components
C	Station Interior Construction and Finishes	lump sum	50	5	10% of initial capital cost of all 20.01 components	—	—	—
D	Station Mechanical Electrical System	lump sum	100	—	—	35	30	10% of initial capital cost of all 20.01 components
E	Station Elements – Landscape and Utilities	lump sum	50	5	15% of initial capital cost of all 20.01 components	—	—	—
20.02	Station buildings: Joint use (commuter rail, intercity bus)	lump sum	see below	see below	see below	see below	see below	see below

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
A	Station structure	lump sum	> 100	5	15% of initial capital cost of all 20.02 components	—	—	—
B	Station Envelope	lump sum	100	5	15% of initial capital cost of all 20.02 components	50	1	4% of initial capital cost of all 20.02 components
C	Station Interior Construction and Finishes	lump sum	50	5	10% of initial capital cost of all 20.02 components	—	—	—
D	Station Mechanical Electrical System	lump sum	100	—	—	35	30	10% of initial capital cost of all 20.02 components
E	Station Elements – Landscape and Utilities	lump sum	100	5	15% of initial capital cost of all 20.01 components	—	—	—
20.06	Pedestrian/bike access and accommodation, landscaping, parking lots	lump sum	100	2	100% of initial capital cost of 20.06	35	2	30% of initial capital cost of 20.06
20.07	Automobile, bus, van accessways including roads	lump sum	100	2	100% of initial capital cost of 20.07	35	2	30% of initial capital cost of 20.07

8.2 Assumption Changes since the *2016 Business Plan*

The following assumption changes have occurred since the *2016 Business Plan*, based on input from the Network Rail Consulting Design Life for SE Operational Property Guidance Note for stations in the United Kingdom.

- 20.01 Station buildings: Intercity passenger rail only
    - 20.01 A Station Structure
        - The *2016 Business Plan* assumed that replacement will occur every 100 years, and will cost 27 percent of the initial cost of all 20.01 components, spread over 30 years
        - The *2018 Business Plan* assume that service life of 20.01 Stations Structure is greater than 100 years, and will cost 15 percent of the initial cost of all 20.02 components, spread over 5 years
- 20.02 Station buildings: Joint use (commuter rail, intercity bus)
    - 20.02 A Station Structure
        - The *2016 Business Plan* assumed that replacement will occur every 100 years, and will cost 27 percent of the initial cost of all 20.02 components, spread over 30 years
        - The *2018 Business Plan* assume that service life of 20.02 Stations Structure is greater than 100 years, and will cost 15 percent of the initial cost of all 20.02 components, spread over 5 years
- 20.06 Pedestrian/bike access and accommodation, landscaping, parking lots
    - The *2016 Business Plan* assumed that rehabilitation will occur after 10 years, and will cost 50 percent of the initial capital cost
    - The *2018 Business Plan* assumes that rehabilitation will occur after 35 years, and will cost 30 percent of the initial capital cost
    - The *2016 Business Plan* assumed that replacement will occur after 50 years
    - The *2018 Business Plan* assumes that replacement will occur after 100 years
- 20.07 Automobile, bus, van accessways including roads
    - The *2016 Business Plan* assumed that rehabilitation will occur after 10 years, and will cost 50 percent of the initial capital cost
    - The *2018 Business Plan* assumes that rehabilitation will occur after 35 years, and will cost 30 percent of the initial capital cost

  - The *2016 Business Plan* assumed that replacement will occur after 50 years
  - The *2018 Business Plan* assumes that replacement will occur after 100 years

The following second level categories were listed from the *2016 Business Plan*, and are not listed in the *2018 Business Plan*:

- Within 20.01 Station buildings: Intercity passenger rail only
  - 20.01 B Station architecture (finishes, glazing, roofing, etc.)
  - 20.01 C Station mechanical ductwork and piping (plumbing, fire protection)
  - 20.01 D Station mechanical HVAC (plumbing, fire protection)
  - 20.01 E Station electrical, lighting
  - 20.01 F Station site elements
  - 20.01 G Escalators – Trusses (replacement only)
  - 20.01 H Escalators – Moving parts
  - 20.01 I Elevators
- Within 20.02 Station buildings: Joint use (commuter rail, intercity bus)
  - 20.02 B Station architecture (finishes, glazing, roofing, etc.)
  - 20.02 C Station mechanical ductwork and piping (plumbing, fire protection)
  - 20.02 D Station mechanical HVAC (plumbing, fire protection)
  - 20.02 E Station electrical, lighting
  - 20.02 F Station site elements
  - 20.02 G Escalators – Trusses (replacement only)
  - 20.02 H Escalators – Moving parts
  - 20.02 I Elevators

The *2018 Business Plan* introduces the following as new second level categories:

- Within 20.01 Station buildings: Intercity passenger rail only
  - 20.01 B Station Envelope
  - 20.01 C Station Interior Construction and Finishes
  - 20.01 D Station Mechanical Electrical System
  - 20.01 E Station Elements – Landscape and Utilities

- Within 20.02 Station buildings: Joint use (commuter rail, intercity bus)
    - 20.02 B Station Envelope
    - 20.02 C Station Interior Construction and Finishes
    - 20.02 D Station Mechanical Electrical System
    - 20.02 E Station Elements – Landscape and Utilities

The description of their rehabilitation and replacement cycles is detailed in section 8.1.

Subject matter experts reviewed all other station assumptions and inputs previously used for the *2016 Business Plan* and found them to be consistent with current industry best practices.

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9 SUPPORT FACILITIES, YARDS, SHOPS AND ADMINISTRATION BUILDINGS

Category *30 Support Facilities, Yards, Shops and Administration Buildings* includes the following asset classes:

- *30.02 Light maintenance facility*
    - *30.02 A Structure*
    - *30.02 B Interior Construction and Finishes*
    - *30.02 C Track*
    - *30.02 D Inspection pits/drainage*
    - *30.02 E Overhead Contact System - Catenary*
    - *30.02 F Drop tables*
    - *30.02 G Overhead cranes*
    - *30.02 H Toilet evac. system*
    - *30.02 I Auto wheel inspection system*
    - *30.02 J Auto trainset car wash*
    - *30.02 K Water recycling plant*
    - *30.02 L Pantograph repair platform*
    - *30.02 M Undercar vehicle inspection system*
- *30.03 Heavy maintenance facility*
    - *30.03 A Structure*
    - *30.03 B Interior Construction and Finishes*
    - *30.03 C Track*
    - *30.03 D Inspection pits/drainage*
    - *30.03 E Overhead Contact System - Catenary*
    - *30.03 F Drop tables*
    - *30.03 G Wheel lathe*
    - *30.03 H Overhead cranes*
    - *30.03 I Toilet evac. system*
    - *30.03 J Auto wheel inspection system*

  - *30.03 K Auto trainset car wash*
  - *30.03 L Pantograph repair platform*
  - *30.03 M Water recycling plant*
  - *30.03 N Undercar vehicle inspection system*
  - *30.03 O Paint shop complete*
  - *30.03 P Trainset lifting system*
  - *30.03 Q Bogie turntable system*
  - *30.03 R Bogie wash system*
  - *30.03 S Shop cranes*
  - *30.03 T Wheel press*
- *30.04 Storage or maintenance of way building/bases*
  - *30.04 A Structure*
  - *30.04 B Interior Construction and Finishes*
  - *30.04 C Track*
  - *30.04 D Inspection pits/drainage*
  - *30.04 E Overhead cranes*
- *30.05 Yard and yard track*
  - *30.05 A Track rehab, ballast and surface*
  - *30.05 B Yard turnouts/crossovers*

9.1 Assumptions and Model Inputs

The following assumptions were made for *30 Support Facilities, Yards, Shops and Administration Buildings*:

- Facilities in *30 Support Facilities, Yards, Shops, and Administration Buildings* are designed to remain in service for more than 50 years but generally less than 100 years; this is contingent upon a systematic plan for building maintenance
- Lifecycle estimates were derived from converted percentage of initial capital cost assumptions (see section 3.2 for detailed information on the conversion process).
- Inputs for the model are outlined in Table 7.

30.02 Light maintenance facility, 30.03 Heavy maintenance facility, and *30.04 Storage or maintenance of way building/bases*

- New second level categories were defined to enable a rational lifecycle analysis of pertaining costs; these new second level categories are demarcated with a letter (e.g., *30.02A Structure*)
- Rehabilitation costs may be higher than the original capital cost since many manufacturers figure a 2 percent per year or higher costs on the remanufacture or replacement of new equipment[12]
- No replacement will occur during the 50-year timeframe for any of these new second level categories
- Unit costs were provided by the following manufacturers:
    - Drop tables—Whiting Corp. (USA), SAFOP Machinery (Italy), Hegenscheidt, Inc. (Germany)
    - Wheel lathes—Simmons Machine Tool Corp. (USA), SAFOP Machinery (Italy)
    - Overhead cranes—Spanco, Inc. (USA), North American Industries (USA), GEMAG, Inc. (Germany)
    - Auto wheel inspection system—Hegenscheidt, Inc. (Germany)
    - Auto trainset carwash—Century Group (USA), Ross-White Inc. (USA)
    - Trainset lifting system—Macton, Inc. (USA), Whiting Corp. (USA)
    - Turntables—SAFOP Machinery (Italy), Macton, Inc. (USA)
    - Toilet evacuation systems—EVAC North America (USA)
    - Wheel presses/machinery—SAFOP Machinery (Italy)
    - Simmons Machine Tool Corp. (USA)
- Inputs for the model are outlined in Table 7.

30.02 Light Maintenance Facility

- *30.02 A Structure*
    - Rehabilitation will occur every 50 years

[12] For example, the refurbishment of an in-ground axle wheel lathe may be less costly than procuring a new wheel lathe (regardless of age) because to replace the entire lathe will require excavation, removal of the old and replacement with the new machinery. The labor costs will be greater versus a refurbishment involving the replacement of some major components, upgrading of electronics, etc.

  - Rehabilitation will cost 10 percent of the initial capital cost for this individual asset category and is spread over 5 years
  - Replacement will occur every 100 years
  - Replacement will cost 35 percent of the initial capital cost of all 30.02 components, spread over 5 years
- *30.02 B Interior Construction and Finishes*
  - Rehabilitation will occur every 35 years
  - Rehabilitation will cost 15 percent of the initial capital cost for this individual asset category and is spread over 30 years
  - Replacement will occur every 100 years
- *30.02 C Track*
  - No replacement and no rehabilitation is anticipated during the 50-year timeframe
- *30.02 D Inspection Pits/Drainage*
  - No replacement and no rehabilitation is anticipated during the 50-year timeframe
- 3*0.02 E OCS Catenary*
  - No replacement and no rehabilitation is anticipated during the 50-year timeframe
- *30.02 F Drop Tables*
  - Rehabilitation will occur every 30 years
  - Rehabilitation will cost 4 percent of the initial capital cost for all 30.02 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.02 G Overhead Cranes*
  - Rehabilitation will occur every 30 years
  - Rehabilitation will cost 4 percent of the initial capital cost for all 30.02 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.02 H Toilet Evacuation System*
  - Rehabilitation will occur every 20 years

  - Rehabilitation will cost 10 percent of the initial capital cost for all 30.02 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.02 I Auto Wheel Inspection System*
  - Rehabilitation will occur every 20 years
  - Rehabilitation will cost 6 percent of the initial capital cost for all 30.02 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.02 J Auto Trainset Car Wash*
  - Rehabilitation will occur every 30 years
  - Rehabilitation will cost 15 percent of the initial capital cost for all 30.02 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.02 K Water Recycling Plant*
  - Rehabilitation will occur every 30 years
  - Rehabilitation will cost 20 percent of the initial capital cost for all 30.02 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.02 L Pantograph Repair Platform*
  - No replacement and no rehabilitation is anticipated during the 50-year timeframe
- *30.02 M Undercar Vehicle Inspection System*
  - Rehabilitation will occur every 20 years
  - Rehabilitation will cost 6 percent of the initial capital cost for all 30.02 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
  - Lifecycle estimates are based on relevant experience with applicable Light Maintenance Facilities.

30.03 Heavy Maintenance Facility

- *30.03 A Structure*

  - Rehabilitation will occur every 50 years
  - Rehabilitation will cost 10 percent of the initial capital cost for all 30.03 components and is spread over 5 years
  - Replacement will occur every 100 years
  - Replacement will cost 35 percent of the initial capital cost for all 30.03 components and is spread over 5 years
- *30.03 B Interior Construction and Finishes*
  - Rehabilitation will occur every 35 years
  - Rehabilitation will cost 15 percent of the initial capital cost for all 30.03 components and is spread over 30 years
  - Replacement will occur every 100 years
- *30.03 C Track*
  - No replacement and no rehabilitation is anticipated during the 50-year timeframe
- *30.03 D Inspection Pits/Drainage*
  - No replacement and no rehabilitation is anticipated during the 50-year timeframe
- *30.03 E OCS Catenary*
  - No replacement and no rehabilitation is anticipated during the 50-year timeframe
- *30.03 F Drop Tables*
  - Rehabilitation will occur every 30 years
  - Rehabilitation will cost 2 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.03 G Wheel Lathe*
  - Rehabilitation will occur every 30 years
  - Rehabilitation will cost 2 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.03 H Overhead Cranes*
  - Rehabilitation will occur every 30 years

  - Rehabilitation will cost 4 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.03 I Toilet Evacuation System*
  - Rehabilitation will occur every 20 years
  - Rehabilitation will cost 3 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.03 J Auto Wheel Inspection System*
  - Rehabilitation will occur every 20 years
  - Rehabilitation will cost 2 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.03 K Auto Trainset Car Wash*
  - Rehabilitation will occur every 30 years
  - Rehabilitation will cost 3 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.03 L Pantograph Repair Platform*
  - Rehabilitation will occur every 20 years
  - Rehabilitation will cost 1 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.03 M Water Recycling Plant*
  - Rehabilitation will occur every 30 years
  - Rehabilitation will cost 4 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.03 N Undercar Vehicle Inspection System*

  - Rehabilitation will occur every 20 years
  - Rehabilitation will cost 2 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.03 O Paint Shop Complete*
  - Rehabilitation will occur every 20 years
  - Rehabilitation will cost 4 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.03 P Trainset Lifting System*
  - Rehabilitation will occur every 30 years
  - Rehabilitation will cost 7 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.03 Q Bogie Turntable System*
  - Rehabilitation will occur every 20 years
  - Rehabilitation will cost 2 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.03 R Bogie Wash System*
  - Rehabilitation will occur every 20 years
  - Rehabilitation will cost 1 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe
- *30.03 S Shop Cranes*
  - Rehabilitation will occur every 20 years
  - Rehabilitation will cost 4 percent of the initial capital cost for all 30.03 components and is spread over 4 years
  - No replacement is anticipated during the 50-year timeframe

- *30.03 T Wheel Press*
    - Rehabilitation will occur every 20 years
    - Rehabilitation will cost 3 percent of the initial capital cost for all 30.03 components and is spread over 4 years
    - No replacement is anticipated during the 50-year timeframe
    - Lifecycle estimates are based on relevant experience with applicable Heavy Maintenance Facilities.

30.04 Storage or Maintenance-of-Way Building/Bases

- *30.04 A Structure*
    - Rehabilitation will occur every 50 years
    - Rehabilitation will cost 10 percent of the initial capital cost for all 30.04 components and is spread over 5 years
    - Replacement will occur every 100 years
    - Replacement will cost 35 percent of the initial capital cost for all 30.04 components and is spread over 5 years
- *30.04 B Interior Construction and Finishes*
    - Rehabilitation will occur every 35 years
    - Rehabilitation will cost 15 percent of the initial capital cost for all 30.04 components and is spread over 30 years
    - Replacement will occur every 100 years
- *30.04 C Track*
    - No replacement and no rehabilitation is anticipated during the 50-year timeframe
- *30.04 D Inspection Pits/Drainage*
    - No replacement and no rehabilitation is anticipated during the 50-year timeframe
- 30.04 E Overhead Cranes
    - No replacement and no rehabilitation is anticipated during the 50-year timeframe
    - Lifecycle estimates are based on relevant experience with applicable Storage/Maintenance buildings.

30.05 Yard and yard track

- *30.05 A Track rehab, ballast and surface*
    - Yard track material will last 2-3 times that of main track (50 years), therefore requiring one replacement after 50 years, or possibly no replacement at all
- *30.05 B Yard turnouts/crossovers*
    - No rehabilitation is anticipated during 50-year timeframe
    - Replacement will occur every 20 years, spread over 5 years
    - Replacement will cost 41 percent of the initial capital cost for all 30.05 components
    - Estimates are based on high-speed rail experience in France, Germany, Taiwan, and conventional American and British railroad operations

Model inputs are presented in Table 7.

Table 7 Support Facilities, Yards, Shops, and Administration Buildings Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
30.02	Light maintenance facility	—	—	—	—	see below	see below	see below
A	Structure	lump sum	100	5	35% of initial capital cost of all 30.02 components	50	5	10% of initial capital cost of all 30.02 components
B	Interior Construction and Finishes	lump sum	100	—	—	35	30	15% of initial capital cost of all 30.02 components
C	Track	lump sum	—	—	—	—	—	—
D	Inspection pits/drainage	lump sum	—	—	—	—	—	—
E	Overhead Contact System catenary	lump sum	—	—	—	—	—	—
F	Drop tables	lump sum	—	—	—	30	4	4% of initial capital cost of all 30.02 components
G	Overhead cranes	lump sum	—	—	—	30	4	4% of initial capital cost of all 30.02 components

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
H	Toilet evac. system	lump sum	—	—	—	20	4	10% of initial capital cost of all 30.02 components
I	Auto wheel inspection system	lump sum	—	—	—	20	4	6% of initial capital cost of all 30.02 components
J	Auto trainset car wash	lump sum	—	—	—	30	4	15% of initial capital cost of all 30.02 components
K	Water recycling plant	lump sum	—	—	—	30	4	20% of initial capital cost of all 30.02 components
L	Pantograph repair platform	lump sum	—	—	—	—	—	—
M	Undercar vehicle inspection system	lump sum	—	—	—	20	4	6% of initial capital cost of all 30.02 components
30.03	Heavy maintenance facility	lump sum	—	—	—	see below	see below	see below
A	Structure	lump sum	100	5	35% of initial capital cost of all 30.03 components	50	5	10% of initial capital cost of all 30.03 components

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
B	Interior Construction and Finishes	lump sum	100	—	—	35	30	15% of initial capital cost of all 30.03 components
C	Track	lump sum	—	—	—	—	—	—
D	Inspection pits/drainage	lump sum	—	—	—	—	—	—
E	Overhead Contact System - Catenary	lump sum	—	—	—	—	—	—
F	Drop tables	lump sum	—	—	—	30	4	2% of initial capital cost of all 30.03 components
G	Wheel lathe	lump sum	—	—	—	30	4	2% of initial capital cost of all 30.03 components
H	Overhead cranes	lump sum	—	—	—	30	4	4% of initial capital cost of all 30.03 components
I	Toilet evac. systems	lump sum	—	—	—	20	4	3% of initial capital cost of all 30.03 components
J	Auto wheel inspection system	lump sum	—	—	—	20	4	2% of initial capital cost of all 30.03 components

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
K	Auto trainset car wash	lump sum	—	—	—	30	4	3% of initial capital cost of all 30.03 components
L	Pantograph repair platform	lump sum	—	—	—	20	4	1% of initial capital cost of all 30.03 components
M	Water recycling plant	lump sum	—	—	—	30	4	4% of initial capital cost of all 30.03 components
N	Undercar vehicle inspection system	lump sum	—	—	—	20	4	2% of initial capital cost of all 30.03 components
O	Paint shop complete	lump sum	—	—	—	20	4	4% of initial capital cost of all 30.03 components
P	Trainset lifting system	lump sum	—	—	—	30	4	7% of initial capital cost of all 30.03 components
Q	Bogie turntable system	lump sum	—	—	—	20	4	2% of initial capital cost of all 30.03 components
R	Bogie wash system	lump sum	—	—	—	20	4	1% of initial capital cost of all 30.03 components

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
S	Shop cranes	lump sum	—	—	—	20	4	4% of initial capital cost of all 30.03 components
T	Wheel press	lump sum	—	—	—	20	4	3% of initial capital cost of all 30.03 components
30.04	Storage or maintenance-of-way building/bases	—	—	—	—	see below	see below	see below
A	Structure	lump sum	100	5	35% of initial capital cost of all 30.04 components	50	5	10% of initial capital cost of all 30.04 components
B	Interior Construction and Finishes	lump sum	100	—	—	35	30	15% of initial capital cost of all 30.04 components
C	Track	lump sum	—	—	—	—	—	—
D	Inspection pits/drainage	lump sum	—	—	—	—	—	—
E	Overhead cranes	lump sum	—	—	—	—	—	—
30.05	Yard track	—	see below	see below	—	—	—	—
A	Track rehab, ballast and surface	lump sum	> 50 years	—	—	—	—	—

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
B	Yard turnouts/cross overs	lump sum	20	5	41% of initial capital cost of all 30.05 components	—	—	—

9.2 Assumption Changes since the *2016 Business Plan*

The following assumption changes have occurred since the *2016 Business Plan*, driven by the input conversions detailed in Section 3.2. and Network Rail Renewal Policies from its Control Period 5 (2014-2019) Delivery Plan, which is Network Rail's five-year business planning and investment plan for its U.K. rail system, and other current strategy documents.

30.02 Light Maintenance Facility

- *30.02 A Structure*
    - The *2016 Business Plan* included rehabilitation and replacement assumptions pertaining to the Light Maintenance Facility Roof under category *30.02 A*
    - The *2018 Business Plan* includes assumptions pertaining to the Light Maintenance Facility Structure under category 30.02 A
    - The *2016 Business Plan* assumed rehabilitation of 30.02 A will occur every 20 years, will cost 5 percent of the initial capital cost of all 30.02 components, spread over 4 years
    - The *2018 Business Plan* assumed rehabilitation of 30.02 A will occur every 50 years, will cost 10 percent of the initial capital cost of all 30.02 components, spread over 5 years
    - The *2016 Business Plan* did not specify an assumption pertaining to replacement of the roof
    - The *2018 Business Plan* assumed replacement of 30.02 A would cost 35 percent of the initial capital cost of all 30.02 components
- *30.02 B Interior Construction and Finishes*
    - The *2016 Business Plan* included rehabilitation and replacement assumptions pertaining to the Light Maintenance Facility Exterior under category 30.02 B
    - The *2018 Business Plan* includes assumptions pertaining to the Light Maintenance Facility Interior Construction and Finishes under category 30.02 B
    - The *2016 Business Plan* assumed rehabilitation of 30.02 B will occur every 30 years, will cost 5 percent of the initial capital cost of all 30.02 components, spread over 4 years
    - The *2018 Business Plan* assumed rehabilitation of 30.02 B will occur every 35 years, will cost 15 percent of the initial capital cost of all 30.02 components, spread over 30 years
    - The *2016 Business Plan* did not specify an assumption pertaining to replacement of the exterior
    - The *2018 Business Plan* assumed replacement of 30.02 B will occur after 100 years
- *30.02 C Track*

  - The *2016 Business Plan* assumed rehabilitation every 20 years
  - The *2018 Business Plan* doesn't assume rehabilitation during the 50-year timeframe
- *30.02 D Inspection pits/drainage*
  - The *2016 Business Plan* assumed rehabilitation every 20 years
  - The *2018 Business Plan* doesn't assume rehabilitation during the 50-year timeframe
- *30.02 E Overhead Contact System catenary*
  - The *2016 Business Plan* assumed rehabilitation every 30 years
  - The *2018 Business Plan* doesn't assume rehabilitation during the 50-year timeframe
- *30.02 L Pantograph Repair Platform*
  - The *2016 Business Plan* assumed rehabilitation every 20 years
  - The *2018 Business Plan* doesn't assume rehabilitation during the 50-year timeframe

30.03 Heavy Maintenance Facility

- *30.03 A Structure*
  - The *2016 Business Plan* included rehabilitation and replacement assumptions pertaining to the Light Maintenance Facility Roof under category 30.03 A
  - The *2018 Business Plan* includes assumptions pertaining to the Heavy Maintenance Facility Structure under category 30.03 A
  - The *2016 Business Plan* assumed rehabilitation of 30.03 A will occur every 20 years, will cost 3 percent of the initial capital cost of all 30.03 components, spread over 4 years
  - The *2018 Business Plan* assumed rehabilitation of 30.03 A will occur every 50 years, will cost 10 percent of the initial capital cost of all 30.03 components, spread over 5 years
  - The *2016 Business Plan* did not specify an assumption pertaining to replacement of the roof
  - The *2018 Business Plan* assumed replacement of 30.03 A would cost 35 percent of the initial capital cost of all 30.03 components
- *30.03 B Interior Construction and Finishes*
  - The *2016 Business Plan* included rehabilitation and replacement assumptions pertaining to the Light Maintenance Facility Exterior under category 30.03 B
  - The *2018 Business Plan* includes assumptions pertaining to the Heavy Maintenance Facility Interior Construction and Finishes under category 30.03 B

  - The *2016 Business Plan* assumed rehabilitation of 30.03 B will occur every 30 years, will cost 3 percent of the initial capital cost of all 30.03 components, spread over 4 years
  - The *2018 Business Plan* assumed rehabilitation of 30.03 B will occur every 35 years, will cost 15 percent of the initial capital cost of all 30.03 components, spread over 30 years
  - The *2016 Business Plan* did not specify an assumption pertaining to replacement of the exterior
  - The *2018 Business Plan* assumed replacement of 30.03 B will occur after 100 years
- *30.03 C Track*
  - The *2016 Business Plan* assumed rehabilitation every 20 years
  - The *2018 Business Plan* doesn't assume rehabilitation during the 50-year timeframe
- *30.03 D Inspection pits/drainage*
  - The *2016 Business Plan* assumed rehabilitation every 20 years
  - The *2018 Business Plan* doesn't assume rehabilitation during the 50-year timeframe
- *30.03 E Overhead Contact System catenary*
  - The *2016 Business Plan* assumed rehabilitation every 30 years
  - The *2018 Business Plan* doesn't assume rehabilitation during the 50-year timeframe

30.04 Storage or Maintenance-of-Way Building/Bases

- *30.04 A Structure*
  - The *2016 Business Plan* included rehabilitation and replacement assumptions pertaining to the Storage or Maintenance-of-Way Building/Bases Roof under category 30.04 A
  - The *2018 Business Plan* includes assumptions pertaining to the Storage or Maintenance-of-Way Building/Bases Structure under category 30.04 A
  - The *2016 Business Plan* assumed rehabilitation of 30.04 A will occur every 20 years, will cost 5 percent of the initial capital cost of all 30.04 components, spread over 4 years
  - The *2018 Business Plan* assumed rehabilitation of 30.04 A will occur every 50 years, will cost 10 percent of the initial capital cost of all 30.04 components, spread over 5 years
  - The *2016 Business Plan* did not specify an assumption pertaining to replacement of the roof
  - The *2018 Business Plan* assumed replacement of 30.04 A would cost 35 percent of the initial capital cost of all 30.04 components

- *30.04 B Interior Construction and Finishes*
    - The *2016 Business Plan* included rehabilitation and replacement assumptions pertaining to the Storage or Maintenance-of-Way Building/Bases Exterior under category 30.04 B
    - The *2018 Business Plan* includes assumptions pertaining to the Storage or Maintenance-of-Way Building/Bases Interior Construction and Finishes under category 30.04 B
    - The *2016 Business Plan* assumed rehabilitation of 30.04 B will occur every 30 years, will cost 5 percent of the initial capital cost of all 30.04 components, spread over 4 years
    - The *2018 Business Plan* assumed rehabilitation of 30.04 B will occur every 35 years, will cost 15 percent of the initial capital cost of all 30.04 components, spread over 30 years
    - The *2016 Business Plan* did not specify an assumption pertaining to replacement of the exterior
    - The *2018 Business Plan* assumed replacement of 30.04 B will occur after 100 years
- *30.04 C Track*
    - The *2016 Business Plan* assumed rehabilitation every 20 years
    - The *2018 Business Plan* doesn't assume rehabilitation during the 50-year timeframe
- *30.04 D Inspection pits/drainage*
    - The *2016 Business Plan* assumed rehabilitation every 20 years
    - The *2018 Business Plan* doesn't assume rehabilitation during the 50-year timeframe
- *30.04 E Overhead Contact System catenary*
    - The *2016 Business Plan* assumed rehabilitation every 30 years
    - The *2018 Business Plan* doesn't assume rehabilitation during the 50-year timeframe

Industry subject matter experts reviewed all other support facility assumptions and inputs previously used for the *2016 Business Plan* and found them to be consistent with current industry best practices.

10 SITEWORK, RIGHT-OF-WAY, LAND, AND EXISTING IMPROVEMENTS

Category *40 Sitework, Right-of-Way, Land and Existing Improvements* include the following asset class:

- *40.05 Site structures including retaining walls, sound walls*

10.1 Assumptions and Model Inputs

The following assumptions were made to *40 Stations Sitework, Right-of-Way, Land, and Existing Improvements*:

- Cost categories *40.01–40.04* and *40.06–40.09* have been excluded since they are not applicable to capital rehabilitation and replacement
- There are no costs for category *40 Sitework, Right-of-Way, Land, and Existing Improvements*; assets in *40.05 Site structures, including retaining walls, sound walls* are designed for 100 years, as referenced in California High-Speed Train Project Technical Memorandum 1.1.2, and no rehabilitation or replacement is anticipated during 50-year timeframe; inspections and repairs are part of O&M costs

10.2 Assumption Changes since the *2016 Business Plan*

No assumptions have changed since the *2016 Business Plan*, as category 40 assets are not rehabilitated or replaced during the 50-year model timeframe.

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11 COMMUNICATIONS AND SIGNALING

Category *50 Communications and Signaling* asset category includes the following asset classes:

- *50.01 Wayside signaling equipment*
- *50.04 Traffic Control and Dispatching Systems*
- *50.05 Communication*
    - *50.05 A: Shelters, cabinets, towers, duct banks, manholes, fiber optic, HVAC, radiax*
    - *50.05 B: Wide area networking, networked storage, etc.*
    - *50.05 C: Radio systems (operations radio system, broadband radio system)*
    - *50.05 D: Application systems: closed circuit TV, fixed asset software, electronic access control Systems, intrusion detection system, passenger address and communication system, etc.*
- *50.06 Grade Crossing Protection*
- *50.07 Hazard Detectors*

11.1 Assumptions and Model Inputs

The following assumptions were made to *50 Communications and signaling*:

50.01 Wayside signaling equipment

- Rehabilitation costs include an average of uninterruptible power supply battery replacement and commercial off-the-shelf hardware replacement for every 10 years; the cost of these items on average is approximately 20 percent of the initial capital cost of 50.01 (15 percent for commercial off-the-shelf hardware and 5 percent for switch machines)
- Rehabilitation will occur every 15 years and is spread over 3 years
- Replacement will occur every 30 years, spread over 5 years
- Replacement will cost 80 percent of the initial capital cost of 50.01
- Contingencies, testing and commissioning, systems engineering, warranty, spectrum, etc. are not included in replacement and rehabilitation cost percentages
- Lifecycle estimates are based on Building Industry Consulting Service International Telecommunications Distribution Methods Manual, IT standard practice, and conventional American and British rail operations

50.04 Traffic Control and Dispatching Systems

- Rehabilitation of Traffic Control and Dispatching Systems will occur every 15 years

- Rehabilitation will cost 3 percent of the initial capital cost of 50.04, spread over 15 years
- Replacement will occur every 25 years
- Replacement will cost 100 percent of the initial capital cost of 50.04, and will be done the same year

50.05 Communications

The following sub-classes were defined to enable a rational lifecycle analysis of pertaining costs:

- *50.05 A: Shelters, cabinets, towers, duct banks, manholes, fiber optic, HVAC, radiax* (40 percent of the initial capital cost of 50.05)
- *50.05 B: Wide area networking, networked storage, etc.* (15 percent of initial capital cost of 50.05)
- *50.05 C: Radio systems (operations radio system, broadband radio system)* (20 percent of the initial capital cost of 50.05)
- *50.05 D: Application systems: closed circuit TV, fixed asset software, electronic access control systems, intrusion detection system, passenger address and communication system, etc.* (15 percent of the initial capital cost of 50.05)

50.05 A: Shelters, cabinets, towers, duct banks, manholes, fiber optic, HVAC, radiax

- Rehabilitation occurs 10 years into the life of the asset and is spread over 5 years
    - The rehabilitation cycles occur years 10-14, 20-24 and 40-44
- Rehabilitation costs 3 percent of the initial capital cost for all 50.05 components
    - Rehabilitation will cost 0.5 percent each year rehabilitation takes place for both cycles
- Replacement occurs every 30 years, spread over 5 years
    - Replacement will occur during years 30-34
- Replacement will cost 10 percent of the initial capital cost for all 50.05 components each cycle
    - Replacement will cost 2 percent each year replacement takes places for the two cycles that occur during the 50-year timeframe

50.05 B: Wide area networking, networked storage, etc. (replacement only)

- This asset category will not be rehabilitated, only replaced
- Replacement will occur every 10 years, spread over 2 years
    - There will be 5 replacement cycles during the 50-year timeframe: during years 10-11, 20-21, 30-31, 40-41, 50-51

- Replacement will cost 15 percent of the initial capital cost for all 50.05 components for each cycle
    - Replacement will cost 8 percent each year replacement takes place for the five cycles that occur during the 50-year timeframe

50.05 C: Radio systems (operations radio system, broadband radio system)

- Rehabilitation will occur 10 years into the life of the asset and is spread over 5 years
    - The rehabilitation cycles occur years 10-14, 20-24 and 40-44
- Rehabilitation costs 1 percent of the initial capital cost of all 50.05 components
    - Rehabilitation will cost 0.3 percent each year rehabilitation takes place
- Replacement occurs every 30 years, spread over 5 years
    - Replacement will occur during years 30-34
- Replacement will cost 5 percent of the initial capital cost of all 50.05 components for each cycle
    - Replacement will cost 1 percent each year replacement takes place for the two cycles that occur during the 50-year timeframe

50.05 D: Application systems: closed circuit TV, fixed asset software, electronic access control systems, intrusion detection system, passenger address and communication system, etc.

- Rehabilitation will occur 10 years into the life of the asset and is spread over 5 years
    - The rehabilitation cycles occur years 10-14, 20-24 and 40-44
- Rehabilitation costs 1 percent of the initial capital cost of all 50.05 components for each cycle
    - Rehabilitation will cost 0.2 percent each year rehabilitation takes place
- Replacement occurs every 30 years, spread over 5 years
    - Replacement will occur during years 30-34
- Replacement costs 4 percent of the initial capital cost for all 50.05 components for each cycle
    - Replacement will cost 1 percent each year replacement takes places

50.06 Grade Crossing Protection

- Rehabilitation of Grade Crossing Protection will occur every 20 years
- Rehabilitation will cost 30 percent of the initial capital cost of 50.06, spread over 10 years
- Replacement will occur every 30 years
- Replacement will cost 90 percent of the initial capital cost of 50.06, spread over 10 years

50.07 Hazard Detector

- Rehabilitation of Hazard Detector will occur every 15 years
- Rehabilitation will cost 20 percent of the initial capital cost of 50.07, spread over 3 years
- Replacement will occur every 30 years
- Replacement will cost 80 percent of the initial capital cost of 50.07, spread over 5 years

Model inputs are presented in Table 8.

Table 8 Communications and Signaling Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
50.01	Wayside signaling equipment	lump sum	30	5	80% of initial capital cost of 50.01	15	3	20% of initial capital cost of 50.01
50.04	Traffic Control and Dispatching Systems	lump sum	25	1	100% of initial capital cost of 50.04	15	15	3% of initial capital cost of 50.04
50.05	Communications	lump sum	see below	see below	see below	see below	see below	see below
A	Shelters, cabinets, towers, duct banks, manholes, fiber optic, HVAC, radiax	lump sum	30	Years 30-34	10% of initial capital cost of all 50.05 components (2% each year for one cycle)	10	Years 10-14, 20-24 and 40-44	3% of initial capital cost of all 50.05 components (0.5% each year rehab takes place, for both cycles)
B	Wide Area Networking, Networked Storage, etc.	lump sum	10	5 cycles during 50-year timeframe: during years 10-11, 20-21, 30-31, 40-41 50-51	15% of initial capital cost of all 50.05 components (7.5% each year for one cycle)	—	—	—
C	Radio Systems (Operations Radio System, Broadband Radio System)	lump sum	30	Years 30-34	5% of initial capital cost of all 50.05 components (1% each year for one cycle)	10	Years 10-14, 20-24 and 40-44	1% of initial capital cost of all 50.05 components (0.3% each year rehab takes place)

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
D	Application Systems: closed circuit TV, fixed asset software, electronic access control systems, intrusion detection system, passenger address and communication system, etc.	lump sum	30	Years 30-34	4% of initial capital cost of all 50.05 components (1% each year for one cycle)	10	Years 10-14, 20-24 and 40-44	1% of initial capital cost of all 50.05 components (0.2% each year rehab takes place)
50.06	Grade Crossing Protection[13]	lump sum	30	10	90% of initial capital cost of 50.06	20	10	30% of initial capital cost of 50.06
50.07	Hazard Detectors	lump sum	30	5	80% of initial capital cost of 50.07	15	3	20% of initial capital cost of 50.07

[13] Costs include upgrades to existing grade crossings, to allow for higher speed and more frequent trains. Costs also include rehabilitation and replacement of grade crossings owned by the Authority

11.2 Assumption Changes since the *2016 Business Plan*

A summary of the assumption changes since the *2016 Business Plan* are presented below, driven by the conversion methodology outlined in Section 3.2 and Network Rail Renewal Policies from its Control Period 5 (2014-2019) Delivery Plan, which is Network Rail's five-year business planning and investment plan for its U.K. rail system, and other current strategy documents.

The *2018 Business Plan* introduces the following categories:

- 50.04 Traffic Control Dispatching Systems
- 50.06 Grade Crossing Protection
- 50.07 Hazard Protection

The description of their rehabilitation and replacement cycles is detailed in Section 11.1.

Industry subject matter experts reviewed all other signaling and communications assumptions previously used for the *2016 Business Plan* and found them to be consistent with current industry best practices.

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12 ELECTRIC TRACTION

Category *60 Electric traction* includes the following asset classes:

- *60.02 Traction power supply: Substations*
- *60.03 Traction power distribution: Catenary and third rail*
- *60.04 Traction power control*

12.1 Assumptions and Model Inputs

The following assumptions were made to *60 Electric Traction*:

60.02 Traction power supply: Substations

- This asset category includes switching stations and paralleling stations, and wayside power control cubicles. All switching arrangements have the ability to quickly isolate power to allow lifecycle work to take place.
- This asset category excludes the cost of land for traction power facilities, captive traction substation at rolling stock maintenance facilities, grading and paving, layer of gravel, prefabricated structures, buildings, gantries, and testing and commissioning.
- Rehabilitation cost encompasses replacement of low maintenance storage batteries and assemblies with moving components such as switchgear, circuit breakers, and disconnect switches
- Rehabilitation costs assumes that the Authority will not have any obligation for replacement cost for high voltage utility assets created especially for the California High-Speed Rail System
- Rehabilitation will cost 20 percent of the initial capital cost for 60.02
- A mid-life rehabilitation cycle will occur during years 25-39 of the asset's lifecycle (1.3 percent each year)
- Rehabilitation timing for *60.02 Traction power supply: Substations* is based on experience from international high-speed rail systems, and domestic and British conventional rail systems
- Lifecycle estimates are based on experience of international high-speed rail systems, California High-Speed Train Project Technical Memorandum 1.1.2, asset class specialist expertise, and conventional American and British rail operations
- Replacement will occur every 50 years, with each cycle worth 25 percent of the initial capital costs of 60.02

60.03 Traction power distribution: Catenary and third rail

- Rehabilitation will consist of replacing contact wire when the wear reaches 25 percent of the wire cross section
- Rehabilitation will cost 30 percent of the initial capital cost estimate for the asset, based on subject matter expert recommendations.
- A mid-life rehabilitation cycle will occur during years 30-39 of the asset's lifecycle
- Lifecycle estimates are based on, Technical Memorandum 1.1.2 and Design Criteria Chapter 1 of the California High-Speed Train Project book "Contact Lines for Electric Railways," discussion with industry experts, conventional American and British rail operations, and a literature survey
- The design life of Overhead Contact System wire and assemblies is 60 years; replacement will not occur during the 50-year timeframe; replacement will begin at year 61 of asset age and costs will be spread uniformly over 20 years after that
- Replacement will cost 61 percent of the initial capital cost for Overhead Contact System - Catenary assemblies

60.04 Traction power control

- Rehabilitation will cost 20 percent of the initial capital cost for 60.04.
- A mid-life rehabilitation cycle will occur during years 25-39 of the asset's lifecycle (1.3 percent each year).
- Replacement will occur every 50 years, with each cycle worth 25 percent of the initial capital costs of 60.04.

Model inputs are presented in Table 9.

Table 9 Electric Traction Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
60.02	Traction power supply: Substations	lump sum	50	20 from 51st year	25% of 60.02	25	15 years	20% of initial capital cost of 60.02
60.03	Traction power distribution: Catenary and third rail	lump sum	60	20 from 61st year	61% of initial capital cost for Overhead Contact System - Catenary assemblies	30	10 years	30% of initial capital cost of 60.03
60.04	Traction power control	lump sum	50	20 from 51st year	25% of 60.04	25	15 years	20% of initial capital cost of 60.04

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12.2 Assumption Changes since the *2016 Business Plan*

The assumptions haven't been changed since the *2016 Business Plan* for category 60 assets.

Industry subject matter experts reviewed all other electric traction assumptions previously used for the *2016 Business Plan* and found them to be consistent with current industry best practices.

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13 VEHICLES

Category *70 Vehicles* includes the following asset classes:

- *70.02 Vehicle acquisition: Electric multiple unit*
- *70.06 Vehicle acquisition: Maintenance of way vehicles*
- *70.07 Vehicle acquisition: Non-railroad support vehicles*

13.1 Assumptions and Model Inputs

The following assumptions were made for Category *70 Vehicles*:

70.02 Vehicle acquisition: Electric multiple unit

- Daily inspections, servicing and cleaning, bogey inspections, and general inspections are considered as part of regular operations and maintenance costs and not accounted for in the capital replacement costs (they are accounted for in the operations and maintenance costs).
- Each trainset will cost $52 million in 2017 dollars[14] based off estimates from various trainset manufacturers.
- Replacement of Vehicle acquisition: Electric multiple unit will occur every 30 years
- Replacement will cost 100 percent of the initial capital cost for 70.02, spread over 5 years
- Rehabilitation of Vehicle acquisition: Electric multiple unit, also called Mid-life overhauls, will occur every 15 years
- Rehabilitation will cost 75 percent of the initial capital estimate of 70.02, spread on 5 years
- Lifecycle estimates are based on Asian, American, and European rehabilitation models for Rolling Stock.

Model inputs are presented in Table 10.

[14] This amount does not include contingency rates.

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Table 10 Vehicles Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Replacement Spread (years)	Replacement Cost (per unit)	Rehab Timing (years)	Rehab Spread (years)	Rehab Cost (per unit)
70.02	Vehicle acquisition: Electric multiple unit	per trainset	30	5	$52,000,000	15	5	75% of initial capital cost of 70.02
70.06	Vehicle acquisition: Maintenance of way vehicles[15]	N/A	N/A	N/A	N/A	N/A	N/A	N/A
70.07	Vehicle acquisition: Non-railroad support vehicles[16]	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[15] The high-speed rail system will include category *70.06, but inputs are not yet available for this category.*

[16] The high-speed rail system will include category *70.07, but inputs are not yet available for this category.*

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13.2 Assumptions changes since the *2016 Business Plan*

- Each trainset cost $46,700,000 (in 2015 dollars) in the *2016 Business Plan*
- Each trainset costs $52,000,000 (in 2017 dollars) in the *2018 Business Plan*
- Mid-life overhauls of each trainset were not included in the lifecycle model for the *2016 Business Plan*, considering that it would be funded by the trainset operator's reserve account for trainset rehabilitation
- The *2018 Business Plan* introduces 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

13.3 Unit Quantities

The following unit quantities apply to *70.02 Vehicle acquisition: Electric multiple unit*:

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

Table 11 outlines the number of trainsets per group.

Table 11 Number of Trainsets and Start Years

Group	Number of Trainsets (Valley to Valley Line)	Start Year	Phase
1	10	2029	Valley to Valley
2	6 *	2030	Valley to Valley
3	— *	2031	Valley to Valley
4	— *	2032	Valley to Valley
5	34*	2033	Phase 1
6	10	2034	Phase 1
7	7	2035	Phase 1
8	5	2036	Phase 1

*Trainsets beyond 10 sets in these years delivered before Phase 1, but assumed to be placed in service after Phase 1 commences.

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14 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.[17]

Table 12 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 *2018 Business Plan* are consistent with those assumed in the *2016 Business Plan*.

Table 12 Professional Services Cost Allowances for Categories 10, 20, 30 and 40

Group	Number of Trainsets (Valley to Valley Line)	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%[18]
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%
Total		10.0%[19]

Final design for categories 50 and 60 is assumed to be 20.0, percent consisting of 15.0 percent for system engineering and 5.0 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.

[17] As defined by the FRA Standard Cost Categories (SCC) for Capital Projects: http://www.fta.dot.gov/13070_2580.html. However, not all of these categories would apply to the rehabilitation or replacement of assets.

[18] Only applicable to categories 10-40. Final design for categories 50-60 is 20.0 percent, 15.0 percent for system engineering and 5.0 percent for integration, testing and commissioning.

[19] The total professional services allocation for categories 50-60 is 26.0 percent.

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15 CONTINGENCY

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

15.1 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 unknown unknowns that cannot be anticipated.

15.2 Allocated Contingency

Allocated contingency percentages ranging from 11 percent to 31 percent were applied to account for unknowns, risk, and uncertainties that are specific to each asset category. The range for allocated contingencies mirror the percentages applied to the capital cost estimate in the *2018 Business Plan*. The allocated contingency percentages are presented in Table 13. 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).[20]

Table 13 Allocated Contingency Percentages by Cost Category

FRA Standard Cost Categories for Capital Projects/Programs		Allocated Contingency %
10	Track Structures and Track	
10.01	Track structure: Viaduct (includes culverts and drainage)	20.0
10.02	Track structure: Major/Movable bridge	20.0
10.05	Track structure: Cut and Fill (> 4' height/depth)	25.0
10.06	Track structure: At-grade (grading and subgrade stabilization)	19.0
10.07	Track structure: Tunnel	31.0
10.08	Track structure: Retaining walls and system	20.0
10.09	Track new construction: Conventional ballasted	11.0
10.10	Track new construction: Non-ballasted	11.0
10.14	Track-special track work (switches, turnout, insulated joints)	11.0
20	Stations, Terminals, Intermodal	
20.01	Station buildings: Intercity passenger rail only	21.0
20.02	Station buildings: Joint use (commuter rail, intercity bus)	21.0
20.06	Pedestrian / bike access and accommodation, landscaping, parking lots	21.0

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

FRA Standard Cost Categories for Capital Projects/Programs		Allocated Contingency %
20.07	Automobile, bus, van accessways including roads	21.0
30	Support Facilities, Yards, Shops, and Administration Buildings	
30.02	Light Maintenance Facility	21.0
30.03	Heavy Maintenance Facility	21.0
30.04	Storage or maintenance-of-way building/bases	21.0
30.05	Yard and yard track	20.0
40	Sitework Right-of-Way, Land, and Existing Improvements	
40.05	Site structures including retaining walls, sound walls	21.0
50	Communications and Signaling	
50.01	Wayside signaling equipment	11.0
50.04	Traffic Controls and Dispatching Systems	11.0
50.05	Communications	11.0
50.06	Grade Crossing Protection	11.0
50.07	Hazard Detectors	11.0
60	Electric Traction	
60.02	Traction power supply: Substations	11.0
60.03	Traction power distribution: Catenary and third rail	11.0
60.04	Traction power control	11.0

16 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 those outcomes. Monte Carlo simulations are used in a variety of ways on this 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. This approach cannot provide the granularity of a traditional or bottom-up approach described in the side-bar, the results of which are typically captured and tracked in a risk register documenting the description, assessment and any identified management strategies or mitigations. As recommended in United States Department of Transportation (USDOT) Inspector General guidance and elsewhere, the risk register is eminently useful for systematizing and memorializing the identification, assessment and mitigation of individual risks. For this reason, it is key tool in The Authority's risk management efforts as described in its Risk Management Plan.

The risk register or bottom-up approach does, however, have potentially significant limitations with regards to the accurate quantification of risk exposure. 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, it 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

Monte Carlo simulations rely on repeated random sampling from a range of variable inputs to determine the probability of different cost, schedule, revenue or other outcomes.

In a traditional, 'bottom-up', analysis, point estimates, e.g., how long a planned activity in a schedule is expected to take, are replaced with a range of possible durations so that instead of '45 days' the activity is assessed as taking between 40 and 60 days. The possibility of unplanned activities or unexpected costs (risks) may also be included as inputs. The algorithm takes this information and simulates a possible outcome given the underlying schedule or cost estimate and uncertainty/risk. By doing this thousands of times, the program can determine the probability of an outcome.

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, e.g., that, a revenue projection will be met or costs will be below a certain target.

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 planning 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 an 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.[21]
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:

[21] 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.

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 matches that of Operations and Maintenance.

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 3). 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.

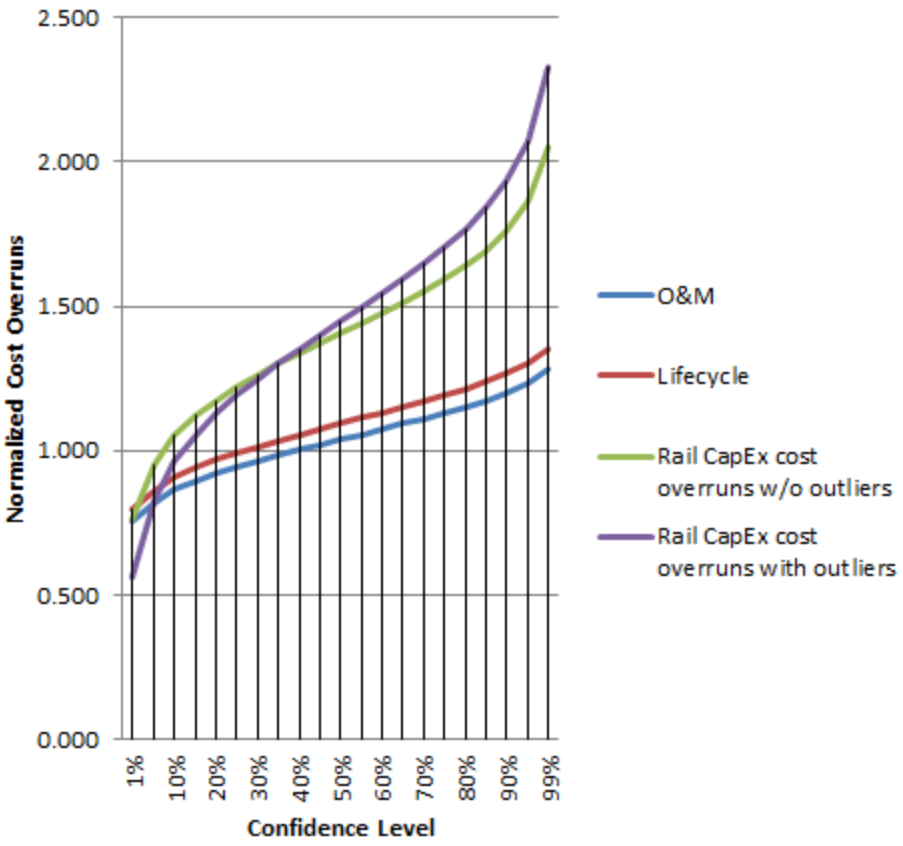

Figure 3 Risk exposure: O&M, Lifecycle and Capital Expenditure Curves

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 84%/+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 in Figure 3 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.

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