CALIFORNIA
High-Speed Rail Authority

50-Year Lifecycle Capital Cost Model Documentation

2014 BUSINESS PLAN

Section 3: *Capital and Lifecycle Costs*

California High-Speed Rail System

2014 BUSINESS PLAN
TECHNICAL SUPPORTING DOCUMENT

50-Year Lifecycle Capital Cost Model Documentation

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Prepared by PARSONS BRINCKERHOFF

for the California High-Speed Rail Authority

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Acronyms

Authority	California High Speed Rail Authority
CTRL	Channel Tunnel Rail Link
O&M	Operations and Maintenance
SCC	Standard Cost Category
UK	United Kingdom
YOE	Year of Expenditure

1 Introduction

1.1 The California High Speed Rail System

The California High-Speed Rail Authority (Authority) is responsible for developing and implementing California's high-speed rail system. The system will consist of over 800 miles of track and up to 24 stations. Electrically-powered trains will travel speeds of up to 220 miles per hour, with a travel time of less than 2 hours and 40 minutes between San Francisco and Los Angeles. Initial service will serve San Francisco to Los Angeles via the Central Valley; service will then be added to Sacramento and San Diego. The system will also be integrated with existing rail systems to enhance rail service and improve efficiency. Funding will be provided by a mix of federal, state, and private sources and the project will be a partnership between the public and private sectors.

1.2 Model Scope

This Technical Memorandum documents 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 2012 dollars
- Year-of-expenditure dollars—Estimates can be inflated to year-of-expenditure dollars, using 2012 dollars as a baseline

The team worked closely with subject matter experts for various system components to compile the technical data and used the *2012 Business Plan* and *Draft Concept of Operations* to establish 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.

3 Forecasting and Costing Methodology

The cost estimates include all the resources and activities necessary to perform the rehabilitation and replacements 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. The *2012 Business Plan* and the *Draft Concept of Operations* were used as references for service level and other system assumptions. Various procurement options and contracting arrangements were not considered in the development of the model but can be appropriately applied to adjust model results.

3.1 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 component 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).

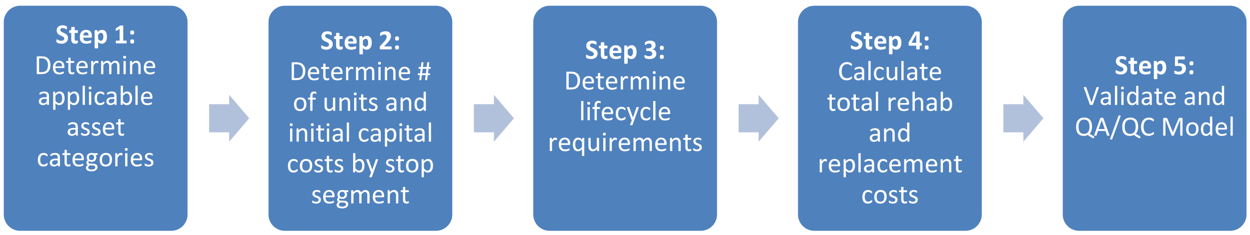
Figure 1. Capital Rehabilitation and Replacement Model Components

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

3.2 Capital Rehabilitation and 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



3.2.1 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 FRA standard cost categories (SCC) that are part of the system's design (and corresponding unit quantities and 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, shop, admin buildings*—includes light maintenance facility, heavy maintenance facility, storage/maintenance of way building, and yard and track
- *40 Sitework, right of way, land, 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 *2012 Business Plan*.

3.2.2 Step 2: Determine # of units and initial capital costs by segment

In step 2, the team identified the unit quantities and initial capital costs (in 2012 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 *2012 Business Plan*. Since initial capital costs for some asset categories vary slightly between various stop segments, a uniform weighted average of all the costs reported for each asset category is used for the capital rehabilitation and replacement model.

Table 1 lists the stop segments of the system and their start dates, as presented in the *2012 Business Plan.*

Table 1. System Route Segments as Proposed in the 2012 Business Plan

Stop Segments	Anticipated Opening Year
San Francisco Transbay Terminal (SFT)–Millbrae	2029
Millbrae–San Jose (SJC)	2029
San Jose (SJC)–Gilroy	2027
Gilroy–Wye	2027
Merced (MCD)–Wye	2022
Wye	2022
Wye–Fresno (FNO)	2022
Fresno (FNO)–Kings/Tulare	2022
Kings/Tulare–Bakersfield (BFD)	2022
Bakersfield (BFD)–Palmdale (PMD)	2022
Palmdale (PMD)–San Fernando Valley (SFV)	2022
San Fernando Valley (SFV)–Los Angeles Union Station (LAU)	2029

3.2.3 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 and to help. The information that was developed for each asset class included:

- Unit of measure
- Design life
- Rehabilitation timing (when rehabilitation occurs during the asset's lifecycle)
- Rehabilitation cost (either reported as a hard unit cost or a percentage of the initial capital cost)
- Rehabilitation spread (number of years over which rehabilitation costs are spread)
- Replacement cycle
- Replacement spread (number of years over which replacement costs are spread)

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

3.2.4 Step 4: Calculate total rehabilitation and replacement costs

In step 4, the initial capital costs of each asset category for each stop segment were calculated by multiplying the initial capital cost by the number of units and a unit conversion factor. A unit conversion factor was created where it was necessary to create cost categories consistent with the rehabilitation and replacement assumptions (for example, a double-track section unit cost would be divided by two to create a unit-cost per track-mile if the rehabilitation and replacement cost categories relied on track miles). The initial capital cost 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. The two 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 2012 dollars or in nominal 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.

3.2.5 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. A thorough QA/QC process was conducted on the model to assure calculations were being made correctly and model inputs/assumptions were logically consistent.

3.3 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 geographical 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.

4 Literature Review

4.1 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 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 (LCAT)* 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

4.2 Track Cost

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 2014 lifecycle model does not breakout costs into these categories so it is hard to compare “apples to apples.”

4.3 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 2.

Table 2. Lifecycle Requirements Comparison

Asset	UIC Lifecycle (years)	EIB Lifecycle (years)	2014 Model (years)
Track Structure (e.g., tunnels, viaducts, etc.)	—	80-100	100[1]
Concrete Ties	40	40	50[1]
Slab Track	60	—	>50
Fastenings	40	—	40
Ballast	35	20	50[1,2]
Overhead Contact System Piles and Portals	40	—	50[3]
Signaling Systems	15	—	30[4]
Vehicles	—	15-25	25
Access Facilities: Structural Elements	—	10-50	40-45

[1] 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.

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

[3] The overhead contact system is assumed to have at least one rehabilitation cycle at approximately 30 years, or when the wire cross section reaches 25 percent wear. This will prolong the lifecycle of the system and therefore the entire system does not need to be replaced until after 50 years.

[4] Rehabilitation for signaling systems is assumed to occur every 10 years (throughout the 50 year lifecycle) and includes UPS battery replacement and COTS 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.

5 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.[5]
2. In some cases, new second level categories were defined to enable a rational lifecycle analysis of pertaining costs when the lifecycle variables were derived at levels that were different from the SCC 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 will have a number of units associated with a geographical segment (defined from one stop to the next) of the CA HSR 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. CA HSR asset classes, quantities, and initial capital costs were pulled directly from the CA HSR capital cost model for the *2012 Business Plan*. Since initial capital costs in the CA HSR capital cost model are priced at the third level, the second level asset class unit costs are calculated as a sum of all costs from the third level.
6. When unit costs vary by stop segment, a weighted average of the costs is used to represent the initial capital cost.
7. The base year for model cost estimates is 2012; meaning real costs are reported in 2012 dollars.
8. Model outputs are designed to reflect both real (year 2012) 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.
9. Capital costs are assumed to include all labor, materials, and contractor costs associated with the asset's construction and subsequent rehabilitation or replacement.
10. Assets are procured as close as possible to specifications.
11. 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 replacement model assumes that preventive maintenance will occur on schedule so the effects of deferred maintenance are not considered.

[5] The first level of SCC categories is, for example, *10: Track structures and track*. The second level is, for example, *10.01: Track structures: Viaduct*. The third level is, 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 are considered as part of the third level.

12. 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.
13. 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 18.b below).
14. 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).
15. Replacement costs are reported as a percentage of initial capital cost (plus inflation, where applicable) to reflect only the portions of the asset that will be replaced throughout the 50-year timeframe, unless otherwise noted.
16. Rehabilitation and replacement costs are either reported as a per-unit dollar amount, or as a percentage of the initial capital cost.
17. Model inputs are based on industry standards and experience of existing systems when applicable; sources were documented accordingly.
18. 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 either a dollar amount, or 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.
19. 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.
20. Unit quantities by stop segment for each asset category were taken from the capital cost model prepared for the *2012 Business Plan*.
21. The Evaluation Period refers to the 50-year timeframe, spanning from 2022-2071.
22. For many asset classes, the unit for rehabilitation and replacement cost estimates is track miles. A factor has been built into the model for unit conversion (e.g., route miles to track miles). If no factor is needed, the default value of 1.0 is used.
23. An unallocated contingency of 5 percent has been applied to each second level asset category. The total unallocated contingency for all second level asset categories is included as a separate first level cost category ("90 Unallocated Contingency").

24. Allocated contingency (15 to 25 percent based on the capital cost model) has also been applied to each second level asset category, and is included in each second level category's cost estimate.

25. An allowance for professional services of 10 percent of total costs has been applied to *10 Track and Track Structures, 20 Stations, Terminals, Intermodal, 30 Support Facilities, Yards, Shops, Admin Building*, and *40 Sitework, Right of Way, Land, Existing Improvements* and 20 percent of total costs has been applied to *50 Communications and Signaling* and *60 Electric Traction*.[6] Professional services is 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 13, Professional Services, of this memo.

26. Four additional segments have been included in the model as placeholders in the event new stop segments are added (or existing stop segments are split in half).

27. The results were escalated from 2012 $ (as presented here) to 2013 $ (as presented in the 2014 Business Plan) using the Engineering News Record Construction Cost Index from the average of the 3rd quarter of 2012 to the 3rd quarter of 2013. This amounted to an escalation rate of 0.19 percent.

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

[6] No costs were included for *40 Sitework, right of way, land, 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.

6 Track Structures and Track

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

- *10.01 Track structure: Viaduct*
- *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*

6.1 Assumptions and Model Inputs

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

- 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., *10.09A Ditching and drainage*)
- Asset categories *10.01 Track structure: Viaduct, 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* and *10.02 Track structure: Major/Movable bridge*

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 year 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 20% of the replacement cost, or $80,000
    - Replacement will occur every 50 years and is spread over 10 years
    - Replacement will cost $400,000 per track mile
    - 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 and is spread over 10 years
    - Replacement will cost $260,000 per track mile
    - Concrete ties are imputed to have a 50-year life expectancy. The extremely light vehicle weights should also lengthen the span of wood ties owing to less stress.
  - *10.09 D Rail (replacement only)*
    - No rehabilitation is anticipated during the 50-year timeframe
    - Lifecycle is 50 years, spread over 10 years
    - The cost to replace each track mile is equal to $500,000
- The Authority will not be responsible for the rehabilitation and replacement of ballasted freight track and ballasted track relocation (cost categories *10.09.810—10.09.924*); the costs for these asset classes are not included in this analysis/report
- Estimates are based on HSR experience in France, Germany, and conventional American 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 40 years, spread over 30 years
        - Replacement will cost $500,000 per track mile
    - *10.10 C Rail (replacement only)*
        - No rehabilitation is anticipated during 50-year timeframe
        - Lifecycle is 50 years, spread over 10 years
        - The cost to replace each track mile is equal to $500,000
- Estimates are based on HSR experience in France, Germany, and Taiwan, and conventional American railroad operations

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

- *10.14 A Turnouts*
    - Rehabilitation will occur every 25 years, spread over 10 years
    - Rehabilitation will cost 30% of the initial capital cost
    - Replacement will occur every 50 years, spread over 20 years
    - Replacement will cost 100 percent of the initial capital cost for turnouts per stop segment
- *10.14 B Crossovers*
    - Rehabilitation will occur every 50 years, spread over 10 years
    - Rehabilitation will cost 30% of the initial capital cost
    - 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 10.014 A and 10.14 B
- Estimates are based on HSR experience in France, Germany, and Taiwan, and conventional American railroad operations

Model inputs are presented in Table 3.

Table 3. Track and Track Structure Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement 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	track mile	>50	at full life	see below	see below	see below	see below
A	Ditching and drainage	track mile	—	—	—	—	—	—
B	Ballast	track mile	50	Year 16 and Year 33	$80,000	First cycle between years 16-21, second cycle between 33-38	10	$400,000
C	Ties	track mile	50	—	—	—	10	$260,000
D	Rail	track mile	50	—	—	—	10	$500,000
10.10	Track new construction: Non-ballasted	track mile	>50	at full life	see below	see below	see below	see below
A	Ditching and drainage	track mile	—	—	—	—	—	—
B	Track fasteners	track mile	40	—	—	—	30	$500,000
C	Rail	track mile	50	—	—	—	10	$500,000

Table 3. Track and Track Structure Inputs (continued)

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
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	each	50	25	30% of initial capital cost	10	20	100 % of initial capital cost
B	Crossovers	each	100	50	30% of initial capital cost	10	—	100 % of initial capital cost
C	Switch heaters	each	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

6.2 Unit Quantities

The following unit conversion assignments were applied:

- *10.09.110-10.09.162*
  - The unit conversion factors were set based on the number of tracks per route segment; for example, *10.09.120 Ballasted Track—2 track* represents a route segment with 2 tracks and the unit conversion factor to convert route miles to track miles is set to 2
  - The unit quantities in route miles were converted to track miles by multiplying the unit conversion factor with the unit quantity
- *10.10.110-10.10.240*
  - The unit conversion factors were set based on number of tracks per route segment; for example, *10.10.120 Slab track tunnel/viaduct—2 track* represents a route segment with 2 tracks and the unit conversion factor to convert route miles to track miles is set to 2
  - The unit quantities in route miles were converted to track miles by multiplying the unit conversion factor with the unit quantity

The following unit quantity calculations were applied:

- *10.09 A Ditching and drainage—10.09 D Rail*
  - Since ditching and drainage, ballast, tie, and rail replacement applies to each track mile of ballasted track, the unit quantity is equal to the sum of the following quantities under *10.09: 10.09.110, 10.09.112, 10.09.120, 10.09.122, 10.09.132, 10.09.142, 10.09.152, 10.09.162*
- *10.10 A Ditching and drainage—10.09 C Rail*
  - Since ditching and drainage, track fasteners, and rail replacement applies to each track mile of non-ballasted track, the unit quantity is equal to the sum of all quantities under *10.10*
- *10.14 A Turnouts*
  - The unit quantities for the number of turnouts were calculated by adding up the applicable FRA third-level categories for turnouts under *10.14*; these FRA third-level categories are *10.14.100, 10.14.105, 10.14.110, 10.14.115, 10.14.199, 10.14.200, 10.12.205, 10.12.210,* and *10.14.215, NC 004, NC015, NC024*
- *10.14 B Crossovers*
  - The unit quantities for the number of turnouts were calculated by adding up the applicable FRA third-level categories for crossovers under *10.14*; these FRA third-level categories are *10.14.130, 10.14.135,10.14.140, 10.14.145, 10.14.146, 10.14.300, 10.14.305, 10.14.310, and 10.14.315, NC009, NC010*
- 10.14 C Switch heaters
  - The FRA third-level categories under 10.14 do not include switch heaters; however, the rehabilitation and replacement costs for switch heaters have been included in 10.14 A and 10.14 B

7 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 architecture (finishes, glazing, roofing, etc.)*
  - *20.01 C Station mechanical ductwork and piping (plumbing, fire protection)*
  - *20.01 D Station mechanical HVAC*
  - *20.01 E Station electrical, lighting*
  - *20.01 F Station site elements*
  - *20.01 G Escalators—Trusses*
  - *20.01 H Escalators—Moving Parts*
  - *20.01 I Escalators—Elevators*
- *20.02 Station buildings: Joint use (commuter rail, intercity bus)*
  - *20.02 A Station structure*
  - *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*
  - *20.02 E Station electrical, lighting*
  - *20.02 F Station site elements*
  - *20.02 G Escalators—Trusses*
  - *20.02 H Escalators—Moving Parts*
  - *20.02 I Escalators—Elevators*
- *20.06 Pedestrian / bike access and accommodation, landscaping parking lots*
- *20.07 Automobile, bus, van accessways including roads*

7.1 Assumptions and Model Inputs

The following assumptions were made to *20 Stations, Terminals, 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* (27 percent of initial capital cost of 20.01)
  - *B Station architecture* (finishes, glazing, roofing, etc.; 22 percent of initial capital cost of 20.01)
  - *C-D Station mechanical, plumbing, fire protection* (9 percent of initial capital cost of 20.01)
  - *E Station electrical, lighting* (9 percent of initial capital cost of 20.01)
  - *F Station site elements* (30 percent of initial capital cost of 20.01)
  - *G-I Escalators* (3 percent of initial capital cost of 20.01)
- Station modernization programs for *20.01 Station buildings: Intercity passenger rail only* should be a continuous rotation after 20 years of operations

- Lifecycle estimates are based on TM 1.1.2, references from BART, Caltrain, Metrolink, the French HSR system, CTRL (UK), and additional sources listed below

20.01 A Station structure

- The lifecycle of the structure is 100 years; the station structure will only be replaced and not rehabilitated
- Replacement will be spread over 30 years, during years 100-129 (0.9 percent each year)
- Replacement of station structure is estimated to cost 27 percent of the initial capital cost of 20.01
- Lifecycle estimates are based on TM 1.1.2

20.01 B Station architecture (finishes, glazing, roofing, etc.)

- Rehabilitation of station architecture will occur every 20 years
- Rehabilitation will cost 6.6 percent of the initial capital cost (30 percent of replacement, which is 22 percent of the initial capital cost of 20.01), spread over 10 years, during years 20-29 (0.66 percent each year)
- Rehabilitation will include finish materials, minor reconfiguration of spaces, glazing, etc.
- Replacement will occur every 40 years
- Replacement of station architecture is estimated to cost 22 percent of the initial capital cost of 20.01, spread over 10 years, during years 40-49 (2.2 percent each year)
- Lifecycle estimates are based on BART

20.01 C Station mechanical ductwork and piping (plumbing, fire protection)

- Rehabilitation of mechanical ductwork and piping will include equipment and fixtures
- No rehabilitation is anticipated during the 50-year timeframe
- The initial capital cost of station mechanical work (including ductwork and piping and HVAC) is estimated to be 9 percent of the initial capital cost of 20.01
- Replacement of ductwork and piping will occur every 40 years
- Replacement of ductwork and piping is estimated to cost 20 percent of the station mechanical cost, which is 9 percent of the initial capital cost of 20.01, spread over 10 years, during years 40-49 (0.18 percent each year)
- Lifecycle estimates are based on relevant experience with applicable transit stations

20.01 D Station mechanical HVAC (plumbing, fire protection)

- Rehabilitation of HVAC will occur every 20 years
- Rehabilitation will cost 7.2 percent of the initial capital cost (which is 80 percent of the station mechanical cost, which is 9 percent of the initial capital cost of 20.01), spread over 10 years during years 20-29 (0.72 percent each year)
- The initial capital cost of station mechanical work (including ductwork and piping and HVAC) is estimated to be 9 percent of the initial capital cost of 20.01
- Lifecycle estimates are based on relevant experience with applicable transit stations

20.01 E Station electrical, lighting

- Rehabilitation will occur every 15 years
- Rehabilitation will cost 50 percent of the replacement cost, which is 9 percent of the initial capital cost of 20.01, spread over 10 years during years 15-24 (0.45 percent each year)
- Rehabilitation will including lighting, connection boxes, etc. but not wiring or transformers, etc.
- Replacement will occur every 30 years
- Replacement of station lighting is estimated to cost 9 percent of the initial capital cost of 20.01, spread over 10 years, during years 30-39 (0.9 percent each year)
- Lifecycle estimates are based on BART experience with relevant station examples

20.01 F Station site elements

- Rehabilitation will occur every 15 years
- Rehabilitation will cost 30 percent of the replacement cost, which is 30 percent of the initial capital cost of 20.01, spread over 10 years during years 20-29 (0.09 percent each year)
- Replacement will occur every 50 years
- Replacement of station site elements is estimated to cost 30 percent of the initial capital cost of 20.01, spread over 15 years during years 50-64 (2 percent each year)
- Lifecycle estimates are based on BART

20.01 G Escalators—Trusses

- Trusses will not be rehabilitated during the 50-year timeframe
- Replacement will occur every 50 years
- Trusses account for 30 percent of the cost of escalators, which is 70 percent of the total cost of elevators and escalators, which is 3 percent of the initial capital cost of 20.01

- The cost to replace trusses will be spread over 10 years during years 40-49 (0.147 percent each year)
- Lifecycle estimates are based on Kone Elevator Co. and Schindler Elevator Co.

20.01 H Escalators—Moving parts

- *20.04 Elevators/escalators* was redefined as *20.01 H Escalators—Moving parts* and *20.01 I Elevators* to enable a rational lifecycle analysis of pertaining costs
- Rehabilitation occurs every 20 years
- Rehabilitation will cost 50 percent of the replacement cost (which is 70 percent of the cost of escalators, which is 70 percent of the total cost of elevators and escalators, which is 3 percent of the initial capital cost of 20.01), spread over 10 years during years 20-29 (0.0735 percent each year)
- Rehabilitation includes all moving equipment including treads, rails, finishes, controls, excludes structural components such as shaftways, trusses, etc.
- Replacement will occur every 40 years
- Moving parts account for 70 percent of the cost of escalators, which is 70 percent of the total cost of elevators and escalators, which is 3 percent of the initial capital cost of 20.01
- The cost to replace moving parts will be spread over 10 years during years 40-49 (0.147 percent each year)
- Lifecycle estimates are based on Kone Elevator Co. and Schindler Elevator Co.

20.01 I Elevators

- *20.04 Elevators/escalators* was redefined as *20.01 H Escalators—Moving parts* and *20.01 I Elevators* to enable a rational lifecycle analysis of pertaining costs
- Rehabilitation occurs every 20 years
- Rehabilitation will cost 50 percent of the replacement cost (which is 30 percent of the total cost of elevators and escalators, which is 3 percent of the initial capital cost of 20.01), spread over 10 years during years 20-29 (0.045 percent each year)
- Rehabilitation includes all moving equipment including treads, rails, finishes, controls, excludes structural components such as shaftways, trusses, etc.
- Replacement will occur every 40 years
- Elevators account for 30 percent of the total cost of elevators and escalators, which is 3 percent of the initial capital cost of 20.01
- The cost to replace elevators will be spread over 10 years during years 40-49 (0.09 percent each year)
- Lifecycle estimates are based on Kone Elevator Co. and Schindler Elevator Co.

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* (27 percent of initial capital cost of 20.02)
  - *B Station architecture* (finishes, glazing, roofing, etc.; 22 percent of initial capital cost of 20.02)
  - *C-D Station mechanical, plumbing, fire protection* (9 percent of initial capital cost of 20.02)
  - *E Station electrical, lighting* (9 percent of initial capital cost of 20.02)
  - *F Station site elements* (30 percent of initial capital cost of 20.02)
  - *G-I Escalators* (3 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 TM 1.1.2, references from BART, Caltrain, Metrolink, the French HSR system, CTRL (UK), and additional sources listed below

20.02 A Station structure

- The lifecycle of the structure is 100 years; the station structure will only be replaced and not rehabilitated
- Replacement will be spread over 30 years, during years 100-129 (0.9 percent each year)
- Replacement of station structure is estimated to cost 27 percent of the initial capital cost of 20.02
- Lifecycle estimates are based on TM 1.1.2

20.02 B Station architecture (finishes, glazing, roofing, etc.)

- Rehabilitation of station architecture will occur every 20 years
- Rehabilitation will cost 6.6 percent of the initial capital cost (30 percent of replacement, which is 22 percent of the initial capital cost of 20.02), spread over 10 years, during years 20-29 (0.66 percent each year)
- Rehabilitation will include finish materials, minor reconfiguration of spaces, glazing, etc.
- Replacement will occur every 40 years
- Replacement of station architecture is estimated to cost 22 percent of the initial capital cost of 20.02, spread over 10 years , during years 40-49 (2.2 percent each year)
- Lifecycle estimates are based on BART

20.02 C Station mechanical ductwork and piping (plumbing, fire protection)

- Rehabilitation of mechanical ductwork and piping will include equipment and fixtures
- No rehabilitation is anticipated during the 50-year timeframe

- The initial capital cost of station mechanical work (including ductwork and piping and HVAC) is estimated to be 9 percent of the initial capital cost of 20.02
- Replacement of ductwork and piping will occur every 40 years
- Replacement of ductwork and piping is estimated to cost 20 percent of the station mechanical cost, which is 9 percent of the initial capital cost of 20.02, spread over 10 years, during years 40-49 (0.18 percent each year)
- Lifecycle estimates are based on relevant experience with applicable transit stations

20.02 D Station mechanical HVAC (plumbing, fire protection)

- Rehabilitation of HVAC will occur every 20 years
- Rehabilitation will cost 7.2 percent of the initial capital cost (which is 80 percent of the station mechanical cost, which is 9 percent of the initial capital cost of 20.02), spread over 10 years during years 20-29 (0.72 percent each year)
- The initial capital cost of station mechanical work (including ductwork and piping and HVAC) is estimated to be 9 percent of the initial capital cost of 20.02
- Lifecycle estimates are based on relevant experience with applicable transit stations

20.02 E Station electrical, lighting

- Rehabilitation will occur every 15 years
- Rehabilitation will cost 50 percent of the replacement cost, which is 9 percent of the initial capital cost of 20.02, spread over 10 years during years 15-24 (0.45 percent each year)
- Rehabilitation will including lighting, connection boxes, etc. but not wiring or transformers, etc.
- Replacement will occur every 30 years
- Replacement of station lighting is estimated to cost 9 percent of the initial capital cost of 20.02, spread over 10 years, during years 30-39 (0.9 percent each year)
- Lifecycle estimates are based on BART

20.02 F Station site elements

- Rehabilitation will occur every 15 years
- Rehabilitation will cost 30 percent of the replacement cost, which is 30 percent of the initial capital cost of 20.02, spread over 10 years during years 20-29 (0.09 percent each year)
- Replacement will occur every 50 years
- Replacement of station site elements is estimated to cost 30 percent of the initial capital cost of 20.02, spread over 15 years during years 50-64 (2 percent each year)
- Lifecycle estimates are based on BART

20.02 G Escalators—Trusses

- Trusses will not be rehabilitated during the 50-year timeframe
- Replacement will occur every 50 years
- Trusses account for 30 percent of the cost of escalators, which is 70 percent of the total cost of elevators and escalators, which is 3 percent of the initial capital cost of 20.02
- The cost to replace trusses will be spread over 10 years during years 40-49 (0.147 percent each year)
- Lifecycle estimates are based on Kone Elevator Co. and Schindler Elevator Co.

20.02 H Escalators—Moving parts

- *20.04 Elevators/escalators* was redefined as *20.02 H Escalators—Moving parts* and *20.02 I Elevators* to enable a rational lifecycle analysis of pertaining costs
- Rehabilitation occurs every 20 years
- Rehabilitation will cost 50 percent of the replacement cost (which is 70 percent of the cost of escalators, which is 70 percent of the total cost of elevators and escalators, which is 3 percent of the initial capital cost of 20.02), spread over 10 years during years 20-29 (0.0735 percent each year)
- Rehabilitation includes all moving equipment including treads, rails, finishes, controls, excludes structural components such as shaftways, trusses, etc.
- Replacement will occur every 40 years
- Moving parts account for 70 percent of the cost of escalators, which is 70 percent of the total cost of elevators and escalators, which is 3 percent of the initial capital cost of 20.02
- The cost to replace moving parts will be spread over 10 years during years 40-49 (0.147 percent each year)
- Lifecycle estimates are based on Kone Elevator Co. and Schindler Elevator Co.

20.02 I Elevators

- *20.04 Elevators/escalators* was redefined as *20.02 H Escalators—Moving parts* and *20.02 I Elevators* to enable a rational lifecycle analysis of pertaining costs
- Rehabilitation occurs every 20 years
- Rehabilitation will cost 50 percent of the replacement cost (which is 30 percent of the total cost of elevators and escalators, which is 3 percent of the initial capital cost of 20.02), spread over 10 years during years 20-29 (0.045 percent each year)
- Rehabilitation includes all moving equipment including treads, rails, finishes, controls, excludes structural components such as shaftways, trusses, etc.
- Replacement will occur every 40 years

- Elevators account for 30 percent of the total cost of elevators and escalators, which is 3 percent of the initial capital cost of 20.02
- The cost to replace elevators will be spread over 10 years during years 40-49 (0.09 percent each year)
- Lifecycle estimates are based on Kone Elevator Co. and Schindler Elevator Co.

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

- Assuming average use of the asset, rehabilitation will occur every 10 years, and will cost 50 percent of the initial capital cost, spread over 2 years
- Replacement will occur every 50 years, over 2 years
- Lifecycle estimates are based on CHSTP TM 1.1.2 and Caltrain and Caltrans

20.07 Automobile, bus, van accessways including roads

- Assuming average use of the asset, rehabilitation will occur every 10 years, and will cost 50 percent of the initial capital cost, spread over 2 years
- Replacement will occur every 50 years, over 2 years
- Lifecycle estimates are based on CHSTP TM 1.1.2 and Caltrain and Caltrans

Model inputs are presented in Table 4.

Table 4. Stations, Terminals, Intermodal Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement 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	—	—	—	30; during years 100-129	27% of initial capital cost of 20.01
B	Station architecture (finishes, glazing, roofing, etc.)	lump sum	40	20	6.6% of initial capital cost of 20.01	10; years 20-29	10; years 40-49	22% of initial capital cost of 20.01
C	Station mechanical, ductwork and piping (plumbing, fire protection)	lump sum	40	—	—	—	10; years 40-49	1.8% of initial capital cost of 20.01
D	Station mechanical, HVAC	lump sum	—	20	7.2% of initial capital cost of 20.01	10; years 20-29	—	—
E	Station electrical, lighting	lump sum	30	15	4.5% of initial capital cost of 20.01	10; years 15-24	10; years 30-39	9% of initial capital cost of 20.01
F	Station site elements	lump sum	50	20	9% of initial capital cost of 20.01	10; years 20-29	15; years 50-64	30% of initial capital cost of 20.01
G	Escalators—Trusses	lump sum	40	—	—	—	10; years 40-49	0.63% of initial capital cost of 20.01
H	Escalators—Moving Parts	lump sum	40	20	0.735% of initial capital cost of 20.01	10; years 20-29	10; years 40-49	1.47% of initial capital cost of 20.01
I	Elevators	lump sum	40	20	0.45% of initial capital cost of 20.01	10; years 20-29	10; years 40-49	0.9% of initial capital cost of 20.01

Table 4. Stations, Terminals, Intermodal Inputs (continued)

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
20.02	Station buildings: Joint use	lump sum	see below	see below	see below	see below	see below	see below
A	Station structure	lump sum	100	—	—	—	30; during years 100-129	27% of initial capital cost of 20.02
B	Station architecture (finishes, glazing, roofing, etc.)	lump sum	40	20	6.6% of initial capital cost of 20.01	10; years 10-29	10; years 40-49	22% of initial capital cost of 20.02
C	Station mechanical, ductwork and piping (plumbing, fire protection)	lump sum	40	—	—	—	10; years 40-49	1.8% of initial capital cost of 20.02
D	Station mechanical, HVAC	lump sum	—	20	7.2% of initial capital cost of 20.01	10; years 20-29	—	—
E	Station electrical, lighting		30	15	4.5% of initial capital cost of 20.01	10; years 15-24	10; years 30-39	9% of initial capital cost of 20.02
F	Station site elements	lump sum	50	20	9% of initial capital cost of 20.01	10; years 20-29	15; years 50-64	30% of initial capital cost of 20.02
G	Escalators—Trusses	lump sum	40	—	—	—	10; years 40-49	0.63% of initial capital cost of 20.02
H	Escalators—Moving Parts	lump sum	40	20	0.735% of initial capital cost of 20.01	10; years 20-29	10; years 40-49	1.47% of initial capital cost of 20.02
I	Elevators	lump sum	40	20	0.45% of initial capital cost of 20.01	10; years 20-29	10; years 40-49	0.9% of initial capital cost of 20.02

Table 4. Stations, Terminals, Intermodal Inputs (continued)

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
20.06	Pedestrian/bike access and accommodation, landscaping, parking lots	lump sum	50	10	50% of initial capital cost	2	2	100% of initial capital cost
20.07	Automobile, bus, van accessways including roads	lump sum (cy)	50	10 (average use)	50% of initial capital cost	2	2	100% of initial capital cost

7.2 Unit Quantities

The following unit quantity calculations were applied:

- *20.01 A Station Structure -20.01 I Elevators*
  - Unit quantities were calculated by adding the quantities for all applicable FRA third-level categories for *20.01*, excluding FRA third-level categories for Site Elements
- *20.02 A Station Structure -20.02 I Elevators*
  - Unit quantities were calculated by adding the quantities for all applicable FRA third-level categories for *20.02*, excluding FRA third-level categories for Site Elements

8 Support Facilities, Yards, Shops, Administration Buildings

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

- *30.02 Light maintenance facility*
  - *30.02 A Roof*
  - *30.02 B Exterior*
  - *30.02 C Track*
  - *30.02 D Inspection pits/drainage*
  - *30.02 E OCS catenary*
  - *30.02 F Drop table*
  - *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 Roof*
  - *30.03 B Exterior*
  - *30.03 C Track*
  - *30.03 D Inspection pits/drainage*
  - *30.03 E OCS 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 Roof*
  - *30.04 B Exterior*
  - *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*

8.1 Assumptions and Model Inputs

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

- Facilities in *30 Support Facilities, Yards, Shops, 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
- Inputs for the model are outlined in Table 5

30.02 Light maintenance facility—30.03 Heavy maintenance facility

- 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 Roof*)
- 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[7]
- No replacement will occur during the 50-year timeframe for any of these new second level categories
- Lifecycle estimates are based on 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)

[7] 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.

- Wheel presses/machinery—SAFOP Machinery (Italy)
- Simmons Machine Tool Corp. (USA)

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*
  - Includes *30.05.200—Ballasted turnout no. 15 and 30.05.210—Ballasted diamond crossover no. 15*
  - No rehabilitation is anticipated during 50-year timeframe
  - Replacement will occur every 20 years, spread over 5 years
  - Replacement will cost 100 percent of the initial capital cost per stop segment
- Estimates are based on HSR experience in France, Germany, and Taiwan, and conventional American railroad operations

Model inputs are presented in Table 5.

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

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
30.02	Light maintenance facility	each	—	see below	see below	see below	—	—
A	Roof	—	—	20	$1,200,000	4	—	—
B	Exterior	—	—	30	$1,300,000	4	—	—
C	Track	—	—	20	$3,000,000	4	—	—
D	Inspection pits/ drainage	—	—	20	$6,000,000	4	—	—
E	OCS catenary	—	—	30	$6,000,000	4	—	—
F	Drop table	—	—	30	$5,200,000	4	—	—
G	Overhead cranes	—	—	30	$2,600,000	4	—	—
H	Toilet evac. system	—	—	20	$12,000,000	4	—	—
I	Auto wheel inspection system	—	—	20	$3,500,000	4	—	—
J	Auto trainset car wash	—	—	30	$16,000,000	4	—	—
K	Water recycling plant	—	—	30	$24,000,000	4	—	—
L	Pantograph repair platform	—	—	20	$4,200,000	4	—	—
M	Undercar vehicle inspection system	—	—	20	$7,000,000	4	—	—
30.03	Heavy maintenance facility	each	—	see below	see below	see below	—	—
A	Roof	—	—	20	$1,400,000	4	—	—
B	Exterior	—	—	30	$1,600,000	4	—	—
C	Track	—	—	20	$14,000,000	4	—	—
D	Inspection pits/ drainage	—	—	20	$14,000,000	4	—	—

Table 5. Support Facilities, Yards, Shops, Administration Buildings Inputs (continued)

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
E	OCS catenary	—	—	30	$24,000,000	4	—	—
F	Drop tables	—	—	30	$6,400,000	4	—	—
G	Wheel lathe	—	—	30	$8,000,000	4	—	—
H	Overhead cranes	—	—	30	$3,200,000	4	—	—
I	Toilet evac. systems	—	—	20	$14,000,000	4	—	—
J	Auto wheel inspection system	—	—	20	$3,500,000	4	—	—
K	Auto trainset car wash	—	—	30	$16,000,000	4	—	—
L	Pantograph repair platform	—	—	20	$4,200,000	4	—	—
M	Water recycling plant	—	—	30	$24,000,000	4	—	—
N	Undercar vehicle inspection system	—	—	20	$7,000,000	4	—	—
O	Paint shop complete	—	—	20	$14,000,000	4	—	—
P	Trainset lifting system	—	—	30	$24,000,000	4	—	—
Q	Bogie turntable system	—	—	20	$7,000,000	4	—	—
R	Bogie wash system	—	—	20	$4,200,000	4	—	—
S	Shop cranes	—	—	20	$4,200,000	4	—	—
T	Wheel press	—	—	20	$11,200,000	4	—	—

Table 5. Support Facilities, Yards, Shops, Administration Buildings Inputs (continued)

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
30.04	Storage or maintenance-or-way building/bases	each	—	see below	see below	see below	—	—
A	Roof	—	—	20	$700,000	4	—	—
B	Exterior	—	—	30	$700,000	4	—	—
C	Track	—	—	20	$350,000	4	—	—
D	Inspection pits/ drainage	—	—	20	$2,800,000	4	—	—
E	Overhead cranes	—	—	30	$3,200,000 ea	4	—	—
30.05	Yard track	see below	see below	—	—	—	see below	—
A	Track rehab, ballast, and surface	track mile	> 50 years	—	—	—	—	—
B	Yard turnouts/ crossovers	per turnout	20	—	—	—	5	100% of initial capital cost

8.2 Unit Quantities

The following unit quantity assumptions apply to *30.02 Light maintenance facility, 30.03 Heavy maintenance facility,* and *30.04 Maintenance of way facility:*

- Unit quantities for *30.02 A Roof—30.02 M Undercar vehicle inspection system* were calculated by adding the quantities for all FRA third level categories for *30.02 Light maintenance facility*
- Unit quantities for *30.03 A Roof—30.03 T Wheel press* were calculated by adding the quantities for all FRA third level categories for *30.03 Heavy maintenance facility*
- Unit quantities for *30.04 A Roof—30.04 E Overhead cranes* were calculated by adding the quantities for all FRA third level categories for *30.04 Maintenance of way facility*

The following unit quantity calculations apply to *30.05 Yard track*

- The unit conversion factor for *30.05.210 Ballasted diamond crossover, no. 15* was set to two to reflect the fact that a diamond crossover consists of two turnouts. This was done to capture the costs under *30.05 B Yard turnouts/crossovers*, the unit for which is turnouts.
- The unit quantities for *30.05 A Track rehab, ballast, and surface* were calculated by adding up the quantities for the applicable FRA third level categories under *30.05*. This FRA third level category is *30.05.110 Ballasted track—Yard track*
- The unit quantities for *30.05 B Yard turnouts/crossovers* were calculated by adding up the quantities for the applicable FRA third level categories under *30.05* (*30.05.200 Ballasted turnout no. 15, 30.05.210 Ballasted diamond crossover, no. 15)*

9 Sitework, Right of Way, Land, Existing Improvements

Category *40 Sitework, right of way, land, existing improvements* includes the following asset class:

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

9.1 Assumptions and Model Inputs

The following assumptions were made to *40 Stations Sitework, Right of Way, Land, 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, existing improvements*; assets in *40.05 Site structures including retaining walls, sound walls* are designed for 100 years, as referenced in 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 Communications and Signaling

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

- *50.01 Wayside signaling equipment*
- *50.05 Communication*
  - *50.05 A: Shelters, cabinets, towers, ductbanks, 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: CCTV, FAS, EACS, IDS, PA/CIS, etc.*

10.1 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 UPS battery replacement and COTS hardware replacement for every 10 years; the cost of these items on average is approximately 20 percent of the total capital cost (15 percent for COTS hardware and 5 percent for switch machines)
- Rehabilitation will occur every 10 years and is spread over 3 years
- Replacement will occur every 30 years, spread over 5 years
- Replacement will cost 80 percent of initial capital cost
- 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 and IT standard practice

50.05 Communications

- The following sub-classes were defined to enable a rational lifecycle analysis of pertaining costs:
  - *50.05 A: Shelters, cabinets, towers, ductbanks, manholes, fiber optic, HVAC, radiax* (40 percent of 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 initial capital cost of 50.05)
  - *50.05 D: Application systems: CCTV, FAS, EACS, IDS, PA/CIS, etc.* (15 percent of initial capital cost of 50.05)
- 10 percent of the initial capital cost has been withheld to account for items that would never be replaced

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

- Rehabilitation occurs every 10 years and is spread over 10 years
  - The first cycle occurs during years 10-19, the second cycle occurs during years 20-29
- Rehabilitation costs 2 percent of the replacement cycle
  - Rehabilitation will cost 0.08 percent each year rehabilitation takes place for both cycles
- Replacement occurs every 25 years, spread over 15 years
  - Replacement will occur during years 25-39
- Replacement will cost 40 percent of the initial capital cost for each cycle
  - Replacement will cost 2.67 percent each year replacement takes places for the one cycle that occurs during the 50-year timeframe

50.05 B: Wide area networking, networked storage, etc.

- 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 each cycle
  - Replacement will cost 7.5 percent each year replacement takes place for the one cycle that occurs during the 50-year timeframe

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

- Rehabilitation will occur every 10 years and is spread over 10 years during the first cycle and 5 years during the second cycle
  - The first cycle occurs during years 10-19, the second cycle occurs during years 20-24
- Rehabilitation costs 2 percent of the replacement cycle
  - Rehabilitation will cost 0.04 percent each year rehabilitation takes place for the first cycle and 0.08 percent each year for the second cycle
- Replacement occurs every 25 years, spread over 2 years
  - Replacement will occur during years 25-26
- Replacement will cost 20 percent of the initial capital cost for each cycle
  - Replacement will cost 10 percent each year replacement takes place for the one cycle that occurs during the 50-year timeframe

50.05 D: Application systems: CCTV, FAS, EACS, IDS, PA/CIS, etc.

- Rehabilitation will occur every 10 years, spread over 10 years for the first cycle and 5 years during the second cycle
  - The first cycle occurs during years 10-19, the second cycle occurs during years 20-24

- Rehabilitation costs 10 percent of the replacement cost for each cycle
  - Rehabilitation will cost 0.15 percent each year rehabilitation takes place for the first cycle and 0.3 percent for the second cycle
- Replacement occurs every 25 years, spread over 10 years
  - Replacement will occur during years 25-34
- Replacement costs 15 percent of initial capital cost for each cycle
  - Replacement will cost 1.5 percent each year replacement takes places for the one cycle that occurs during the 50-year timeframe

Model inputs are presented in Table 6.

Table 6. Communications and Signaling Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
50.01	Wayside signaling equipment	lump sum	30	10	20%	3	5	80% of initial capital cost
50.05	Communications	lump sum	see below	see below	see below	see below	see below	see below
A	Shelters, cabinets, towers, ductbanks, manholes, fiber optic, HVAC, radiax	lump sum	25	10	2% of replacement cost for each cycle (0.08% each year rehab takes place, for both cycles)	First cycle is spread during years 10-19, second cycle is spread during 20-29	Replacement cycle is spread during years 25-39	40% (2.67% each year for one cycle)
B	Wide Area Networking, Networked Storage, etc.	lump sum	10	—	—	—	5 cycles during 50-year timeframe: during years 10-11, 20-21, 30-31, 40-411 50-51	15% (7.5% each year for one cycle)
C	Radio Systems (Operations Radio System, Broadband Radio System)	lump sum	25	10	2% of replacement cost for each cycle (0.04% each year rehab takes place for first cycle; 0.08% each year for second cycle)	First cycle occurs during years 10-19, second cycle occurs during years 20-24	Replacement cycle is spread during years 25 and 26	20% (10% each year for one cycle)
D	Application Systems: CCTV. FAS, EACS, IDS, PA/CIS, etc.	lump sum	25	10	10% of replacement cost for each cycle (0.15% each year rehab takes place for first cycle; 0.3% each year for second cycle)	First cycle occurs during years 10-19, second cycle occurs during years 20-24	Replacement cycle is during years 25 and 34	15% (1.5% each year for one cycle)

11 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*

11.1 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
- 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 that have a design life of less than 40 years
- Rehabilitation costs assumes that the Authority will not have any obligation for replacement cost for HV utility assets created especially for the California high-speed rail system
- Rehabilitation will cost 6.5 percent of the initial capital cost (15 percent of the 43 percent of the initial capital cost to replace asset)
- For the first rehabilitation cycle, rehabilitation will occur during years 16-25 of the asset's lifecycle (0.65 percent each year)
  - For all subsequent rehabilitation cycles, rehab will be spread over 15 years (0.43 percent each year)
- Rehabilitation timing for *60.02 Traction power supply: Substations* is based on experience from international HSR systems and domestic conventional rail systems
- Lifecycle estimates are based on experience of international HSR systems and TM 1.1.2 of CHSTP
  - Replacement will occur during years 31-50 of the asset's lifecycle, spread evenly throughout the 20 years (2.15 percent each year)
  - For all subsequent replacement cycles, replacement will be spread over 30 years (1.43 percent each year)

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 (approximately 30 years)

- Rehabilitation will cost $20 per foot or $105,600 per mile
- Rehabilitation will occur every 30 years, spread over 20 years ($5,280 per mile per year)
- Lifecycle estimates are based on TM 1.1.2 and Design Criteria Chapter 1 of the CHSTP book "Contact Lines for Electric Railways," discussion with other experts, experience of other systems, and a literature survey
- The design life of OCS wire and assemblies is 50 years; replacement will not occur during the 50-year timeframe; replacement will begin at year 51 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 OCS assemblies
- Lifecycle estimates are based on TM 1.1.2 and Design Criteria Chapter 1 of the CHSTP Book "Contact Lines for Electric Railways," discussion with other experts, experience of other systems, and a literature survey
- *60.04 Traction power control* is not included because it has been accounted for in *60.02 Traction power supply: Substations*

Model inputs are presented in Table 7.

Table 7. Electric Traction Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
60.02	Traction power supply: Substations	Route mile	40	20	6.5% of initial capital cost	First cycle, between 16-25; subsequent cycles, 15 years thereafter	First cycle, between 31-50; subsequent cycles, 30 years thereafter	43% of initial capital cost
60.03	Traction power distribution: Catenary and third rail	—	50	30	$20 per ft	20 years for contact wire	20 from 51st year	61% of initial capital cost for OCS assemblies

11.2 Unit Quantities

The following unit quantity calculations are applicable to *60.03 Traction power distribution: Catenary and third rail*

- The unit conversion factors for *60.03.100-60.03.400* were set based on number of track miles per route segment. For example, *60.03.100—Traction power distribution* represents a route segment with 2 tracks, the unit conversion factor to convert route miles to track miles is set to 2
- The unit quantities for *60.03 Traction power distribution: Catenary and third rail* were converted from route miles to track miles by multiplying the unit conversion factor with the unit quantity

12 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*

12.1 Assumptions and Model Inputs

The following assumptions were made for *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 $45 million
- Replacement will occur every 30 years spread over 5 years
- Lifecycle estimates are based on the 2012 Business Plan Capital Cost model

Model inputs are presented in Table 8.

Table 8. Vehicles Inputs

FRA Standard Cost Categories for		Unit	Lifecycle	Rehab Timing	Rehab Cost	Rehab Spread	Replacement	Replacement
70.02	Vehicle acquisition: Electric multiple unit	per trainset	30	—	—	—	5	$45,000,000
70.06	Vehicle acquisition: Maintenance of way vehicles[8]	N/A	N/A	N/A	N/A	N/A	N/A	N/A
70.07	Vehicle acquisition: Non-railroad support vehicles[9]	N/A	N/A	N/A	N/A	N/A	N/A	N/A

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

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

12.2 Unit Quantities

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

- 27 sets for Initial Operating Segment
- 50 sets for Bay to Basin
- 72 sets for Phase 1 Blended

Table 9 outlines the number of trainsets per group.

Table 9. Number of Trainsets and Start Dates

Group	Number of Trainsets	Start Date
1	15	2022
2	7	2023
3	7	2024
4	7	2025
5	7	2026
6	7	2027
7	4	2028
8	4	2029
9	4	2030
10	4	2031
11	4	2032
12	2	2033

13 Professional Services

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.[10]

Table 10 shows the professional cost allowances as percentages of construction costs, adjusted from category 80 in the capital cost model to reflect only those costs that would be relevant for capital rehabilitation and replacement.

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

Category	Assumptions	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%[11]
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%[12]

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 CA HSR system. These are consistent with inputs for the capital cost model.

[10] 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.

[11] 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.

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

14 Contingency

The model contains two sets of contingencies: unallocated contingency to account for unknown 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.

14.1 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.

14.2 Allocated Contingency

Allocated contingency percentages ranging from 15 percent to 25 percent were applied to account for unknowns, risk, and uncertainties that are specific to each asset category. The range for allocated contingencies mirror the same percentages applied the initial capital cost of each asset category in the capital cost model. The allocated contingency percentages are presented in Table 11.

Table 11. Allocated contingency percentages by cost category

FRA Standard Cost Categories for Capital Projects/Programs		Allocated Contingency %
10	Track Structures and Track	
10.09	Track new construction: Conventional ballasted	15.0
10.10	Track new construction: Non-ballasted	15.0
10.14	Track: Special track work (switches, turnouts, insulated joints)—Crossovers, each	15.0
20	Stations, Terminals, Intermodal	
20.01	Station buildings: Intercity passenger rail only, including:	25.0
20.02	Station buildings: Joint use (commuter rail, intercity bus)	25.0
20.06	Pedestrian/bike access and accommodation, landscaping, parking lots	25.0
20.07	Automobile, bus, van accessways including roads	25.0
30	Support Facilities, Yards, Shops, Admin Bldgs	
30.02	Light maintenance facility	25.0
30.03	Heavy maintenance facility	25.0
30.04	Storage or maintenance-or-way building/bases	25.0
30.05	Yard track	25.0
50	Communications and Signaling	
50.01	Wayside signaling equipment	15.0
50.05	Communications	15.0
60	Electric Traction	
60.02	Traction power supply: Substations	15.0
60.03	Traction power distribution: Catenary and third rail	15.0
70	Vehicles	
70.02	Vehicle acquisition: Electric multiple unit	0.0

15 Monte Carlo Risk Analysis

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 may take 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 a particular 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 particular revenue projection will be met or costs will be below a certain target.

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 DOT IG 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 CHSTP's risk management efforts as described in CHSTP's 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, In order to be complete, this methodology also requires a determination of the dollar value of any identified schedule impacts, which in turn requires a significant amount of foresight regarding not just *what* risks may strike a project but also *when*. The extent to which these activities are carried out by project personnel and/or stakeholders also introduces the potential for optimism bias. For business planning purposes, as opposed to internal tracking and risk management purposes, the key objective for CHSTP 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, CHSTP is employing a reference-class methodology to quantify the risk exposure associated with Lifecycle costs.

In reference-class analysis, the algorithm is given a set of outcomes from other, similar projects and then uses these in a Monte Carlo simulation to, in a sense, work backwards to determine a probability distribution that would lead to the given set of outcomes. From this resulting distribution, we can determine how likely a particular 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% chance that your trip will take between 41 and 57 minutes' or 'there is a 2% 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 HSR 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[13]
3. Rail Capital Expenditure curve with outliers, based on 58 Rail projects

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

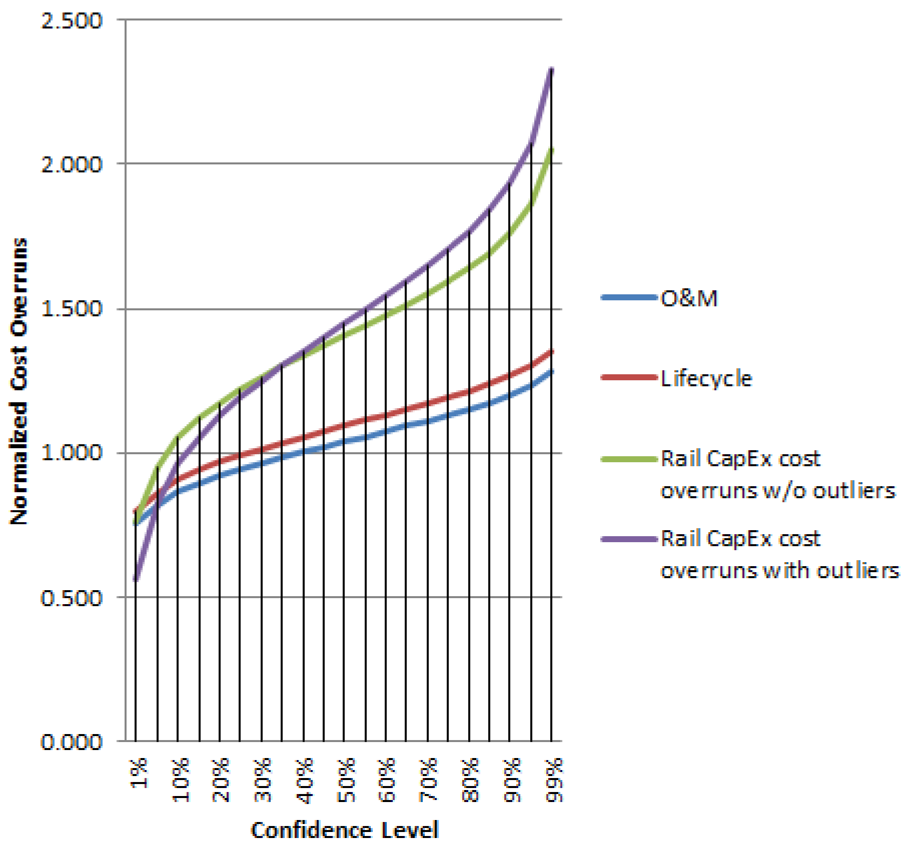
1. There is greater risk/uncertainty in Lifecycle cost than in O&M due to lack of data on HSR systems, larger time interval between when costs are estimated and when they are realized and because current Lifecycle costs are largely based on current capital cost estimates.
2. There is a less risk/uncertainty 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 ROW, stakeholder issues) are largely or completely resolved by the time Lifecycle costs are realized.

[13] 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

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% or higher, the Rail CapEx cost risk exposure is greater and significantly greater at confidence levels above 20%, 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 CapEx w/o outliers and Rail CapEx were 1.038, 1.094, 1.407 and 1.450, indicating median cost overruns of 3.8%, 9.4%, 40.7% and 45%, respectively.

Figure 3. Risk exposure associated with 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% of Lifecycle cost estimate with contingency
- Most Likely: Lifecycle cost estimate with contingency +10.7%
- Maximum: Medium cost scenario with contingency + 41.28%

For comparison, the equivalent parameters, in percentage terms, applied to the Medium O&M cost with contingency were 67%/+5%/+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, IOS, B2B and P1B as well as for each year of 'All' (combined IOS, B2B, and P1B phases), based on the risk-adjusted cost estimates for those years and phases. To avoid correlation between years, the totals were calculated independently of the individual years by applying the same parameterization to the total cost (all years combined in $2012) for each of IOS, B2B, P1B and All phases. Each simulation consisted of 5,000 iterations. The overall results of these analyses, the totals for each phase and combined ('All'), are presented in Table 12.

Table 12. Probabilistic outcomes of Monte Carlo simulations for each phase and combined ('All').[14]

Phase	IOS LC_{TOT} $2012	B2B LC_{TOT} $2012	P1B LC_{TOT} $2012	ALL LC_{TOT} $2012
Mean	$ 4,977	$ 2,255	$ 2,522	$ 9,754
Standard Deviation	$ 612	$ 277	$ 310	$ 1,200
Percentile				
Minimum	$ 3,286	$ 1,500	$ 1,669	$ 6,481
1%	$ 3,632	$ 1,645	$ 1,840	$ 7,117
5%	$ 3,939	$ 1,785	$ 1,996	$ 7,720
10%	$ 4,143	$ 1,877	$ 2,099	$ 8,119
15%	$ 4,293	$ 1,946	$ 2,175	$ 8,414
20%	$ 4,419	$ 2,003	$ 2,239	$ 8,661
25%	$ 4,531	$ 2,053	$ 2,296	$ 8,879
30%	$ 4,632	$ 2,099	$ 2,348	$ 9,079
35%	$ 4,728	$ 2,143	$ 2,396	$ 9,266
40%	$ 4,820	$ 2,184	$ 2,442	$ 9,446
45%	$ 4,908	$ 2,224	$ 2,487	$ 9,619
50%	$ 4,995	$ 2,263	$ 2,531	$ 9,789
55%	$ 5,081	$ 2,302	$ 2,575	$ 9,958
60%	$ 5,167	$ 2,342	$ 2,618	$ 10,127
65%	$ 5,255	$ 2,381	$ 2,663	$ 10,299
70%	$ 5,345	$ 2,422	$ 2,709	$ 10,476
75%	$ 5,440	$ 2,465	$ 2,757	$ 10,662
80%	$ 5,541	$ 2,511	$ 2,808	$ 10,860
85%	$ 5,653	$ 2,562	$ 2,864	$ 11,079
90%	$ 5,782	$ 2,620	$ 2,930	$ 11,334
95%	$ 5,951	$ 2,697	$ 3,016	$ 11,662
99%	$ 6,186	$ 2,804	$ 3,135	$ 12,125
Maximum	$ 6,397	$ 2,901	$ 3,251	$ 12,526
Values in $Millions				

[14] Note that each column, IOS, B2B, P1B and All is the product of an individual simulation and values for any particular probability in IOS, B2B and P1 cannot be summed to determine equivalent probability value for All.