3. IDENTIFICATION AND EVALUATION OF MAJOR RISK FACTORS

Four risk factors are considered in this chapter:

- Tunneling geological risks (derived from Geodata's analysis);
- Cost escalation risks;
- Schedule slippage and financial costs; and
- Methodological uncertainty.

The risk factors are described in the sections below, along with key assumptions used in the analysis.

3.1 Tunneling Geological Risks

The tunneling risks considered in this study are based solely on the assumptions and simulation results provided by Geodata[2].

Geodata simulations were performed with a computer tool called DAT, or Decision Aids in Tunneling. The software is described briefly in Section 3.1.1 below; key findings are shown in Section 3.1.2. For more details see Geodata technical report.

3.1.1 Overview of Geodata Methodology and Assumptions

The DAT software was developed to estimate the cost and time of constructing a tunnel (or a series of tunnels) considering geologic and construction uncertainty and variability. DAT uses the Monte Carlo method to combine various sources of uncertainty resulting in distributions of project duration and cost. DAT provides probabilistic diagrams of project cost vs. time as well as probabilistic diagrams of position vs. time.[3]

The software has two modules:

- **Geology Module:** to model variability and uncertainty in geological and geomechanical conditions; and

[2] "A Comparative Analysis of the Tunnel-Construction Times and Costs as well as Risks Associated with the Choice of High-Speed Rail Alignment between Los Angeles and Bakersfield," Draft Report, prepared for the City of Palmdale, California, by Geodata S.p.A., January 2003

[3] This section borrows heavily from the document "DAT Analysis Report," prepared by Geodata

- **Construction Module:** construction methods (simulation of construction cycle activity by activity - model variability in perforation rate, advance rate, unit costs, etc.) and tunnel network - model sequence of realization of tunnel and project.

Key inputs for the analysis include:

- **Geological and Geo-Mechanical Data:** The alignment was subdivided in geologically homogeneous zones. Definition of "behavioral categories" (for excavation). Tunnel corridors were subdivided in zones associated with high abrasivity, possible presence of gas, and problematic water inflow. Possibility of geologically induced "accidents" (costs associated with geologically-induced delays) was simulated.

- **Construction-Related Input**: The cost components considered in the model include Tunnel Boring Machine (TBM) depreciation,[4] assembly and disassembly of the TBM system, labor costs, consumables including utensils, and energy consumption, and segmental lining and injections of pea-gravel and/or grout. Data items comprise: advance rates and unit costs for various technical classes (standard conditions) and with respect to different proposed excavation diameters (main and service tunnels); and unit costs and advance rates evaluated for other construction items (e.g. seismic chamber, shaft, portal zones, etc.)

Geodata's assumptions concerning tunneling length along the two competing alignments are shown in the table below.

Table 7: Geodata Assumptions, Tunneling Length and Other Works

Summary of Construction Phases	Units	Antelope Valley		I-5	
		3.5%	2.5%	3.5%	2.5%
1) Main tunnels					
Number of Main Tunnels	[-]	36	14	8	8
Cumulative Tunnel Length (Twin-Tunnel)	[miles]	31.2	40.0	32.8	33.7
Total Tunneling Length, for both Tubes	[miles]	62.3	80.0	65.4	67.3
Breakdown of Total Tunneling Length by Tunneling Methods					
By TBM	[miles]	49.2	71.1	62.9	64.8
By Cut & Cover	[miles]	6.2	2.8	1.3	1.3
By Conventional Method	[miles]	6.9	6.1	1.2	1.2
2) Service Tunnels					
Number of Service Tunnels	[-]	1	3	2	2
Total Length of Service Tunnels	[miles]	8.1	15.5	27.1	27.1

[4] Average 60% of the cost of the TBM, TBM acquisition cost in the range of 11-12 million USD for the TBM for the railway tunnel, and 6-7 million USD for the service tunnel TBM.

3) Trenches					
Total Length of Trenches due to Adjustment of Tunnel Profiles	[miles]	2.5	0.9	1.7	0.0
4) Other works					
Excavation Sites / Portals	[-]	50	41	23	23
Number of Shafts	[-]	0	1	1	1
Number of Major Fault Crossing Seismic Chambers	[-]	0	2	2	4

Source: Geodata, January 2003

All cost estimates in the model are inclusive of overhead (12%) and profits (10%). All the conditions that could negatively affect the tunnel construction (poor geomechanical conditions, "geo-events", etc.) were quantified in terms of their economic impact. *Financial costs are not included in the DAT analysis.*

3.1.2 Summary of Geodata Results

Monte Carlo simulation results from the DAT software for the construction time analysis are summarized in the table below.

Table 8: Geodata Construction Time Analysis

In Working Days	Antelope Valley		I-5	
	3.5%	2.5%	3.5%	2.5%
Mean value	1,125	1,430	2,218	2,124
Median value	1,089	1,321	2,111	2,027
St. Deviation	217	370	471	431
Minimum value	962	1,060	1,492	1,470
Value at 95%	1,250	2,050	3,100	2,900
Difference between 95% value and mean value	125	620	882	776
Difference between 95% value and Min value	288	990	1,608	1,430

Source: Geodata, January 2003

Histograms derived from Geodata simulation results are shown in the figures below, with 3.5% maximum grades (Figure 3) and 2.5% maximum grades (Figure 4).

Figure 3: Geodata Construction Time Analysis, 3.5% Maximum Grades

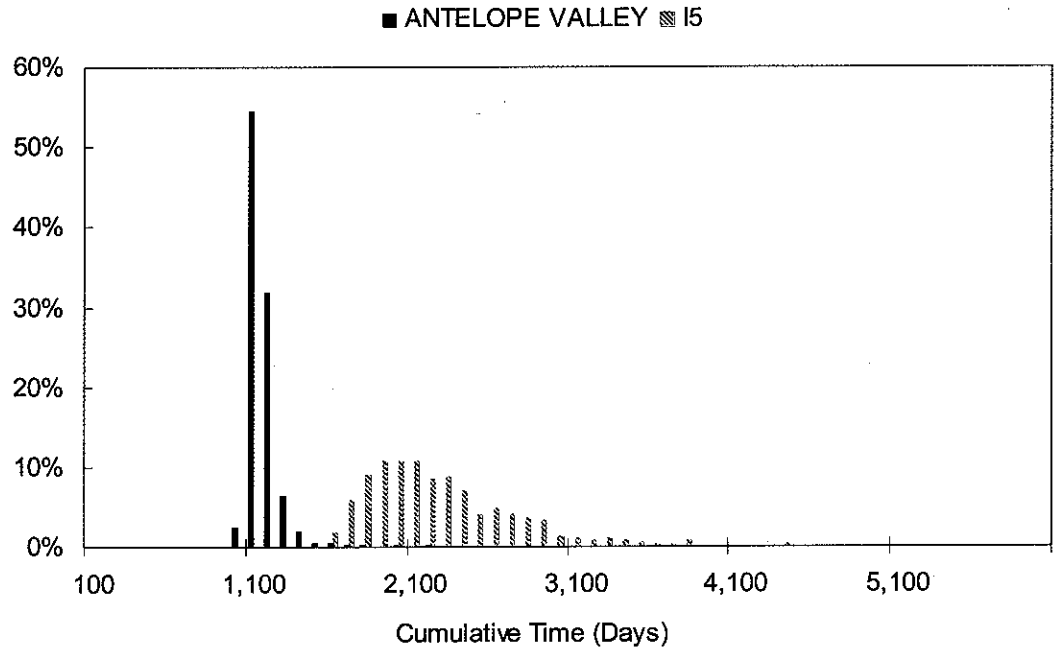
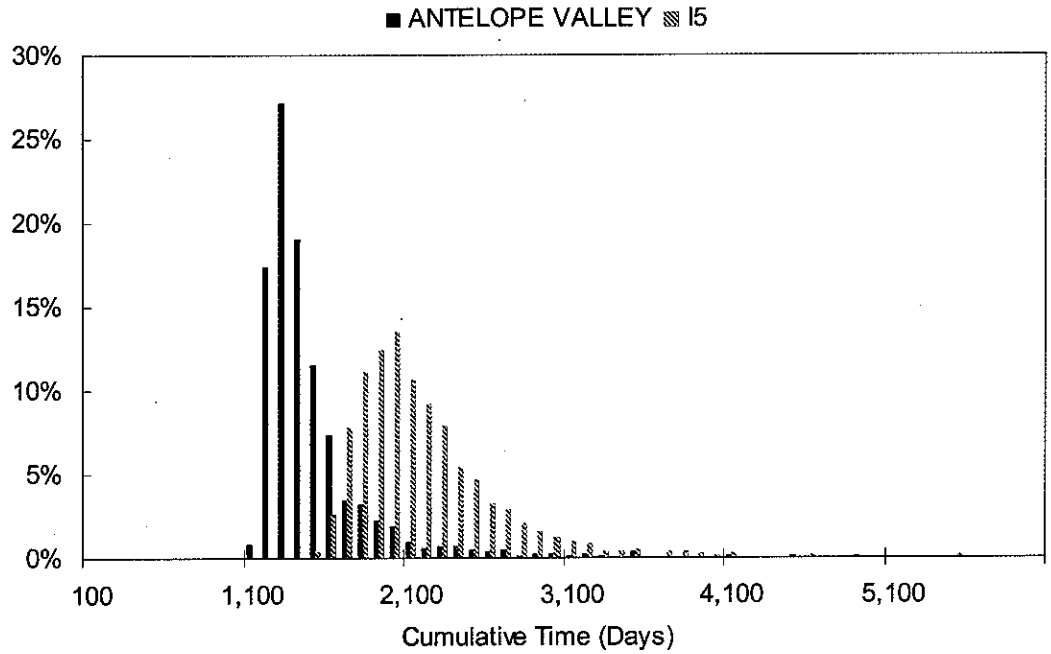


Figure 4: Geodata Construction Time Analysis, 2.5% Maximum Grades



Simulation outcomes for tunnel construction costs are shown in Table 9, below. The associated histograms with 3.5 and 2.5% maximum grades are provided in Figure 5 and Figure 6.

Table 9: Geodata Construction Cost Analysis

In Millions of Dollars	Antelope Valley		I-5	
	3.5%	2.5%	3.5%	2.5%
Mean value	$1,127.5	$1,614.8	$1,670.1	$1,779.1
Median value	$1,125.9	$1,610.1	$1,643.4	$1,758.4
St. Deviation	$21.0	$34.0	$133.5	$110.2
Minimum value	$1,073.2	$1,537.2	$1,420.4	$1,576.3
Value at 95%	$1,150.0	$1,675.0	$1,925.0	$1,975.0
Difference between 95% value and mean value	$22.5	$60.2	$254.9	$195.9
Difference between 95% value and min value	$76.8	$137.8	$504.6	$398.7

Source: Geodata, January 2003

Figure 5: Geodata Construction Cost Analysis, 3.5% Maximum Grades

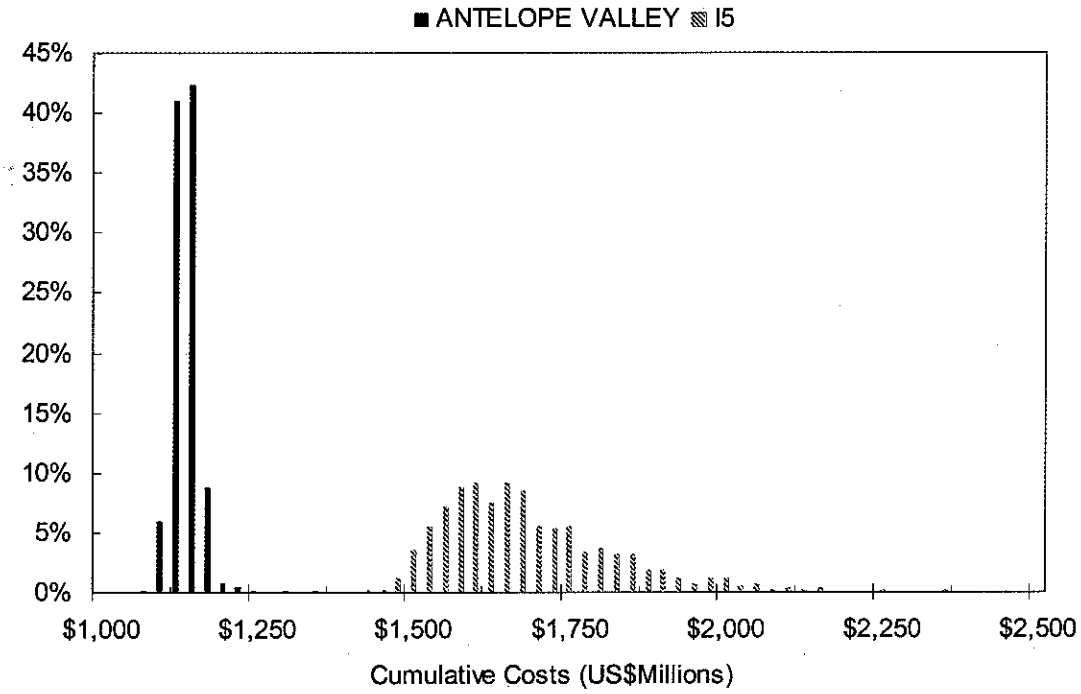
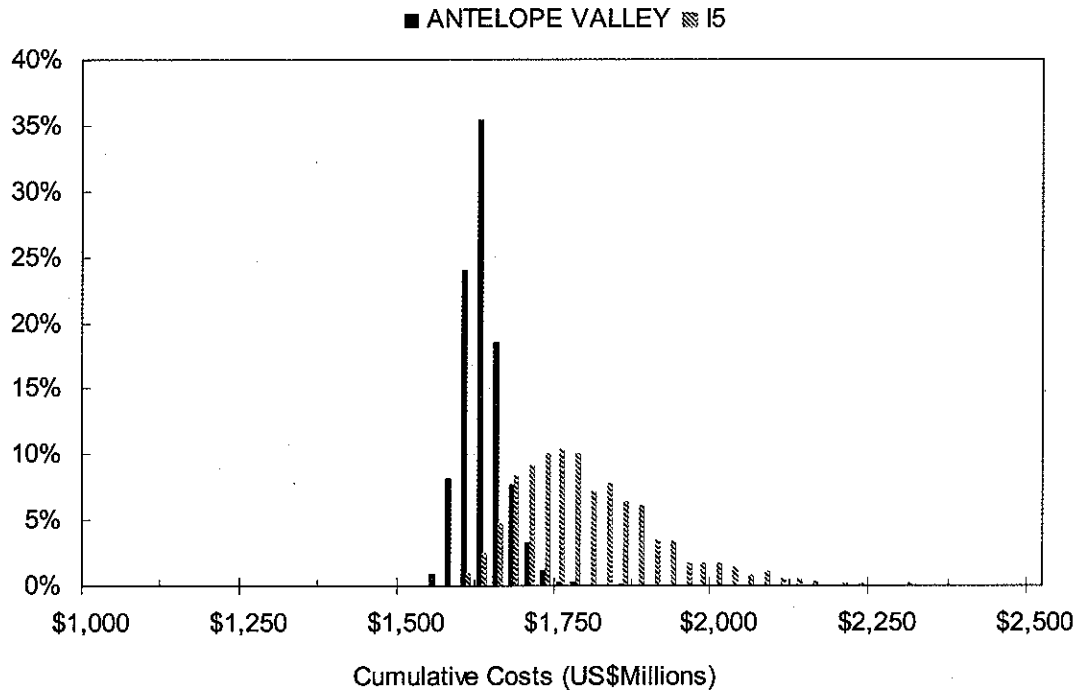


Figure 6: Geodata Construction Cost Analysis, 2.5% Maximum Grades



Summary statistics for the construction costs per mile of tunneling implied in the DAT are provided in Table 10 below.

Table 10: Geodata Implied Tunneling Cost per Mile of Tunneling

In Millions of Dollars per Mile	Antelope Valley		I-5	
	3.5%	2.5%	3.5%	2.5%
Total Tunneling Length (Main and service tunnels)	70.4	95.6	92.6	94.4
Mean	$16.0	$16.9	$18.0	$18.8
Median	$16.0	$16.8	$17.8	$18.6
Minimum	$15.2	$16.1	$15.3	$16.7
Value at 95%	$16.3	$17.5	$20.8	$20.9

Source: Derived by HLB from Geodata, January 2003

3.1.3 Tunneling Risk Inputs for this Study

The assumptions used in *this* paper to control, and account, for geological risks are based entirely on the simulation outcomes summarized in the above section. The parameters of the

probability distributions (the central, lower 10% and upper 10% values) used in HLB's economic risk analysis are provided in the tables below.

Cumulative time with **3.5%** maximum grades:

In Days	Median	Lower 10%	Upper 10%	80% Interval
Antelope Valley	1,089	1,023	1,207	184
I-5	2,111	1,731	2,814	1,083

Source: Geodata, January 2003

Cumulative time with **2.5%** maximum grades:

In Days	Median	Lower 10%	Upper 10%	80% Interval
Antelope Valley	1,321	1,175	1,789	614
I-5	2,027	1,694	2,662	968

Source: Geodata, January 2003

Cumulative costs with **3.5%** maximum grades:

In $Millions	Median	Lower 10%	Upper 10%	80% Interval
Antelope Valley	$1,126	$1,105	$1,151	$46
I-5	$1,643	$1,523	$1,847	$324

Source: Geodata, January 2003

Cumulative costs with **2.5%** maximum grades:

In $Millions	Median	Lower 10%	Upper 10%	80% Interval
Antelope Valley	$1,610	$1,576	$1,657	$80
I-5	$1,758	$1,656	$1,921	$265

Source: Geodata, January 2003

The corresponding probability density functions are shown in Appendix 2 at the end of this report.

3.2 Cost Escalation Risks

The cost escalation risk is the risk of cost increase in real terms (beyond and above general price inflation) associated with *unforeseen* schedule slippages.[5]

The DAT model included five major cost components:

- Depreciation (about 60% of TBM acquisition costs: in the range of $11-$12 million for the railway tunnel, and $6-7 million for the service tunnel): **17%** of total tunneling costs;
- Assembly and disassembly of the TBM system: **5%** of total tunneling costs;

[5] All cost estimates provided in this paper are in (constant) dollars of 2003.

EXHIBIT R: ANTELOPE VALLEY-ENTERPRISE ZONE

- Labor costs: **20%** of total;
- Consumables, including utensils and energy consumption: **15%** of total; and
- Segmental lining and injections of pea-gravel and/or grout: **43%** of total.

Historical data series for escalation factors associated with the cost components outlined above are shown in Table 11.

Table 11: Historical Cost Escalation Factors

Year	General Price Inflation (1)		Excavation Equipment (2)		Segmental Lining and Injections (3)		Labor Costs (4)	
1985	107.6	n/a	101.2	n/a	108.5	n/a	$12.3	n/a
1986	109.6	1.86%	101.8	0.59%	109.4	0.83%	$12.5	1.30%
1987	113.6	3.65%	102.6	0.79%	110.4	0.91%	$12.7	1.84%
1988	118.3	4.14%	105.9	3.22%	112	1.45%	$13.1	2.91%
1989	124.0	4.82%	109.8	3.68%	113.2	1.07%	$13.5	3.52%
1990	130.7	5.40%	113.5	3.37%	115.3	1.86%	$13.8	1.70%
1991	136.2	4.21%	117.5	3.52%	118.4	2.69%	$14.0	1.67%
1992	140.3	3.01%	120.1	2.21%	119.4	0.84%	$14.2	1.07%
1993	144.5	2.99%	122.9	2.33%	123.4	3.35%	$14.4	1.63%
1994	148.2	2.56%	125.0	1.71%	128.7	4.29%	$14.7	2.43%
1995	152.4	2.83%	128.1	2.48%	134.7	4.66%	$15.1	2.44%
1996	156.9	2.95%	131.4	2.58%	138.8	3.04%	$15.5	2.52%
1997	160.5	2.29%	133.7	1.75%	142.5	2.67%	$16.0	3.68%
1998	163.0	1.56%	136.0	1.72%	147.6	3.58%	$16.6	3.55%
1999	166.6	2.21%	138.0	1.47%	152.1	3.05%	$17.2	3.49%
2000	172.2	3.36%	139.4	1.01%	155.6	2.30%	$17.9	4.01%
2001	177.1	2.85%	141.1	1.22%	159.1	2.25%	$18.3	2.57%
2002	179.9	1.58%	142.7	1.13%	162.5	2.14%	$18.9	2.89%
Average		**3.08%**		**2.05%**		**2.41%**		**2.54%**
Std. Deviation		**1.09%**		**0.98%**		**1.18%**		**0.91%**
Minimum		**1.56%**		**0.59%**		**0.83%**		**1.07%**
Lower 10%		**1.75%**		**0.92%**		**0.89%**		**1.49%**
Median		**2.95%**		**1.75%**		**2.30%**		**2.52%**
Upper 10%		**4.45%**		**3.43%**		**3.87%**		**3.61%**
Maximum		**5.40%**		**3.68%**		**4.66%**		**4.01%**

Source: Bureau of Labor Statistics, http://www.bls.gov
(1) BLS Consumer Price Index, U.S. city average, all items, 1982-84=100
(2) BLS Producer Price Index, construction, mining, and materials handling machinery and equipment
(3) BLS Producer Price Index, concrete ingredients and related products
(4) BLS, Average hourly earnings of construction workers

In HLB's economic model, real cost escalation is applied to Geodata's (and other engineering) estimates whenever simulated construction time exceeds the mean expected

completion date.[6] Real cost escalation is estimated as simulated nominal cost increase, by cost component, *minus* an assumed fixed 2.5 percent general price inflation.

The probability ranges used in the model are shown in the table below. They are based on the variations *observed* between 1985 and 2002, and summarized in Table 11. As a simplifying assumption, the inflation factors are held constant across the construction period.

Annual cost escalation factors, in nominal terms:

	Median	Lower 10%	Upper 10%
Depreciation	2.0%	0.9%	3.4%
TBM Assembly and Disassembly	2.5%	1.5%	3.6%
Labor	2.5%	1.5%	3.6%
Consumables (utensils, energy, etc.)	3.1%	1.7%	4.5%
Segmental lining and injections of pea-gravel and grout	2.4%	0.9%	3.9%
Railroad equipment	1.5%	-0.2%	3.9%

Source: HLB based on historical cost data

3.3 Schedule Slippage and Financial Costs

Financial costs per day of delay are estimated as the product of mean capital outlay by a *daily* interest rate (representing the cost of capital). The cost assumptions used in HLB's economic risk analysis are summarized below.

Financial costs, annual and daily real rate of interest:

	Median	Lower 10%	Upper 10%
Annual	4.00%	2.00%	6.00%
Daily	0.011%	0.005%	0.016%

Source: HLB

3.4 Methodological Uncertainty

This risk factor accounts for the error in the cost estimates due to methodological uncertainty. A positive value means that the base cost estimates are too low while a negative value means the estimates are over-estimated (a higher percentage implies a higher cost).

[6] In other words, construction delay is calculated as simulated construction time minus mean expected construction time.

A median value of zero percent was assumed. This meant that, at the median, the methodology in use had no "built in" bias – either to yield conservatively "high" estimates or, alternatively, to yield estimates that are consistently below cost.

Methodological Uncertainty with **3.5%** and **2.5%** maximum grades:

In Percent	Median	Lower 10%	Upper 10%
Antelope Valley	0.0%	-5.0%	+10.0%
I-5	0.0%	-5.0%	+10.0%

Source: HLB

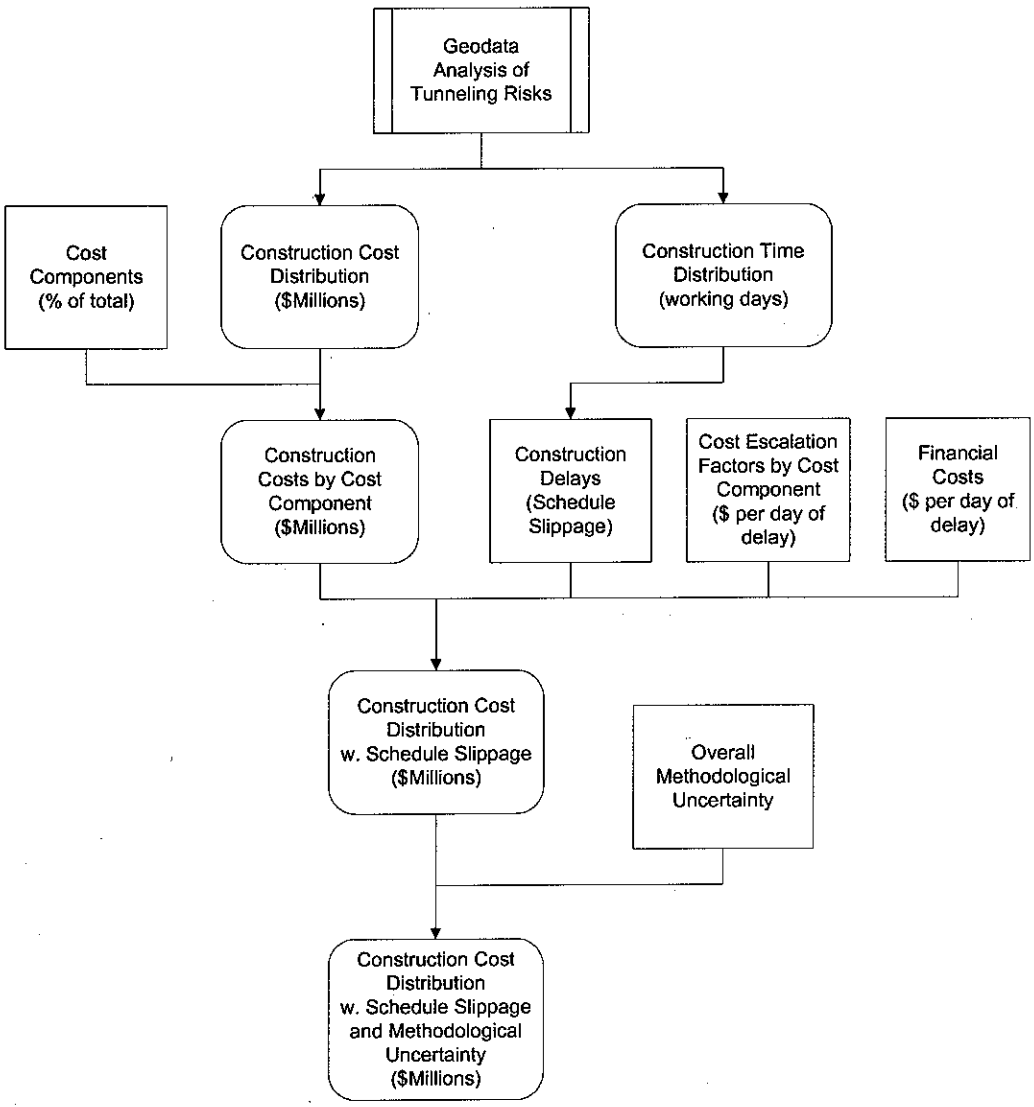
4. TEHACHAPI MOUNTAIN CROSSING SCHEDULE AND COSTS

This chapter provides simulation results for the schedule and costs associated with constructing high speed rail across the Tehachapi Mountains (between Bakersfield and Sylmar). A brief presentation of the methodology is provided first.

4.1 Assumptions and Methodology

The methodology used in this study is illustrated in the Structure and Logic diagram shown below. The diagram shows, in particular, how the risk factors introduced in the previous chapter are combined to arrive at an overall probability distribution for total segment construction costs.

Figure 7: Structure and Logic Diagram for Estimating Total Construction Costs



4.2 Simulation Results

Monte Carlo simulation results for the Tehachapi crossing are shown below: segment schedule is based solely on the construction time analysis provided by Geodata. HLB assumed that the non-tunneling sections could be completed within the time frame allowed for the tunneling sections. Simulated segment costs reflect both the geological risks highlighted by Geodata and the economic risks (cost escalation, financial costs, methodological uncertainty) introduced in this paper.

4.2.1 Simulated Segment Schedule

Simulated segment construction time is shown both in cumulative number of workdays and number of years (assuming 300 workdays per year).

Table 12: Simulation Results for Tehachapi Mountain Crossing Completion Schedule

Number of Workdays (and Years to Complete)	Mean Expected Outcome	80% Confidence Interval	
		Lower Bound	Upper Bound
With 3.5% Maximum Grades			
Antelope Valley	1,111 (3.7)	1,023 (3.4)	1,207 (4)
I-5	2,250 (7.5)	1,731 (5.8)	2,814 (9.4)
Difference	-1,138 (-3.8)	-708 (-2.4)	-1,606 (-5.4)
With 2.5% Maximum Grades			
Antelope Valley	1,460 (4.9)	1,175 (3.9)	1,789 (6)
I-5	2,157 (7.2)	1,694 (5.6)	2,662 (8.9)
Difference	-697 (-2.3)	-519 (-1.7)	-873 (-2.9)

4.2.2 Simulated Segment Costs

Geodata's simulation results were used for the tunneling sections. For the non-tunneling sections, estimated non-tunneling length was multiplied by an estimate of average cost per mile derived from engineering findings.

Construction cost[7] per mile of non-tunneling sections, in Millions of 2003 dollars per mile:

In $M per Mile	Median	Lower 10%	Upper 10%
Antelope Valley	$12.0	$10.8	$14.5
I-5	$12.0	$10.8	$14.5

Source: Derived from Leavitt D, Hall P, Vaca E, and Hall P (1994), and Parsons Brinckerhoff (1996) escalated with U.S. general price inflation

[7] The key cost components considered here include right-of-way, earthworks, structures (tunnels), rail, and power and signals.

Length of non-tunneling sections, with **3.5%** maximum grades

In Miles	Median	Lower 10%	Upper 10%
Antelope Valley	112	109	115
I-5	79	75	83

Source: Derived from Geodata (2003) and Parsons Brinckerhoff (1996)

Length of non-tunneling sections, with **2.5%** maximum grades

In Miles	Median	Lower 10%	Upper 10%
Antelope Valley	103	100	106
I-5	78	74	82

Source: Derived from Geodata (2003) and Parsons Brinckerhoff (1996)

Simulated construction costs for the Bakersfield – Sylmar section of the HSR are shown in Table 13, below.

Table 13: Simulation Results for Tehachapi Mountain Crossing Construction Costs

In Millions of 2003 Dollars	Mean Expected Outcome	80% Confidence Interval	
		Lower Bound	Upper Bound
With 3.5% Maximum Grades			
Antelope Valley	$2,342	$2,106	$2,597
I-5	$2,594	$2,315	$2,887
Difference	*-$252*	*-$209*	*-$289*
With 2.5% Maximum Grades			
Antelope Valley	$3,001	$2,724	$3,287
I-5	$2,969	$2,621	$3,331
Difference	*$31*	*$102*	*-$44*

Including contingencies, excluding stations and support facilities

As shown in the table, with 3.5% maximum grades, the extra costs and risks associated with tunnel construction along the I-5 alignment more than offset the extra miles of construction necessary along the longer Antelope Valley Alignment. At any probability level, the I-5 construction costs are larger than the Antelope Valley costs. This is clearly shown in Figure 8, below.

With 2.5% maximum grades, total construction cost along the Antelope Valley alignment is only marginally larger than along the I-5 alignment ($31million at the median). Figure 9 also shows that the range of possible costs for I-5 is larger than for the Antelope Valley, reflecting the considerable uncertainty associated with I-5 ground conditions, highlighted by Geodata in their assessment of geological risks.

Figure 8: Simulated Segment Construction Costs, 3.5% Maximum Grades

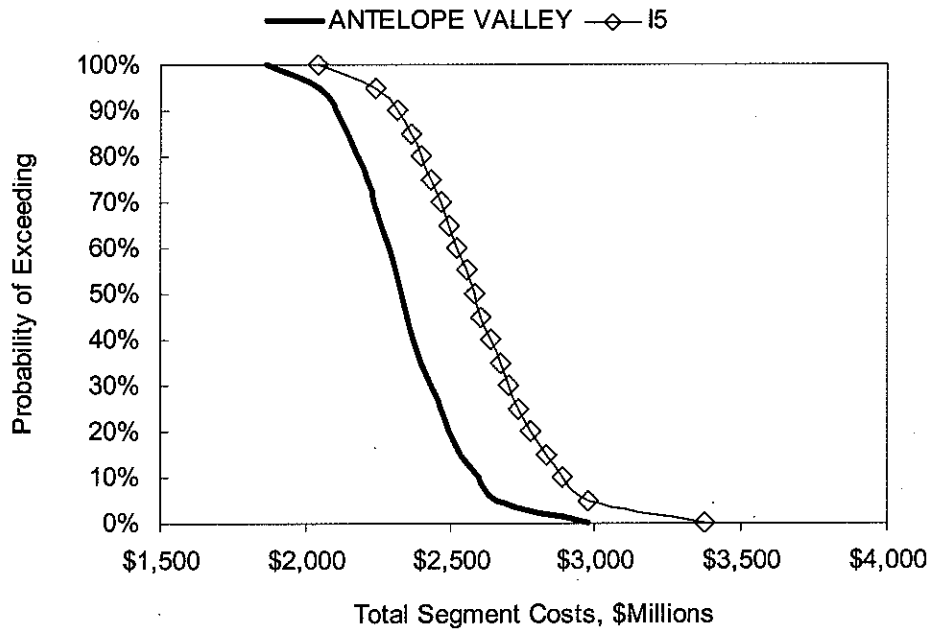
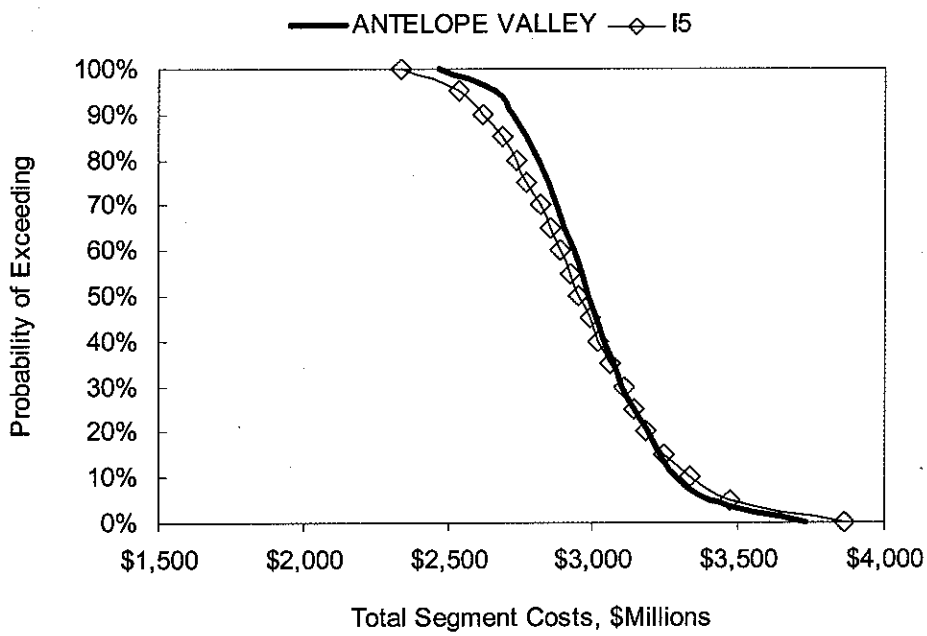


Figure 9: Simulated Segment Construction Costs, 2.5% Maximum Grades



5. HSR PROJECT SCHEDULE AND COSTS

This chapter provides estimates for total construction costs and grand total costs (including vehicle acquisition, stations, support facilities, and program implementation) for the entire HSR corridor (the "project") in California.[8] The cost estimates are built upon the findings presented in Chapter 4, engineering estimates for various cost components, and assumptions derived by HLB.

5.1 Assumptions and Methodology

The methodology used for estimating total project costs is similar to that introduced in Section 4.1. Financial costs and real cost escalation risks are estimated on the same basis. The potential schedule slippage is based on delays estimated for the Tehachapi crossing, augmented by a gross-up factor; the underlying assumption being that delays along the mountain crossing would postpone the overall project completion and opening date, without the possibility of compensation along other sections.

Baseline construction costs along the non Tehachapi sections are estimated from total project length (net of Tehachapi project length) and an estimate of construction cost per mile.

Overall project length (including Tehachapi Mountain crossing)

In Miles	Median	Lower 10%	Upper 10%
Antelope Valley	743	731	756
I-5	712	698	725

Source: HLB Decision Economics (1999), based upon Parsons Brinckerhoff (1996) and CHSRA (1999)
With a total of 300 miles added under Phase 2

Tehachapi Mountain crossing length (Tunnel and non-tunnel sections)

In Miles	Median	Lower 10%	Upper 10%
Antelope Valley	143	141	146
I-5	112	108	115

Source: HLB Decision Economics (1999), based upon Parsons Brinckerhoff (1996)

HSR construction costs (including contingencies), millions of 2003 dollars per mile (excluding Tehachapi Mountain crossing)

In $M per Mile	Median	Lower 10%	Upper 10%

[8] For Phase 1 (San Jose - Fresno to Los Angeles) and Phase 2 (adding connections to Sacramento – Modesto in the North, and San Diego in the South)

Antelope Valley	$27.0	$24.3	$32.4
I-5	$27.0	$24.3	$32.4

Sources: Derived from Leavitt D, Hall P, Vaca E, and Hall P (1994) and Parsons Brinckerhoff (1996), escalated with U.S. general price inflation

5.2 Simulation Results

Simulation results are provided for both total construction costs and grand total project costs (including vehicle acquisition, stations, support facilities, and program implementation).

5.2.1 Simulated Project Construction Costs

Simulated construction costs are summarized in Table 14, below. As can be seen in the table, when considering the impacts of potentially large schedule slippage under the I-5 option, the Antelope Valley alternative is, overall, the low-cost alternative, in-spite of its 30 or so extra miles of track.

Table 14: Simulation Results for Project Construction Costs

In Millions of 2003 Dollars	Mean Expected Outcome	80% Confidence Interval	
		Lower Bound	Upper Bound
With 3.5% Maximum Grades			
Antelope Valley	$19,683	$17,239	$22,341
I-5	$20,661	$17,756	$23,774
Difference	*-$977*	*-$516*	*-$1,433*
With 2.5% Maximum Grades			
Antelope Valley	$20,463	$17,915	$23,093
I-5	$20,819	$17,967	$23,868
Difference	*-$356*	*-$52*	*-$775*

Including contingencies, excluding stations and support facilities

5.2.2 Simulated Grand Total Project Costs

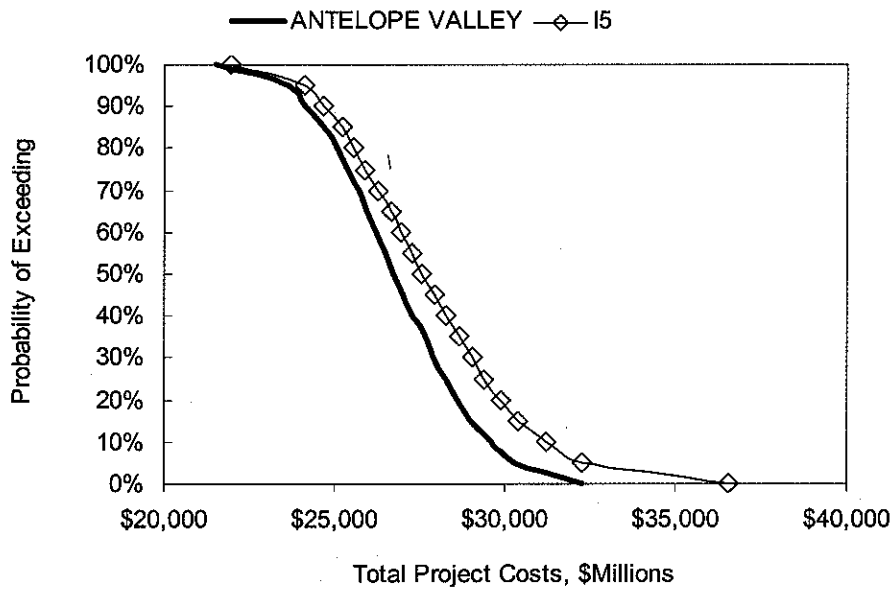
Grand total project costs, under both the I-5 and Antelope Valley options are shown in Table 15, below. The figures shown are based on the California High Speed Rail Authority estimates (See Appendix 4). These estimates include project construction costs plus vehicle acquisition, stations, support facilities, and program implementation

Table 15: Simulation Results for Grand Total Project Costs

In Millions of 2003 Dollars	Mean Expected Outcome	80% Confidence Interval	
		Lower Bound	Upper Bound
With 3.5% Maximum Grades			
Antelope Valley	$26,830	$24,116	$29,598
I-5	$27,808	$24,691	$31,210
Difference	*-$977*	*-$575*	*-$1,612*
With 2.5% Maximum Grades			
Antelope Valley	$27,610	$24,945	$30,393
I-5	$27,966	$25,086	$31,153
Difference	*-$356*	*-$141*	*-$760*

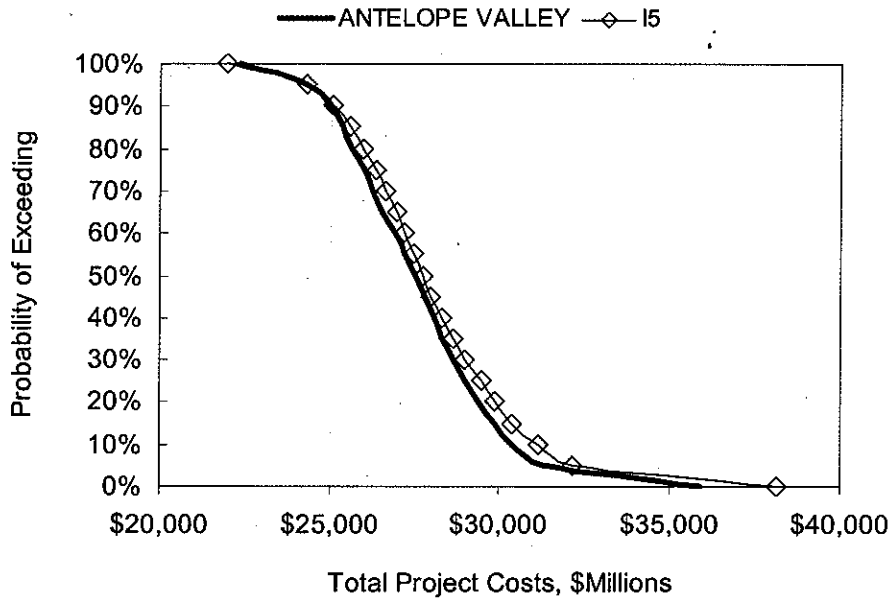
Again, overall, the Antelope Valley alternative appears less costly than the I-5 alignment when controlling for potential construction delays, geological risks, cost escalation and differences in financial costs.[9]

Figure 10: Simulated Total Project Costs, 3.5% Maximum Grades



[9] The difference between the two alternative, however, is relatively small given the range of uncertainty surrounding the two sets of estimates.

Figure 11: Simulated Total Project Costs, 2.5% Maximum Grades



6. ECONOMIC BENEFIT ANALYIS

Given the trivial differences in the cost categories between the two alignments, the focus should be given to the benefits and the economic effects of the two alignments. Indeed, the California High-Speed Rail Act of 1996 called for *a network of high-speed rail systems that will generate jobs and economic growth.* Therefore, in addition to evaluating the two alternatives from the cost perspective (based on the cost analysis, the difference is expected to be trivial), decision makers should focus on the economic benefit perspective of the alignments.

In its October 2001 economic evaluation of the two route options, HLB addressed the demand side of the two options, that is, which alignment offers the best prospects for maximizing ridership and revenue, transportation and economic integration, and economic viability. The findings from that analysis are presented below in order to provide a comprehensive assessment.

6.1 Ridership and Revenue

It is well known by rail planners that assessing the trade-offs between length and accessibility to users (number and location of stations) is key to selecting an alignment that will maximize ridership and fare revenue. Whereas a shorter and faster route will attract more passengers than a longer and slower one, a course plotted through heavily populated regions will attract more demand than one through lightly-populated and wilderness areas. Our analysis indicates that the additional ridership generated by the greater access to users (residents and employers) under the Antelope Valley option will more than offset the potential ridership advantage of a modestly shorter end-to-end journey time using along the I-5 Grapevine alignment. Over the initial project life-cycle period (2017 to 2050), we estimate that total cumulative ridership under the Antelope Valley alternative would exceed that under the I-5 Grapevine option by over 3 percent.

The conclusion that passenger demand and revenue from fares are maximized under the Antelope Valley alternative stems from the nature of the potential time savings under the I-5 Grapevine option and from the nature of growth patterns in the regions served by the two alignment choices. Studies commissioned by the Authority assume that the average journey time from Los Angeles to San Francisco using the I-5 Grapevine alignment would be 2 hours and 30 minutes to 2 hours and 33 minutes. (The range reflects engineering uncertainty about tunnel gradients – see risk analysis below). The same journey under the Antelope Valley alternative would take, on average, an estimated 2 hours and 42 minutes.

However, while the saving in average travel time under the I-5 Grapevine Pass option would be between 9 and 12 minutes, 1,400 travelers recently surveyed in southern California (National Cooperative Highway Research Program Report 431, *Valuation of Travel Time Savings and Predictability in Congested Conditions)* were found to be fully two and a half times more sensitive to variability (uncertainty) in travel time than to differences in average travel time, per se. Whereas the 9 to 12 minute saving in average travel time is less than five percent of the total LA/SF journey time, travel times by high-speed rail in Europe are found to vary from scheduled

times by 3 to 5 minutes from one run to another. Thus, when average time savings and running time variability are combined, the impact on ridership of the I-5 Grapevine's route length advantage is found to be minimal.

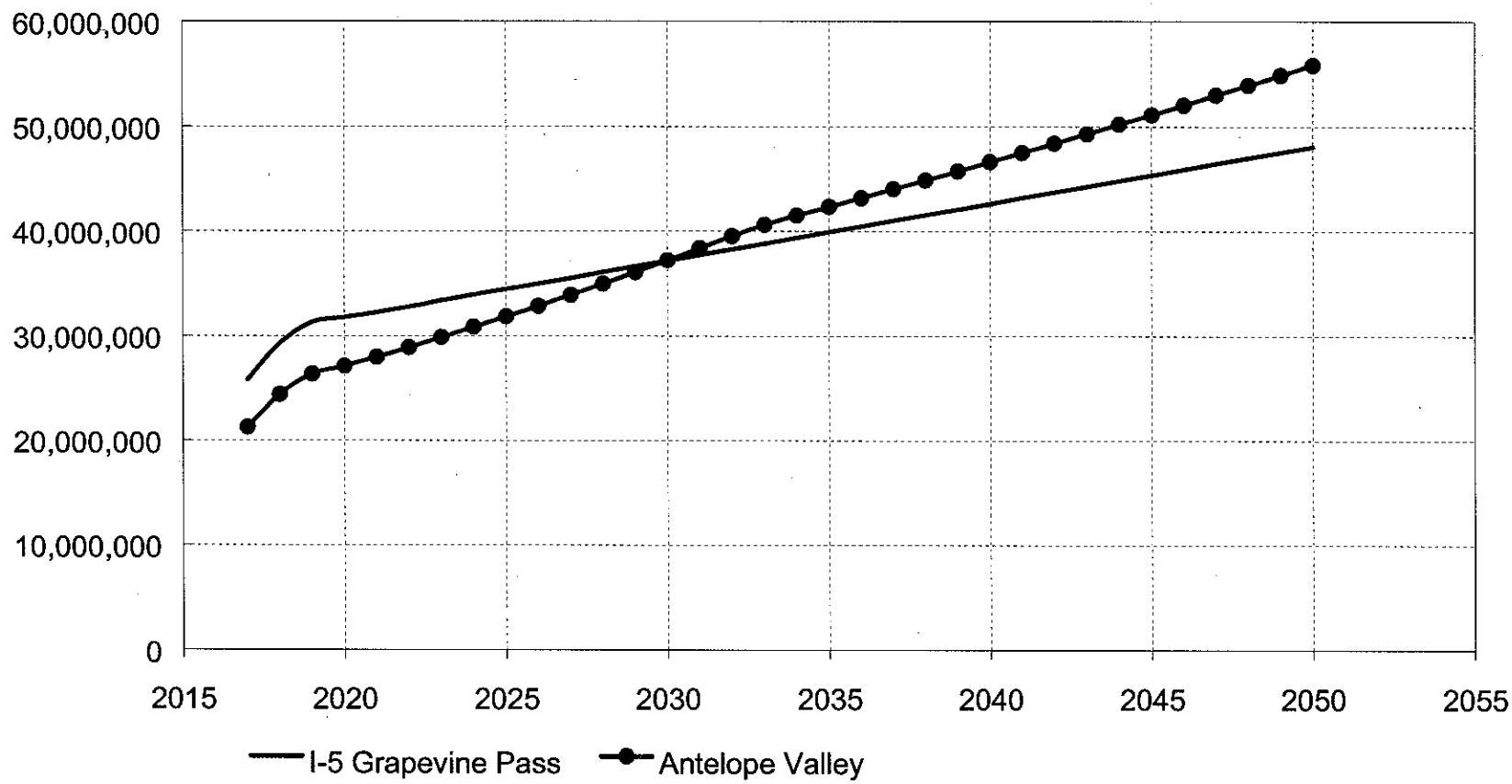
The second factor driving higher ridership and revenue under the Antelope Valley option above that of I-5 Grapevine is the pattern of population and employment growth. Whereas the routing along the I-5 Grapevine would be cross areas of wilderness and lightly-populated rural districts, the Antelope Valley alignment would serve an the established growth path for population and industry in region. As a key national growth pole for aerospace and other high technology industrial expansion, the Antelope Valley is projected to witness a rate of annual population and employment growth three to four times that of the state overall. Resident population in the Antelope Valley is expected to swell from 360,000 today to some 700,000 by 2020, the implementation and initial ramp-up period for high-speed rail system.

As shown in Figure 12, while ridership (and revenue) would initially be higher under an I-5 Grapevine-aligned system, this relationship quickly changes in favor of the Antelope Valley option as growth in that region surges at the rate several times that of the more established urban centers of Los Angeles and the San Francisco Bay Area.

6.2 Economic Integration

As used in this report, "economic integration" is the extent to which a new investment (such as the high-speed rail system) will connect with, complement, and support other transportation modes and the businesses they serve, thereby maximizing the multiplicative economic effects of these resources. It is through such network effects that transportation infrastructure in general can maximize its contribution to economic efficiency and high living standards in regional economies.

Figure 12: Intercity Ridership Projections



Due principally to the added accessibility afforded by the Antelope Valley over the I-5 Grapevine option, the former is stronger in relation to intermodal connectivity and industrial "agglomeration." Trackage through the Antelope Valley will provide two kinds of modal connectivity, namely an inter-modal connection for air travelers using the Palmdale Regional Airport, and a modal choice for long-distance auto users in the Antelope Valley growth corridor.

Agglomeration is a term for the economies of scale that arise in regional economies (rather than in single companies). Agglomeration economies create wealth and improved living standards at a regional scale. The Antelope Valley alignment would foster economies of scale within and between the aerospace industry and other Antelope Valley growth sectors, while the I-5 Grapevine alignment, a wilderness route, could not be expected to do the same. The estimated value of agglomeration economies associated with the Antelope Valley alignment is $540-818 million over the initial 33-year project life-cycle.

6.3 Economic Viability (Benefit/Cost Analysis)

The Antelope Valley option offers greater promise of economic benefits that exceed the costs of achieving them. As accurately described by the Authority's ridership and revenue consultant (Charles River Associates) the benefits of high-speed rail would occur in the form of travel time savings and vehicle operating cost savings for rail passengers and for remaining highway and aviation users; reduced loss of life, injuries, and property damage in highway accidents; and diminished volumes of air pollutants and greenhouse gases. Over its first 33 years of operation, a high-speed rail system employing the I-5 Grapevine alignment has been estimated to generate as much as $22.7 billion of economic benefit over and above the capital and operating costs of achieving these benefits (present value in 1999, in dollars of 1999 purchasing power). We estimate that the Antelope Valley alignment would generate an additional $.9 billion in net benefits above that expected under the I-5 Grapevine alternative (see Table 16).

It is noteworthy that the Antelope Valley alignment offers greater economic returns to the state of California in spite of the possibility that the I-5 Grapevine alternative could generate about 3.6 percent lower capital and operating costs. As discussed below, lower costs under the I-5 Grapevine option would occur only if the savings associated with building 41 fewer route miles offset the expense of the extra 17 miles of tunneling. While considerable uncertainty attaches to the true nature of this trade-off, the Antelope Valley would nevertheless generate stronger economic returns under even the most optimistic assumptions regarding the cost of tunneling across the I-5 Grapevine.

Table 16: Benefits Evaluation of Alternative Alignments

	Antelope Valley	I-5	Difference
Passenger Revenue (1)	$9,686	$9,651	$35
User Benefits			
Intercity	$8,464	$8,519	($55)
Urban (2)	$350	$317	$33
Subtotal User Benefits	$8,814	$8,835	($21)
Nonuser Benefits			
To Intercity Travelers (3)			
Airline Passenger Delay	$8,028	$7,765	$263
Aircraft Operating Delay	$4,407	$4,283	$125
Highway Delay	$3,760	$3,540	$219
Highway Accident Cost	$779	$780	($1)
Highway Air Pollution	$103	$103	$0
Subtotal	$17,077	$16,471	$607
To Urban Travelers (4)			
Highway Delay	$9,817	$8,822	$995
Highway Accident Cost	$360	$326	$34
Highway Air Pollution	$48	$43	$4
Subtotal	$10,225	$9,192	$1,034
Subtotal Nonuser Benefits	$27,303	$25,662	$1,640
Total Benefits	$45,802	$44,149	$1,654

(1) Does not include revenue from express commuter services

(2) Benefits to HSR express commuters

(3) From diversion of intercity travelers to HSR

(4) From diversion of intercity travelers AND commuters to HSR

6.4 Long Run Economic Impact

The long run total economic impacts associated with the Antelope Valley HSR alignment were estimated over a period of thirty years.[10] The simulation results indicate that total long run impacts could reach $3.1 billion, with an expected 38,603 additional jobs and over $2 billion in earnings. The eighty percent confidence interval shows that the range of possible earnings is between $1.3 billion to $2.9 billion; the range for possible additional jobs is between 26,478 and 53,130 permanent jobs. The range for the overall long run economic impact, with an eighty percent confidence level, is between $2.04 billion and $4.42 billion over the thirty-year period. The investment is expected to attract about 17,267 households to the Antelope Valley region.

Table 17 below summarizes the long-run economic impact estimates. The complete set of risk analysis results, based on the above assumptions, for employment, earnings, and the overall long run economic impacts are shown on the next pages.

Table 17: Long-Run Economic Impact Estimates, Summary Table

	Mean	80% Confidence Interval	
		Lower Bound	Upper Bound
Total Long Run Jobs	38,603	26,478	53,130
Total Long Run Direct Jobs	20,836	14,284	28,673
Total Long Run Indirect and Induced Jobs	17,766	12,165	24,581
Total Long Run Earnings, $Million	$2,033	$1,334	$2,912
Total Long Run Direct Earnings, $Million	$1,073	$706	$1,536
Total Long Run Indirect & Induced Earnings, $Million	$960	$889	$1,380
Incremental New Area Households	17,267	12,116	23,848
Total Long Run Impact, $Million	$3,096	$2,042	$4,424
Present Value of Total Long Run Impact, $Million	$818	$540	$1,169

[10] The estimation of the economic impact can be viewed as conservative, the estimation used a life cycle of only 30 years which is very short for this type of projects.

Figure 13: Long-Run Employment Impacts from Antelope Valley Alignment

Figure 14: Long-Run Earnings Impacts from Antelope Valley Alignment

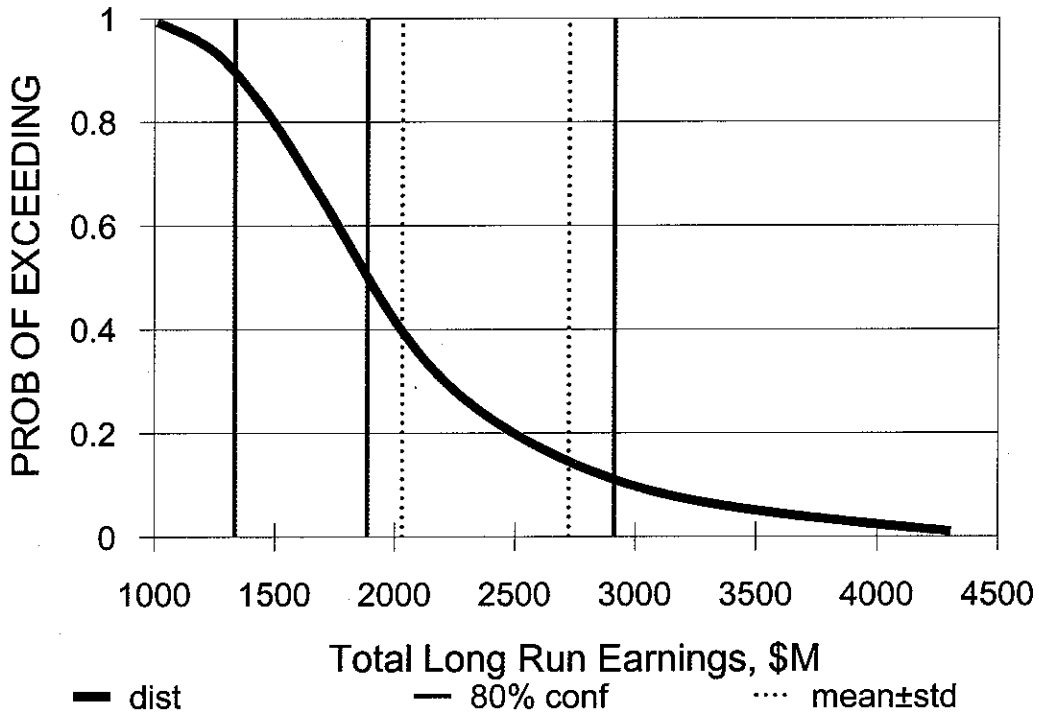
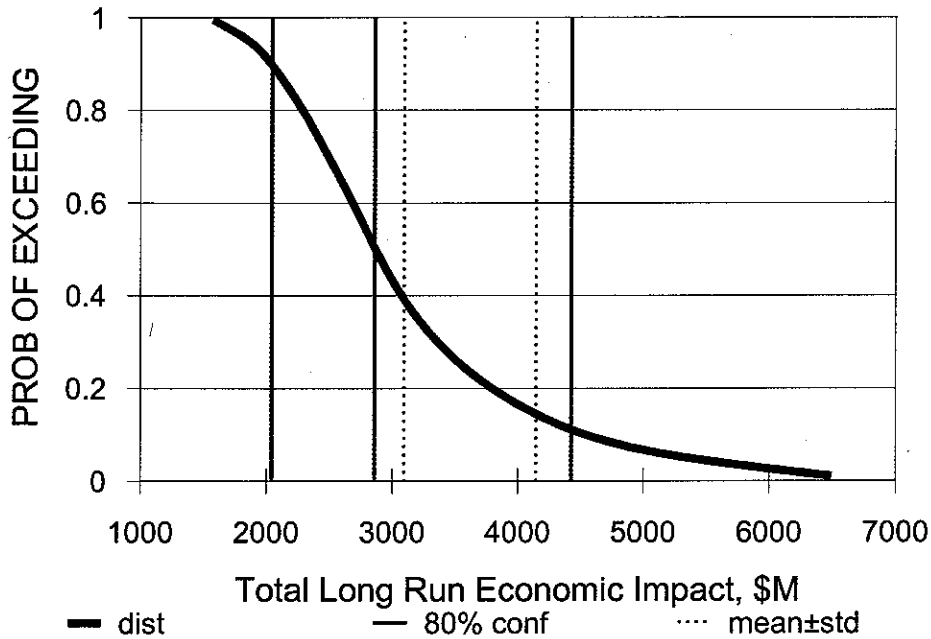


Figure 15: Total Long-Run Economic Impacts from Antelope Valley Alignment



One of the factors supporting the Antelope Valley alignment is the potential for high-speed rail to generate significant long-term economic development impacts. The economic, demographic and physical characteristics of the Antelope Valley community are poised to take advantage of HSR-based economic development activity in the state of California. Based on interviews[11] of the largest housing developers in California to determine the impact of HSR on housing, an HSR system through the Antelope Valley would be of great benefit because of the quick access to major cities, north and south of the valley. The developers stressed that capital expenditures involved in the construction and operation of the HSR will also stimulate the Southern California economy and that Antelope Valley would be a natural location to accommodate future population and housing growth in California.

The estimation in this chapter considers the high-speed rail's contribution in attracting individuals and families to the Antelope Valley, which is one of the few regions in the greater Los Angeles area, which can support residential and industrial growth. It was found that, under conservative assumptions, the economic development potential from high-speed rail in the Antelope Valley is about $3 billion over thirty years. It is clear, that the economic impact alone outweighs the possible increase in capital costs.

[11] ERA "Economic Impact and Benefit/Cost of High Speed Rail for California, Final Report", September 1996.

7. SUMMARY AND CONCLUSIONS

With 3.5% maximum grades, the extra costs and risks associated with tunnel construction along the I-5 alignment more than offset the 30 or so extra miles of construction necessary along the longer Antelope Valley Alignment. At any probability or risk level, the I-5 construction costs are larger than the Antelope Valley costs.

With 2.5% maximum grades, total construction cost along the Antelope Valley alignment is only marginally larger than along the I-5 alignment. Simulation results indicate that the range of possible costs for I-5 is larger than for the Antelope Valley, reflecting the considerable uncertainty associated with I-5 ground conditions, highlighted by Geodata in their assessment of geological risks.

For the HSR project as a whole, when considering the potentially disruptive effects of large schedule and cost slippages under the I-5 alternative, the Antelope Valley option appears as the less risky and less costly alternative. This is true under both maximum grade scenarios.

Broadening the analysis to include the economic benefits related to ridership and revenues, strengthens the finding that the Antelope Valley offers the stronger business case justification. The Antelope Valley option would generate significantly more economic opportunities and benefits than the I-5 alignment:

- The Antelope Valley option would result in higher cumulative ridership and revenue. It would result in a 10 to 12 minute longer travel time (or 7% of total travel time) between Los Angeles and San Francisco, but would also provide access to over 700,000 higher life-cycle population and related high-tech employment.

- The Antelope Valley option would provide greater intermodal connectivity (through the Palmdale Regional Airport), greater access to and support of key industrial resources, and over $540 million in aggregate net new economic stimulus over the project life-cycle.

- The Antelope Valley option offers the best chance for maximizing net project benefits. It would generate $23.5 billion in economic benefit *over and above* capital and operating expenses, or *$0.9 billion more* than the I-5 Alignment.

Overall, the Antelope Valley alternative is the risk minimizing option, when considering both general ridership and revenue risks, and the risks pertaining to construction costs and project schedule, as demonstrated in this report.

APPENDIX 1: PARSONS BRINCKERHOFF'S 1996 COST ESTIMATES

Table A-1: Total Project Costs, Phase 1, in Millions of *1996* Dollars

$ Millions, 1996	Antelope Valley		I-5	
	Low	High	Low	High
Total Length (in miles)	**439**	**448**	**398**	**406**
Station Costs	$536	$646	$481	$564
Track and Guideway Systems	$631	$724	$573	$664
Earthwork and Related Items	$639	$684	$1,180	$1,302
Structures	$2,180	$3,280	$2,220	$3,232
Grade Separations	$758	$1,440	$722	$1,126
Right of Way	$796	$1,191	$551	$881
Environmental Mitigation	$188	$268	$191	$257
Rail & Utility Relocations	$179	$475	$143	$344
Signals and Communications	$314	$319	$280	$288
Electrification Items	$778	$821'	$694	$744
Subtotal	**$6,999**	**$9,848**	**$7,035**	**$9,402**
Subtotal per Mile	**$15.9**	**$22.0**	**$17.7**	**$23.1**
Program Implementation (30%)	$2,100	$2,954	$2,111	$2,821
Contingency (25%)	$1,750	$2,462	$1,759	$2,351
Vehicles	$979	$979	$979	$979
Support Facilities	$285	$285	$285	$285
Total Cost	**$12,112**	**$16,528**	**$12,168**	**$15,837**
Total Cost per Mile	**$27.6**	**$36.9**	**$30.6**	**$39.0**

For Phase 1 only, from Fresno – San Jose to Los Angeles
Source: Parsons Brinckerhoff, 1996

APPENDIX 2: HLB'S INPUT DISTRIBUTIONS

Figure A-1: Density Function for Construction Time, 3.5% Maximum Grades

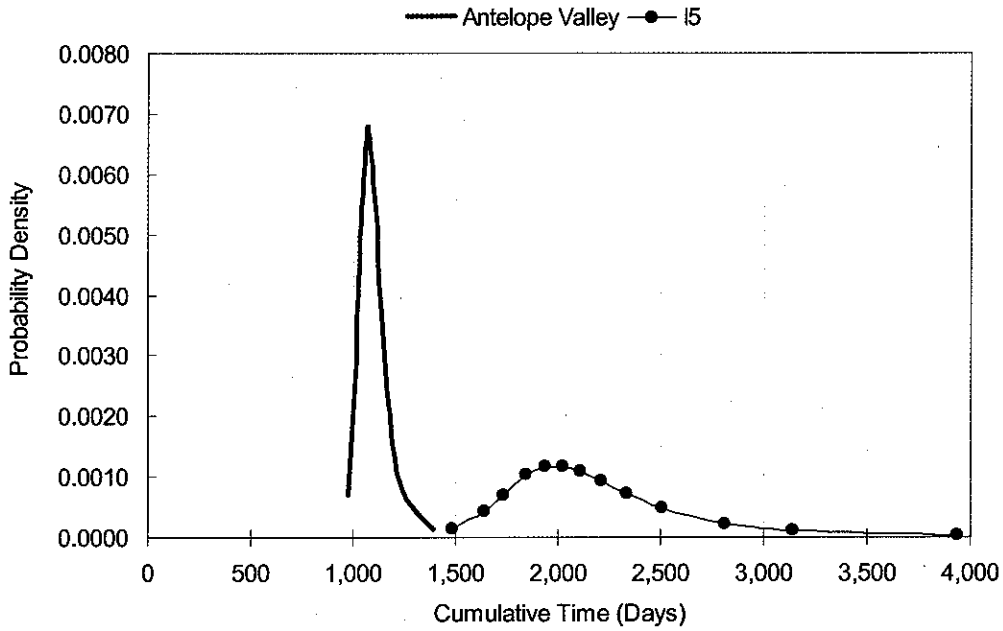


Figure A-2: Density Function for Construction Time, 2.5% Maximum Grades

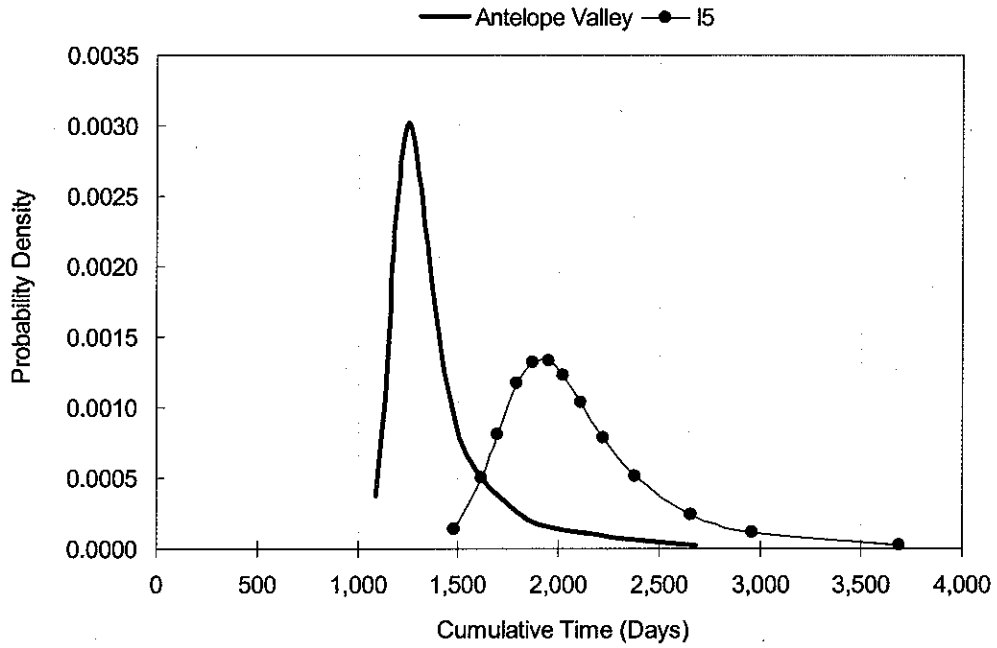


Figure A-3: Density Function for Construction Costs, 3.5% Maximum Grades

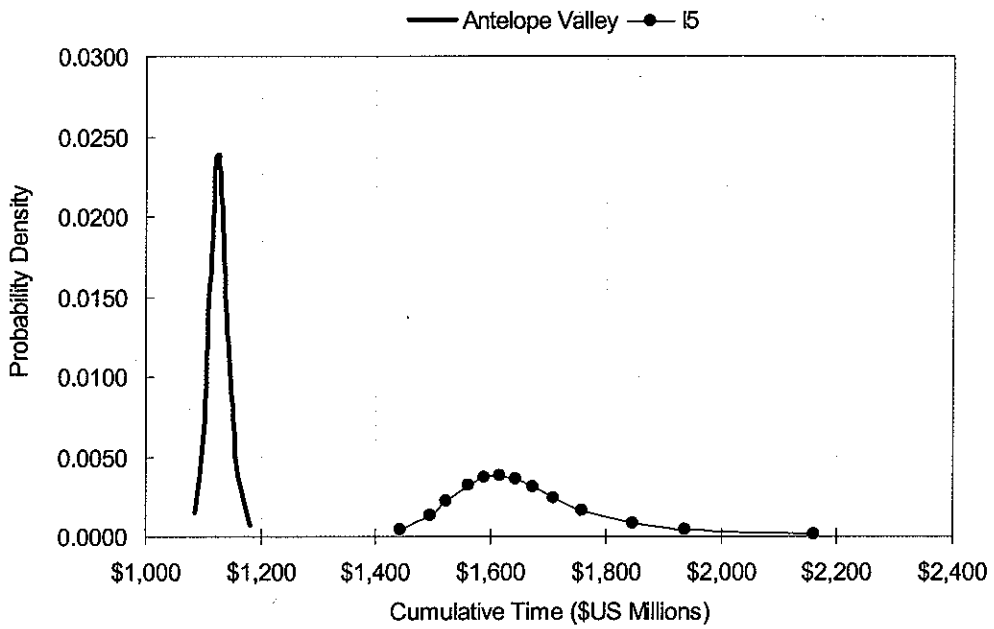


Figure A-4: Density Function for Construction Costs, 2.5% Maximum Grades

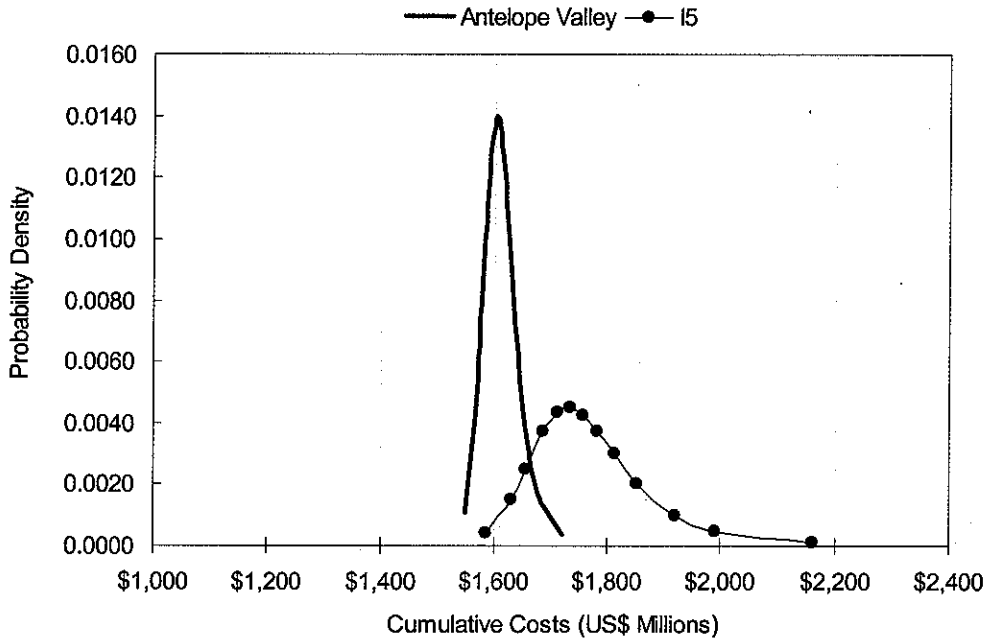


Figure A-5: Geodata Construction Time and Cost Estimates, 3.5% Maximum Grades

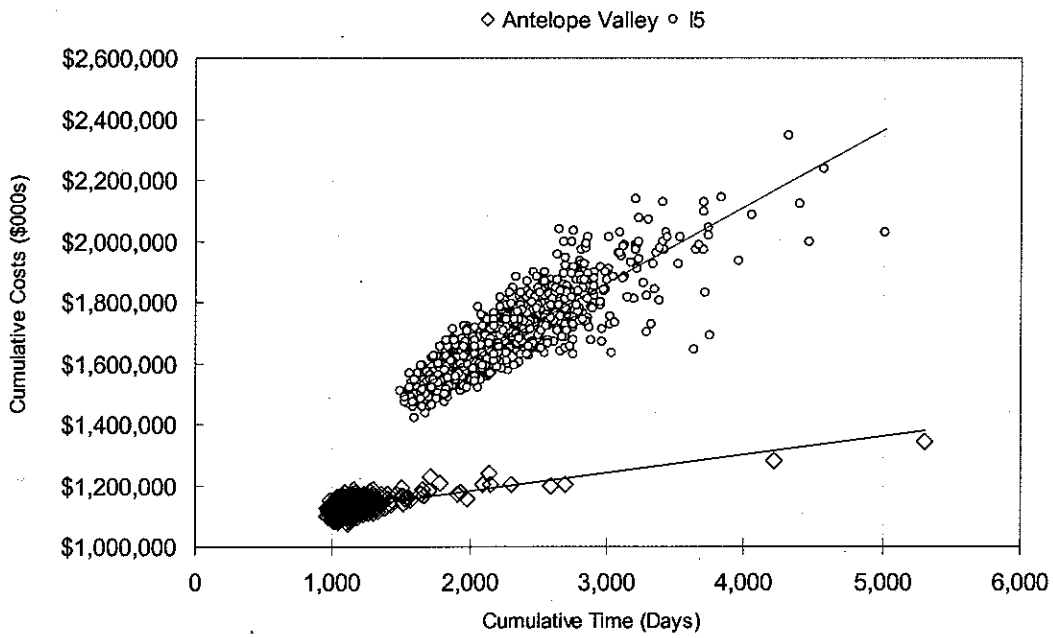


Figure A-6: Geodata Construction Time and Cost Estimates, 2.5% Maximum Grades

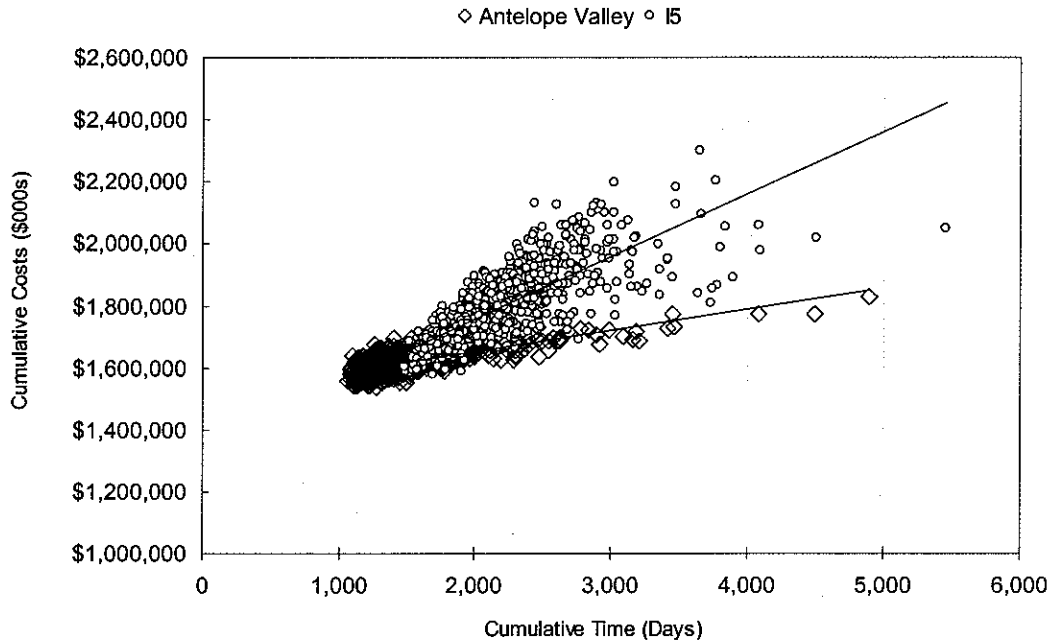


Table A-2: Phasing of Capital Expenditures, Millions of 1999 dollars

	Year																	
Item	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**Total**	**%Total**
PE/Environmental																		
Program Environmental	10	10															**20**	0%
Prelim. Engineering/EIS/EIR			75	100	100	75											**350**	1%
Right-of-Way							271	542	363	363	816						**2,355**	9%
Civil Engineering																		
Stations								83	165	165			214	214	214	214	**1,269**	5%
Line Construction							531	797	797	1,390	1,718	1,718	1,718	1,718	859		**11,246**	45%
Vehicles							98	98	98	98			196	196	196	196	**1,176**	5%
Systems																		
Track work							22	66	66	66	127	254	254	254	254	127	**1,490**	6%
Electrification							20	61	61	61	117	233	233	233	233	117	**1,369**	5%
Signaling & Communication							26	79	79	79	152	304	304	304	304	152	**1,782**	7%
Support Facilities							30	53	53	15		43	43	43	24		**304**	1%
Program Implementation							181	289	325	361	505	433	505	505	361	144	**3,609**	14%
Total	**10**	**10**	**75**	**100**	**100**	**75**	**1,179**	**2,068**	**2,007**	**2,598**	**3,435**	**2,985**	**3,467**	**3,467**	**2,445**	**950**	**24,970**	100%
%Total	0%	0%	0%	0%	0%	0%	5%	8%	8%	10%	14%	12%	14%	14%	10%	4%	100%	

Source: Final High-Speed Train Plan, California High Speed Rail Authority, http://www.cahighspeedrail.ca.gov

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