ATTACHMENTS TO COMMENT LETTER O008

O008
Attachment 1

A PRELIMINARY PROPOSAL

for the

PRIVATE SECTOR FINANCING

of the

PROPOSED TEHACHAPI MOUNTAIN RAILROAD TUNNELS

with the

COMBINATION FREIGHT AND PASSENGER SERVICE

for the

CALIFORNIA HIGH SPEED RAIL PROJECT

Presented to

Governor Arnold Schwarzenegger
State of California
Office of the Governor
State Capitol Building
Sacramento, California 95814

Submitted by

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June 5, 2004

SUMMARY

Project Description: Construction of three major railroad tunnels through the Tehachapi Mountains between Los Angeles and Bakersfield and with a total route distance of 76 miles of a total railroad network of 290 miles for the proposed California High Speed Rail system.

Transportation Modes: Facilitate intercity passenger transportation through high-speed rail passenger transport plus commuter rail passenger service in conjunction with intermodal freight transport of trucks plus long distance transport of containerized and merchandise freight.

Tunnel Facilities: The following specific railroad tunnel projects will be constructed between Los Angeles and Bakersfield.

1. Grapevine Grade Tunnel – 32 miles long triple tube with scheduled intermodal truck haul by rail plus high-speed intercity passenger trains between Grapevine and Castaic parallel to the Interstate 5 freeway route between Los Angeles and Bakersfield.

2. Tehachapi Pass Tunnel – 29 miles long double tube with long distance freight train haul plus high-speed intercity passenger trains between Caliente and Mojave parallel to the State Highway 58 route from Bakersfield to Mojave.

3. Soledad Pass Tunnel – 17 miles long double tube with high speed Intercity passenger trains plus suburban commuter trains to serve the Antelope Valley and Palmdale Airport freight between Ravenna and Saugus for the line between Santa Clarita and Palmdale.

Cost Estimates: The following estimates are made of the capital costs of the three railroad tunnel projects:

1. Grapevine Grade Tunnel:
   Double Tube - $3.5 Billion;
   Triple Tube - $5.3 Billion.

2. Tehachapi Pass Tunnel:
   Double Tube - $3.5 Billion;

3. Soledad Pass Tunnel:
   Double Tube - $1.7 Billion;

4. Total Capital Cost:
   All Three Tunnels: $8.7 – 10.5 Billion.

Financing Mechanism: Long-term debt financing mechanisms are to be considered as follows:

1. Revenue Bond Financing – Issued by California High Speed Rail Authority or by California Department of Transportation;

2. Direct Federal Loan – Issued through Railroad Rehabilitation and Infrastructure Financing (RRIF) program under the Intermodal Surface Transportation Efficiency Act (ISTEA) under Federal Railroad Administration of U. S. Department of Transportation.

3. Federally Guaranteed Loan – Issued through existing commercial banks with a 90 percent principal guarantee plus subsidized interest under Section 511 of the Railroad Revitalization and Regulatory Reform Act (4R – 511) through the Federal Railroad Administration of the U. S. Department of Transportation, Washington, D. C.

Recommended Action: Request a 4R – 511 Federally guaranteed loan through commercial bank(s) of up to $5.0 Billion for construction of the 32 mile long Grapevine Grade railroad tunnel as an initial double track facility for intermodal diversion truck rail haul and Amtrak passenger trains between Los Angeles and Bakersfield followed by high speed passenger trains upon approval of ballot initiative.

Loan Repayment: **Federally guaranteed loan repayment through user fees charged to trucking companies plus railroads for freight plus usage fees charged to the State of California for high speed intercity passenger trains plus the Southern California Regional Rail Authority for commuter trains**

Employment Creation:

The construction of the three railroad tunnels will result in the following numbers of jobs for 10 to 15 years.

1. **Direct Construction – 15,000 – 25,000 lobs;**
2. **Indirect Services - 35,000 – 50,000 jobs;**
3. **Total Employment - 50,000 – 75,000 jobs.**

Project Benefits: **The following benefits are to be expected from the construction of the three railroad tunnels through the Tehachapi Mountains between Los Angeles and Bakersfield:**

1. **It will be possible for the California high speed rail system to have two parallel routes between Los Angeles and Bakersfield via both the Grapevine Grade and the Antelope Valley within the project budget to connect Northern and Southern California;**

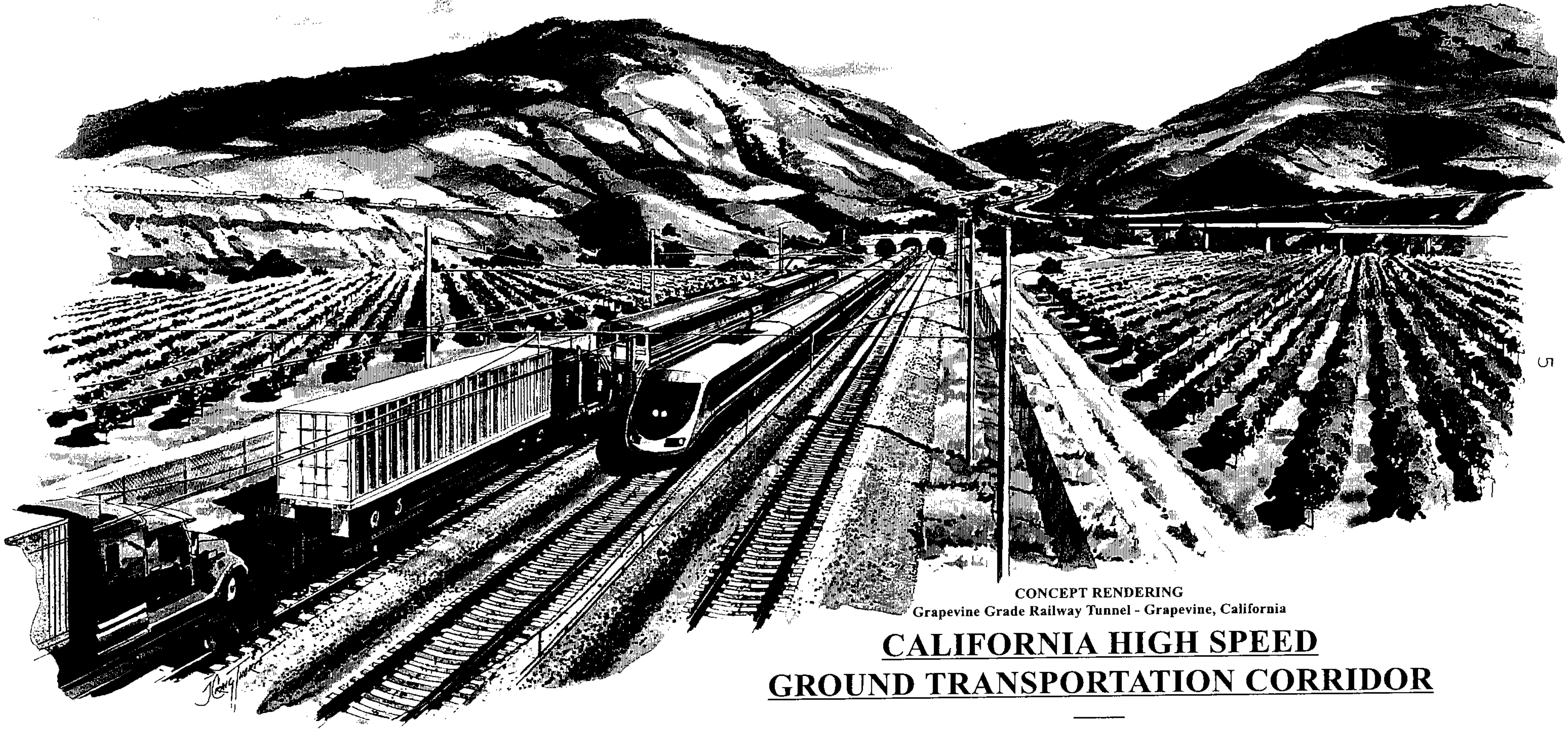
2. **Freight traffic revenues as well as passenger traffic revenues can be used for repayment of the major capital expenditures required for the major railroad tunnel infrastructure through the Tehachapi Mountains between Los Angeles and Bakersfield;**

3. **The very heavy truck traffic along the Interstate 5 freeway over the Grapevine Grade between Los Angeles and Bakersfield can be significantly reduced along with corresponding reductions in highway maintenance costs, roadway traffic congestion and air pollution emissions over a long term period;**

4. **The major railway freight traffic congestion bottleneck over the Tehachapi Mountains through the famous Tehachapi Loop can be Greatly reduced with large-scale rail capacity expansion for long distance containerized and merchandise freight transport between Northern California and the Midwest and South;**

5. **There are significant economic benefits to the State of California through increased employment creation and associated business expansion and improved tax revenues;**

Similar Project: The financing of the Grapevine Grade Railroad tunnel project is very similar to the 22 – mile long Alameda Corridor project between the San Pedro Bay ports and downtown Los Angeles at a cost of $2.45 billion funded by a Federal loan and part revenue bonds with per container transport fees.



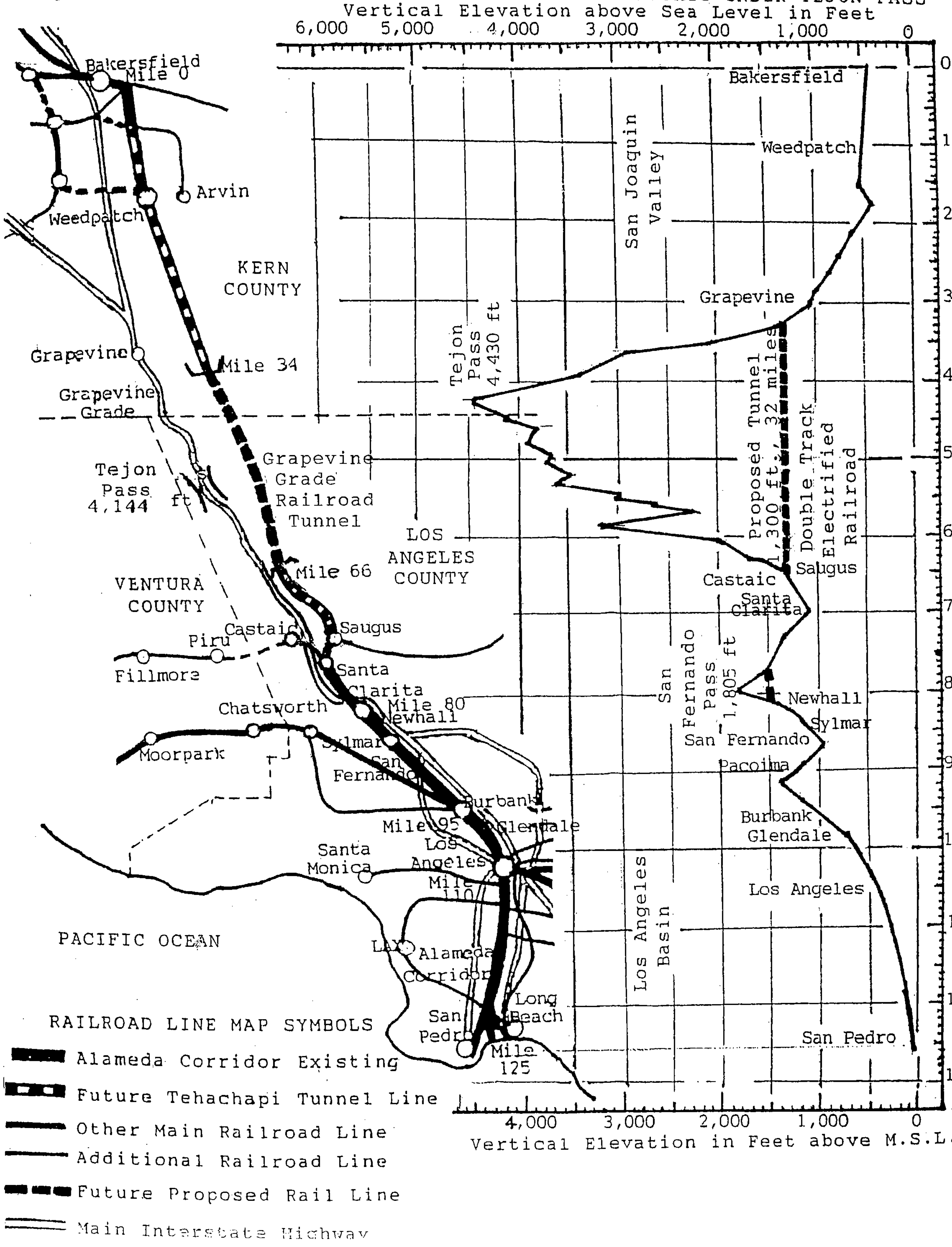
CONCEPT RENDERING
Grapevine Grade Railway Tunnel - Grapevine, California

CALIFORNIA HIGH SPEED GROUND TRANSPORTATION CORRIDOR

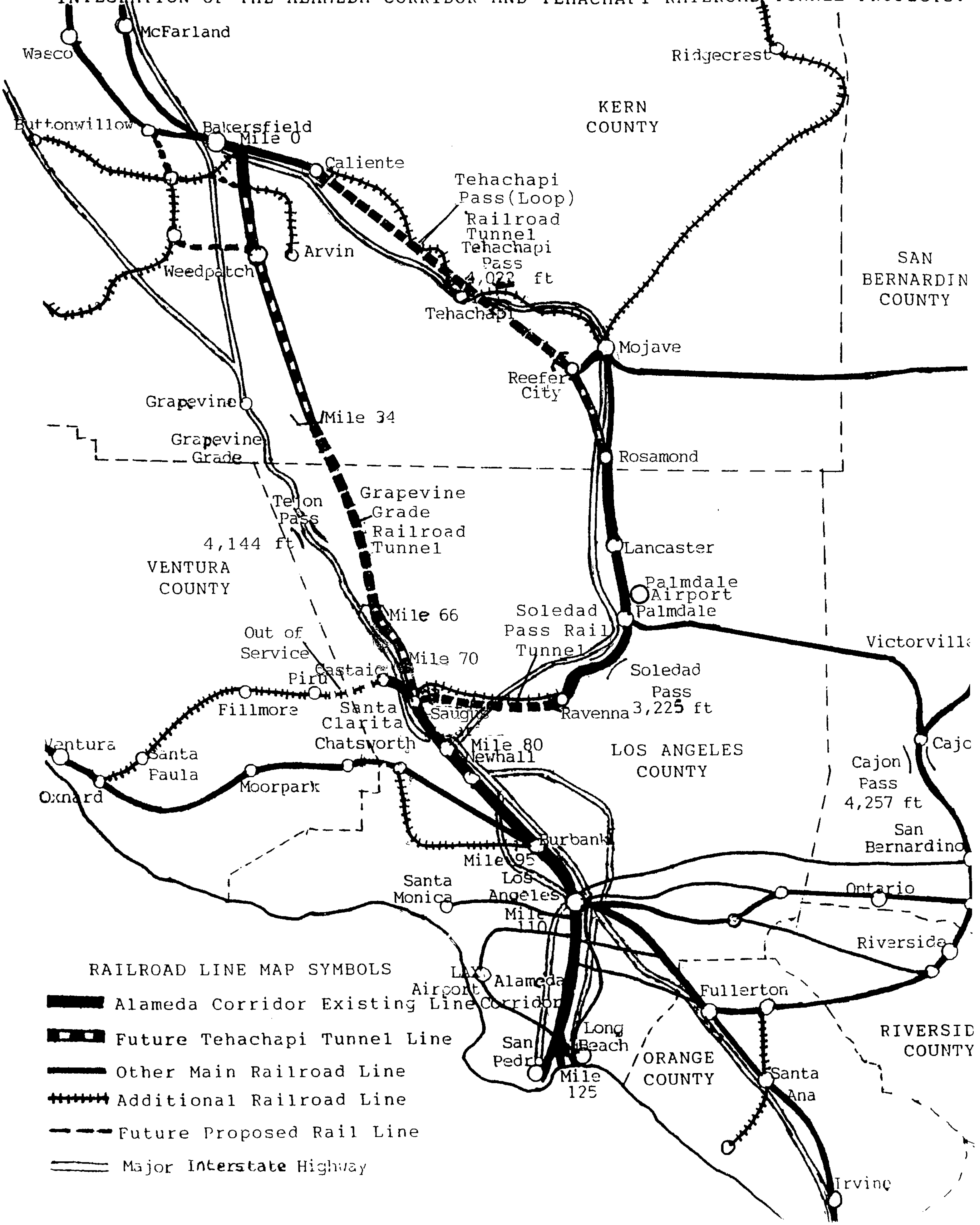
Commissioned by Cooper Consulting Co., Kirkland, WA, for

California Governor Arnold Schwarzenegger

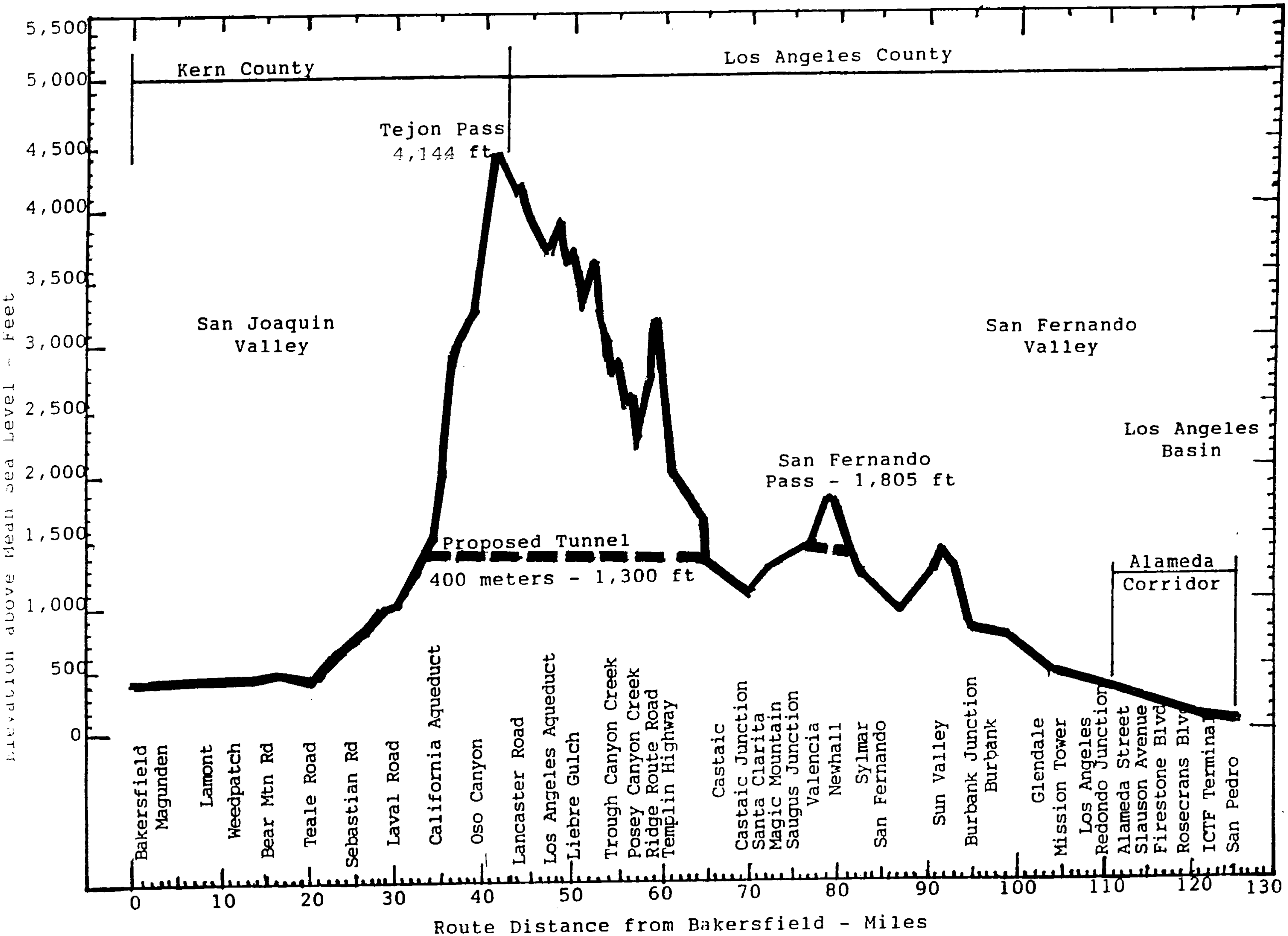
HORIZONTAL AND VERTICAL PROFILE OF THE PROPOSED RAILROAD TUNNEL IN THE TEHACHAPI MOUNTAINS FROM GRAPEVINE TO CASTAIC UNDER TEJON PASS



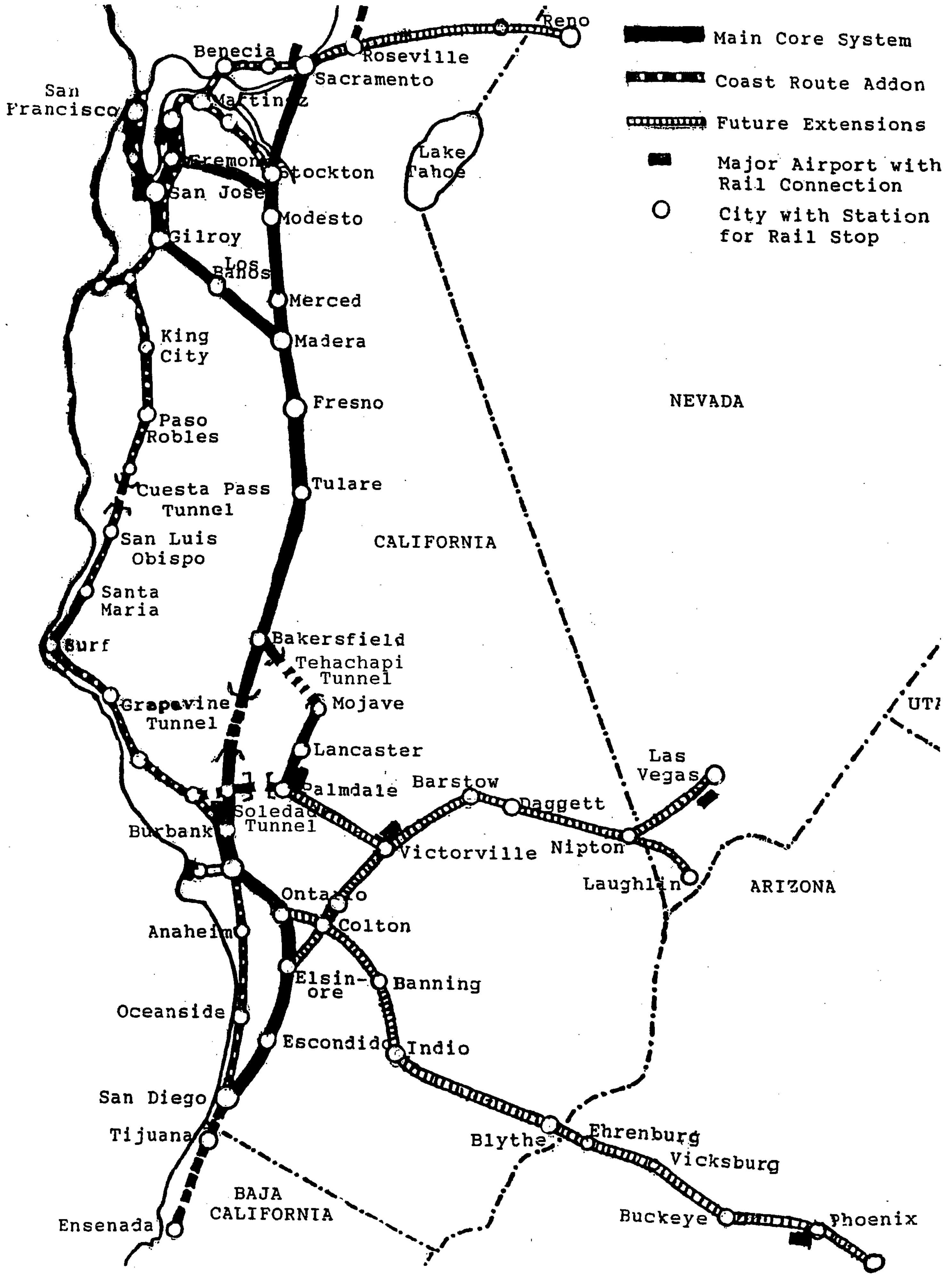
INTEGRATION OF THE ALAMEDA CORRIDOR AND TEHACHAPI RAILROAD TUNNEL PROJECTS.



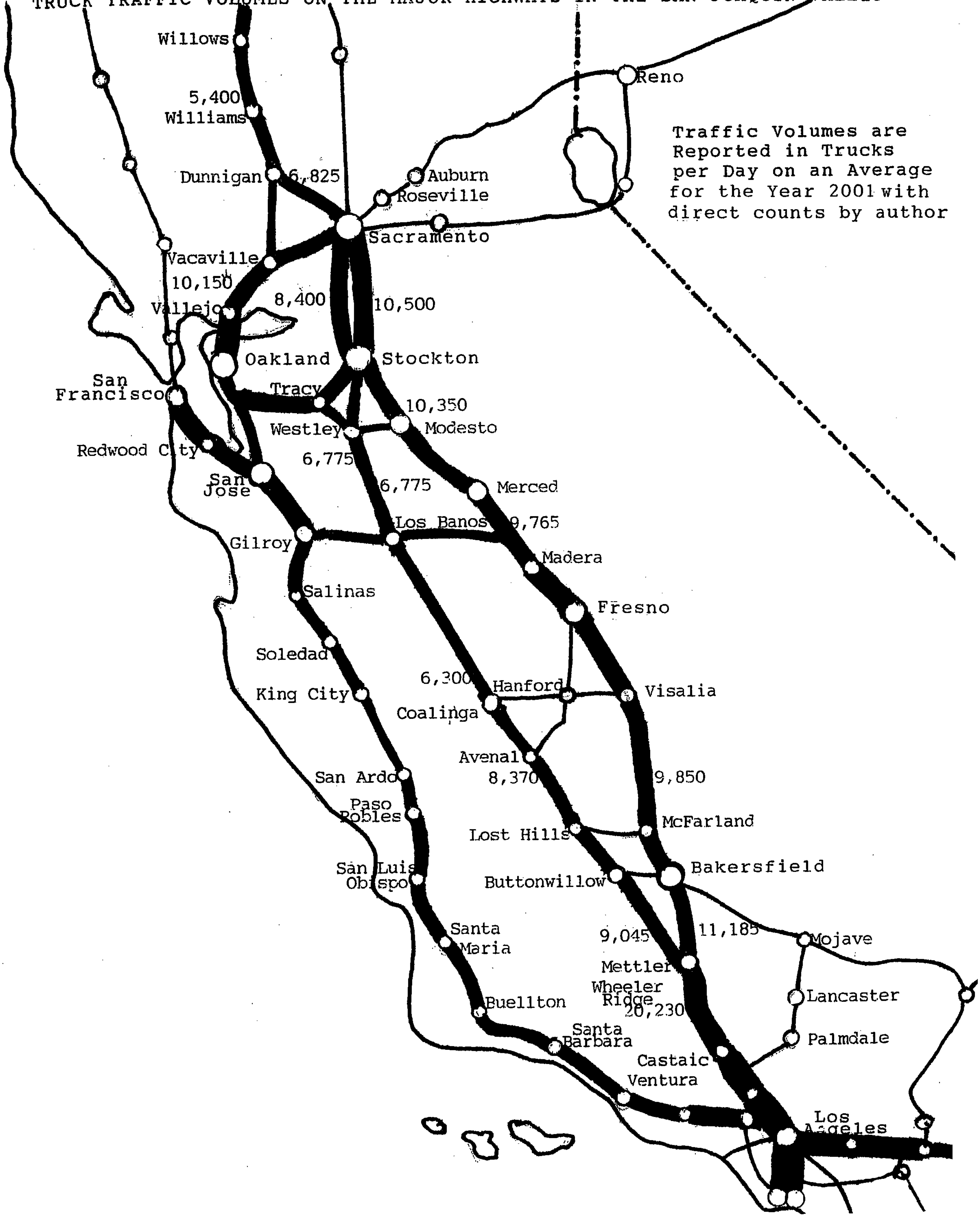
VERTICAL ELEVATION PROFILE FOR THE PROPOSED RAILROAD TUNNEL THROUGH THE TEHACHAPI MOUNTAINS



PROPOSED ROUTING OF THE EXTENDED CALIFORNIA HIGH SPEED RAIL PASSENGER SYSTEM



TRUCK TRAFFIC VOLUMES ON THE MAJOR HIGHWAYS IN THE SAN JOAQUIN VALLEY



O008
Attachment 2

REVISED VERSION

of the

POTENTIAL PRIVATE SECTOR FINANCING MECHANISMS

for the

PROPOSED TEHACHAPI MOUNTAIN RAILROAD TUNNELS

with the

COMBINATION FREIGHT AND PASSENGER SERVICE

of the

CALIFORNIA HIGH SPEED RAIL PROJECT

and the

FUTURE WEST COAST HIGH SPEED RAIL NETWORK

Prepared by

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For Presentation to the
Public Hearing of the
California High Speed Rail Authority
Fresno City Council Chambers
2600 Fresno Street
Fresno, California

April 28, 2004

The State of California is planning to construct a new-electrified high-speed rail passenger system of approximately 700 miles in length at an estimated capital cost of $37 billion which will be designed to carry up to 68 million passengers annually (185,000 passengers/ day). The proposed high speed rail passenger system is planned to connect all of the major metropolitan areas of the State of California together into a single route network in both Southern and Northern California with construction over a 10 to 16 year period. This proposed high speed rail passenger system serving the main urban areas of California can then be built at a much lower cost than the estimated $82 billion which would be required to expand its existing highway and airport system with 2,970 miles of new highway lanes and 60 new airport gates to provide the same expected future traffic volumes.

The high-speed passenger trains are expected to operate at speeds of up to 220 miles per hour with transit times between Los Angeles and San Francisco of less than 2.5 hours.

Perhaps the most difficult and costly part of the entire 700 – mile high speed rail system in California is the 110 to 120 mile section between Los Angeles and Bakersfield because of the alternative routes, the mountainous terrain and the potential geologic activity in the area. There have been two alternative routes proposed for this section between Los Angeles and Bakersfield along the Interstate 5 freeway over the Grapevine Grade and through the Antelope Valley in parallel to State Highway 14 and 58. The proposed Antelope Valley route is longer by 10 to 20 miles but has a significant rider ship potential in the Palmdale and Lancaster areas, and would serve the future Palmdale International Airport as a major air traffic hub. The proposed Interstate 5 freeway route is shorter and saves 10 to 12 minutes for trip times in the main project traffic market between San Francisco and Los Angeles, but involves extensive tunneling. The difficulty is that it adds significantly to the capital cost of the project to build both routes by at least $2.0 to 3.5 billion to serve these areas so that there would be benefits to then developing alternative financing structures.

In addition, there is a significant and growing problem of rapidly increasing truck traffic for freight transport on all of California's highways. Nowhere is this problem of increasing truck traffic of greater concern than along the main Interstate 5 freeway through California because of rising traffic congestion, air pollutant emissions and roadway maintenance costs. Nowhere is the problem of increasing truck traffic volumes along the Interstate 5 freeway as California's main north – south traffic artery greater than over the 45 – miles between Wheeler Ridge and Sylmar via the Tehachapi Mountains, and especially over the steep 7 mile long Grapevine Grade between Grapevine and Castaic.

In parallel, the rapidly increasing freight traffic volumes over its crowded railroad lines are creating a number of congestion bottlenecks. A major cause is the growing container traffic to and from the Ports of Los Angeles and Long Beach in Southern California as well as to and from the Port of Oakland in Northern California. Nowhere is this rail traffic bottleneck more severe than over the 75 mile Tehachapi Mountain line between Bakersfield and Mojave, which is an antiquated largely single-track line built in the 1870's which includes the notorious Tehachapi Loop. This Tehachapi Mountain railroad line has been basically saturated at a traffic level of 60 to 70 freight trains per day for 10 years.It is badly in need of expansion to relieve is probably California's greatest single rail transportation bottleneck.

A solution is proposed herein the present paper which will allow for all of the above – described problems to be either mitigated or eliminated as an discussed in the following paragraphs. It is proposed to construct the three major railroad tunnels which will be required through the Tehachapi Mountains for the California High Speed Rail Passenger System through private long term low interest financing mechanisms via a public – private – partnership vehicle. The financing instruments to be utilized can be either tax-exempt revenue bonds or other suitable long-term low interest rate debt financing instruments. These obligations will be repaid through unit charge assessments on a per train basis to be levied upon the operators of the individual systems.

This financing method is similar to that utilized for repayment of the port revenue bonds and the Federal loan used for the construction of the 22 – mile long Alameda Corridor project in Southern California by the Ports of Los Angeles and Long Beach. For freight transport, the unit charge assessments would be levied against the private railroads (Union Pacific or Burlington Northern Santa Fe) on a per train or per ton basis or against trucking companies who would utilize the intermodal service for diversion of either trailers or whole trucks hauled by flat car from road to rail and or its operator. For the affected commuter rail passenger trains operated by the Southern California Regional Rail Authority (SCRRA) the financing repayment charges would be levied on a unit per train or per passenger basis.

A separate unit per train or per passenger charge would need to be levied against the California High Speed Rail Authority (CHSRA) for the passage of the high speed passenger trains through the individual tunnels to the private entity for debt service repayment as well as track maintenance and electricity cost reimbursement until the financing instruments are retired over a long term period.

The three railroad tunnels to be constructed through the Tehachapi Mountains between Los Angeles and Bakersfield as a part of the proposed long term low interest private sector financing mechanisms are as follows: 1) the 32 mile long north – south Grapevine Grade railroad tunnel through the Tehachapi Mountains between Grapevine and Castaic for the route from Los Angeles to Bakersfield parallel to the Interstate 5 freeway; 2) the 29 mile long east – west Tehachapi Mountain railroad tunnel between Caliente and Reefer City for the route from Bakersfield to Mojave parallel to State Highway 58; 3) the 17 mile long east – west Soledad Canyon railroad tunnel between Ravenna and Saugus for the Antelope Valley line between Santa Clarita and Palmdale. These three railroad tunnels have a total distance of 78 miles, and will constitute critical components of the proposed California High Speed Rail System between Los Angeles and Bakersfield to connect Northern and Southern California together into a single network.

The high speed passenger trains of the public California High Speed Rail Authority are expected to operate in all three of the proposed Grapevine Grade, Tehachapi Mountains and Soledad Canyon railroad tunnels, with the major traffic flow through the Grapevine tunnel. In contrast, the main freight train flows will be through the Tehachapi Mountain railroad tunnel asexpected to be freight trains of the private Union Pacific Railroad and the Burlington Northern Santa Fe Railway carrying intermodal containers and other commodities. In addition, there are expected to be large scale movements of both intermodal trailers plus whole trucks on a scheduled shuttle service between Los Angeles and Bakersfield and beyond through the Grapevine Tunnel plus other traffic as well. The major movement of the public commuter trains will be through either the proposed Grapevine or Soledad tunnels between Los Angeles and either Bakersfield in the San Joaquin Valley or Lancaster in the Antelope Valley with relating little commuter train movements through the Tehachapi Mountain railroad tunnel.

It is expected that the greatest train traffic flows would be through the Grapevine Grade railroad tunnel because of the large-scale high-speed passenger train movements as well as the expected intermodal diversion truck transport service. There would be large-scale long distance intermodal container and merchandise manifest freight train movements through the Tehachapi Mountain railroad tunnel which would be expected to be primarily long distance between California and the Midwest, South and East plus the high-speed passenger trains serving the Antelope Valley. In addition, the Soledad Canyon railroad tunnel would handle the high-speed passenger trains serving the Antelope Valley plus the commuter trains as well as a limited number of freight trains carrying a variety of commodities.

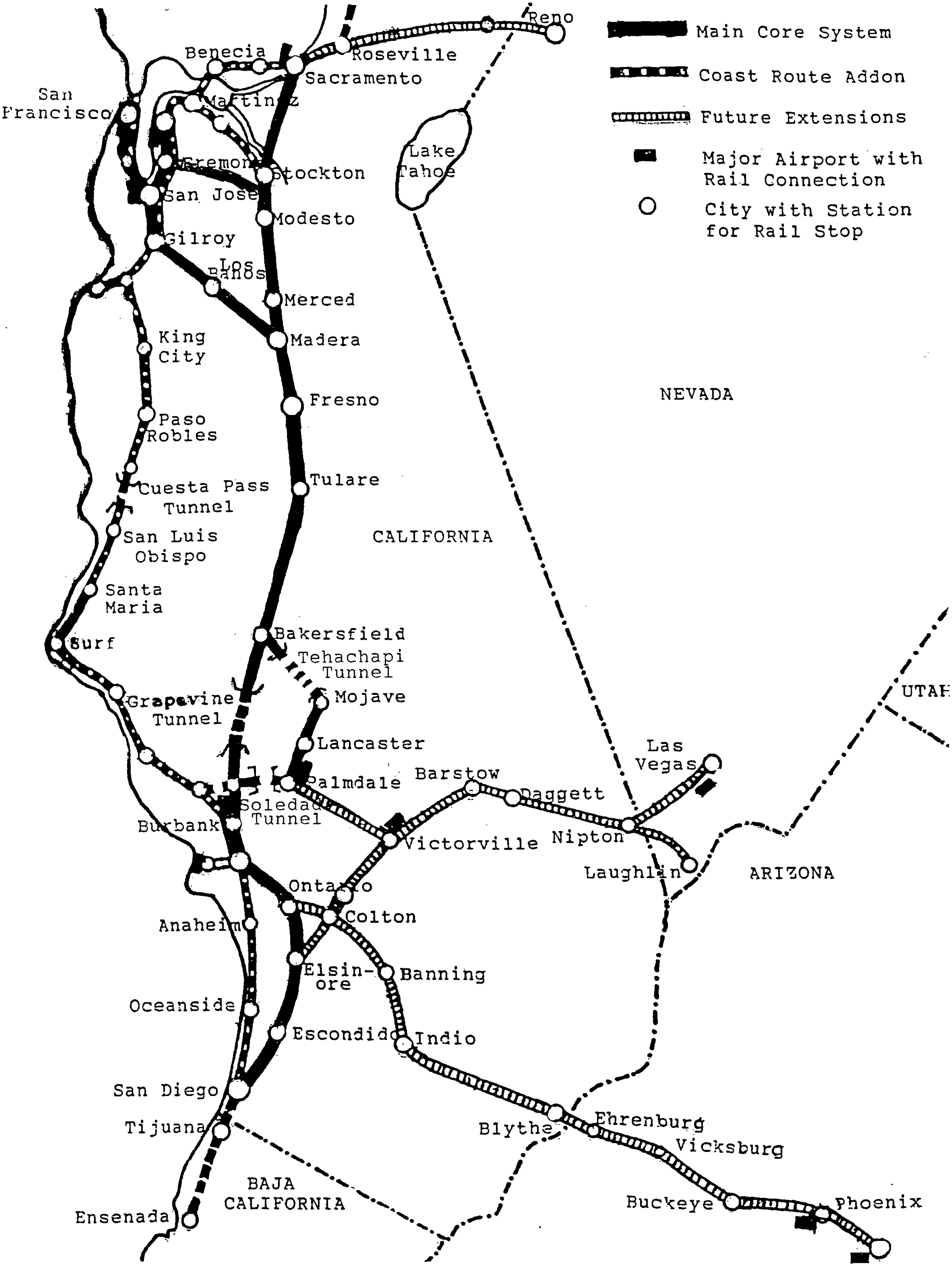
The potential advantage of the proposed financing mechanism for the expected private sector financing of the major railroad tunnel infrastructure projects between Los Angeles and Bakersfield is that the initial capital cost of the high speed rail passenger project to be paid for by funds raised directly by the California High Speed Rail Authority revenue bond issue to be approved by the voters could be significantly reduced by as much as $8 to 11 billion or used elsewhere.

The available funds of the Authority for initial project investment could then be stretched further so that either or both of the Antelope Valley or Inland Empire interior lines could be initially built because capital expenditures can be converted into operating expenditures. The proposed private sector financing mechanism can then be utilized to reduce the direct financial burden upon the already – strapped State of California so that other needs could then be met.

The proposed approach to the partial private sector financing of the California High Speed Rail Project makes it possible to not only make a cost – effective investment in improving intercity passenger mobility but to also improve freight transport capacity as well. The critical rise of intercity truck traffic and its associated roadway congestion, maintenance cost and air pollution burden can then be reduced while the urban benefits of truck transport can still be maintained. In addition, the vital and necessary transport of intercity freight on California's critical railroad network can be maintained and expanded while freeway traffic capacity is relieved. In all, private sector financing of the major railroad infrastructure for the Grapevine Grade, Tehachapi Mountain and Soledad Canyon railroad tunnels, can be and should be an essential element of the proposed California High Speed Rail System between Los Angeles and Bakersfield.

The same concepts could be applied to the subsequent future development of an overall West Coast high-speed rail corridor for freight and passenger service. It would then be possible to connect the California high-speed rail system with the Cascadia Corridor now being developed between Vancouver, British Columbia and Eugene, Oregon by the States of Oregon and Washington. There would also need to be major railroad infrastructure projects to be constructed through the Sacramento River Canyon, through the Siskiyou Mountains and the Cascade Mountains as well as major bridge or tunnel crossings of the Columbia River and the Fraser River. It is suggested that the three States of California, Oregon and Washington consider establishing a so-called Tri State High Speed Rail Development Authority to implement this project.

PROPOSED ROUTING OF THE EXTENDED CALIFORNIA HIGH SPEED RAIL PASSENGER SYSTEM



CONCEPT RENDERING
Grapevine Grade Railway Tunnel - Grapevine, California

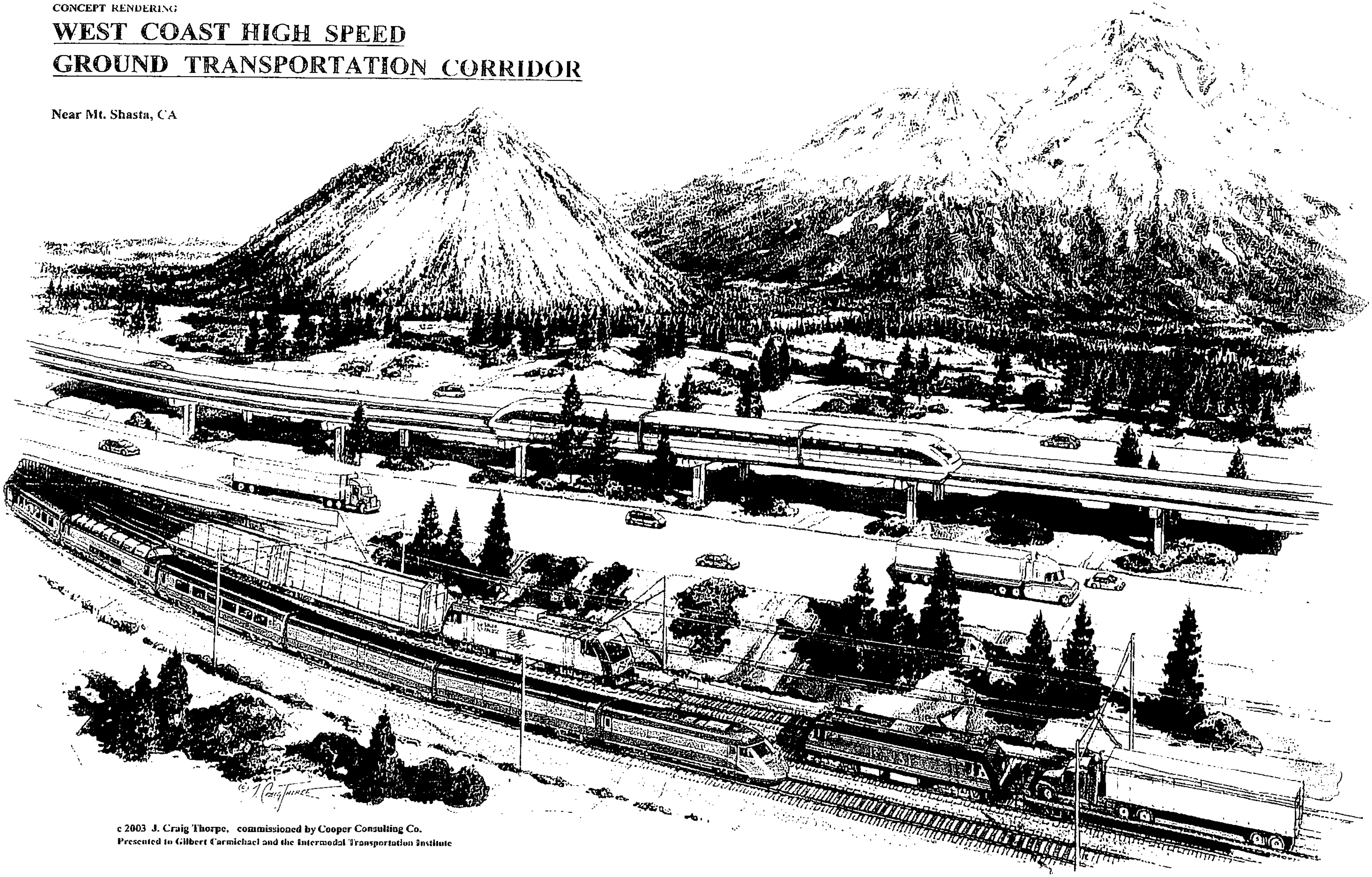
CALIFORNIA HIGH SPEED GROUND TRANSPORTATION CORRIDOR

Commissioned by Cooper Consulting Co., Kirkland, WA, for the California High Speed Rail Authority, Sacramento, CA

CONCEPT RENDERING

WEST COAST HIGH SPEED GROUND TRANSPORTATION CORRIDOR

Near Mt. Shasta, CA

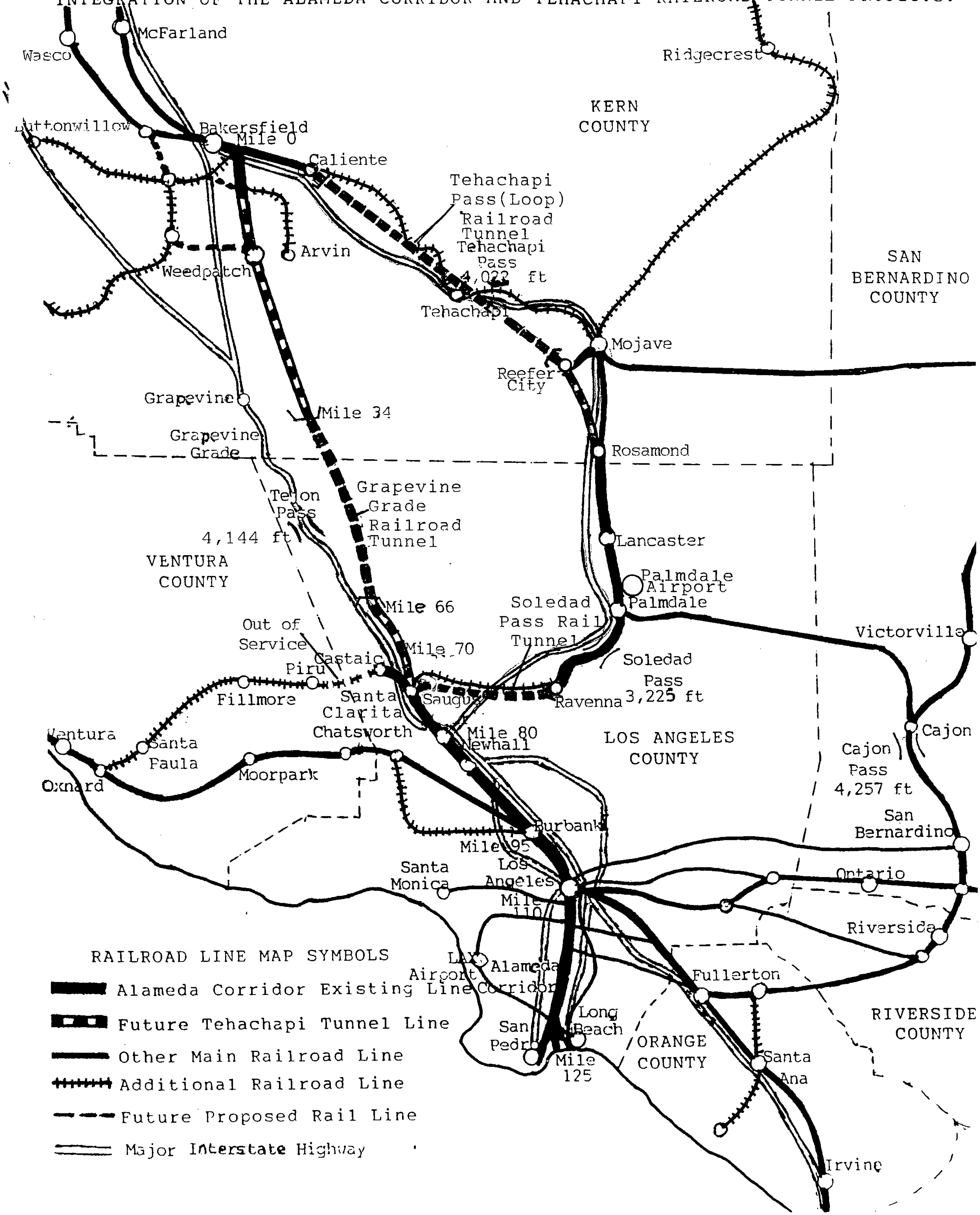


Presented to Gilbert Carmichael and the Intermodal Transportation Institute

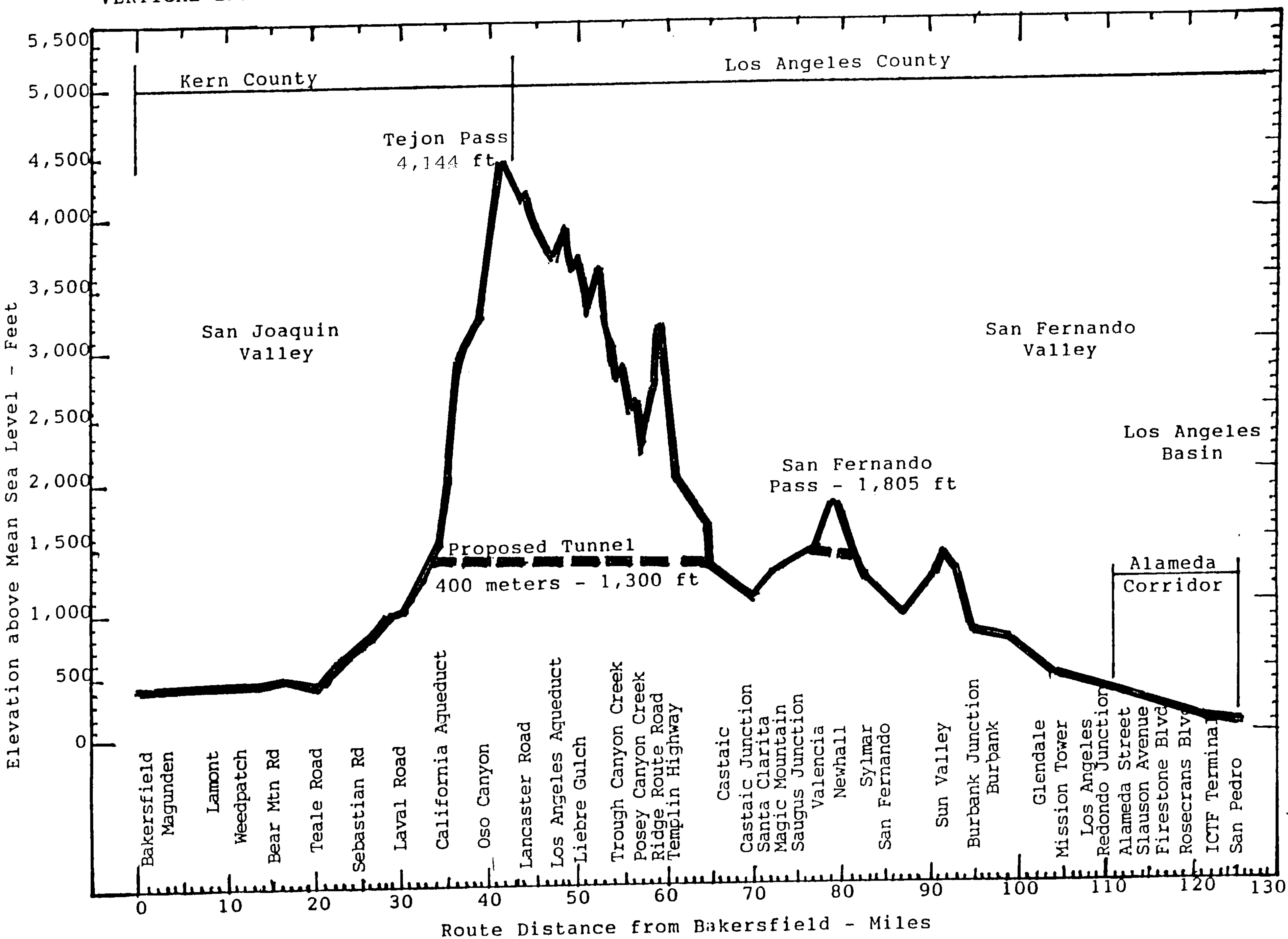
TEHACHAPI MOUNTAIN

RAILROAD TUNNELS

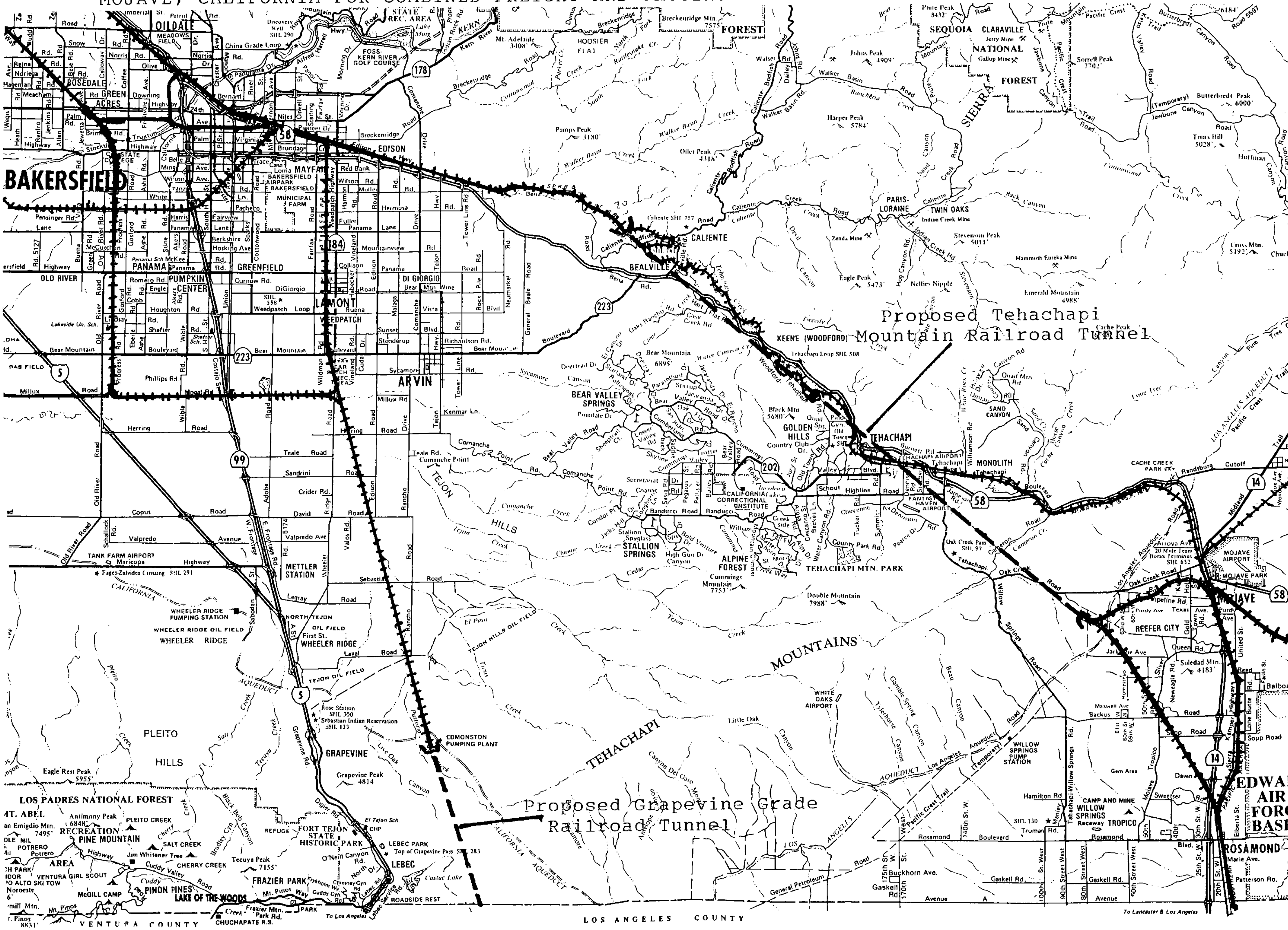
INTEGRATION OF THE ALAMEDA CORRIDOR AND TEHACHAPI RAILROAD TUNNEL PROJECTS.



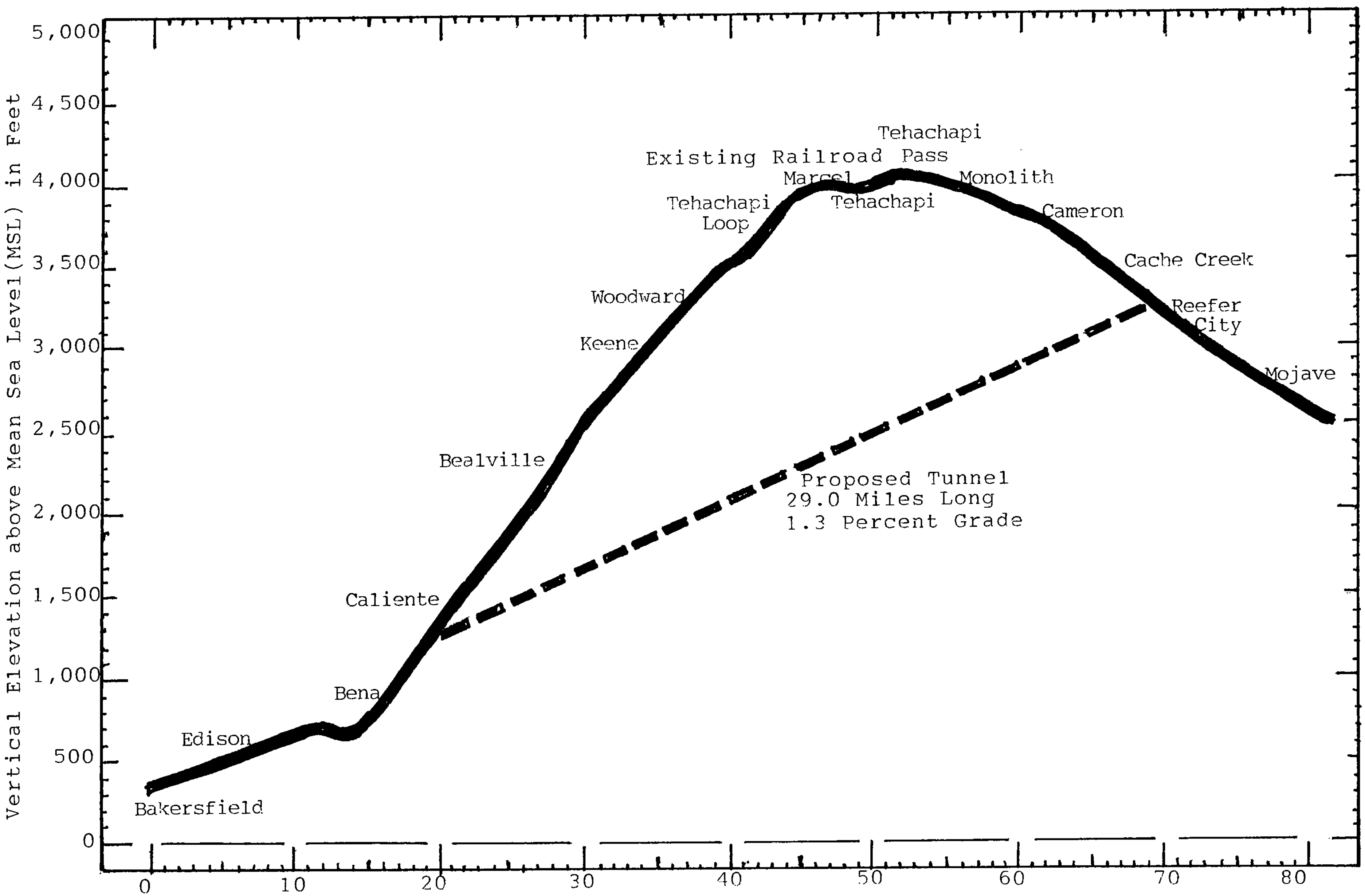
VERTICAL ELEVATION PROFILE FOR THE PROPOSED RAILROAD TUNNEL THROUGH THE TEHACHAPI MOUNTAINS



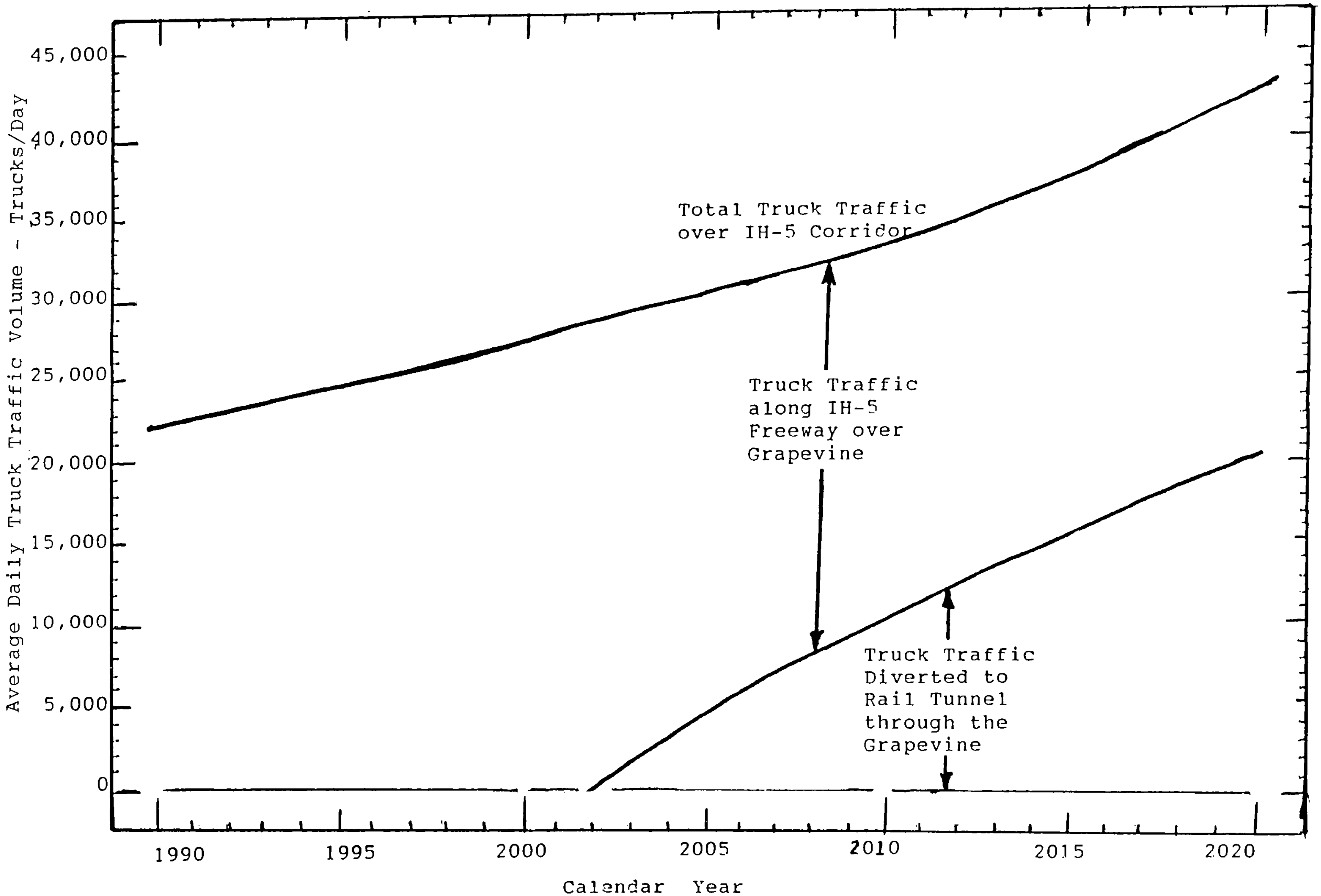
ROUTE LOCATION OF THE PROPOSED TEHACHAPI MOUNTAIN RAILROAD TUNNEL BETWEEN BAKERSFIELD AND MOJAVE, CALIFORNIA FOR COMBINED FREIGHT AND PASSENGER SERVICE WITH THE HIGH SPEED RAIL LINE



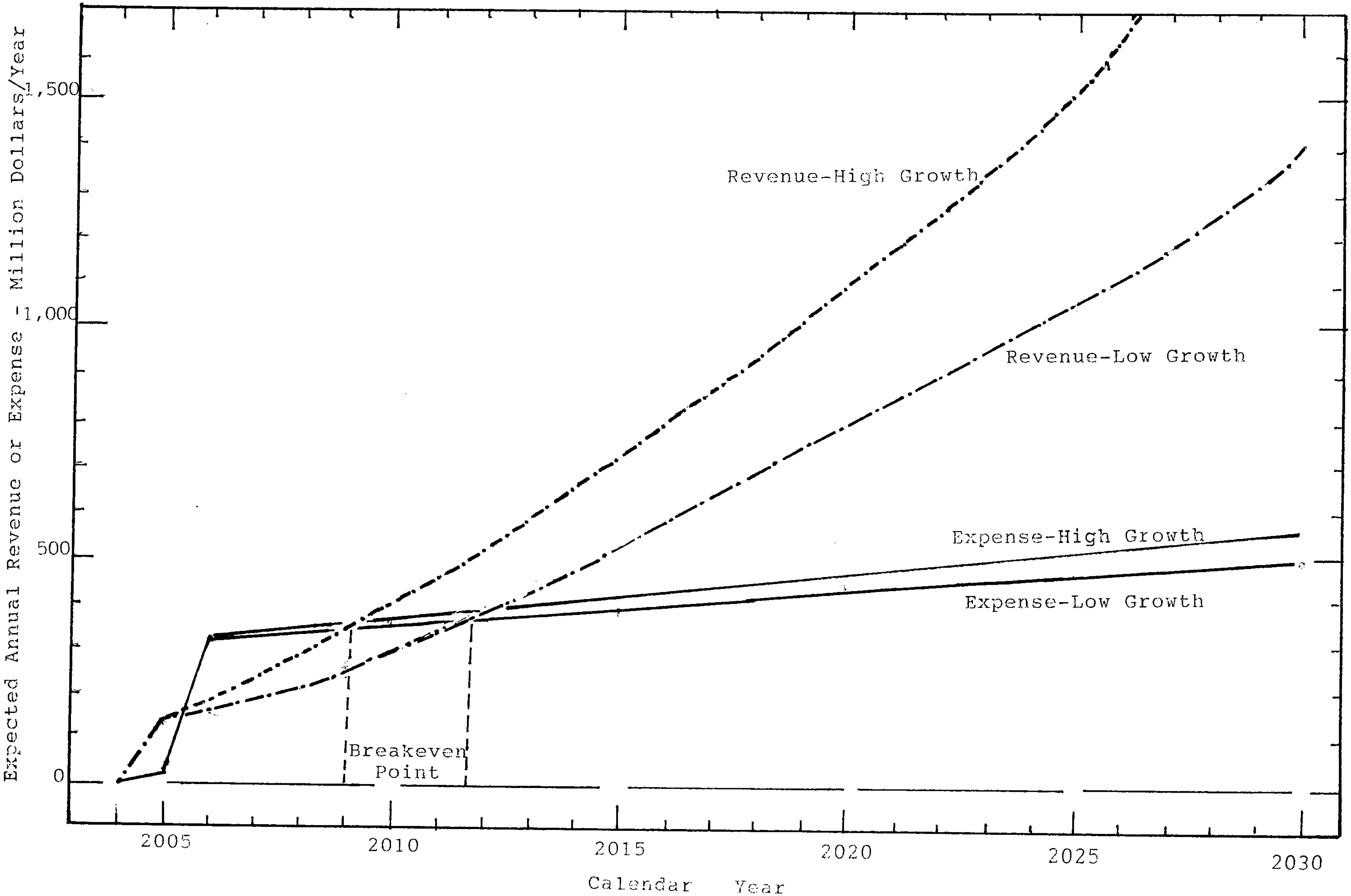
VERTICAL ELEVATION PROFILE OF THE PROPOSED TEHACHAPI MOUNTAIN RAILROAD TUNNEL BETWEEN THE CITIES OF BAKERSFIELD AND MOJAVE, CALIFORNIA AS PART OF THE CALIFORNIA HIGH SPEED RAIL LINE



ESTIMATED EFFECT OF INTERMODAL TRAFFIC DIVERSION OF TRUCK TRAFFIC FROM ROAD TO RAIL ALONG THE INTERSTATE 5 GOLDEN STATE FREEWAY BETWEEN LOS ANGELES AND BAKERSFIELD RESULTING FROM THE PROPOSED CONSTRUCTION OF THE GRAPEVINE GRADE RAILROAD TUNNEL FROM WEEDPATCH TO CASTAIC



PRELIMINARY ESTIMATE OF CASH FLOW PROJECTIONS FOR A PROPOSED TEHACHAPI MOUNTAIN RAILROAD TUNNEL



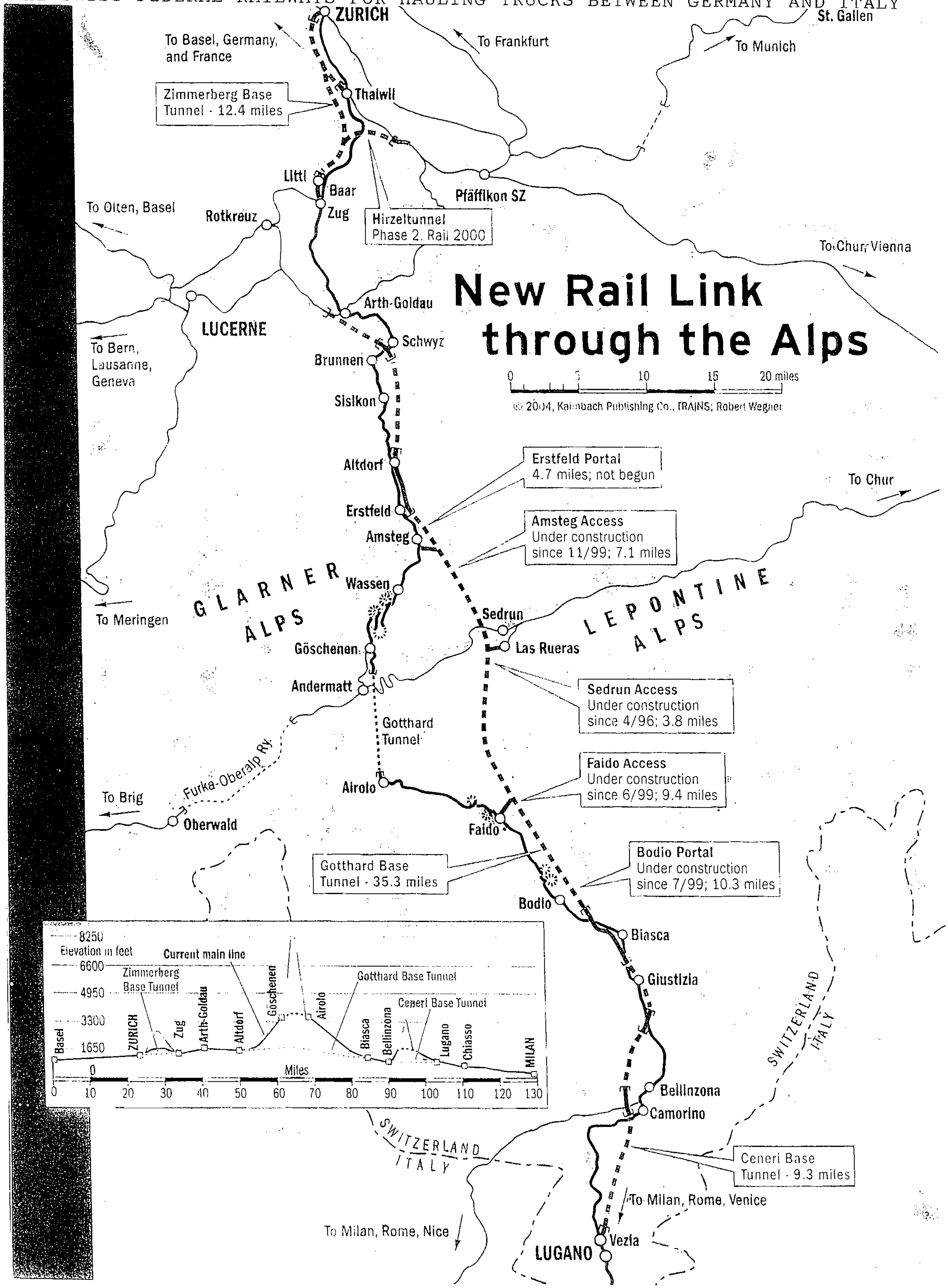
Grapevine Grade
Tunnel Project
Cash Flow Analysis $US

			Utilization of Truck Traffic					
			10%	15%	20%	25%	50%	75%
Traffic Assumptions:								
Truck Traffic (number of trucks per year)	7,300,000		730,000	1,095,000	1,460,000	1,825,000	3,650,000	5,475,000
Passenger Trains	100 /day		36,500	36,500	36,500	36,500	36,500	36,500
Revenue Assumptions:								
Revenue per Truck			$ 140	$ 140	$ 140	$ 140	$ 140	$ 140
Revenue per Passenger Train			$ 7,000	$ 7,000	$ 7,000	$ 7,000	$ 7,000	$ 7,000
Revenue:								
Trains:								
Intermodal Trains			$ 102,200,000	$ 153,300,000	$ 204,400,000	$ 255,500,000	$ 511,000,000	$ 766,500,000
Passenger Trains			$ 255,500,000	$ 255,500,000	$ 255,500,000	$ 255,500,000	$ 255,500,000	$ 255,500,000
Total Train Revenue			$ 357,700,000	$ 408,800,000	$ 459,900,000	$ 511,000,000	$ 766,500,000	$ 1,022,000,000
Truck Stop:								
Fuel	$ 7.50	per trk	$ 5,475,000	$ 8,212,500	$ 10,950,000	$ 13,687,500	$ 27,375,000	$ 41,062,500
Overnight Parking			$ 6,205,000	$ 6,205,000	$ 6,205,000	$ 6,205,000	$ 6,205,000	$ 6,205,000
Food, Showers, etc.			$ 9,125,000	$ 9,125,000	$ 9,125,000	$ 9,125,000	$ 9,125,000	$ 9,125,000
Warehouses			$ 1,920,000	$ 1,920,000	$ 1,920,000	$ 1,920,000	$ 1,920,000	$ 1,920,000
Total Truck Stop Revenue			$ 22,725,000	$ 25,462,500	$ 28,200,000	$ 30,937,500	$ 44,625,000	$ 58,312,500
Total Revenue			$ 380,425,000	$ 434,262,500	$ 488,100,000	$ 541,937,500	$ 811,125,000	$ 1,080,312,500
Expenses:								
Train:								
Operations			$ 1,600,000	$ 1,600,000	$ 1,600,000	$ 1,600,000	$ 1,600,000	$ 1,600,000
Administration	2.0%		$ 7,154,000	$ 8,176,000	$ 9,198,000	$ 10,220,000	$ 15,330,000	$ 20,440,000
Labor	2.0%		$ 7,154,000	$ 8,176,000	$ 9,198,000	$ 10,220,000	$ 15,330,000	$ 20,440,000
Total Train Expense			$ 15,908,000	$ 17,952,000	$ 19,996,000	$ 22,040,000	$ 32,260,000	$ 42,480,000
Truck Stop:								
Fuel	$ 3.75	per trk	$ 2,737,500	$ 4,106,250	$ 5,475,000	$ 6,843,750	$ 13,687,500	$ 20,531,250
Overnight Parking			$ 620,500	$ 620,500	$ 620,500	$ 620,500	$ 620,500	$ 620,500
Food, Showers, etc.			$ 6,387,500	$ 6,387,500	$ 6,387,500	$ 6,387,500	$ 6,387,500	$ 6,387,500
Warehouses			$ 192,000	$ 192,000	$ 192,000	$ 192,000	$ 192,000	$ 192,000
Total Truck Stop Expense			$ 9,937,500	$ 11,306,250	$ 12,675,000	$ 14,043,750	$ 20,887,500	$ 27,731,250
Total Expenses			$ 25,845,500	$ 29,258,250	$ 32,671,000	$ 36,083,750	$ 53,147,500	$ 70,211,250
Operating Profit			**$ 354,579,500**	**$ 405,004,250**	**$ 455,429,000**	**$ 505,853,750**	**$ 757,977,500**	**$ 1,010,101,250**

		Utilization of Truck Traffic					
		10%	15%	20%	25%	50%	75%
Alternative A - **Subsidized Loan at 3% Interest Rate**							
Operating Profit		$ 354,579,500	$ 405,004,250	$ 455,429,000	$ 505,853,750	$ 757,977,500	$ 1,010,101,250
Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Interest Expense (1st Year)		$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009
Profit Before Tax		$ 185,929,491	$ 236,354,241	$ 286,778,991	$ 337,203,741	$ 589,327,491	$ 841,451,241
Income Tax	30%	$ 55,778,847	$ 70,906,272	$ 86,033,697	$ 101,161,122	$ 176,798,247	$ 252,435,372
Net Profit		$ 130,150,644	$ 165,447,969	$ 200,745,294	$ 236,042,619	$ 412,529,244	$ 589,015,869
Add: Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Add: Interest Expense (1st Year)		$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009
Cash Flow Before Debt Service (1st Year)		$ 298,800,653	$ 334,097,978	$ 369,395,303	$ 404,692,628	$ 581,179,253	$ 757,665,878
Interest Expense (1st Year)		103,500,009	103,500,009	103,500,009	103,500,009	103,500,009	103,500,009
Principal Payment (1st Year)		$ 72,685,091	$ 72,685,091	$ 72,685,091	$ 72,685,091	$ 72,685,091	$ 72,685,091
Total Debt Service		176,185,100	176,185,100	176,185,100	176,185,100	176,185,100	176,185,100
Debt Coverage		1.70	1.90	2.10	2.30	3.30	4.30
Alternative B - **Subsidized Loan at 6% Interest Rate**							
Operating Profit		$ 354,579,500	$ 405,004,250	$ 455,429,000	$ 505,853,750	$ 757,977,500	$ 1,010,101,250
Depreciation		65,150,000	65,150,000	65,150,000	65,150,000	65,150,000	65,150,000
Interest Expense (1st Year)		$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845
Profit Before Tax		67,269,655	117,694,405	168,119,155	218,543,905	470,667,655	722,791,405
Income Tax	30%	-	-	-	$ 65,563,172	$ 141,200,297	$ 216,837,422
Net Profit		$ 67,269,655	$ 117,694,405	$ 168,119,155	$ 152,980,734	$ 329,467,359	$ 505,953,984
Add: Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Add: Interest Expense (1st Year)		$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845
Cash Flow Before Debt Service (1st Year)		$ 354,579,500	$ 405,004,250	$ 455,429,000	$ 440,290,578	$ 616,777,203	$ 793,263,828
Interest Expense (1st Year)		222,159,845	222,159,845	222,159,845	222,159,845	222,159,845	222,159,845
Principal Payment (1st Year)		$ 45,932,307	$ 45,932,307	$ 45,932,307	$ 45,932,307	$ 45,932,307	$ 45,932,307
Total Debt Service		268,092,152	268,092,152	268,092,152	268,092,152	268,092,152	268,092,152
Debt Coverage		1.32	1.51	1.70	1.64	2.30	2.96

NORTHERN ENTRANCE TO THE ST. GOTTHARD RAILROAD TUNNEL NEAR GOSHENEN, SWITZERLAND

LOCATION OF THE NEW GOTTHARD BASE TUNNEL BETWEEN ZURICH AND LUGANO, SWITZERLAND OF THE SWISS FEDERAL RAILWAYS FOR HAULING TRUCKS BETWEEN GERMANY AND ITALY



SWITZERLAND AT A GLANCE

Freight crossing the Alps in 2001

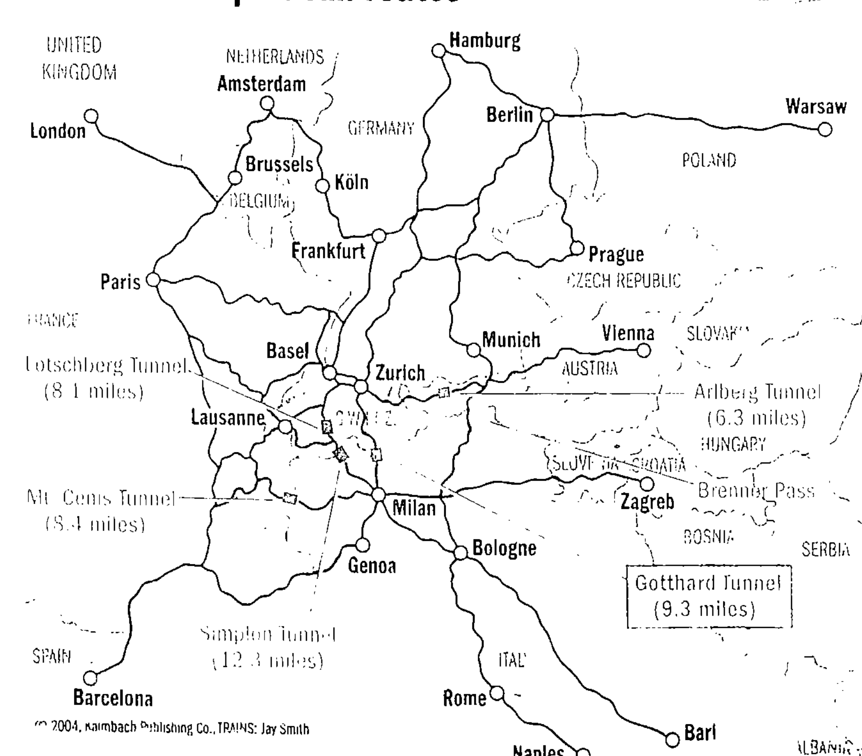
	SWITZERLAND		AUSTRIA		FRANCE		TOTAL	
	million tons	%	million tons	%	million tons	%	million tons	%
Rail	22.8	67	17.3	28	10.4	19	50.5	33
Highway	11.4	33	45.3	72	43.8	81	100.5	67
Total	34.2	100	62.6	100	54.2	100	151.0	100

Source: Litra, Informationsdienst für den öffentlichen Verkehr, www.litra.ch

Panoramic cars on SBB's Intercity trains let passengers take in the mountain scenery.

Engineer Karl Enz, in the cab of an Re 460 electric, takes an Intercity train over Gotthard.

Main trans-Alpine rail routes



Switzerland transportation

POPULATION	
2002	7.2 Million

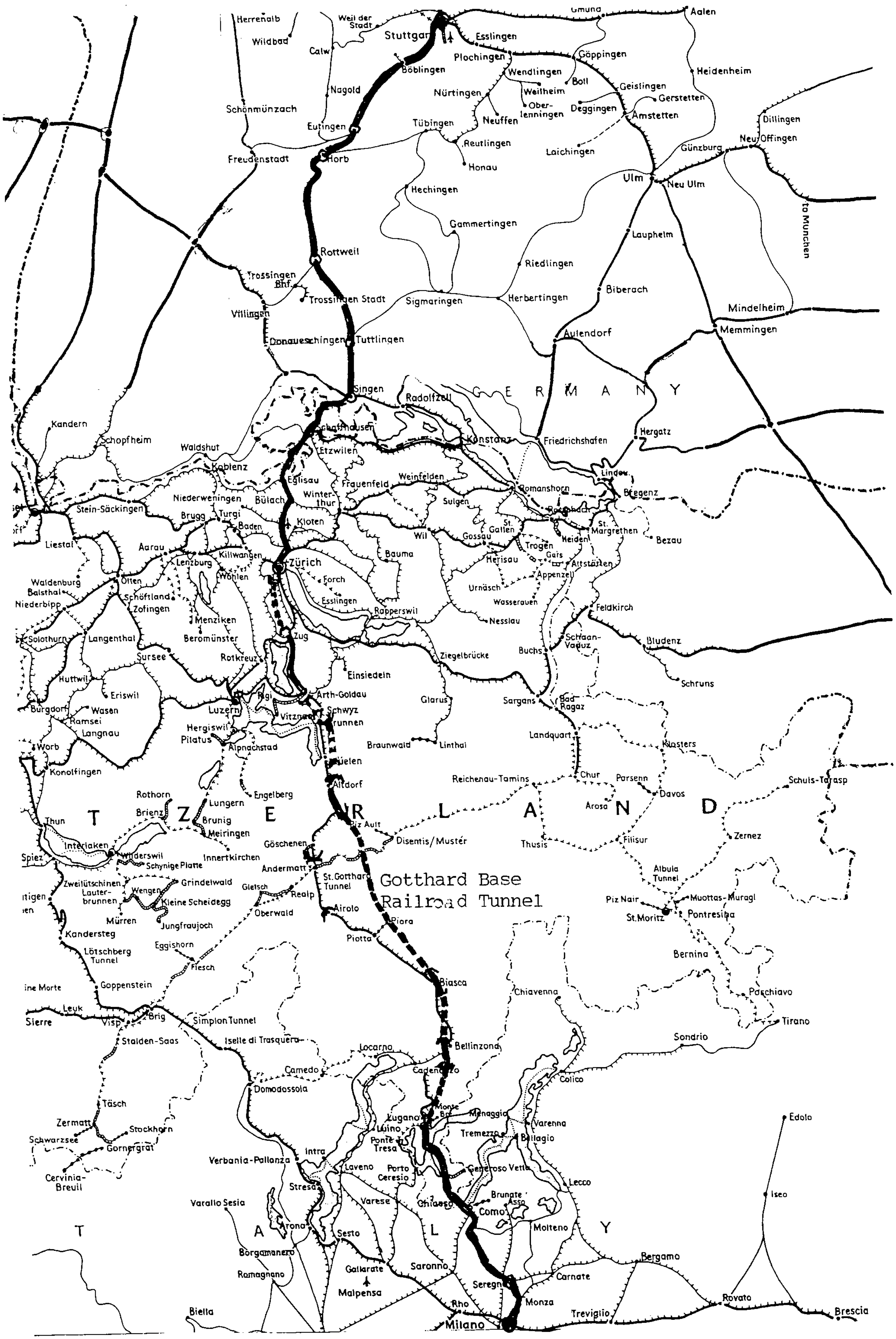
AVERAGE TRAIN JOURNEYS	
Per year/person	47
Average distance	26 miles

RAIL NETWORK	
Freight/passengers moved by rail in 2001 (ton-miles)	4.4 million
Standard gauge	2,269 miles
Narrow gauge	859 miles
Not electrified	less than 12 miles
Railway stations	1,842
Number of Tunnels	700
Total mileage in tunnels	245
Bridges	7,495
Total mileage on bridges	81
Track owned by:	
Swiss Federal Rys. (SBB)	1,868 miles
Bern-Lötschberg-Simplon	152 miles
Other track owners	49 private railways

HIGHWAYS	
Total length	44,118 miles
Autobahn 6 lanes	50 miles
Autobahn 4 lanes	738 miles
Autobahn 2 lanes	174 miles
Freight/passengers moved in 2001 (ton-miles)	14.1 million
Truck trips in Switzerland:	
Over Swiss Alps in 2003	1.29 million

Source: BAV, Bundesamt für Verkehr, www.bav.admin.ch

ROUTE LOCATION OF THE ST. GOTTHARD TUNNEL AND RAILROAD TRUCKWAY BETWEEN STUTTGART, GERMANY AND MILAN, ITALY THROUGH THE ALPS MOUNTAINS IN SWITZERLAND



NEWSPAPER ARTICLES

California high-speed rail line would reduce congestion, boost economy, study says

A new environmental impact report states that a high-speed rail linking California's major cities would be less expensive and more environmentally friendly than building out highways and airports.

According to the 2,000-page document released Jan. 27 by the **California High-Speed Rail Authority** (CHSRA), as many as 68 million riders would use high-speed trains by 2020, significantly reducing congested freeways, improving air quality and boosting the state's economy.

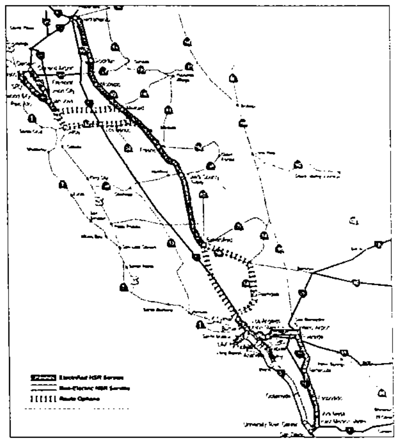
The report compares the 700-mile network option with two other scenarios. Under the first scenario, the state would only complete or build already approved transportation projects. The second one would opt for building more highways and airport gates at a cost of nearly $82 billion.

"The basic conclusion of this report is that the high-speed train is the best solution for California's intercity travel needs," CHSRA Executive Director **Mehdi Morshed** stated in a *Los Angeles Times* article.

The network would eventually link San Francisco, Sacramento, Fresno, Los Angeles and San Diego with trains reaching speeds up to 220 mph. At an estimated cost as high as $37 billion, the system is half as expensive as adding 2,970 miles of new highway lanes, nearly 60 airport gates and five runways.

However, the cost of the project has risen since 1999, when the high-speed rail authority estimated the bullet-train network at $25 billion.

The first leg of the route from Los Angeles to San Francisco could be funded through a $9.95 billion bond on the November ballot. But considering the state's budget deficit, Governor **Arnold Schwarzenegger** proposed to postpone the bond measure until 2006.



A proposed high-speed rail network would link San Francisco, Sacramento, Fresno, Los Angeles and San Diego with trains reaching speeds up to 220 mph.

B4 FRIDAY, MARCH 26, 2004 Los Angeles Times

MTA Backs a Bullet Train Route Through High Desert

By KURT STREETER
Times Staff Writer

The Metropolitan Transportation Authority decided Thursday to back a proposed high-speed rail route through the Antelope Valley.

The route is one of two options being studied by the California High-Speed Rail Authority, which is now nearing completion on a plan for a $37-billion electric-powered bullet train that would go from Los Angeles' Union Station to downtown San Francisco in two hours and 25 minutes.

The state-backed authority proposed two routes in an environmental review that was released in January and is to be completed during the next several months. One plan calls for a route between Bakersfield and Los Angeles that would run roughly parallel to the Golden State Freeway. Another option is to build tracks between Bakersfield and Los Angeles through the Antelope Valley, with a stop in Palmdale.

The cost would be about the same for either route. But travel time — the bullet train's prime selling point in what would likely be fierce competition with air travel — would probably increase on a trip from Los Angeles to San Francisco by at least 12 minutes if the train went through the Antelope Valley.

MTA officials said the time lost would be offset by making the train accessible Antelope Valley commuters..

A $10-billion bond measure allowing construction to begin on the project is set to be placed before voters statewide in November. But legislators and Gov. Arnold Schwarzenegger are working to move the measure to 2006 because of the budget crisis.

Panel wants Riverside County in on rail deal

DAVE DOWNEY
STAFF WRITER

RIVERSIDE — A regional panel Wednesday urged the state not to leave the high-speed train station without Riverside County.

Voting unanimously, the Riverside County Transportation Commission requested that the California High-Speed Rail Authority include the county in the first phase of the $37 billion, 700-mile statewide system, rather than relegate the area to a future expansion that may not take place.

The commission also endorsed the state's plans for stations at Escondido, San Diego, UC Riverside, March Air Reserve Base and the Interstates 15-215 interchange in Murrieta.

The panel, which allocates more than $100 million a year for local freeway, rail and bus projects, also endorsed an alignment of the high-speed rail project that would run from Ontario Airport to Colton, turning south along I-215 through Riverside to Murrieta and Temecula.

Those positions will be forwarded to the rail authority as it prepares to adopt a 2,000-page environmental impact report. Comments are being accepted through May 15.

"As voluminous as it is, it is still missing some material," said Carl Schiermeyer, longtime consultant to the commission.

Schiermeyer said it is clear that a $10 billion bond on the November ballot — at least for now — would fund a first phase defined as Los Angeles to San Francisco. But he said the report is not at all clear on when the section through Riverside County to San Diego would be built; it only suggests pumping extra money from fares into other parts of the system.

Making the picture even more fuzzy, the bond includes $1 billion for improvements to existing rail lines. And the line on the coast between Los Angeles and San Diego is expected to benefit widely from that pot, receiving money for tunnels, bridges and tracks, Schiermeyer said.

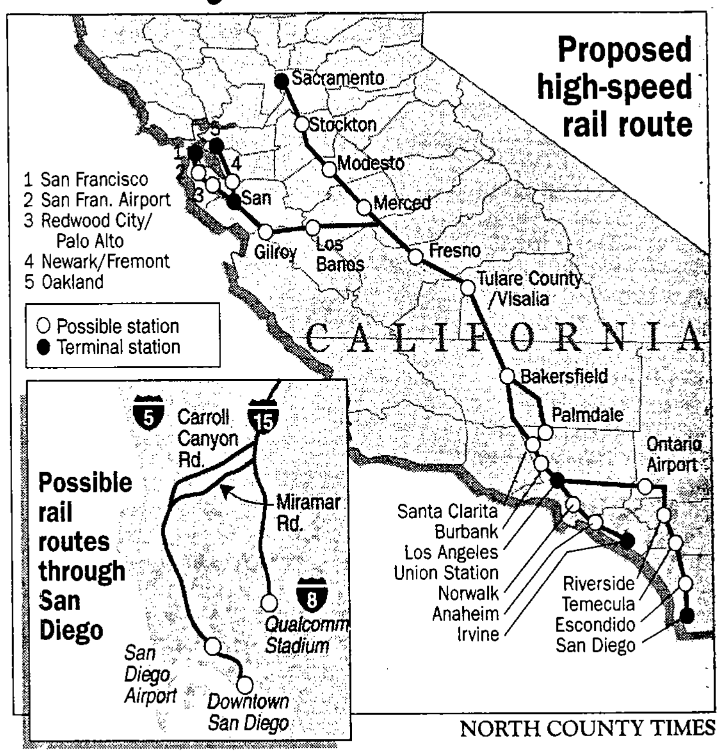
He warned that state politicians might abandon the inland alignment if they see that new high-speed rail between Los Angeles and San Francisco, coupled with improvements farther south, significantly shorten trips between Southern and Northern California.

A few years ago, state rail planners were debating whether to take the high-speed rail down the coast or through the rapidly developing I-15 corridor through Riverside County to San Diego. At that time, seaside cities rose up to protest a coastal high-speed line, saying it would ruin the picturesque and peaceful ambience of the beach.

Then, said Schiermeyer, "We stood up and said, 'We want it.'" And the rail agency designated the inland route through Riverside, Temecula and Escondido as the preferred one for reaching San Diego.

"But," he said, "they have never cut off the coast."

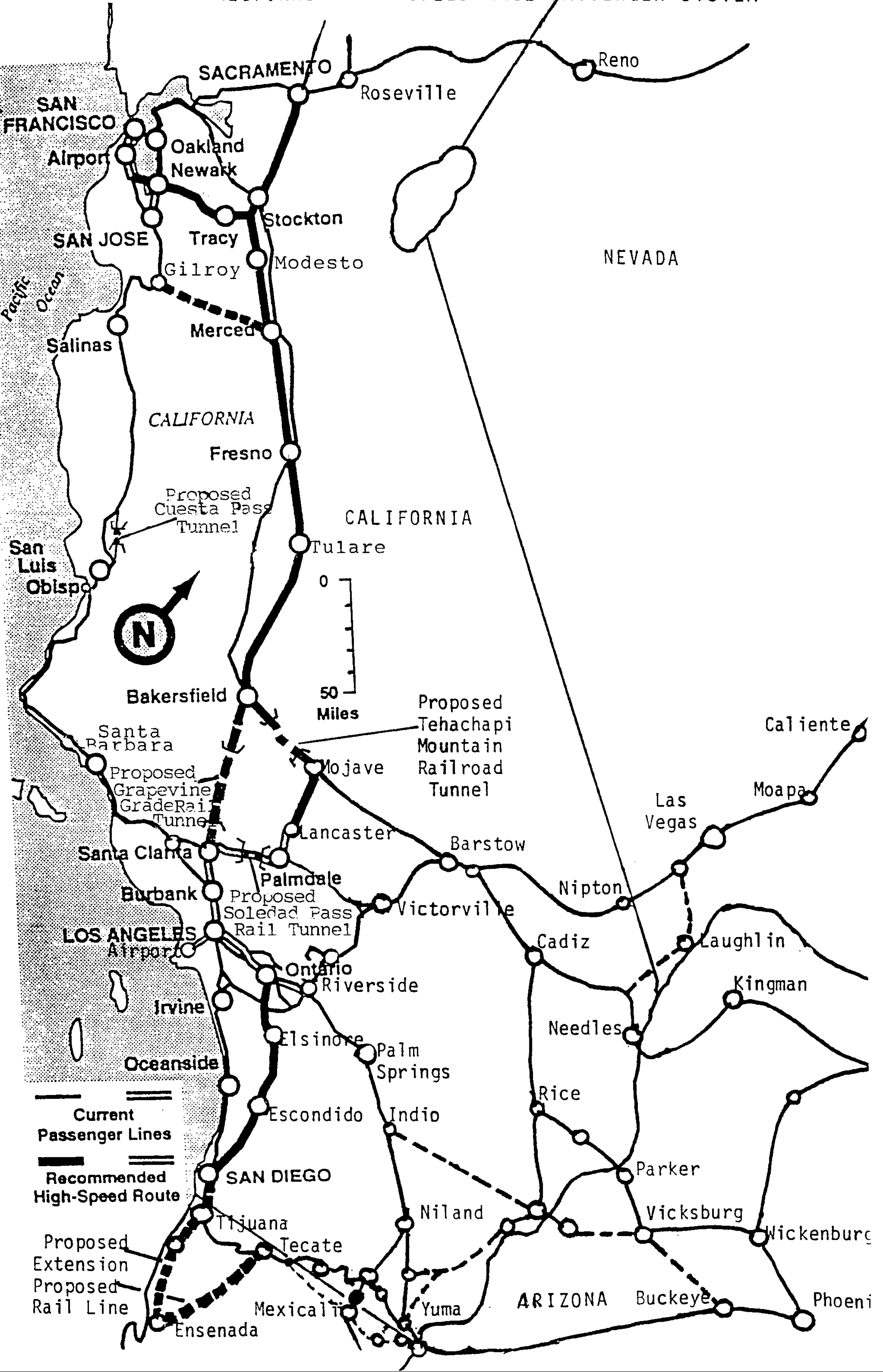
In other business, commissioners voted to create a public transit subcommittee upon the suggestion of an auditor.



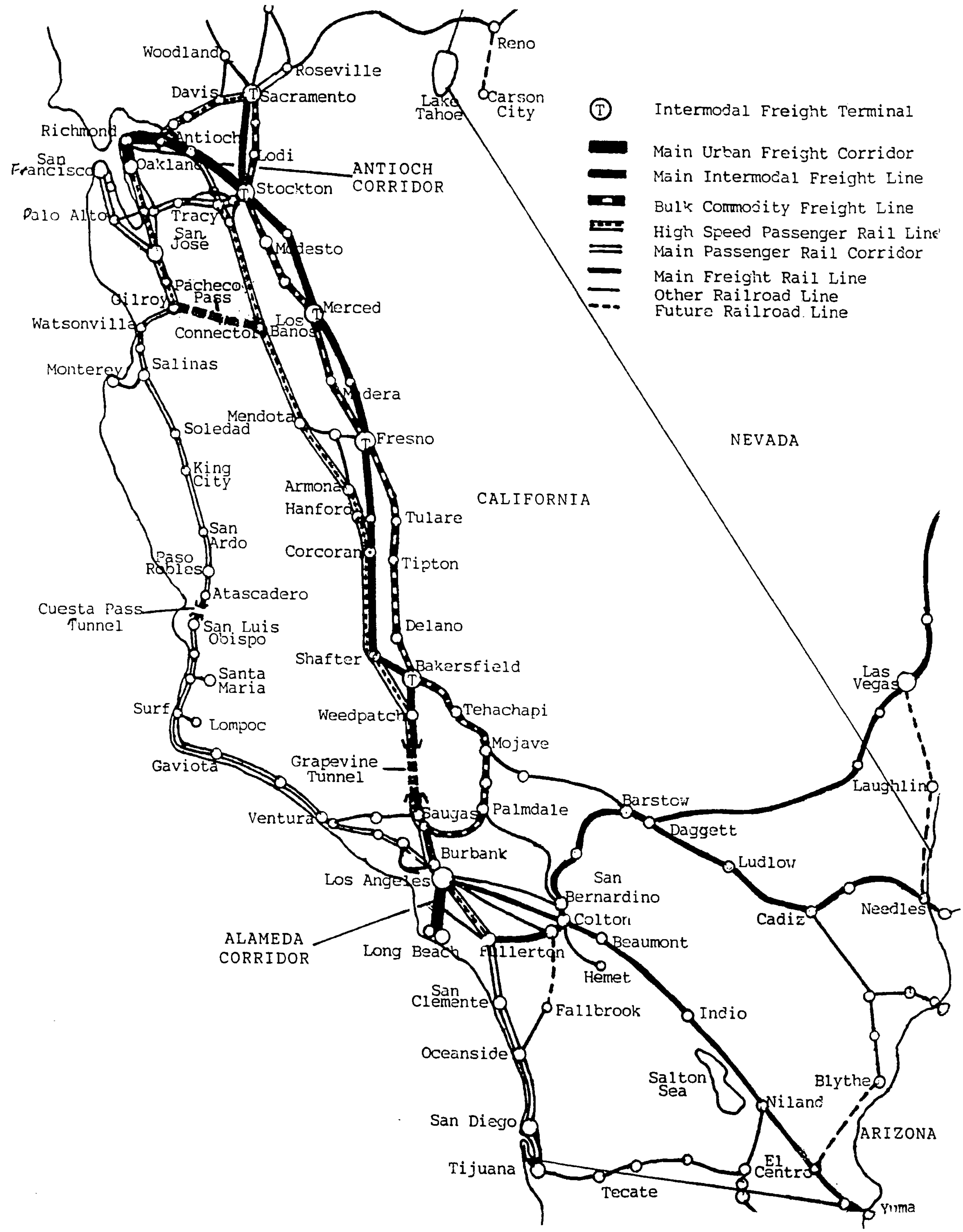
NORTH COUNTY TIMES

HIGH SPEED RAIL ROUTES

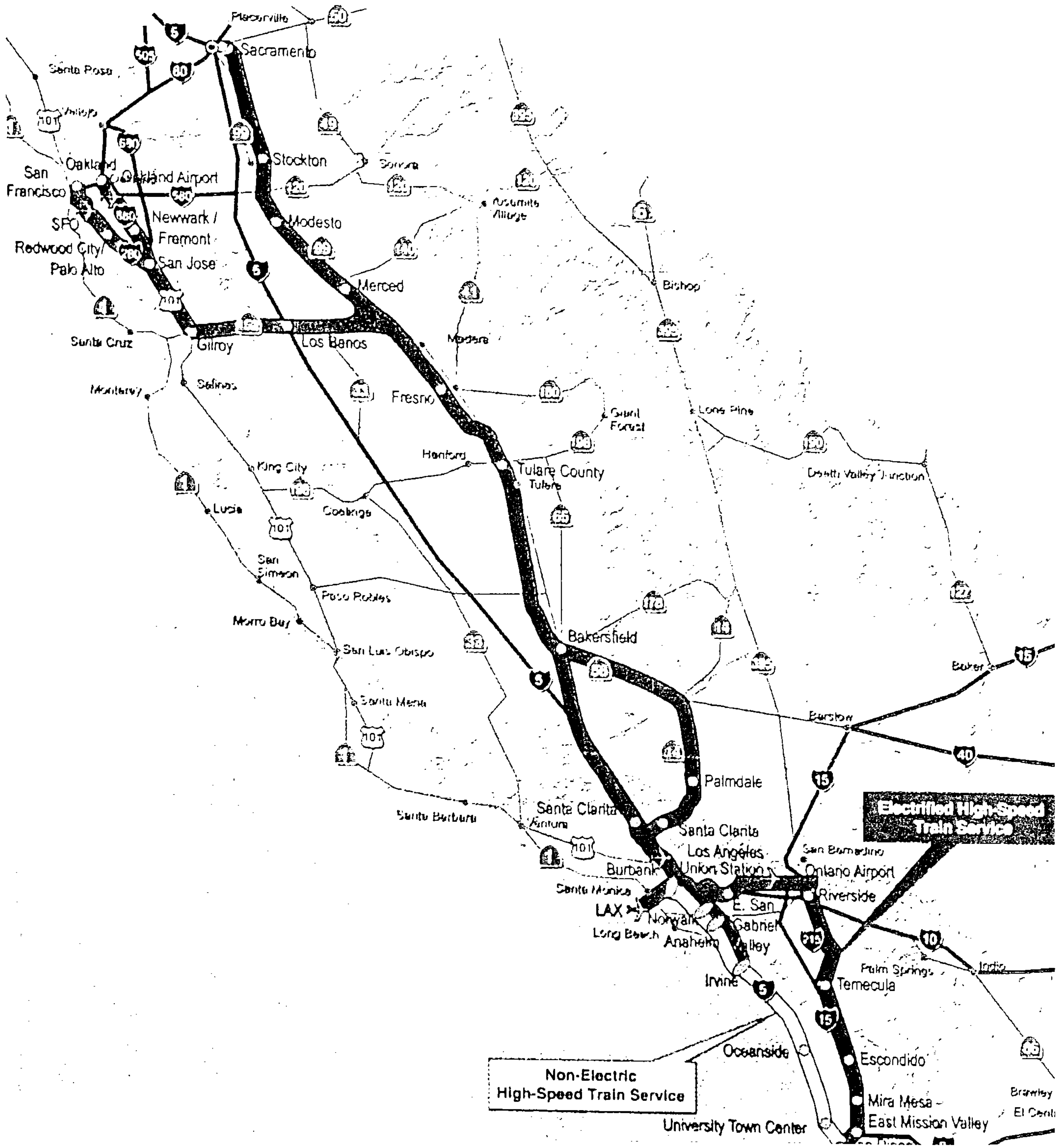
ROUTING FOR THE PROPOSED CALIFORNIA HIGH SPEED RAIL PASSENGER SYSTEM



LOCATION OF INTERMODAL FREIGHT TERMINALS IN THE SAN JOAQUIN VALLEY.

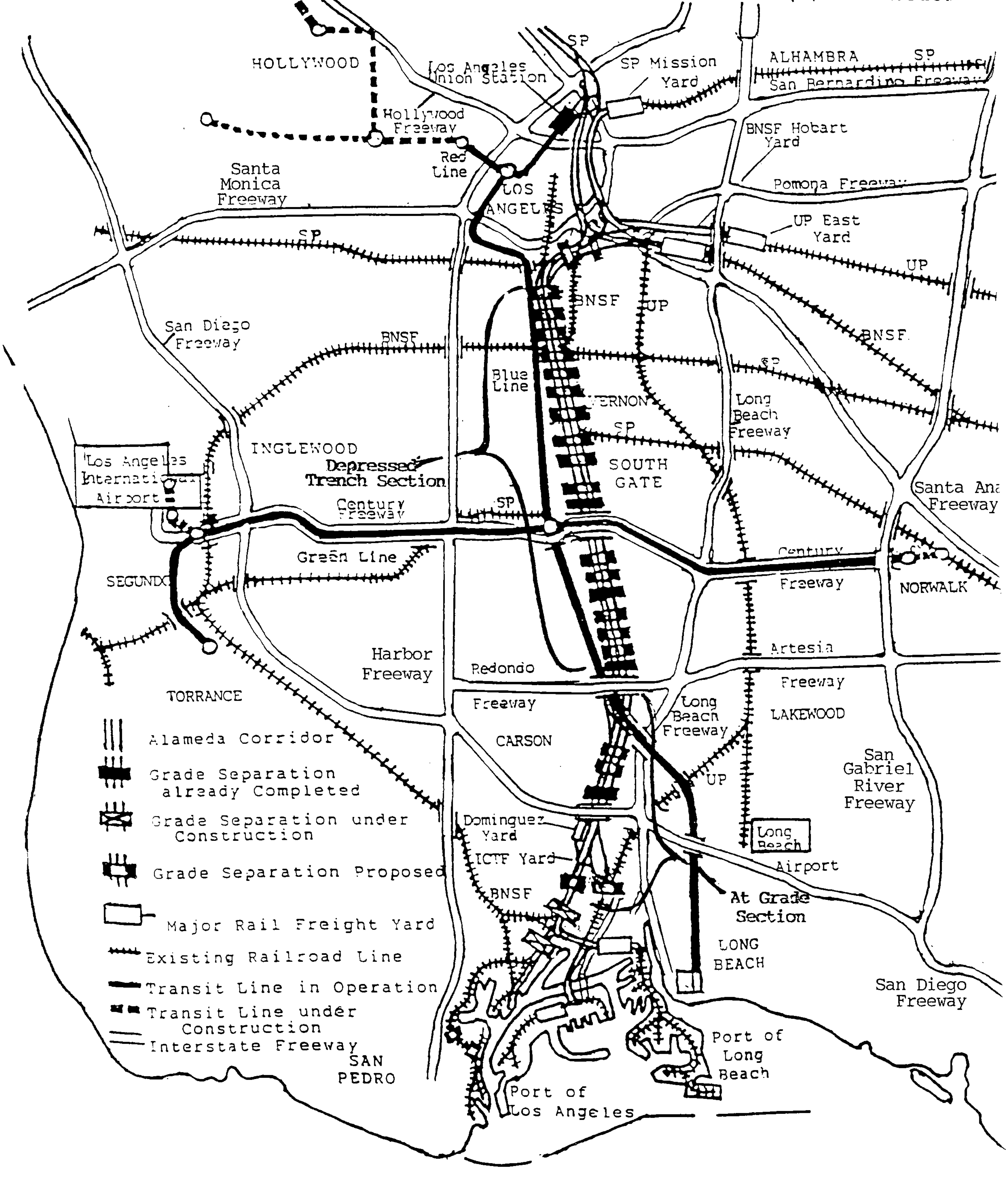


GENERAL PROPOSED ROUTE LOCATION FOR THE CALIFORNIA HIGH SPEED RAIL SYSTEM



ALAMEDA CORRIDOR PROJECT

PLANNED MAJOR RAILROAD AND ROADWAY FEATURES OF THE ALAMEDA CORRIDOR PROJECT



PROPOSED VERTICAL SECTION PROFILE FOR THE ALAMEDA CORRIDOR PROJECT

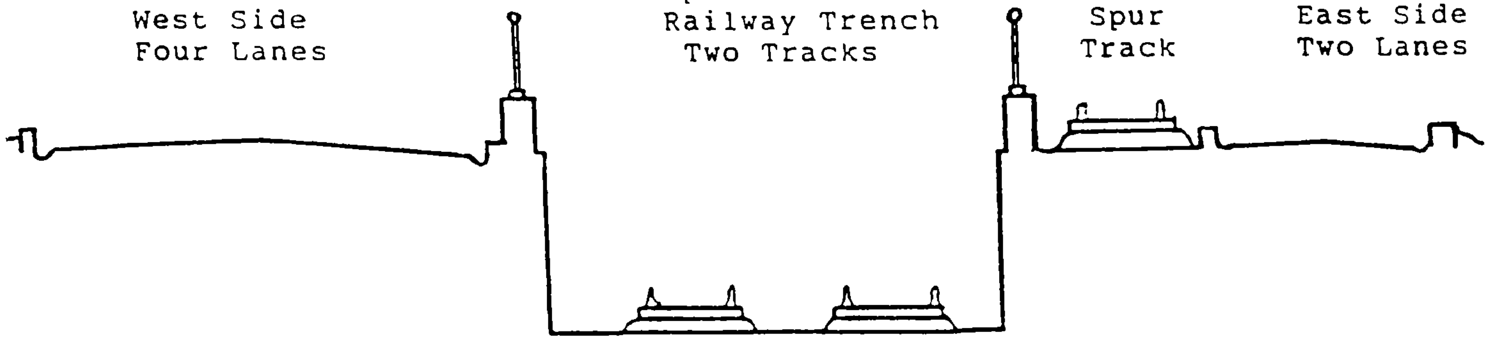
Depressed Railway Section

Alameda Street West Side Four Lanes

Depressed Center Railway Trench Two Tracks

Surface Spur Track

Alameda Street East Side Two Lanes



Artesia Freeway to Washington Blvd. (15 Miles)

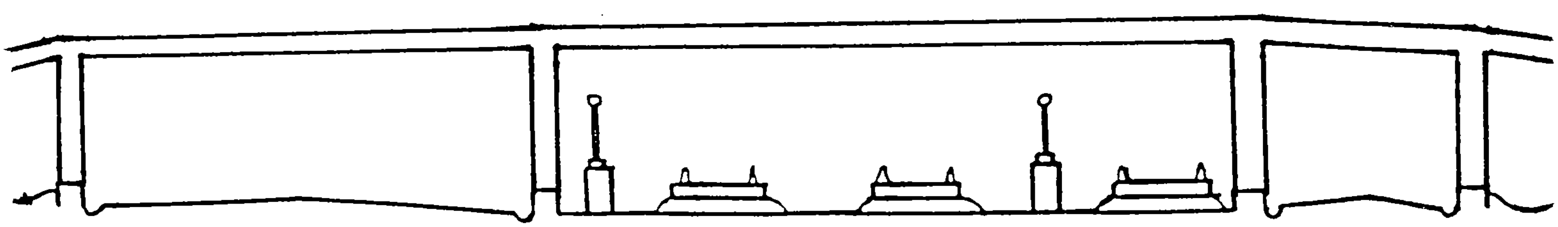
At Grade Railway Section

Alameda Street West Side Four Lanes

Center Surface Railroad Line Two Tracks

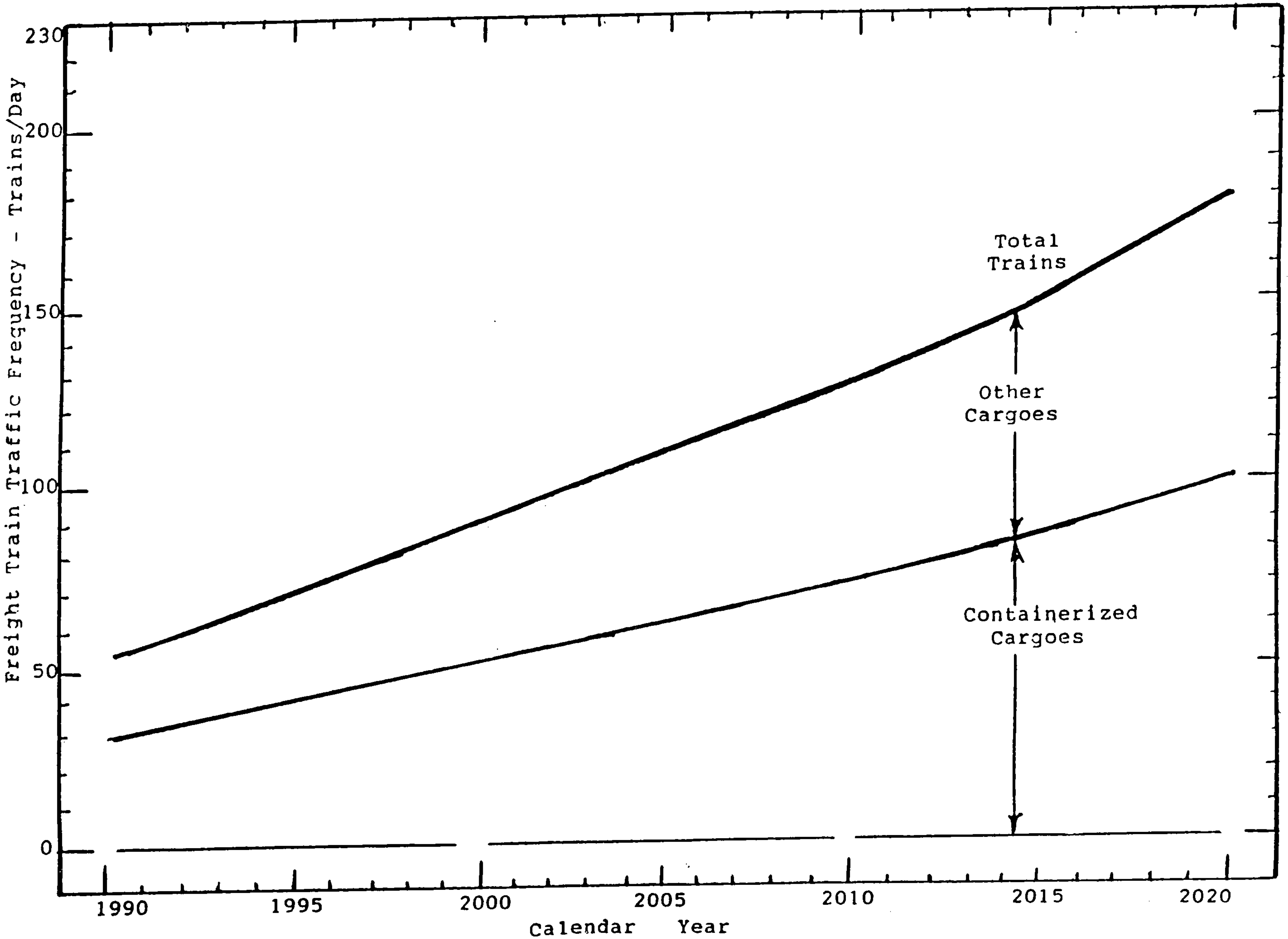
Rail Spur Track

Alameda Street East Side Two Lanes

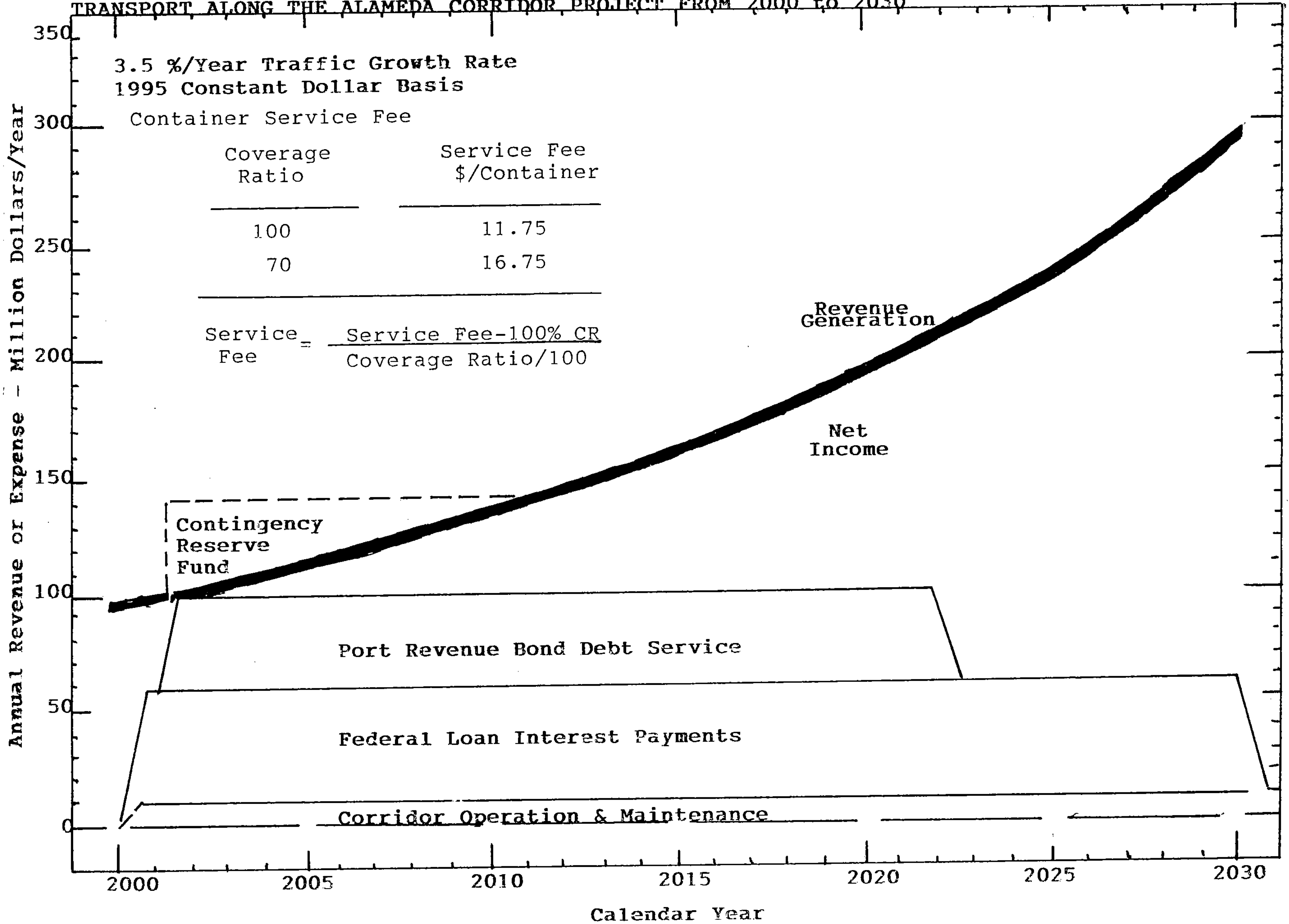


Terminal Island to Artesia Freeway (7 Miles)

EXPECTED INCREASES IN FREIGHT TRAIN MOVEMENTS ALONG THE ALAMEDA CORRIDOR: 1990-2020



PROJECTED INCREASES IN ANNUAL REVENUES AND DEBT SERVICE EXPENSES FOR CONTAINERIZED CARGO TRANSPORT ALONG THE ALAMEDA CORRIDOR PROJECT FROM 2000 to 2030



CAPITAL EXPENSE REQUIREMENTS AND OPERATING FEATURES OF THE ALAMEDA CORRIDOR PROJECT UNDER ALTERNATIVE CONFIGURATIONS[1]

SPECIFIC PARAMETER	FUNDING SOURCE	BASE CASE SINGLE TRACK EXISTING	DOUBLE TRACK WITH NO SEPARATIONS	DOUBLE TRACK WITH SEPARATIONS
Capital Cost (Million $)	Port Contributions	400.00	400.00	400.00
	Port Revenue Bonds	0.0	600.0	600.0
	State and Local Funds MTA Contributions	0.0 0.0	143.0 0.0	143.0 350.0
	Federal Funds	0.0	0.0	400.0
	Total Expense	400.0	1,143.0	1,893.0
	Unit Cost (Million $/Mile)	18.2	52.0	86.0
	Railroad Expense[3]	0.0	25.0	50.0
Railroad Features	Number of Tracks	1	2	2
	Grade Crossings	31	28	0
	Grade Separations	7	10	39
	Average Train Speed (Mile/Hour)	20	35	40
	Track Capacity (Trains/Day)	40	100	150
	Transit Time (Hours)	4	2	1
	Year Completed	-	2005	2001
	Route Length (Miles)	22	22	22
	Signaling System	ABS	CTC	CTC ATC

Notes:

1. Capital cost factors are based on 1995 constant dollars.
2. Abbreviations for signaling systems are as follows:
   ABS=Automatic Block Signals;
   ATC=Automatic Train Control;
   CTC=Centralized Traffic Control.
3. Estimated signalling and communication system cost to be paid for separately by the freight railroads.

EXPECTED PRESENT AND FUTURE ECONOMIC IMPACTS RESULTING FROM THE DEVELOPMENT OF THE PROPOSED DUWAMISH CORRIDOR PROJECT IN THE PUGET SOUND AREA

IMPACT	UNITS	1995	2010	2020
Value of Trade	Billion $/Year	60	100	150
Direct Employment	No. of Jobs	30,000	50,000	70,000
Area Employment	No. of Jobs	120,000	180,000	240,000
Statewide Employment	No. of Jobs	600,000	1,000,000	1,500,000
Direct Payrolls	Million $/Year	530	880	1,230
Econo Business Revenues	Billion $/Year	3	6	10
Port Revenues	Billion $/Year	5	8	12
Economic Activity		10	20	35
Federal Income Tax	Billion $/Year	1.1	1.9	2.7
Federal Customs duties	Million $/Year	560	900	1,250
State & Local Taxes	Million $/Year	170	260	340
Trade Volume	Million Metric Tons/Year	37	75	100
Container Shipments	Million TEU/Year	3	7	10
Total Train Movements	Trains/Day	90	320	440

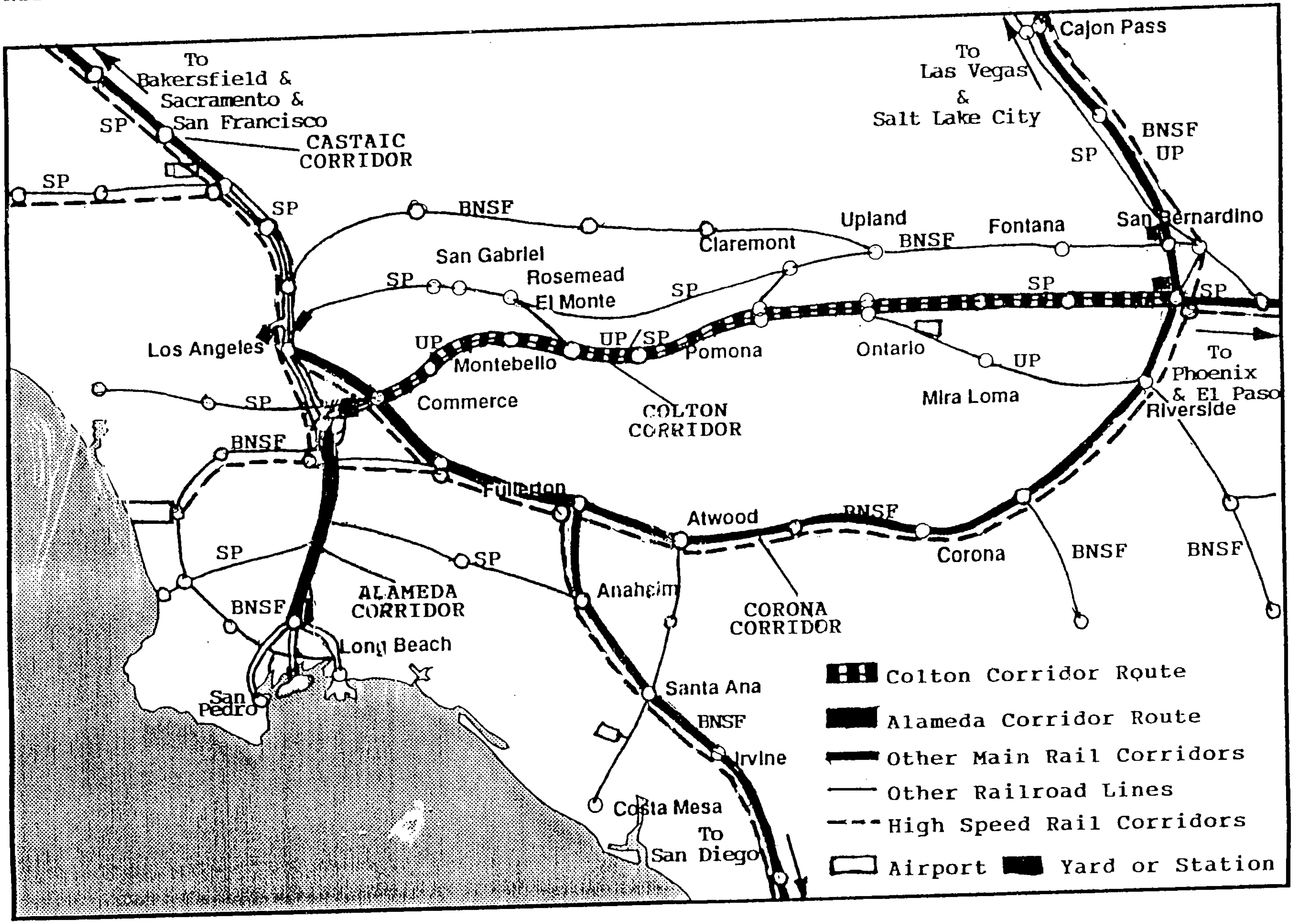
EXPECTED PRESENT AND FUTURE ECONOMIC IMPACTS RESULTING FROM THE DEVELOPMENT OF THE ALAMEDA CORRIDOR PROJECT IN THE SOUTHERN CALIFORNIA REGION

IMPACT	UNITS	1995	2010	2020
Value of Trade	Billion $ Year	116.0	253.0	355.0
Direct Employment	No. of Jobs	30,000	70,000	100,000
Total Employment	No. of Jobs	75,000	180,000	250,000
National Employment	No. of Jobs	2,500,000	5,700,000	8,000,000
Affected Payrolls	Billion $ Year	100.0	230.0	325.0
Federal Income Tax	Billion $ Year	14.2	30.9	95.5
Federal Customs Duties	Billion $ Year	2.9	5.9	8.4
State & Local Taxes	Billion $ Year	5.4	11.6	16.5
Trade Volume	Million Metric Tons/Year	120	180	235
Container Shipments	Million TEU/Year	5	12	17
Total Train Movements	Trains/Day	255	510	710

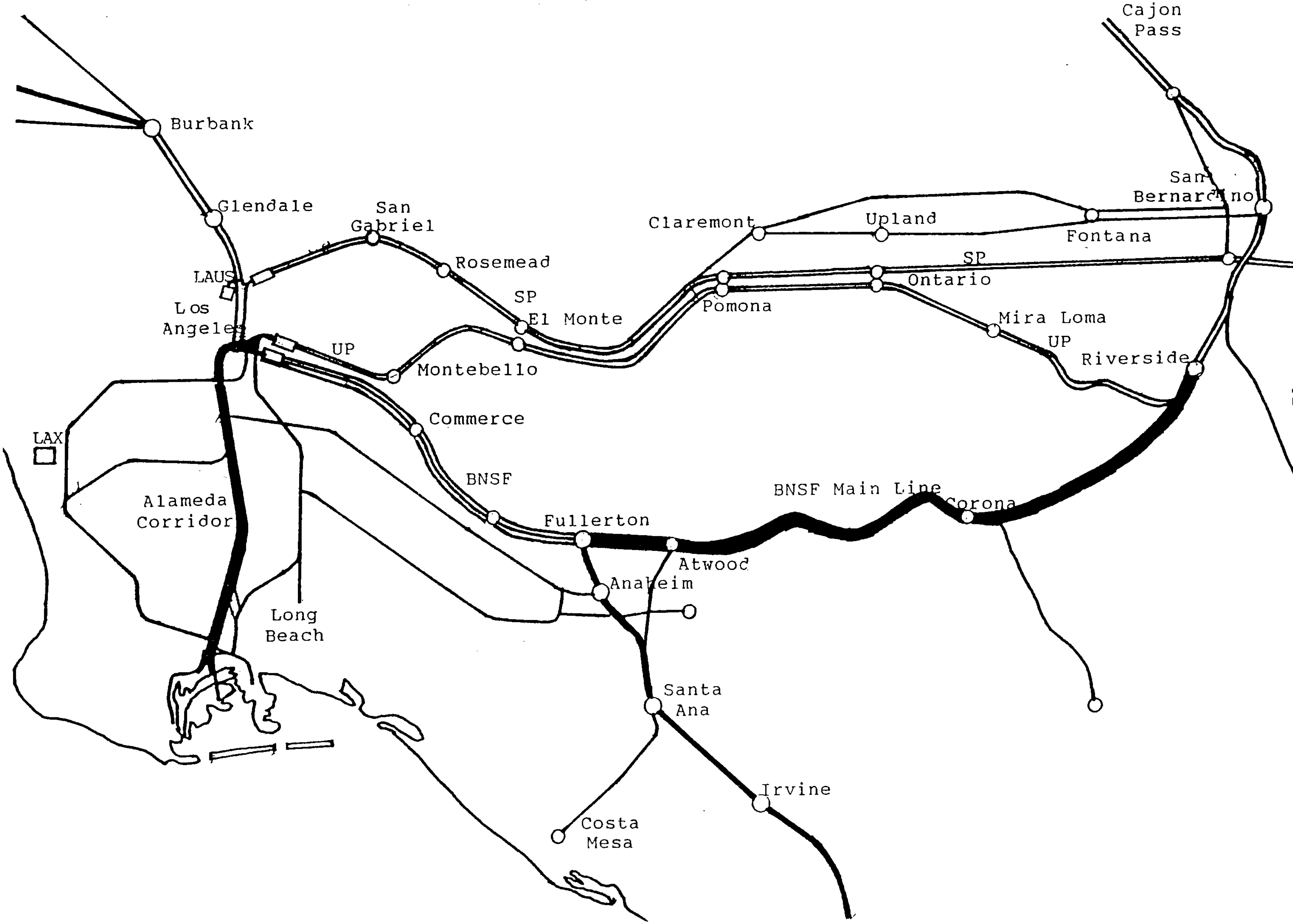
SOUTHERN CALIFORNIA

RAILROAD NETWORKS

PRESENT AND FUTURE FREIGHT AND PASSENGER RAILROAD LINE CORRIDORS IN THE LOS ANGELES BASIN.



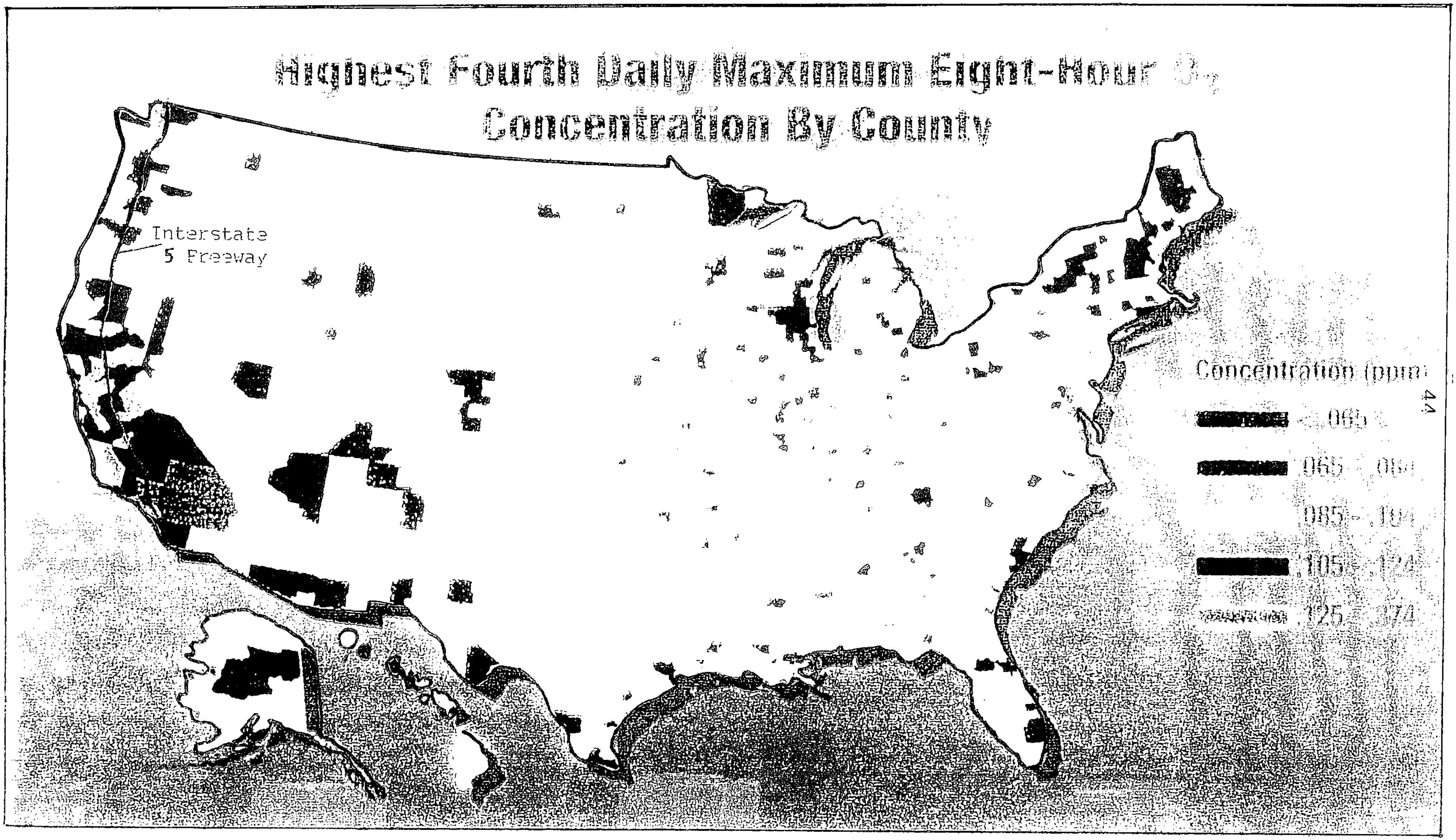
TRIPLE TRACKING EXPANSION OF THE BNSF MAIN RAILROAD LINE FROM FULLERTON TO RIVERSIDE



OZONE AIR QUALITY

NONATTAINMENT AREAS

OBSERVED VALUES FOR THE FOURTH HIGHEST AMBIENT AIR QUALITY READINGS FOR ATMOSPHERIC OZONE LEVELS ACROSS THE UNITED STATES AND ALONG THE INTERSTATE 5 FREEWAY CORRIDOR STATES IN 1998

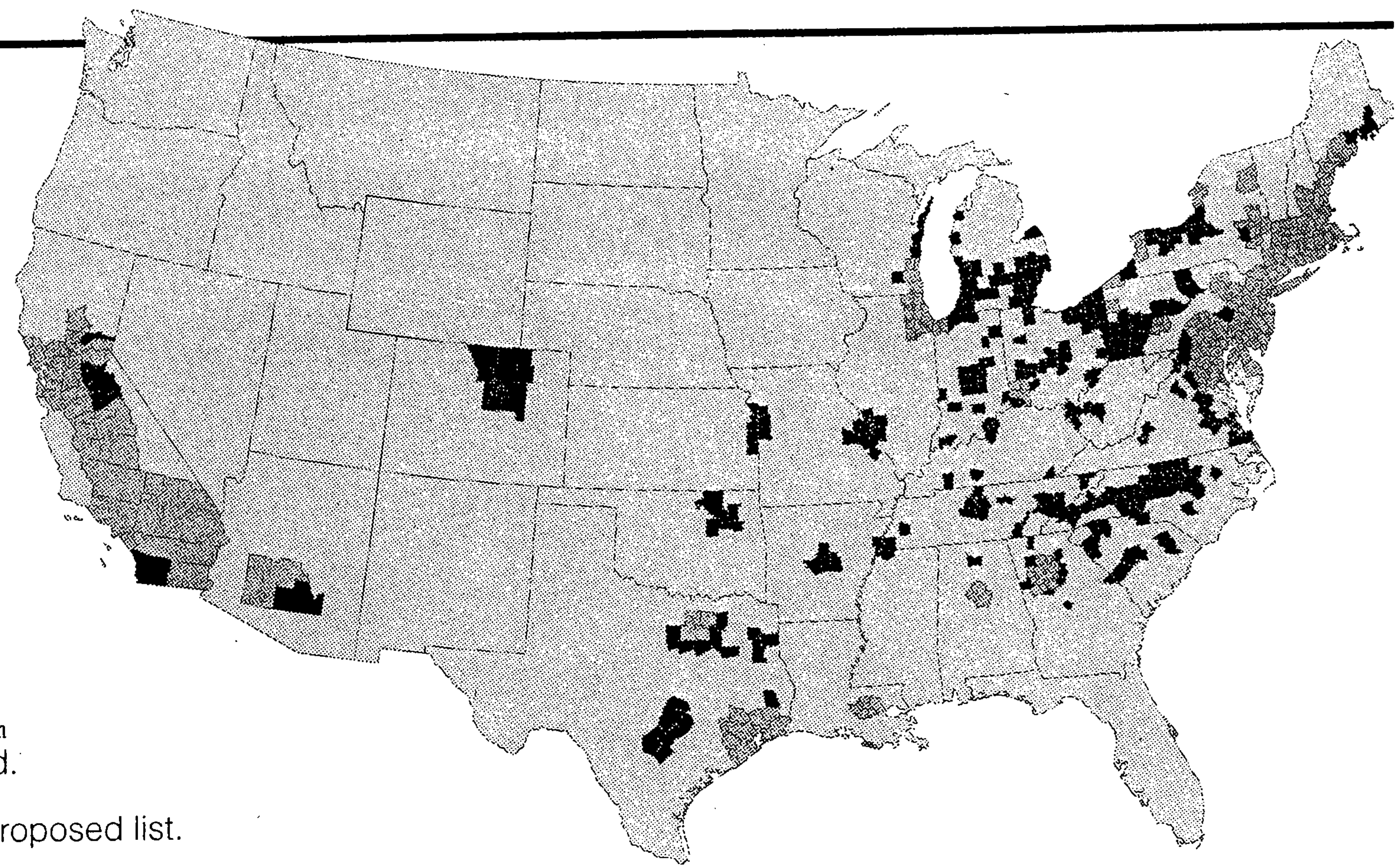


Fourth Highest Maximum Eight Hour Ozone Ambient Air Concentrations during 1998 from the National Air Quality and Emissions Trends Report: 1998. These Areas shown in Color could be Redesignated as Being in Nonattainment by the U.S. Environmental Protection Agency.

COUNTIES IN THE UNITED STATES IN VIOLATION OF THE NEW FEDERAL OZONE AIR QUALITY STANDARD

Polluted Air

When the Environmental Protection Agency announces tighter ozone exposure rules on Thursday, about 500 counties will be in violation of or contribute to violation of new federal clean air standards. Counties shown are on the E.P.A.'s proposed list from December.



Ozone Limit - 0.085 ppm

Counties previously listed.

Counties added on the proposed list.

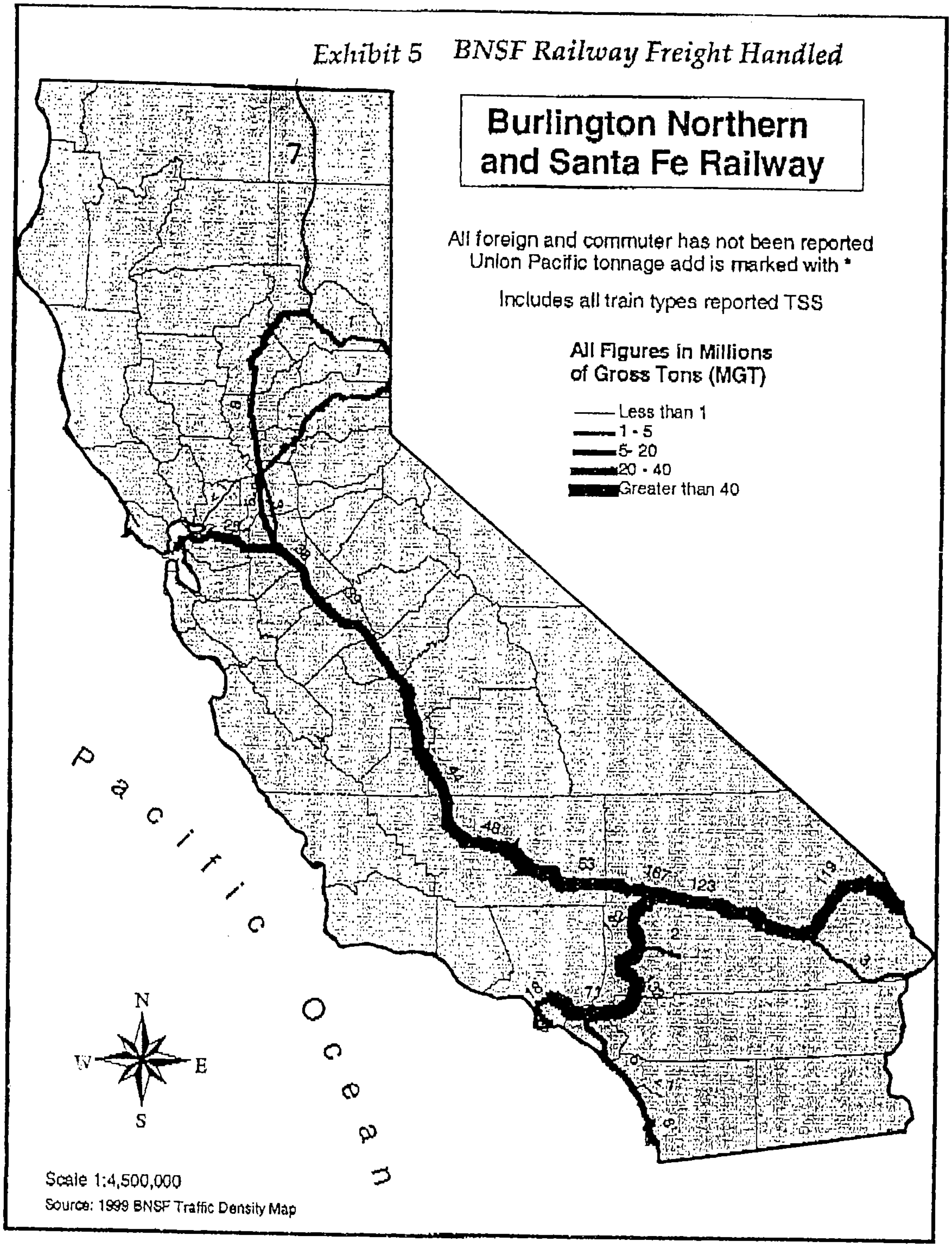
The New York Time

CALIFORNIA RAILROAD

FREIGHT TRAFFIC FLOWS

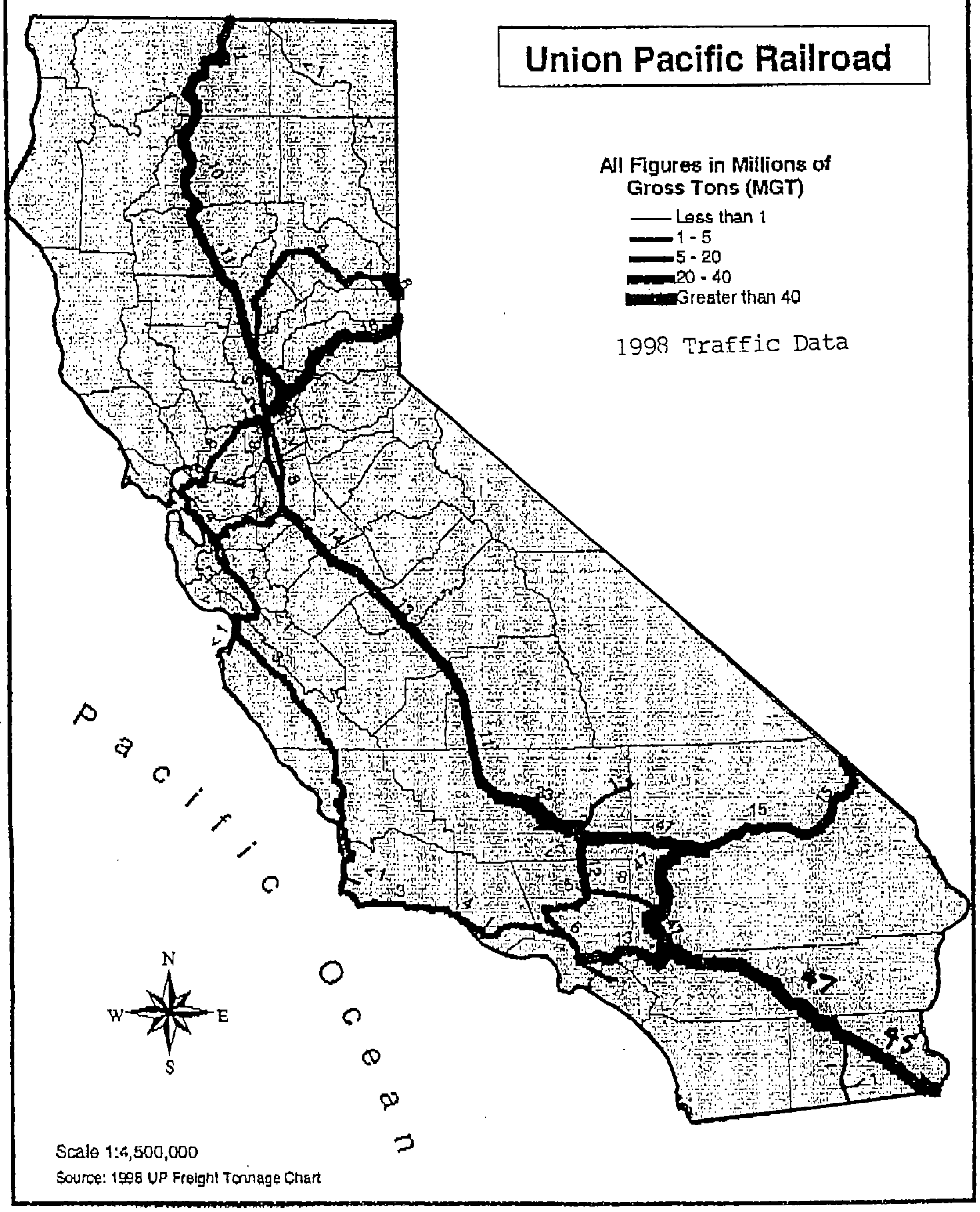
EXISTING FREIGHT TRAFFIC DENSITIES ON THE RAIL LINES OF THE BURLINGTON NORTHERN SANTA FE RAILROAD IN CALIFORNIA IN 1999

Exhibit 5 BNSF Railway Freight Handled



EXISTING FREIGHT TRAFFIC DENSITIES ON THE RAIL LINES OF THE UNION PACIFIC RAILROAD IN THE STATE OF CALIFORNIA FOR THE YEAR 1998

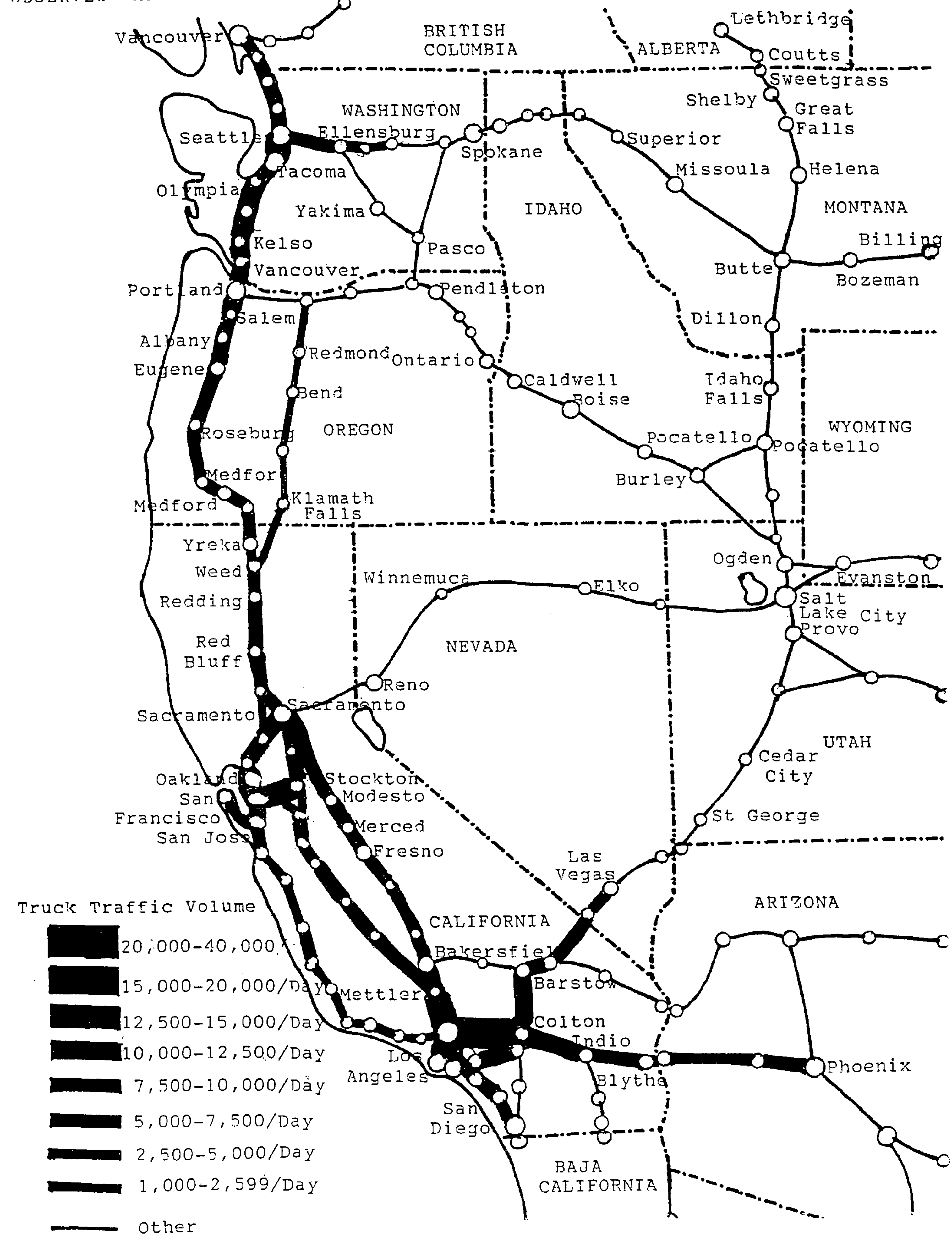
Exhibit 4 UP Railroad Freight Handled



HIGHWAY TRUCK

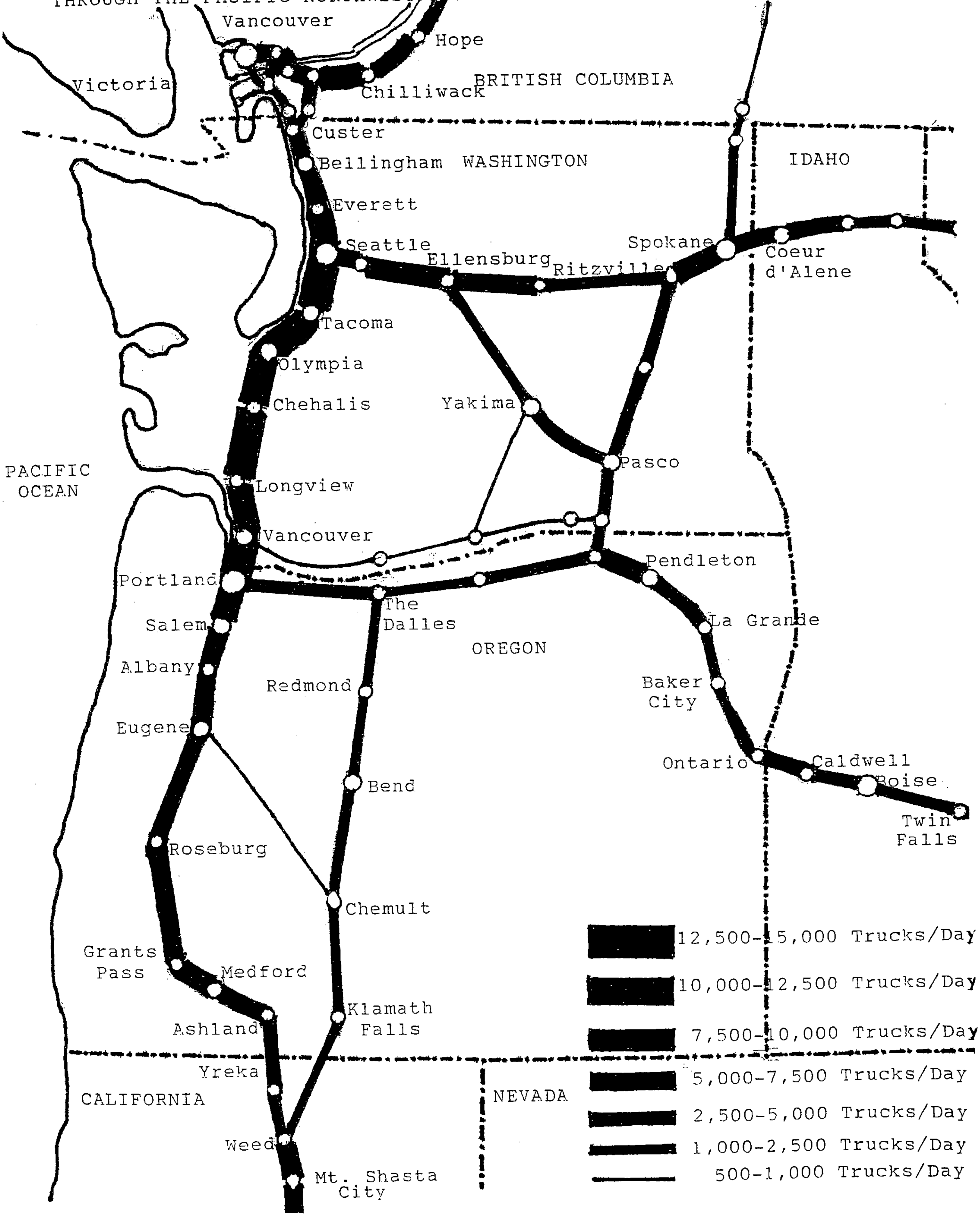
TRAFFIC VOLUMES

OBSERVED VARIATIONS IN TOTAL TRUCK TRAFFIC VOLUMES ALONG THE WEST COAST ROUTE:

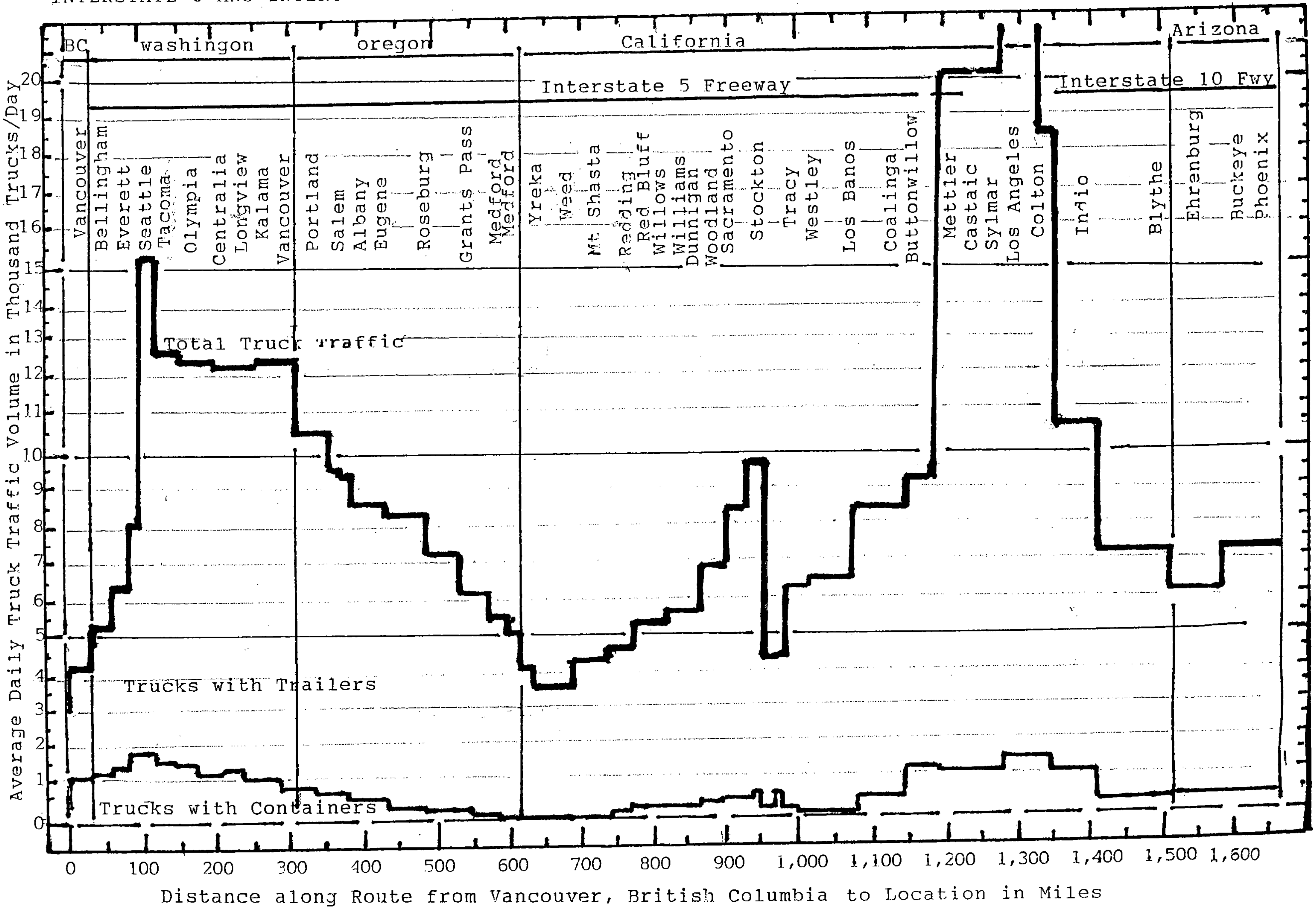


TRUCK TRAFFIC VOLUMES ON THE MAJOR HIGHWAYS IN THE SAN JOAQUIN VALLEY

VARIATIONS IN TRUCK TRAFFIC VOLUMES ALONG THE INTERSTATE 5 FREEWAY THROUGH THE PACIFIC NORTHWEST STATES BETWEEN VANCOUVER AND YREKA



OBSERVED TRENDS IN THE TOTAL TRUCK TRAFFIC VOLUMES AND CONTAINER TRUCK VOLUMES ALONG THE INTERSTATE 5 AND INTERSTATE 10 FREEWAY CORRIDOR BETWEEN VANCOUVER, LOS ANGELES AND PHOENIX



SUMMARY OF CONTAINER AND TRUCK TRAFFIC VOLUMES ALONG THE WEST COAST INTERSTATE FREEWAY CORRIDORS BY RANKING BASED ON TOTAL TRUCK MOVEMENTS

Intercity Corridor	Interstate Highway	Distance (Miles)	Containers (Trucks/day)	Trailers (Trucks/day)	Total Trucks (Trucks/day)	Percent of Total
Sylmar-Mettler	I-5	65	1,045	19,185	20,230	5.17
Seattle-Olympia	I-5	60	1,230	11,520	12,750	9.65
Longview-Portland	I-5	45	815	11,735	12,550	6.49
Centralia-Longview	I-5	50	1,065	11,535	12,450	8.55
Olympia-Centralia	I-5	25	1,165	11,235	12,400	9.40
Hayward-Tracy	I-580	30	1,150	10,870	12,020	9.57
Mettler-Bakersfield	SR-99	25	500	10,685	11,185	4.47
Colton-Indio	I-10	70	1,065	9,540	10,605	10.04
Portland-Salem	I-5	40	800	9,710	10,510	7.61
Sacramento-Vallejo	I-80	60	1,450	8,700	10,150	14.28
Bakersfield-Fresno	SR-99	115	180	9,670	9,850	1.82
Stockton-Fresno	SR-99	115	375	9,390	9,765	3.84
Mettler-Buttonwillow	I-5	40	545	8,500	9,045	6.03
Salem-Eugene	I-5	60	550	7,950	8,500	6.47
Stockton-Sacramento	I-5	45	400	8,000	8,400	4.76
Coalinga-Buttonwillow	I-5	75	140	8,230	8,370	1.67
Tracy-Stockton	I-205	25	575	7,750	8,325	6.91
Eugene-Roseburg	I-5	80	100	8,150	8,250	1.21
Roseburg-Grants Pass	I-5	65	50	7,300	7,350	0.68
Blythe-Indio	I-10	95	320	6,730	7,050	4.54
Dunnigan-Sacramento	I-5	35	200	6,625	6,825	2.93
Westley-Coalinga	I-5	110	210	6,150	6,360	3.30
Seattle-Ellensburg	I-90	75	1,800	4,280	6,080	29.61
Blythe-Tonopah	I-10	70	330	5,730	6,060	5.45
Marysville-Burlington	I-5	25	1,480	4,440	5,920	25.00
Dunningan-Red Bluff	I-5	85	150	5,250	5,400	2.78
Burlington-Bellingham	I-5	25	1,400	3,750	5,150	27.18
Ellensburg-Vantage	I-90	40	980	3,920	4,900	20.00
Red Bluff-Redding	I-5	25	75	4,675	4,750	1.50
Trac y-Wesley	I-580	15	575	3,935	4,510	12.75
Belingham-Vancouver	I-5	15	1,080	2,950	4,040	26.80
Redding-Siskiyou	I-5	120	0	4,000	4,000	0.00
Grants Pass-Siskiyou	I-5	60	0	4,000	4,000	0.00
Urban Corridors	--	305	1,125	15,230	16,405	7.15
TOTAL CORRIDORS	--	2,270	635	8,505	9,140	6.95

Based on actual truck traffic counts by the author in 2001.

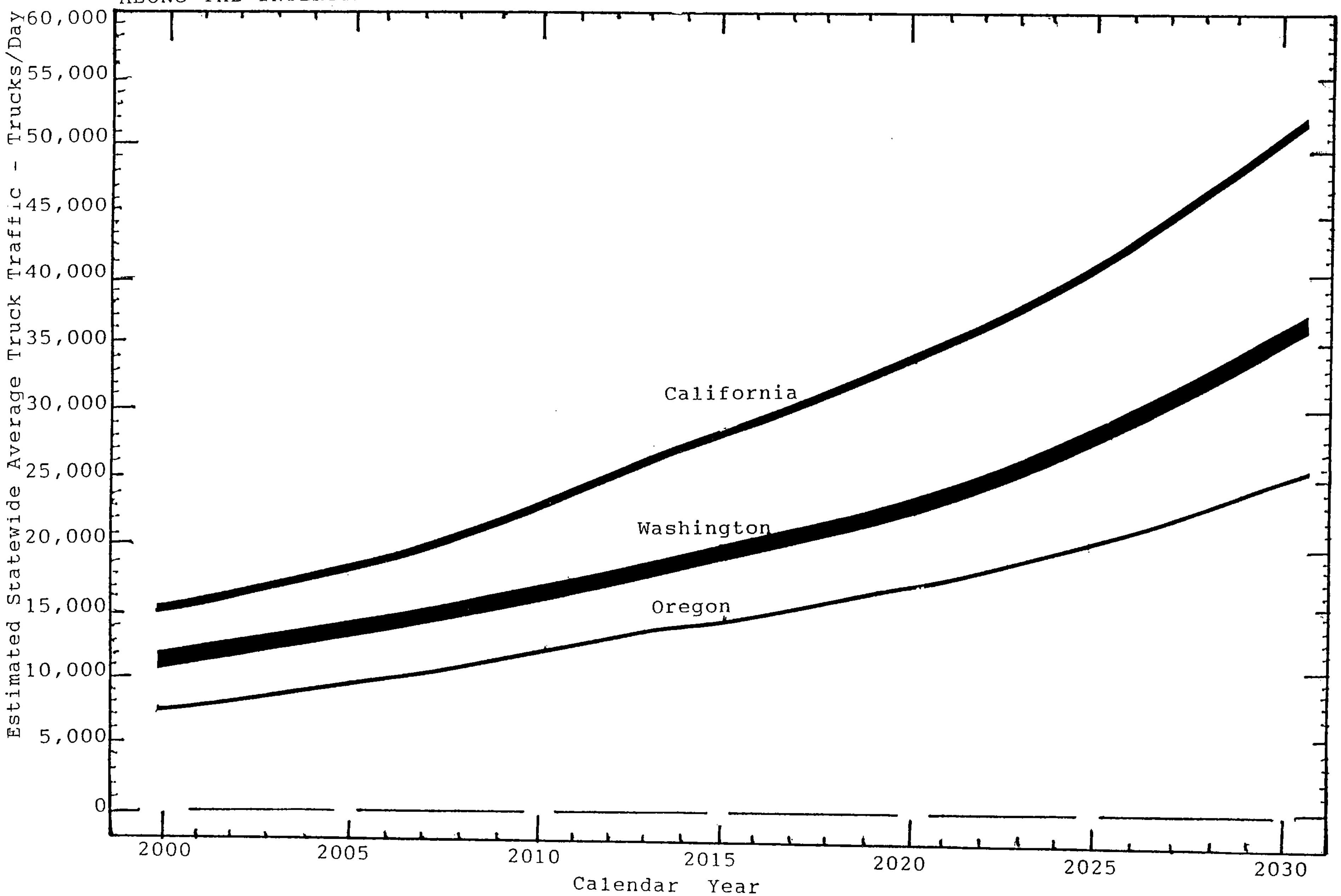
HIGHWAY MAINTENANCE

COST BURDENS

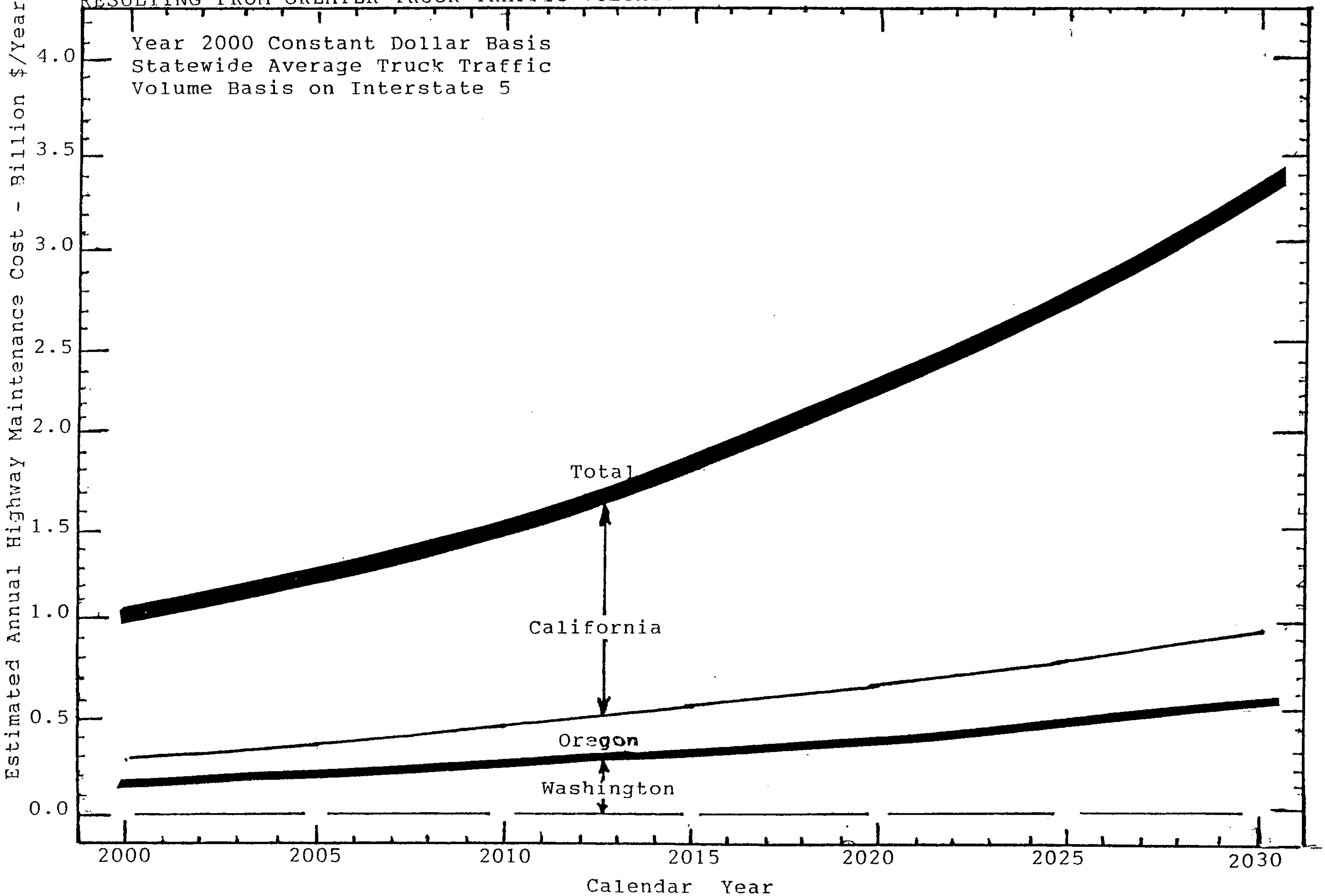
ESTIMATED INCREASES IN THE AVERAGE STATEWIDE TRUCK TRAFFIC VOLUMES ALONG THE INTERSTATE-5 FREEWAY THROUGH THE PACIFIC COAST STATES

Calendar Year	Washington Trucks/Day	Oregon Trucks/Day	California Trucks/Day	Average Trucks/Day
2000	10,855	7,645	15,445	12,895
2005	13,260	9,340	18,840	15,725
2010	16,195	11,405	23,010	19,210
2015	19,780	13,930	28,105	23,460
2020	22,160	17,015	34,330	28,655
2025	29,505	20,780	41,930	34,995
2030	36,040	25,380	51,210	42,745

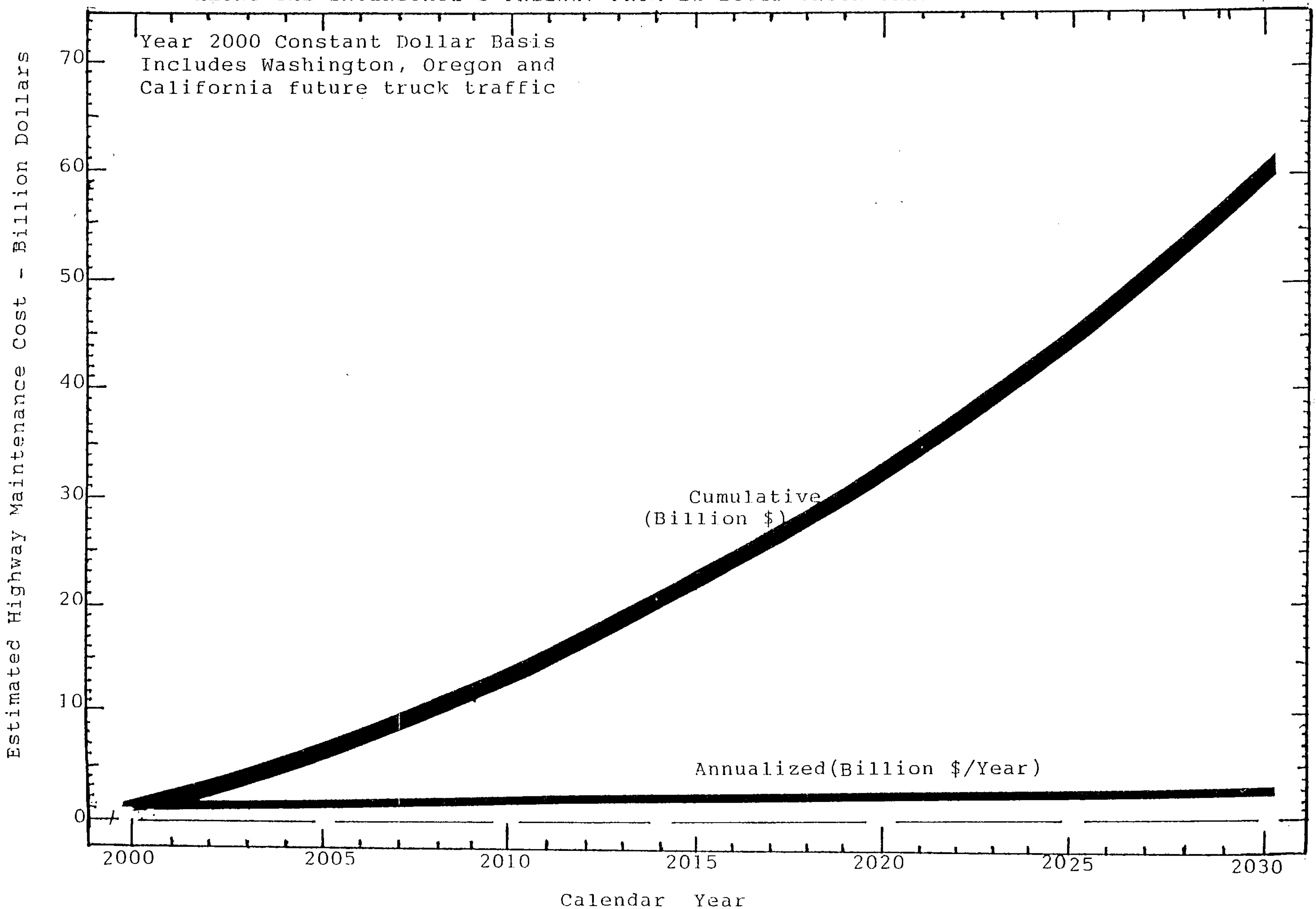
ESTIMATED INCREASES IN THE OVERALL AVERAGE STATEWIDE TRUCK TRAFFIC VOLUME TO BE EXPECTED ALONG THE INTERSTATE 5 FREEWAY THROUGH WASHINGTON OREGON AND CALIFORNIA FROM 2000 TO 2030



ESTIMATED INCREASES IN THE HIGHWAY MAINTENANCE COST BURDEN ALONG THE INTERSTATE 5 FREEWAY RESULTING FROM GREATER TRUCK TRAFFIC VOLUMES IN THE STATES OF WASHINGTON, OREGON & CALIFORNIA



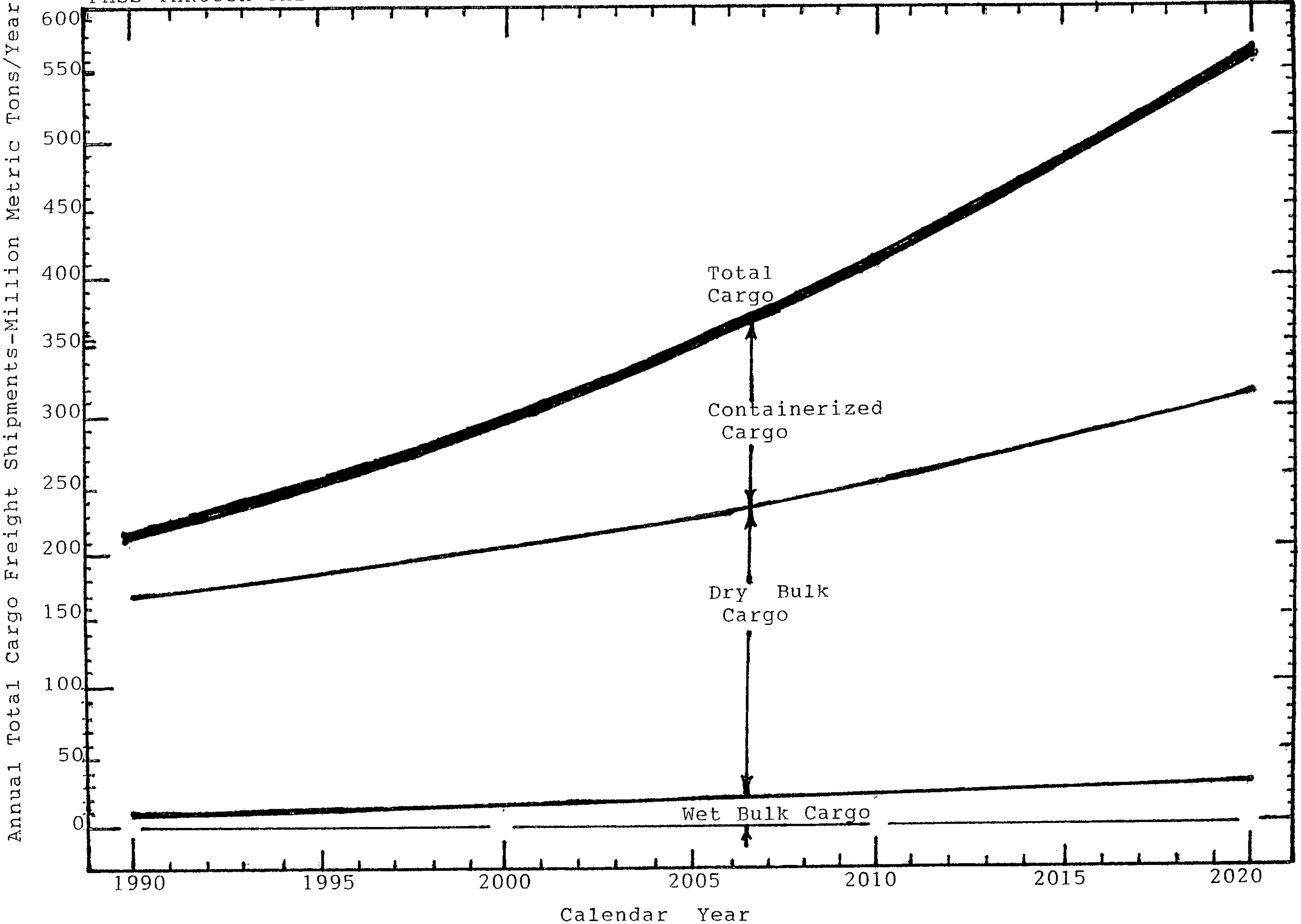
ESTIMATED INCREASES IN THE ANNUALIZED AND CUMULATIVE HIGHWAY MAINTENANCE COST BURDENS ALONG THE INTERSTATE 5 FREEWAY FROM EXPECTEL TRUCK TRAFFIC GROWTH PATTERNS



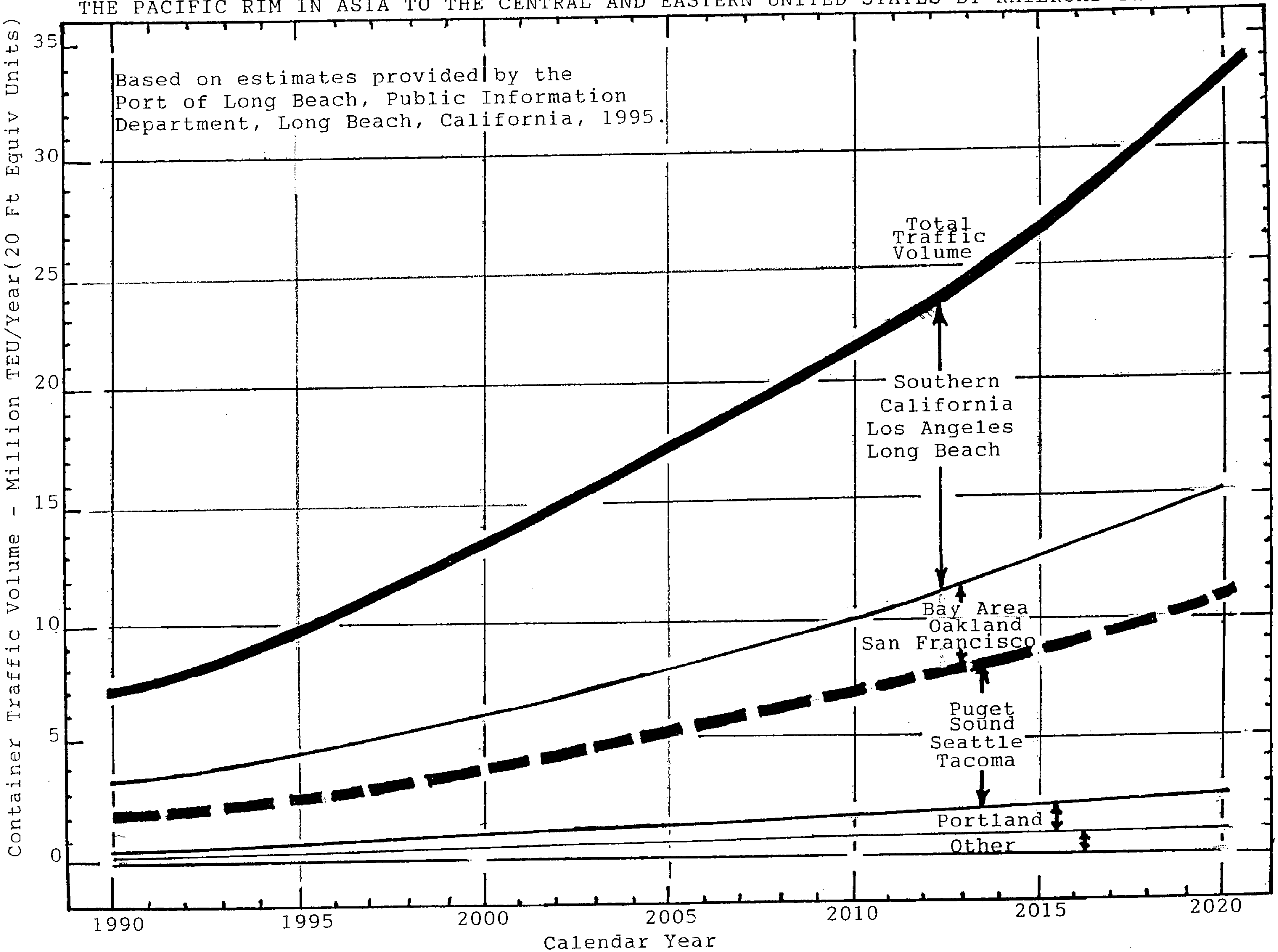
PACIFIC COAST

PORT TRAFFIC

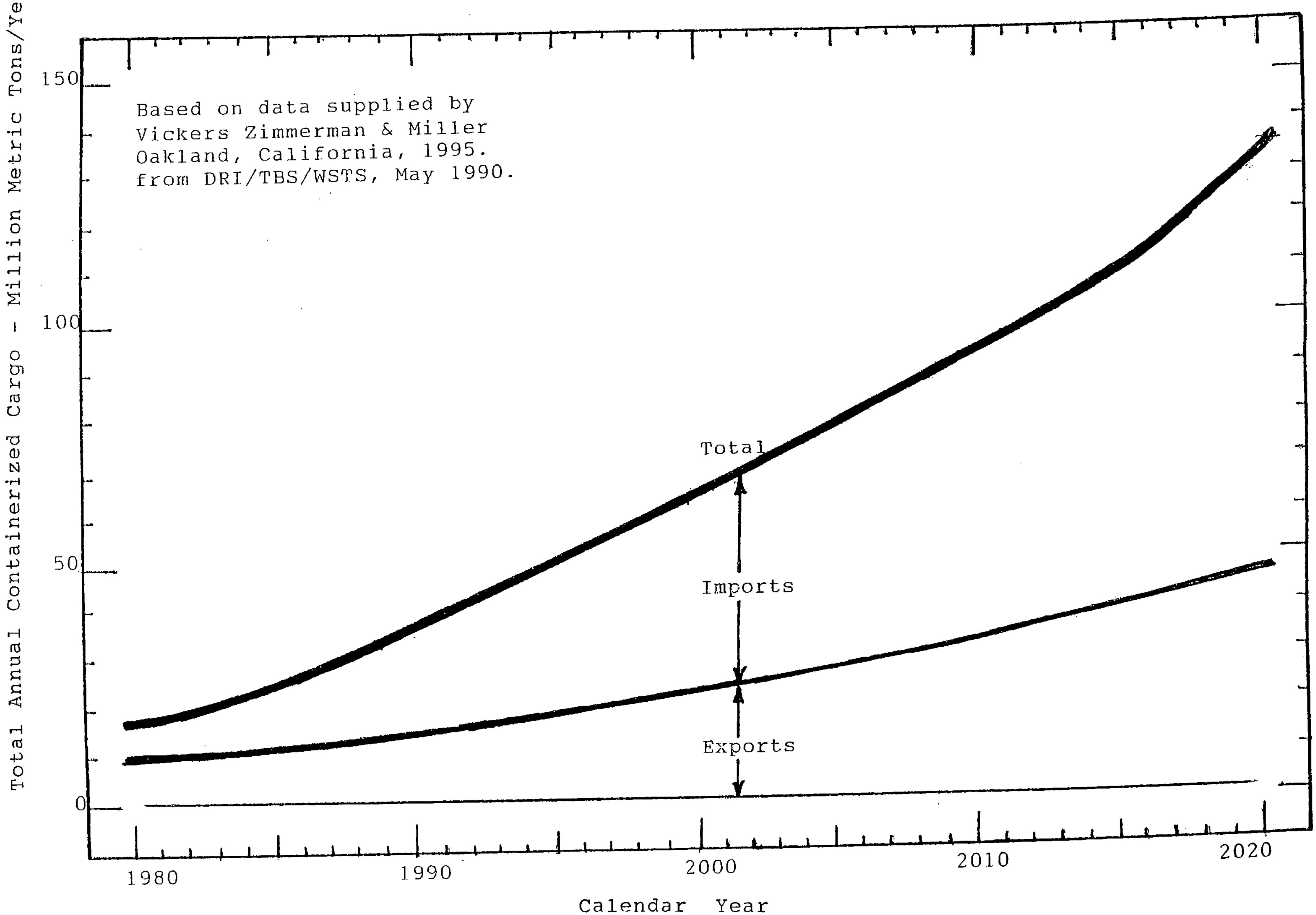
EXPECTED INCREASES IN THE TOTAL CARGO SHIPMENT QUANTITIES BY CATEGORY OF MATERIAL WHICH PASS THROUGH THE WEST COAST PORTS OF NORTH AMERICA BETWEEN THE YEARS OF 1990 TO 2020



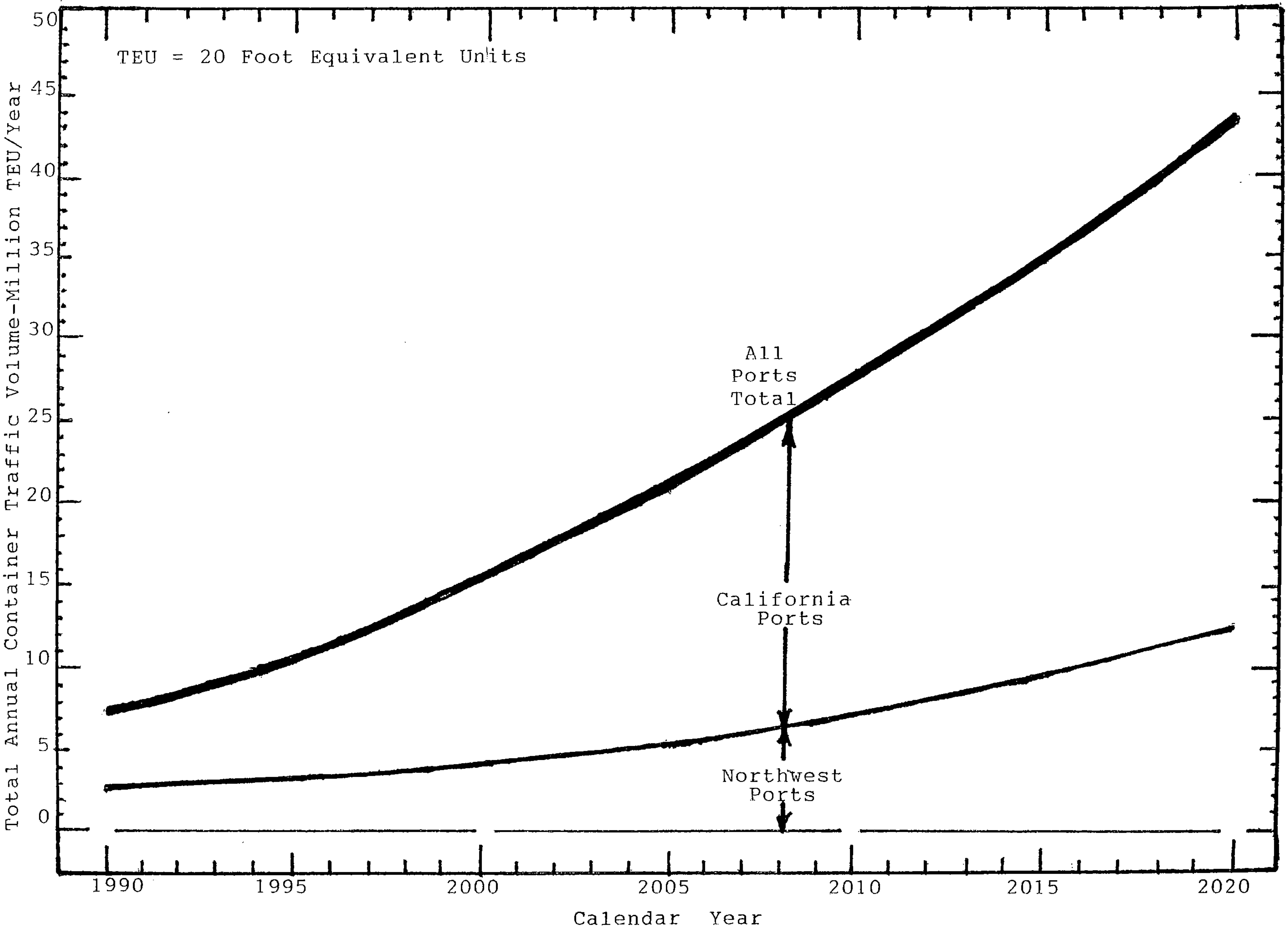
EXPECTED INCREASES IN CONTAINER TRAFFIC VOLUMES PASSING THROUGH WEST COAST PORTS FROM THE PACIFIC RIM IN ASIA TO THE CENTRAL AND EASTERN UNITED STATES BY RAILROAD TRAIN.



EXPECTED INCREASES IN CONTAINERIZED CARGO TRAFFIC GROWTH AT WEST COAST PORTS: 1980-2020.



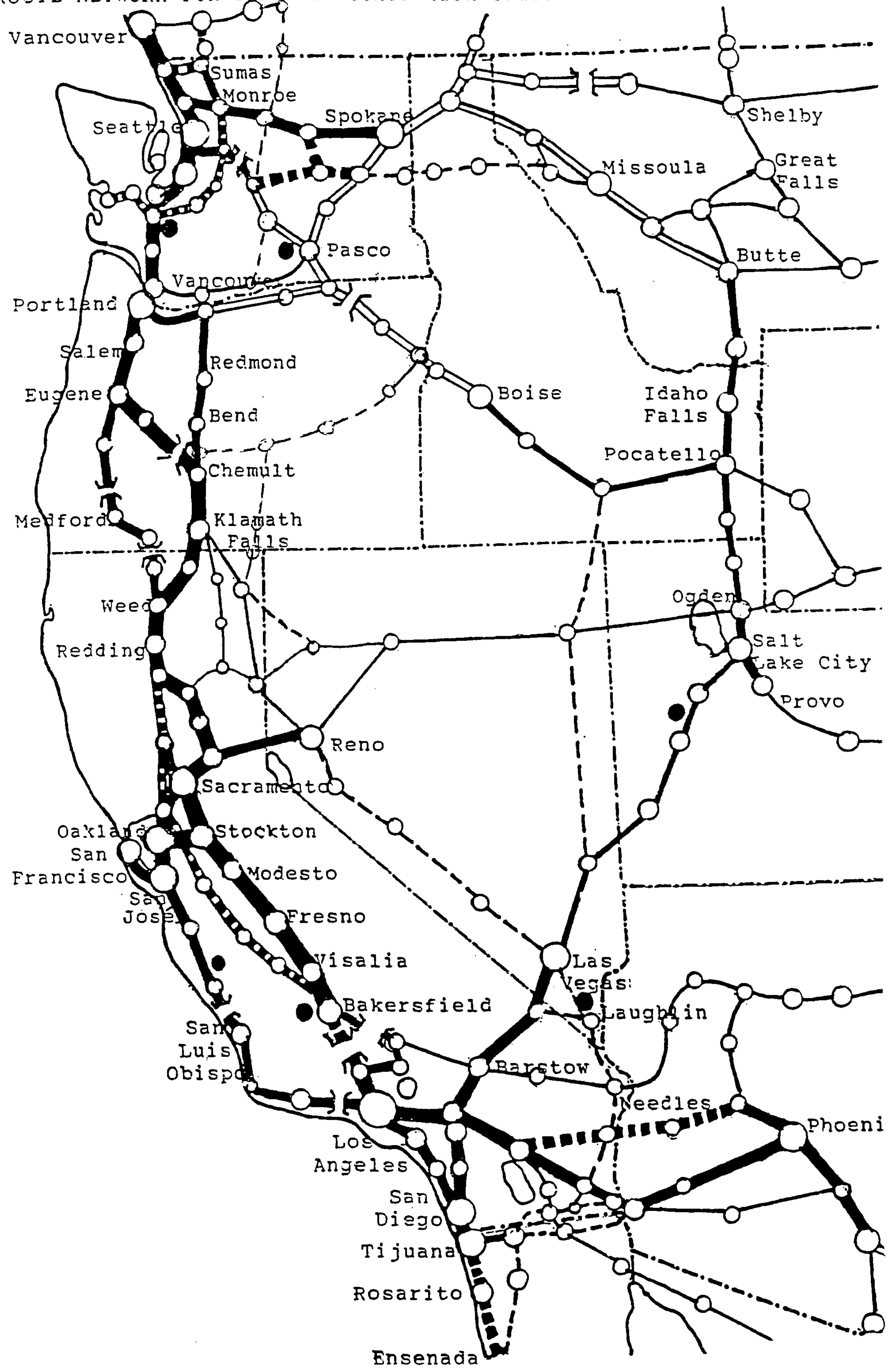
EXPECTED INCREASES IN CONTAINER TRAFFIC VOLUMES AT THE WEST COAST PORTS FROM 1990 TO 2020



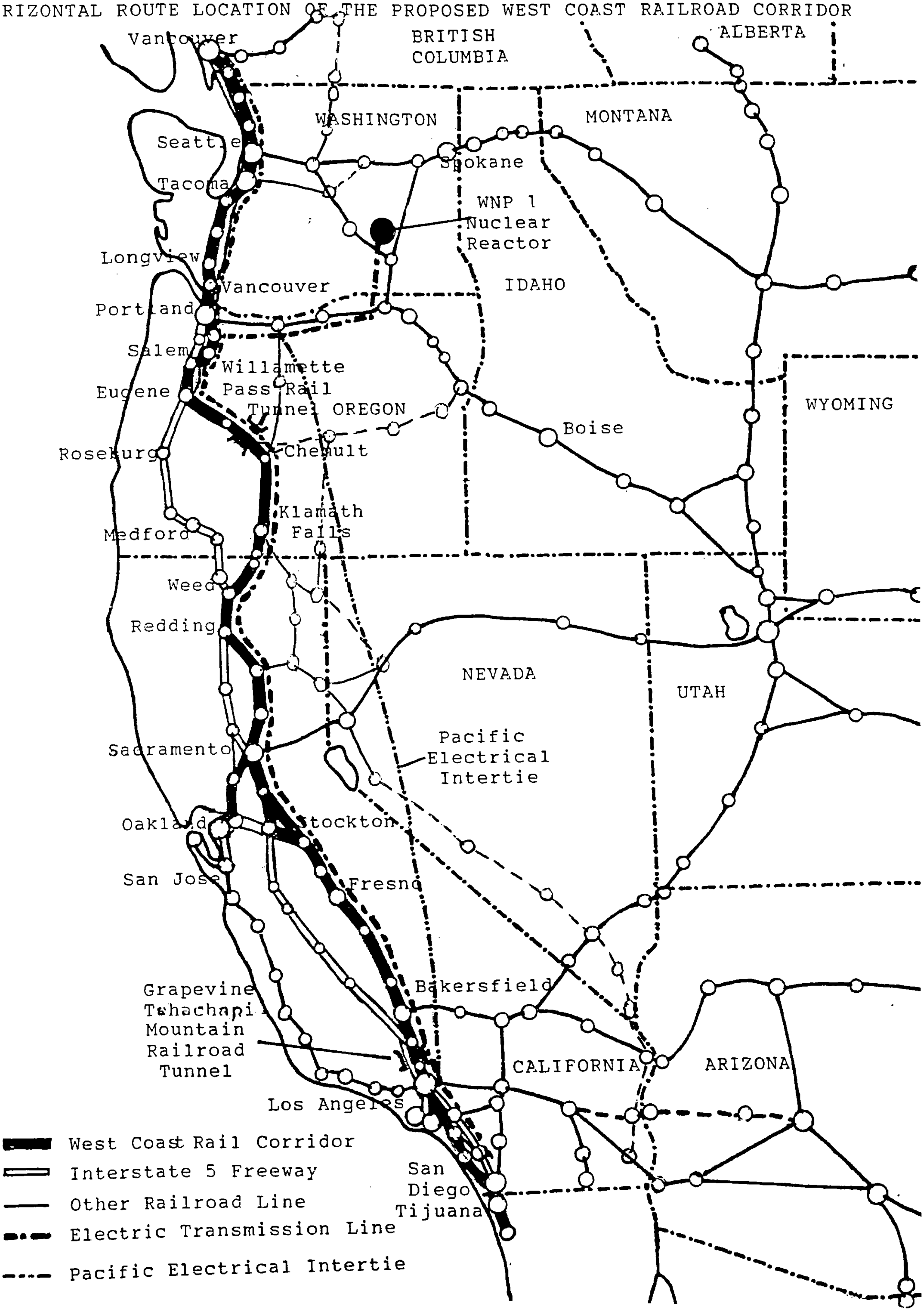
WEST COAST

RAILROAD NETWORK

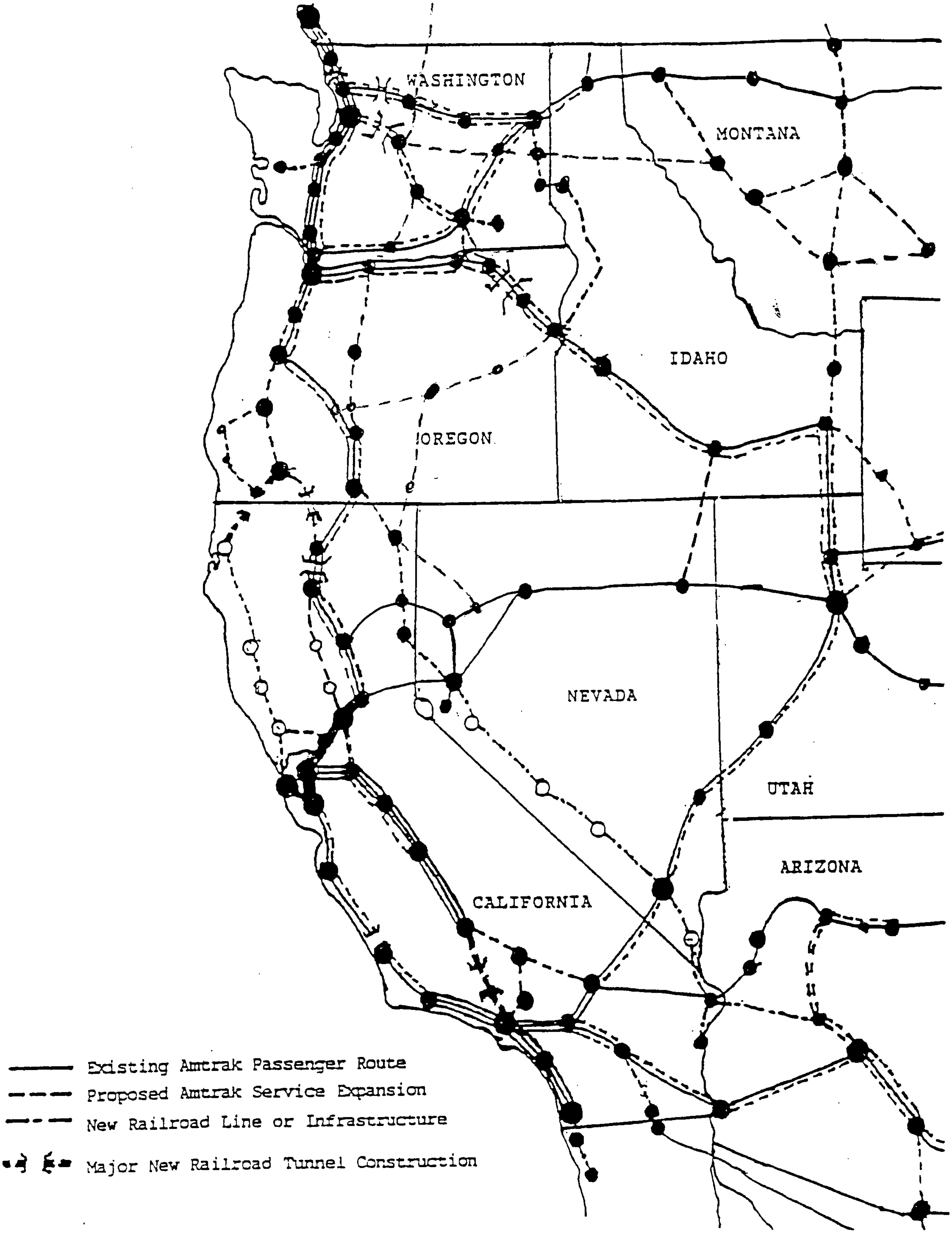
PROPOSED ROUTE NETWORK FOR THE WEST COAST HIGH SPEED PASSENGER RAIL CORRIDOR



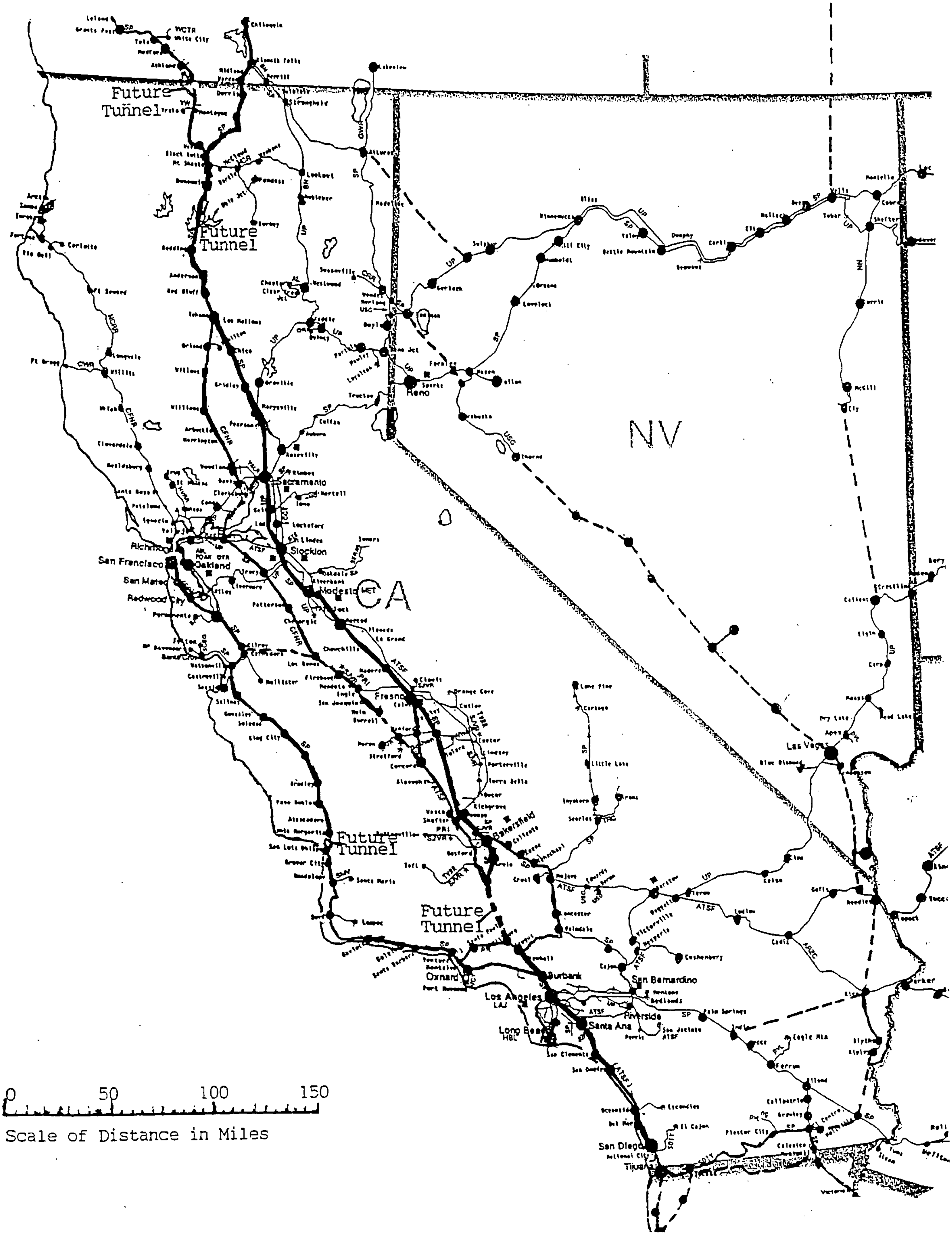
HORIZONTAL ROUTE LOCATION OF THE PROPOSED WEST COAST RAILROAD CORRIDOR



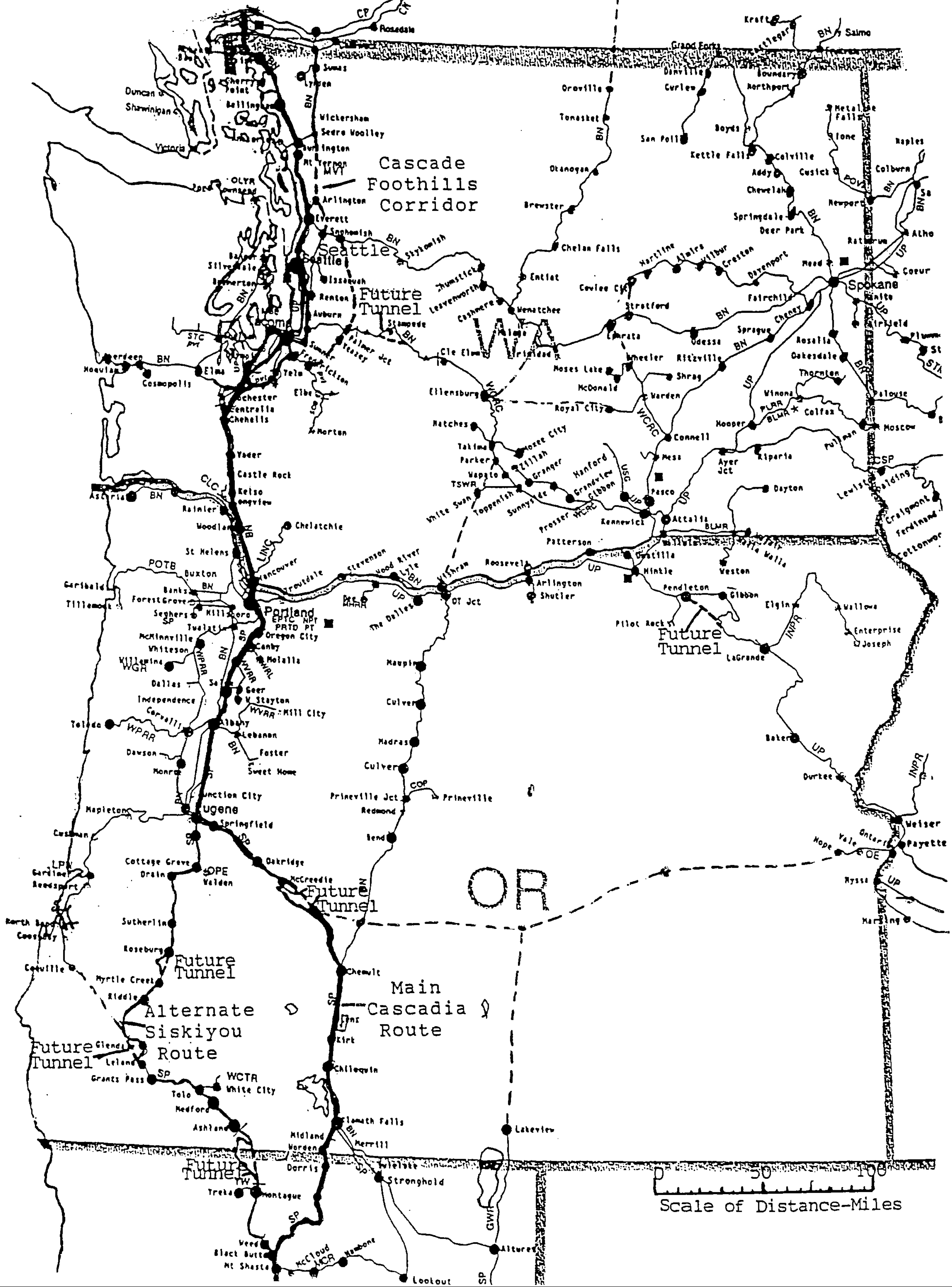
PROPOSED ROUTE NETWORK FOR AN INTERCITY RAIL PASSENGER SYSTEM ON THE WEST COAST



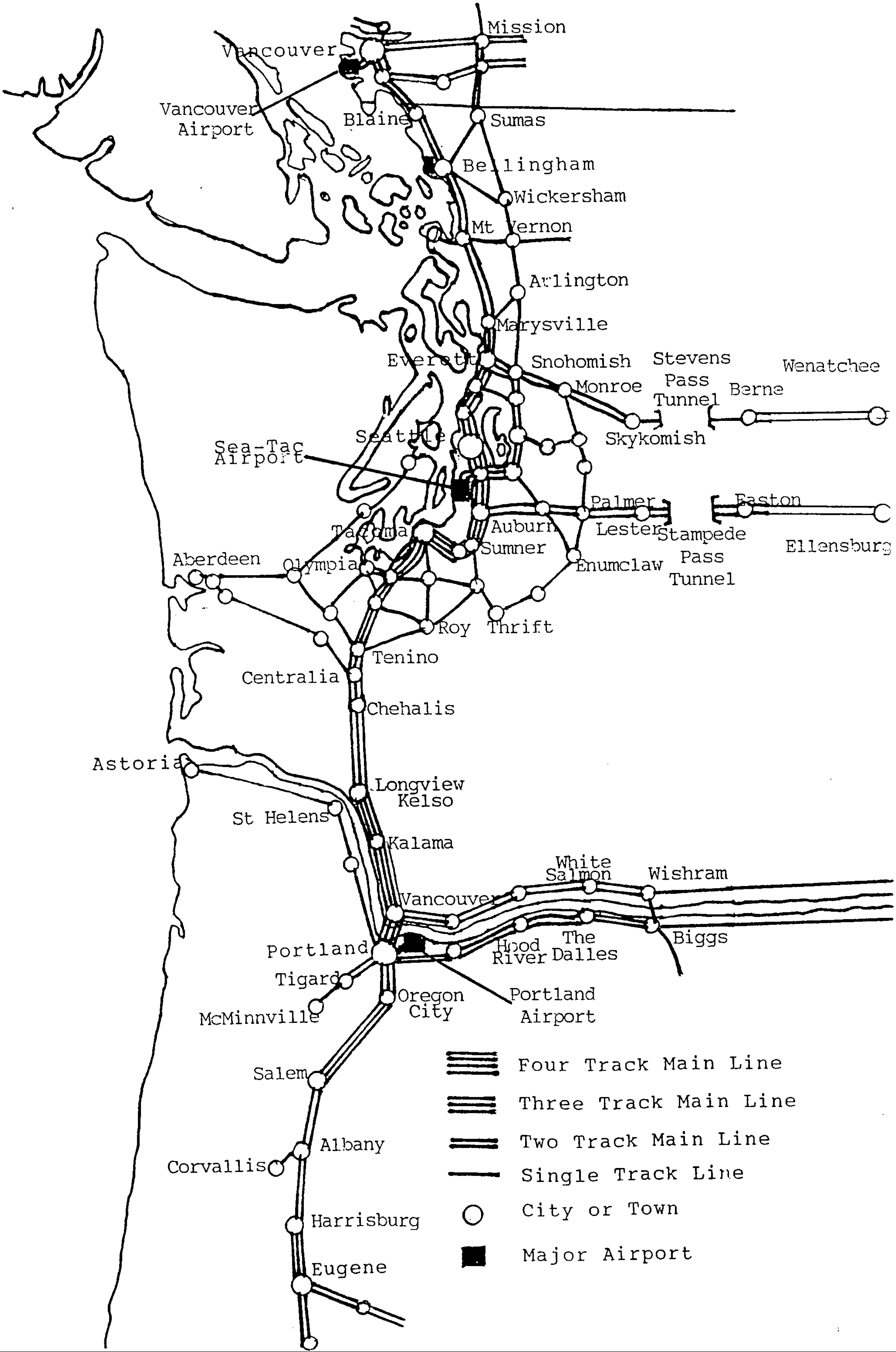
PROPOSED ROUTING OF THE HIGH SPEED RAIL CORRIDOR NETWORK IN CALIFORNIA



PROPOSED HIGH SPEED RAIL TRANSPORT CORRIDOR IN OREGON AND WASHINGTON



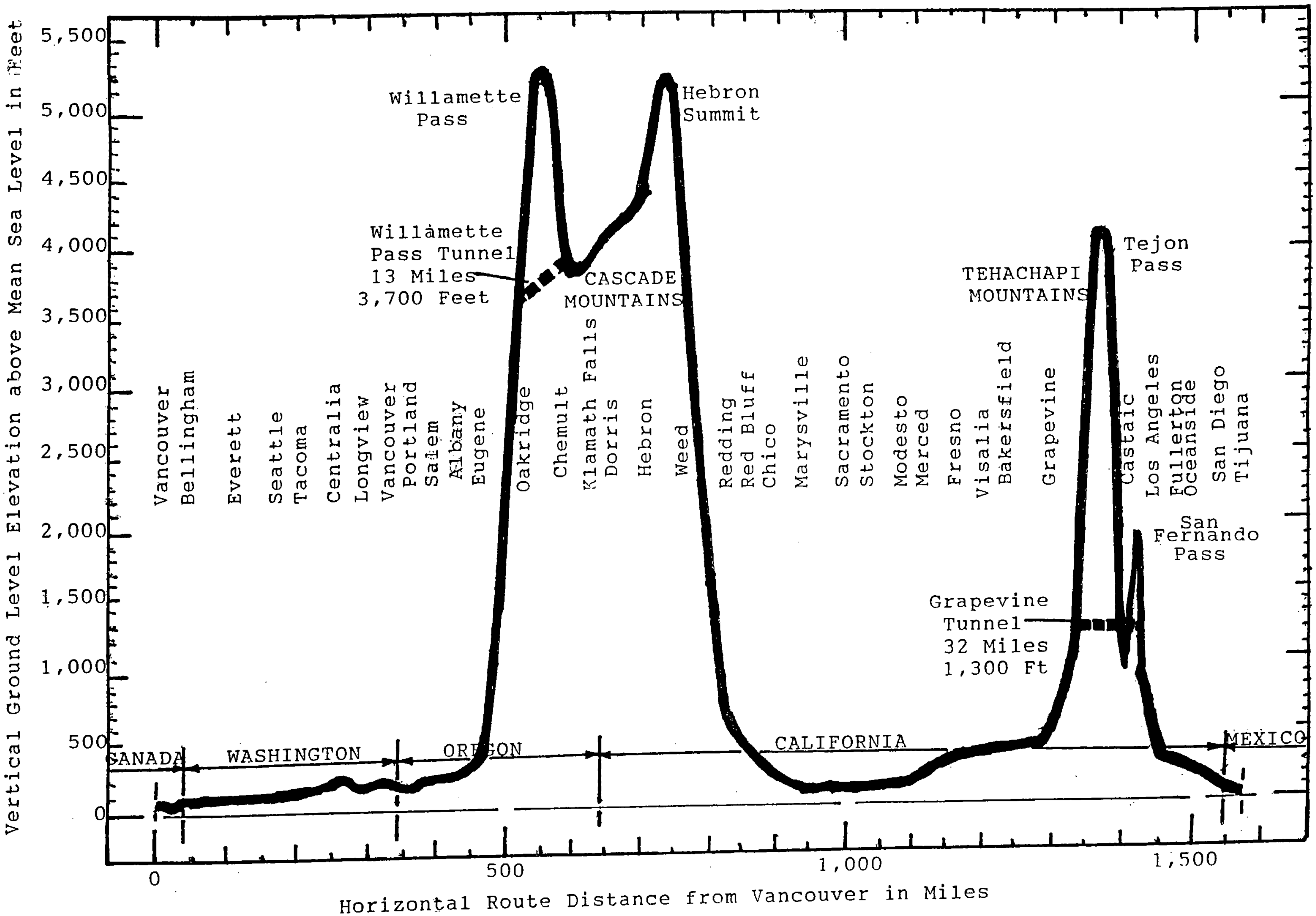
TRACK CONFIGURATION REQUIREMENTS FOR THE PACIFIC NORTHWEST RAIL CORRIDOR.



WEST COAST RAILROAD

ELEVATION PROFILES

VERTICAL ELEVATION PROFILE CONFIGURATION OF THE WEST COAST RAILROAD LINE CORRIDOR FROM VANCOUVER, BRITISH COLUMBIA TO TIJUANA, BAJA CALIFORNIA VIA WASHINGTON, OREGON & CALIFORNIA



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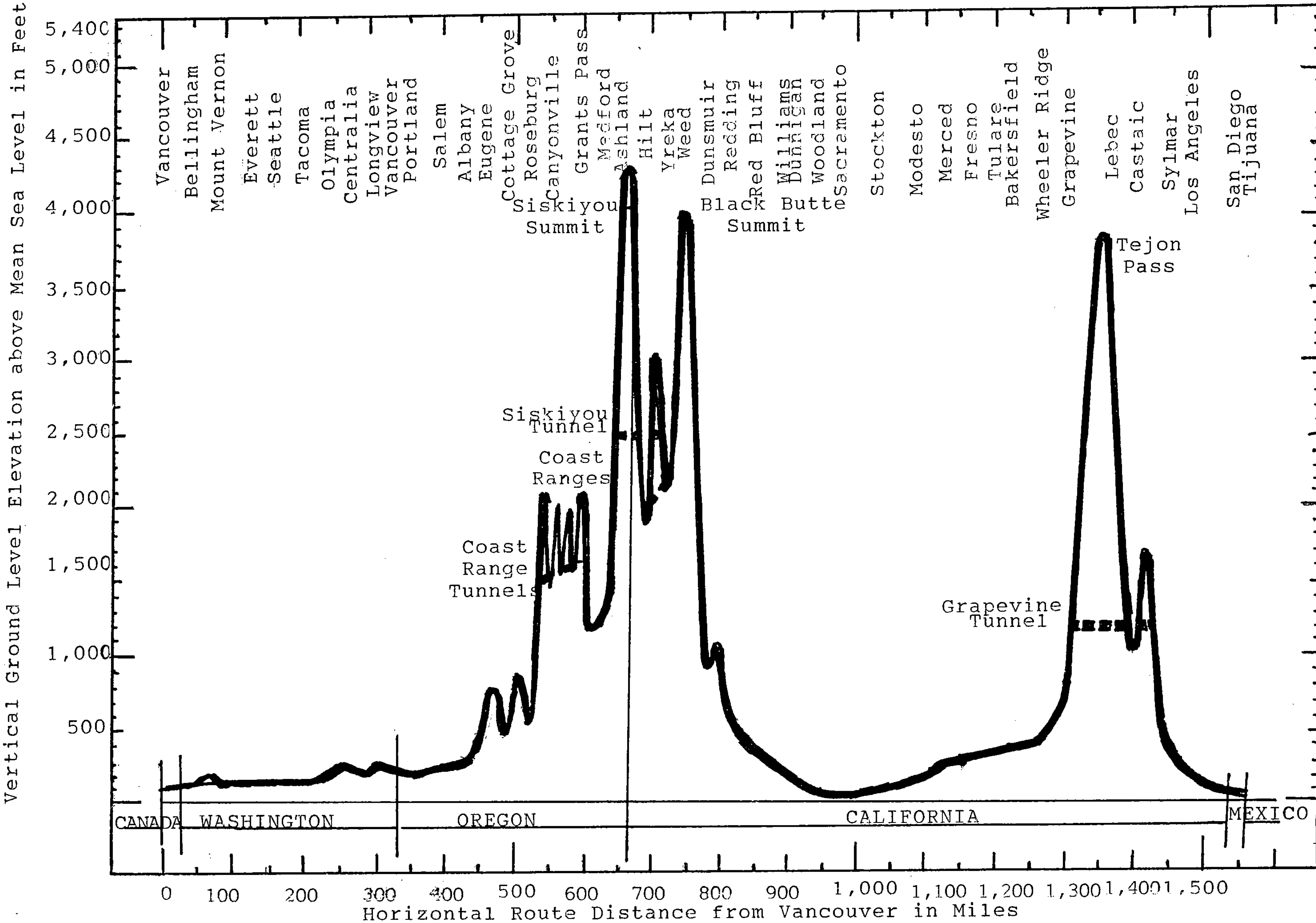
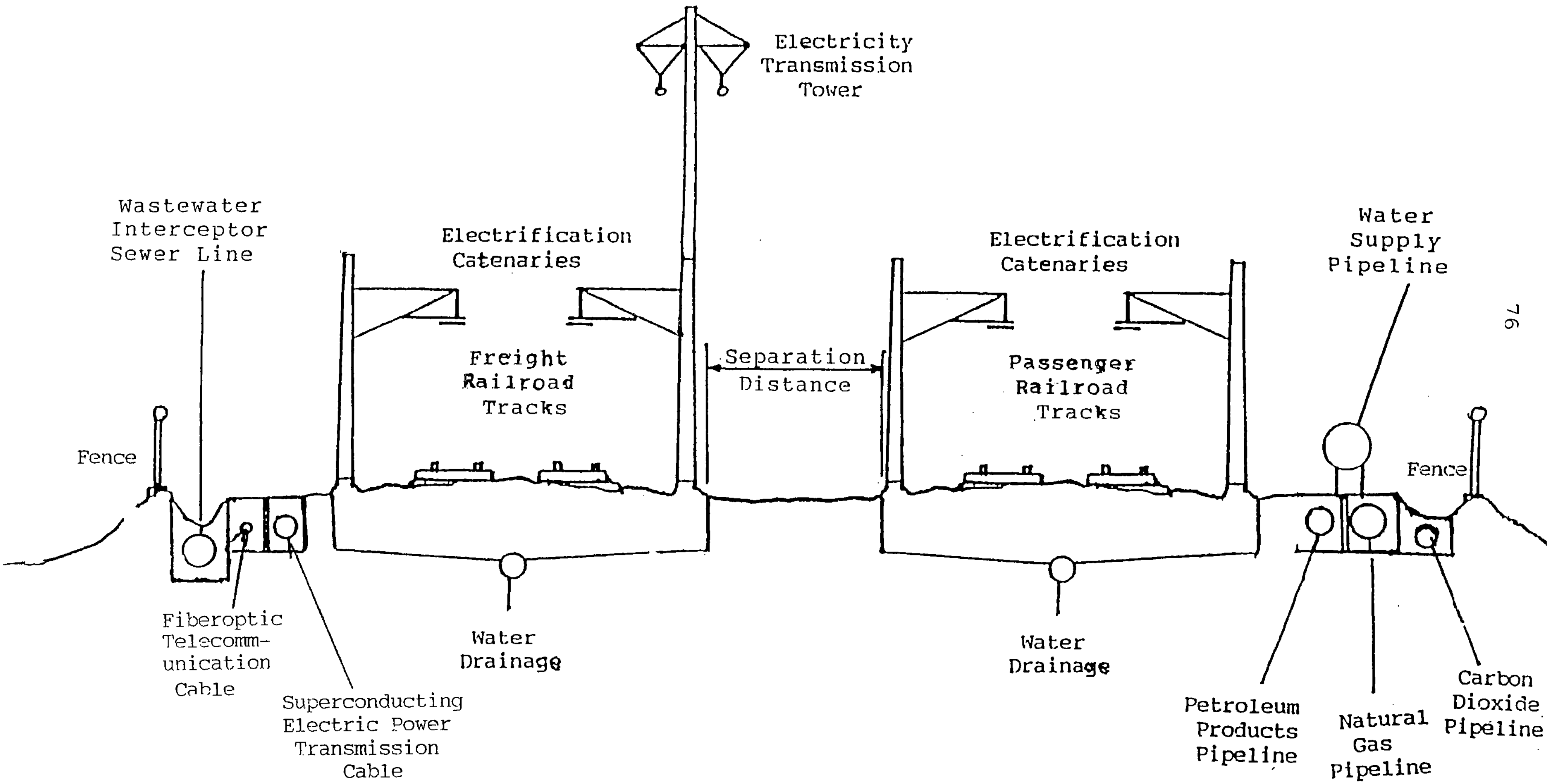
VERTICAL ELEVATION PROFILE CONFIGURATION OF THE PROPOSED WEST COAST RAILROAD LINE ROUTE ALONG THE INTERSTATE 5 FREEWAY CORRIDOR FROM VANCOUVER, BRITISH COLUMBIA, CANADA TO THE TIJUANA, BAJA CALIFORNIA, MEXICO THROUGH THE STATES OF WASHINGTON, OREGON AND CALIFORNIA



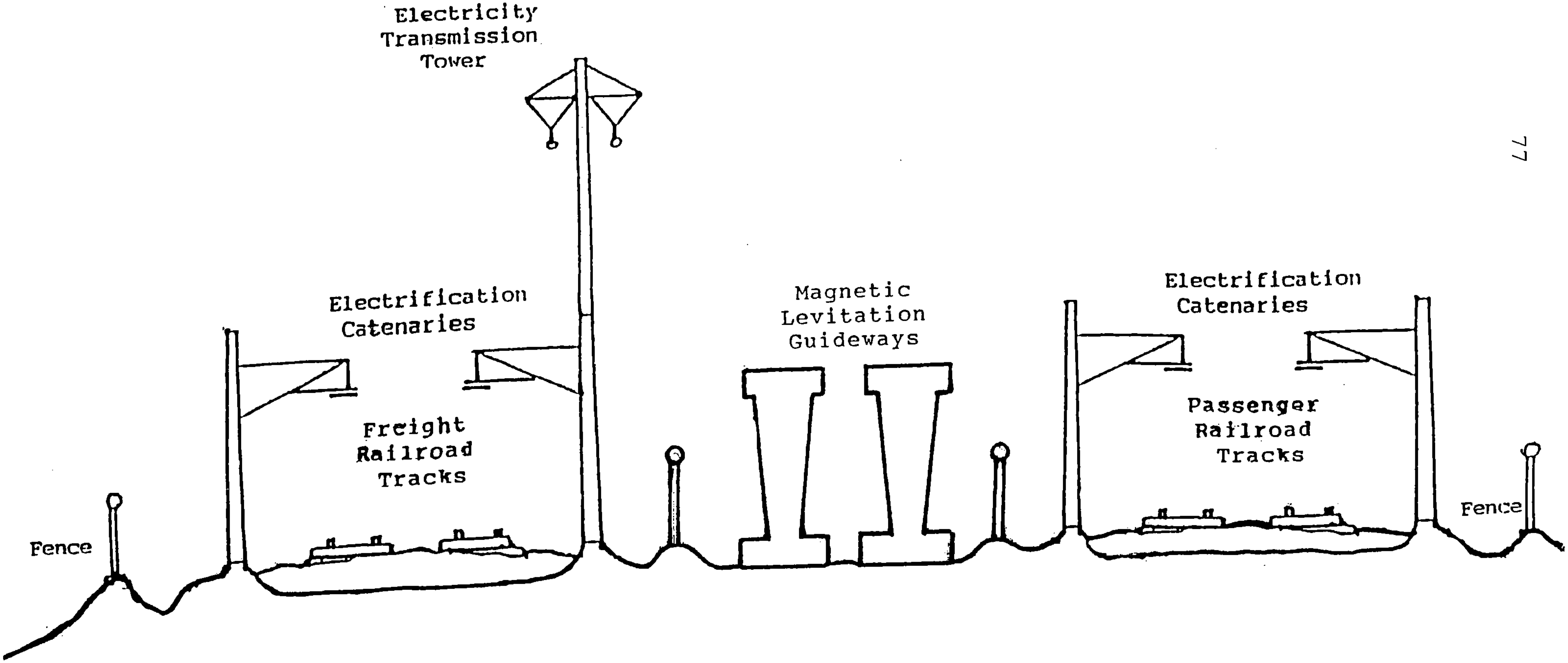
WEST COAST RAILROAD

CROSS SECTION PROFILES

CROSS-SECTIONAL VERTICAL PROFILE OF THE COMBINED HIGH SPEED PASSENGER AND FREIGHT RAILROAD LINE ALONG THE INTERSTATE 5 CORRIDOR BETWEEN THE STATES OF WASHINGTON, OREGON AND CALIFORNIA



VERTICAL CROSS SECTIONAL PROFILE OF THE INTEGRATED HIGH SPEED PASSENGER AND FREIGHT RAIL LINE CORRIDOR ALONG THE WEST COAST IN PARALLEL TO THE INTERSTATE 5 FREEWAY IN THE STATES OF WASHINGTON, OREGON AND CALIFORNIA FROM VANCOUVER, BRITISH COLUMBIA TO TIJUANA, MEXICO



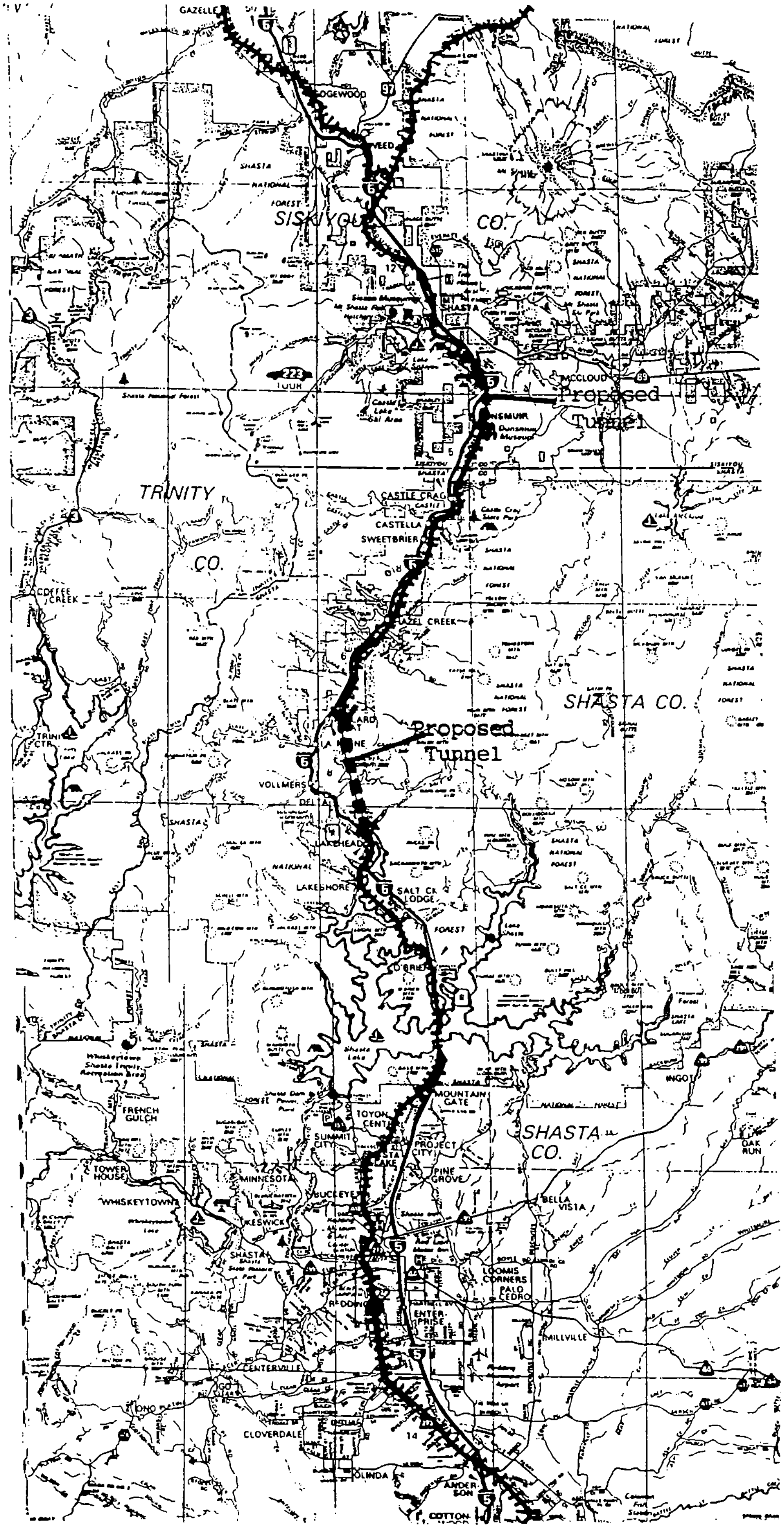
WEST COAST RAILROAD

INFRASTRUCTURE PROJECTS

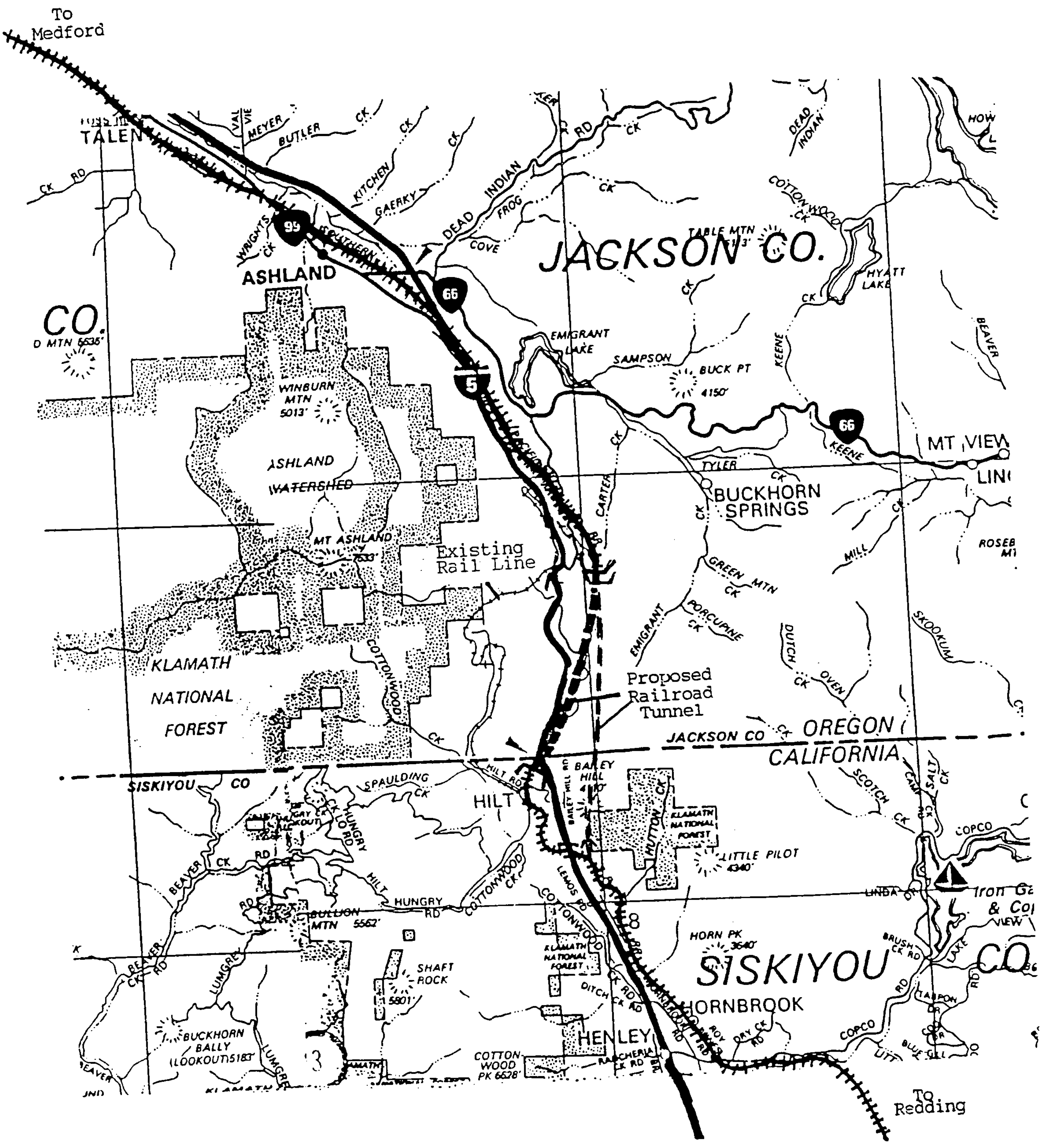
SUMMARY FEATURES OF THE STEPWISE PHASED IMPLEMENTATION PLAN FOR INCREMENTAL IMPROVEMENTS IN THE WESTERN & EASTERN WASHINGTON INTERCITY CORRIDORS TO ALLEVIATE THE RUNWAY CAPACITY CONSTRAINTS AT SEA-TAC AIRPORT

Time Frame	Western Washington Corridor Portland-Seattle-Vancouver	Eastern Washington Corridor Seattle-Spokane & Eastern Washington	Northern California Corridor Southern California Corridor
1996-2000	Buy 4 New Trainsets for Service Build Tukwila Station for Sea-Tac Airport Construct Prarie Line Bypass Line Start Bellevue-Tukwila Line Upgrade Bellevue-Tukwila Line Make Signal & Track Improvements Start Nonstop Train Service from Seattle to Portland via Tukwila Start Bellevue-Portland Service	Start up Stampede Pass Line for Freight Start Sea-Tac Passenger Service for Wenatchee Start up Stampede Pass Line for Passengers Make signal & track improvements on Line Start Yakima River Canyon Line Start construction of Ellensburg-Lind Line Start double-tracking of Lind-Spokane Line Start Seattle-Ellensburge-Yakima Service Start Sea-Tac Airport Rail Connector Construction	Start second Coast Starlight Train via Klamath Falls Begin second Track Construction in Willamette Valley Upgrade Existing Trackage from Bend to Klamath Falls Begin Upgrading of Siskiyou Line from Eugene to Ashland Add second track to Rosevalde-Redding Main Line Upgrade Existing Coast Line from San Jose to Glendale
2000-2005	Buy 4 Additional Trainsets Upgrade Bellevue-Tukwila Line Construct Olympia Connector Line Make Signal & Track Improvements Start Upgrade Bellevue-Snohomish Line for Vancouver Service Start Third Main Track on Seattle to Portland Corridor Line Start Double Tracking of Seattle to Vancouver Corridor Line Start Bellevue Main Terminal Nonstop Seattle-Vancouver Service	Complete construction of Ellensburg-Lind Line Complete construction of Stevens Pass Improvement Start construction of Stampede Pass new Tunnel Upgrade signals for Auburn-Lind-Spokane Line Double-track Stampede Pass access lines Start construction of Renton-Maple Valley Bypass Line Complete construction of Lind-Pasco-Moses Lake Line Complete renovation of Stevens Pass Line Start Seattle-Yakima-Pasco Rail Line Service Complete Sea-Tac Airport Rail Connector Construction Begin Improvements to Idaho and Montana Rail Line	Upgrade Willamette Pass Line Eugene to Chenult Upgrade and Rebuild Sacramento Canyon Line Add second track to Klamath Falls-Weed Line Begin Construction of Siskiyou Mountain Tunnel Begin Construction of Tehachapi Mountain Tunnel Add second track through San Joaquin Valley Line
2005-2010	Buy 4 Additional Trainsets Construct Lake Samish Bypass Line Rebuild Eastside Rail Line Start Sea-Tac Airport Connector Complete Third Main Track from Seattle to Portland Corridor Complete Double Tracking of the Seattle to Vancouver Corridor Expand Track and Signal Upgrading Expand Nonstop Train Services Start Eastside Railroad Tunnel	Add second main track to Ellensburg & Lind Add second Main Track to Moses Lake-Lind-Pasco Line Start direct rail service from Sea-Tac Airport to Moses Lake Airport and Spokane Airport Complete construction of Stampede Pass Tunnel Start rail passenger service to Pullman Extend rail passenger service to Coeur d'Alene, Sandpoint, Bonners Ferry and Whitefish. Continue improvements to Idaho and Montana Rail Line Complete construction of Renton-Maple Valley Bypass Line	Complete Reconstruction of Siskiyou Line Route Complete Construction of Sacramento Canyon Line Complete Construction of Siskiyou Mountain Tunnel Complete Construction of Tehachapi Mountain Tunnel Complete Reconstruction of the Coast Line Route
2010-2020	Full High Speed Rail Operation 150 miles/hour for Passenger Service 90 miles/hour for Freight Service	Increase to Full High Speed Rail Operation 185 miles/hour for Passenger Service 90 miles/hour for Freight Service	Increase to Full High Speed Rail Operation 180 miles/hour for Passenger Service 90 miles/hour for Freight Service

PROPOSED RAILROAD LINE ROUTING THROUGH THE SACRAMENTO RIVER CANYON



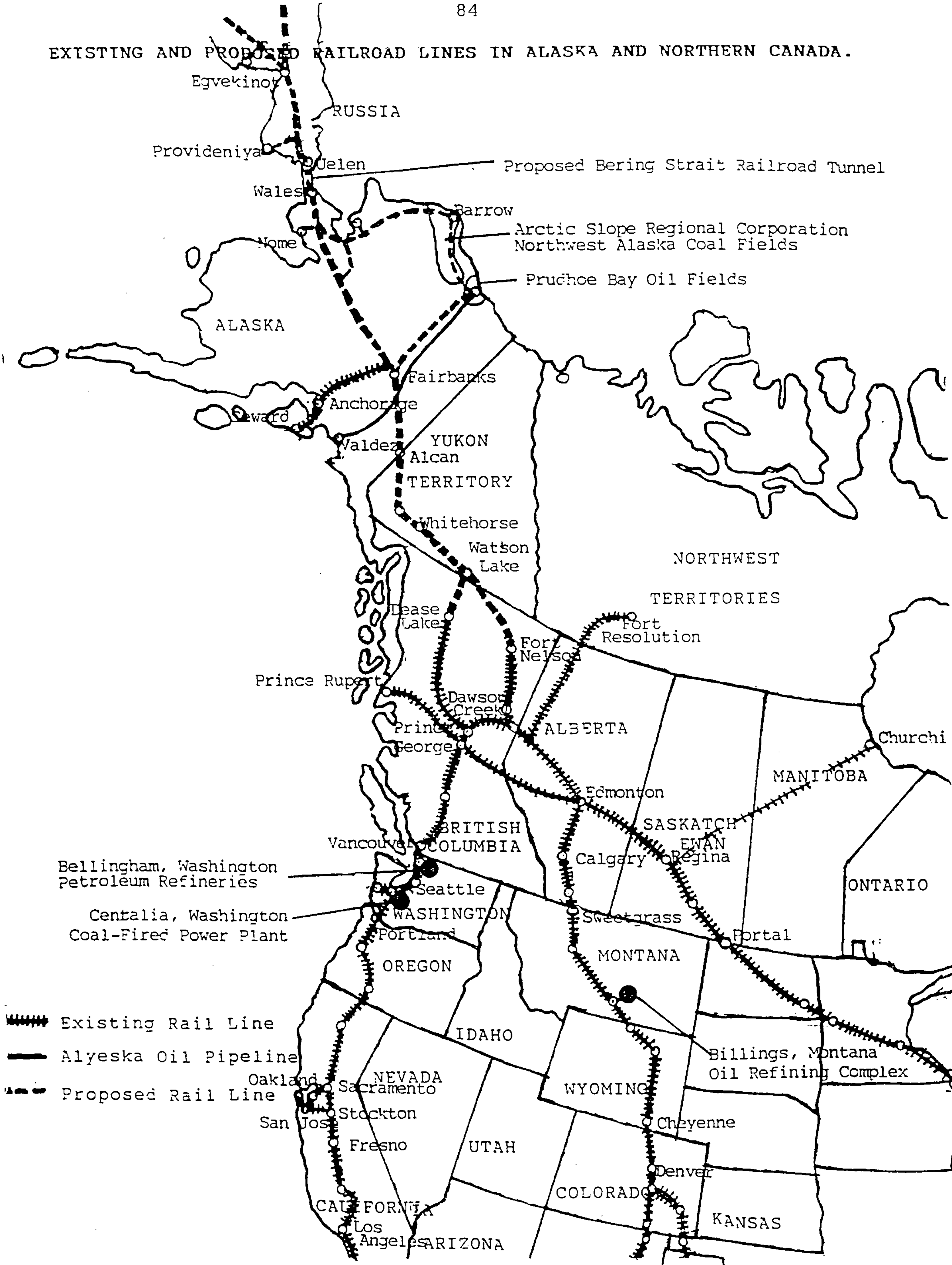
LOCATION OF THE PROPOSED RAILROAD TUNNEL THROUGH THE SISKIYOU MOUNTAINS.



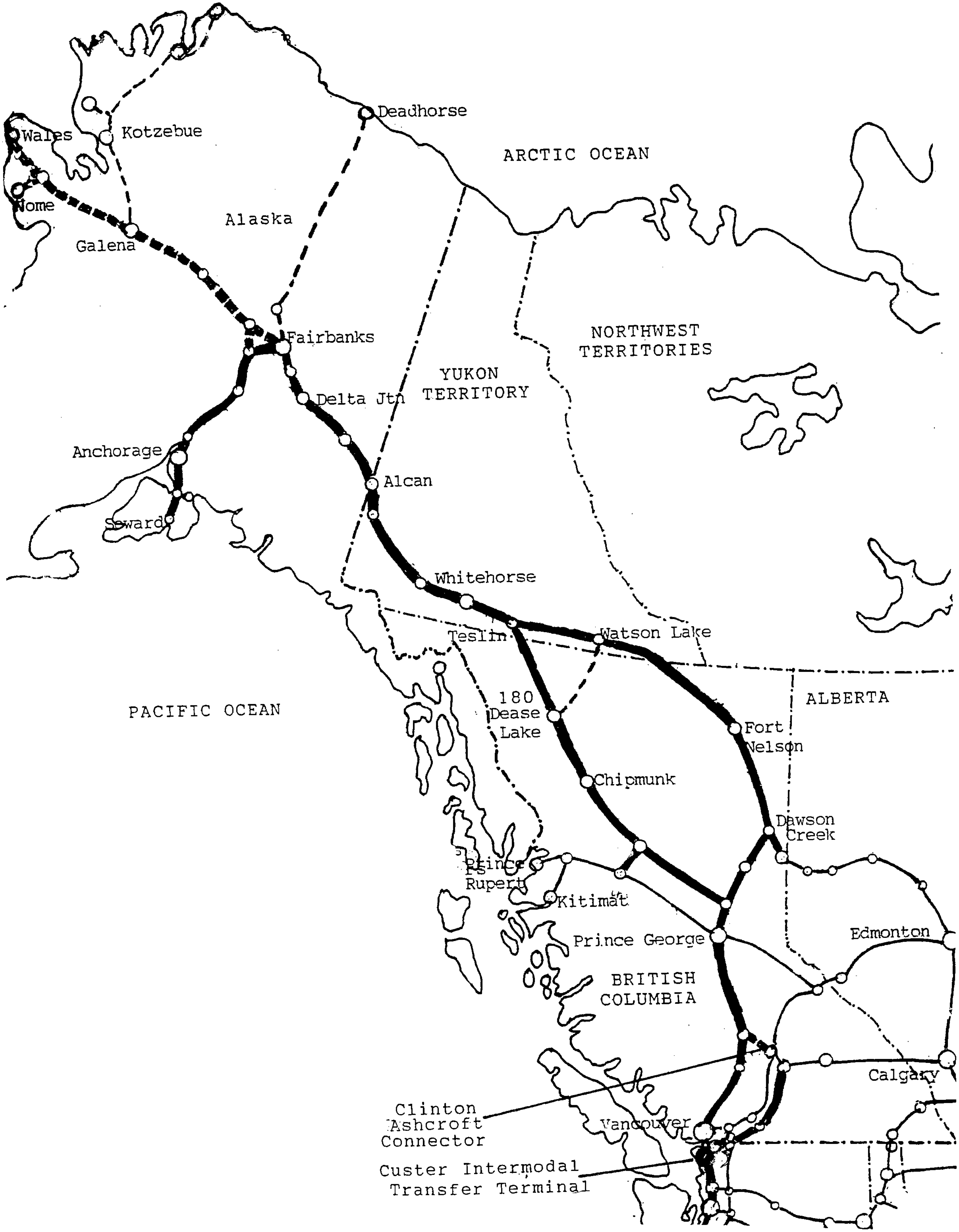
ALASKA CANADA

RAILROAD EXTENSIONS

EXISTING AND PROPOSED RAILROAD LINES IN ALASKA AND NORTHERN CANADA.



PROPOSED ROUTE OF THE CANADIAN ARCTIC RAILWAY FROM CUSTER TO FAIRBANKS



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Attachment 3

GRAPEVINE GRADE

CALIFORNIA TUNNEL PROJECT

ECONOMIC ANALYSIS

Date: August, 10, 2003

Prepared For: Dr. Hal B.H. Cooper, Jr.
President
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Kirkland, Washington 98034

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20208 – 42 NE
Seattle, Washington 98155

GRAPEVINE GRADE TUNNEL PROJECT

Table of Contents:

Grapevine Grade Tunnel Project

I. Assumptions

The cash flows for the economic analysis of this project were based on a series of assumptions as follows:

1. The budgeted capital expenditure was based on a projected cost of Construction of $3,234.500 broken down as follows:

   a. Tunnel costs at $100,000,000 per mile for 32 miles double track under under the Grapevine Grade. $3,200,000.000.

   b. Infrastructure cost for two Intermodal terminals: $10,000,000

   c. Two Intermodal terminals: $10,000,000

   d. Equipment for two Intermodal terminals: $2,000,000

   e. Two truck stop buildings and equipment: $3,000,000

   f. Four 100,000 sq. ft. Warehouse buildings located two at each terminal: $8,000,000

   g. Contingency: $1,500,000

2. Debt servicing based on a 30 year amortization of principal and interest. (1) Alternative A – 6% standard loan; (2) Alternative B – 3% subsidized loan.

3. Operating costs based on $25,000 per mile of track per year. 32 miles of double track.

4. Utilization factors based upon 20,000 trucks per day through the corridor.

5. Passenger trains forecast at 100 trains per day through the corridor.

6. Capitalized interest cost in the five year construction period:
   6% - $485,175,000
   3% - $242,587,500

7. The utilization assumptions for 10%, 15%, 20% and 25% were based on the ability of the tunnel operators and authority to capture certain percentages of the existing truck traffic over the Grapevine Grade under current conditions. The utilization assumptions for 50% and 75% were based on legal statues banning trucks or a percentage of truck operators from using the highway corridor due to the high costs in California to maintain the highway and preserve the highway corridor from continued damage and maintenance costs.

Grapevine Grade Tunnel Project

II. Conclusion

Cooper Energy and Fertilizer Company proposes to construct a 32 mile double track railroad tunnel under the "Grapevine Grade" section of the I-5 corridor linking the existing rail lines between Los Angeles, San Fernando, Castaic and Bakersfield. The tunnel would support Intermodal truck freight and high speed passenger trains. The intermodal services would be supported by two truck terminals and truck stop facilities on each side of the tunnel located in San Fernando and Bakersfield. It is the conclusion of Ronald E. Rafter, Director of China Distribution & Development Co. Inc. and author of this economic analysis that the Grapevine Grade Tunnel Project can be a very viable and sustainable project but this will require certain percentages of utilization from trucks currently using the I-5 highway through the corridor and minimum fees from trucks and passenger trains using the proposed tunnel.

The Grapevine Grade Tunnel Project is a cost sensitive project with limited upgrading of revenues from truck fees and passenger trains. At a 6% interest rate the net revenues after tax produce marginal debt servicing capabilities until the project receives 25% utilization with truck fees of $140/truck and $7,000/passenger train. The cash flows from 3% financing combined with truck fees of $120/truck at 15% utilization and $6,000/passenger train demonstrates the profitability potential and adequacy of debt servicing. This is the minimum level and any other combinations of higher utilization and/or fees with 3% subsidized loans increases the profitability potential for the project.

With some forms of subsidized loans and/or government mandated useage of the Grapevine Grade Tunnel from the State of California changes the numbers significantly and increases profitability potential to greater levels of debt servicing coverage acceptable to lenders and investors alike. Mandated useage levels of 50% and 75% create very acceptable levels of debt servicing coverage for both 3% loan costs and 6% loan costs. Subsidized loans and mandated useage are both items that the State of California should consider fully for this project. It is estimated that every truck using the existing I-5 highway through the corridor costs the State of California $25 for maintenance and damage repair to the highway. This relates to an expense of over $182,500,000 per annum to the California taxpayers. A good portion of this cost would be saved by trucks substituting the intermodal rail useage rather than the highway corridor.

Grapevine Grade Tunnel Project

III. Narrative of Analysis

The Grapevine Grade Tunnel Project proposes to construct a 32 mile double track railroad tunnel under the Grapevine Grade corridor of the I-5 highway linking Los Angeles, San Fernando and Bakersfield. The rail corridor would provide intermodal movement of truck freight by rail along the 120 mile corridor between Los Angeles and Bakersfield, California. Additionally, the rail corridor would provide high speed passenger trains linking northern and southern California. The project would provide a more efficient movement of freight and people through the corridor while reducing the heavy volume of trucks and automobiles presently restricted to the I-5 highway and the delays caused by the existing Grapevine Grade. Additionally, the project would reduce the maintenance and repair costs associated with the truck and automobile traffic presently using this corridor. The project would provide for two intermodal terminals and truck stops on each end of the tunnel to be located in San Fernando and Bakersfield. The intermodal terminals would load and unload the truck tractors and trailers and the truck stops would provide full services for the truck operators and their equipment.

The purpose of this analysis is to determine the revenue from intermodal truck fees and passenger train required to amortize the debt and provide for a fair internal rate of return for investment risk. The truck fee in particular has to be priced competitively in order to attract truck freight users who presently travel the corridor via highway. It is estimated that it costs truck operators $1.25 per mile to operate a class 8 vehicle with trailer. Consequently, the 120 mile distance between Los Angeles and Bakersfield would cost truckers approximately $150 per trip. The intermodal method of moving the truck tractor, trailer and driver will have to compete with the actual costs of moving the same load via highway. An additional factor to consider is that the movement of truck freight via intermodal rail service is faster, causes less stress and is more efficient than highway useage. It is also important to incorporate the value of speedy movement of cargo in and out of the primary Southern California ports of San Pedro and Los Angeles. Delays in the movement of cargo in and out of these ports has cost importers and exporters millions of dollars per year and the traffic volumes that persist on the inadequate surface transportation system is a major contributor to this cost. Additionally, the cost to the State of California to maintain and repair their surface transportation systems is enormous. It is estimated that every truck using the Grapevine Grade corridor costs the State $25 or $182,500,000 per annum.

It is important to remember that when dealing with longer term infrastructure projects such as the "Grapevine Grade Tunnel Project" that debt servicing adequacy is measured in terms of "coverage". Coverage is the ratio between the funds available from cash flow for the payment of debt and the actual amortization requirements for principal and interest. Industry standards for infrastructure projects consider coverage of 1.4x (times) or above adequate for debt servicing and consequently project loan approval.

For the Grapevine Grade Tunnel Project we looked at the utilization of existing truck traffic on the existing corridor which is approximately 20,000 units per day, a fee for the intermodal service and a fee for high speed passenger trains using the rail link. Additionally, a much higher utilization factor assuming a legal useage mandate would be issued by the State of California requiring truck operators to use the rail corridor in order to greatlt reduce present State outlays for maintenance and repair. The scenarios that were used consist of:

1. Utilizations of truck traffic of 10%, 15%, 20% and 25% with a fee of $100 and Passenger Train of $5,000.
2. Utilizations of truck traffic of 10%, 15%, 20% and 25% with a fee of $120 and Passenger Train of $6,000.
3. Utilizations of truck traffic of 10%, 15%, 20% and 25% with a fee of $140 and Passenger Train of $7,000.
4. Utilizations of truck traffic of 10%, 15%, 20%, 25%, 50% and 75% with a fee of $140 and Passenger Train of $7,000.

The pricing was then matched to the costs to operate and also includes the revenues and costs of operating two intermodal facilities and truck stops. The results were then matched to the two debt servicing alternatives used in the assumptions to show debt servicing adequacy for each price and utilization alternative.

(1) Using the initial assumptions of truck fees at $100 per truck and passenger trains at $5,000 per train we find only marginal results and limited debt servicing capability. The only two scenarios that generate acceptable albeit limited coverage require subsidized funding with an interest rate of 3%. The standard loan with a 6% interest generates no acceptable coverage levels.

3% subsidized financing produces a net profit after tax at all levels of utilization but limited coverage. The results are as follows:

Utilization:	10%	15%	20%	25%
Net Profit:	$30.8MM	$56.3MM	$81.8MM	$107.3MM
Coverage:	1.13x	1.28x	1.42x	1.57x

With a 25% utilization of truck traffic through the corridor the project creates an acceptable coverage level but, in the opinion of the author, does not represent a level high enough or consistent with the risk of the investment or potential return to investor.

The 6% standard loan with these scenarios produces no level of income or coverage acceptable and can not be considered as a viable alternative. The results show losses at the lowest three levels of utilization and only a small profit at 25% which is indicated below.

Utilization:	10%	15%	20%	25%
Net Profit:	($74.6MM)	($38.2MM)	($1.8MM)	$24.2MM
Coverage:	0.79	0.93	1.06	1.16

The fees charged for the trucks and passenger trains using the rail link corridor are too low in this scenario for an adequate return on investment and can not demonstrate any ability to arrange financing for a project of this nature.

(2) The second scenario raises the truck fees to $120 per truck which is competitive with surface transportation costs over the corridor and raises the fees for passenger trains to $6,000 per train. Although the subsidized

loan alternative produces profits at all levels of utilization, it does not produce acceptable coverage of debt servicing until the utilization factor improves to 20% or higher. The chart as shown below indicates the levels of profitability and coverage. It is noted that the 6% standard loan does not produce a profit in the three lowest utilization scenarios and only a very marginal profit at 25% utilization. Coverage for debt servicing on the standard loan is inadequate at all levels.

3% subsidized financing produces the following with truck fees at $120/truck and passenger trains at $6,000/train.

Utilization:	10%	15%	20%	25%
Net Profit:	$59.1MM	$89.4MM	$119.8MM	$150.1MM
Coverage:	1.29	1.46	1.64	1.81

6% standard financing using the same assumptions produces the following:

Utilization:	10%	15%	20%	25%
Net Profit:	($34.3MM)	$9.1MM	$52.5MM	$67.1MM
Coverage:	0.94	1.11	1.27	1.32

Although the standard financing alternative begins to make a small profit in this scenario it does not produce an adequate debt servicing coverage in any scenario and is not financially viable. The subsidized financing alternative is financially viable with coverages of 1.64 and 1.81; if the operators could achieve the utilizations required to produce these results the project would be satisfactory but only due to a subsidy to keep net interest costs at the level assumed.

(3) The third scenario raises the fees to a level of $140 per truck using the rail link and $7,000 per passenger train on the same corridor. We have seen in scenario's 1 and 2 that financial viability is virtually impossible using a standard loan and only possible in the highest two levels of utilization requiring a loan subsidy. At $140 per truck and $7,000 per passenger train the operators are approaching fee levels that may cause users to look for alternatives to move their freight and passengers through the corridor.

At this level of fees the 3% subsidized loan program is profitable at all levels of utilization and coverage is also adequate at all levels of utilization. The 6% standard loan program is also profitable at all levels of utilization but debt servicing coverage only meets minimum industry standards in the two highest utilization factors of 20% and 25%. The table below shows the profitability and coverages at the various utilization factors using the fee scheduled as outlined above.

3% Subsidized Financing:

Utilization:	10%	15%	20%	25%
Net Profit:	$87.2MM	$122.5MM	$157.8MM	$193.1MM
Coverage:	1.45	1.65	1.85	2.05

6% Standard Financing:

Utilization:	10%	15%	20%	25%
Net Profit:	$5.9MM	$56.4MM	$106.8MM	$110.0MM
Coverage:	1.09	1.28	1.47	1.48

The above table indicates that with subsidized financing the operator could produce results that would be acceptable to lenders/investors particularly at the higher utilization factors of 20% and 25%. The question arises that can the operator achieve the fee levels required, the utilizations required at the higher levels and the subsidy itself. These questions would need to be answered and demonstrated prior to lender/investor participation.

The standard financing alternative continues to struggle even at the highest of the three fee scenarios although it produces adequate profitability and coverage at the higher utilization factors of 20% and 25%. The lender/investor would certainly be looking at the operators feasibility of obtaining these utilization levels.

(4) The 4th fee scenario keeps the fee levels for trucks and passenger trains at the same level as scenario three which is $140 per truck and $7,000 per passenger train. This scenario does, however, make a dramatic utilization assumption which increases the utilization level from a top of

25% to levels of 50% and 75%. Utilization levels this high can only be reached by mandate or legal regulations from the State of California. As we have indicated each truck using the Los Angeles – Bakersfield corridor costs the State of California $25 per trip. This cost is in damage to the highway and highway maintenance. Annually this costs exceeds $182,500,000 and paid from the State's highway budgets and reserves. In a period where the State of California is running approximately $40,000,000,000 deficits the mandated utilization, although unlikely, could be used as a cost saving alternative.

The mandated higher utilizations make dramatic changes to the project cash flow and certainly make both subsidized financing or standard loans profitable at these levels with more than adequate debt servicing coverage. Looking at the table below we find:

3% Subsidized Loan

Utilization:	50%	75%
Net Profit:	$412.5MM	$589.1MM
Coverage:	3.30	4.30

6% Standard Loan

Utilization:	50%	75%
Net Profit:	$329.5MM	$505.9MM
Coverage:	2.30	2.96

Mandated regulations moving truck operators off of the highways in the State of California, in particular the I-5 Grapevine Grade corridor, and onto rail link intermodal services remains unlikely, however the movement of the State to push truck operators into intermodal rail links certainly would attract the investors/lenders to the various projects. This could be the most efficient and less costly form of the movement of freight and passengers in the future of the United States.

Grapevine Hill
Tunnel Project
Cash Flow Analysis $US

		Utilization of Truck Traffic			
		10%	15%	20%	25%
Alternative A - Subsidized Loan at 3% Interest Rate					
Operating Profit		$ 293,259,500	$ 343,684,250	$ 394,109,000	$ 444,533,750
Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Interest Expense (1st Year)		$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009
Profit Before Tax		$ 124,609,491	$ 175,034,241	$ 225,458,991	$ 275,883,741
Income Tax	30%	$ 37,382,847	$ 52,510,272	$ 67,637,697	$ 82,765,122
Net Profit		$ 87,226,644	$ 122,523,969	$ 157,821,294	$ 193,118,619
Add: Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Add: Interest Expense (1st Year)		$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009
Cash Flow Before Debt Service (1st Year)		$ 255,876,653	$ 291,173,978	$ 326,471,303	$ 361,768,628
Interest Expense (1st Year)		103,500,009	103,500,009	103,500,009	103,500,009
Principal Payment (1st Year)		$ 72,685,091	$ 72,685,091	$ 72,685,091	$ 72,685,091
Total Debt Service		176,185,100	176,185,100	176,185,100	176,185,100
Debt Coverage		1.45	1.65	1.85	2.05

		10%	15%	20%	25%
Alternative B - Subsidized Loan at 6% Interest Rate					
Operating Profit		$ 293,259,500	$ 343,684,250	$ 394,109,000	$ 444,533,750
Depreciation		65,150,000	65,150,000	65,150,000	65,150,000
Interest Expense (1st Year)		$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845
Profit Before Tax		5,949,655	56,374,405	106,799,155	157,223,905
Income Tax	30%	-	-	-	$ 47,167,172
Net Profit		$ 5,949,655	$ 56,374,405	$ 106,799,155	$ 110,056,734
Add: Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Add: Interest Expense (1st Year)		$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845
Cash Flow Before Debt Service (1st Year)		$ 293,259,500	$ 343,684,250	$ 394,109,000	$ 397,366,578
Interest Expense (1st Year)		222,159,845	222,159,845	222,159,845	222,159,845
Principal Payment (1st Year)		$ 45,932,307	$ 45,932,307	$ 45,932,307	$ 45,932,307
Total Debt Service		268,092,152	268,092,152	268,092,152	268,092,152
Debt Coverage		1.09	1.28	1.47	1.48

Grapevine Hill
Tunnel Project
Cash Flow Analysis $US

			Utilization of Truck Traffic			
			10%	15%	20%	25%
Traffic Assumptions:						
Truck Traffic (number of trucks per year)	7,300,000		730,000	1,095,000	1,460,000	1,825,000
Passenger Trains			27,375	27,375	27,375	27,375
Revenue Assumptions:						
Revenue per Truck			$ 140	$ 140	$ 140	$ 140
Revenue per Passenger Train			$ 7,000	$ 7,000	$ 7,000	$ 7,000
Revenue:						
Trains:						
Intermodal Trains			$ 102,200,000	$ 153,300,000	$ 204,400,000	$ 255,500,000
Passenger Trains			$ 191,625,000	$ 191,625,000	$ 191,625,000	$ 191,625,000
Total Train Revenue			$ 293,825,000	$ 344,925,000	$ 396,025,000	$ 447,125,000
Truck Stop:						
Fuel	$ 7.50	per trk	$ 5,475,000	$ 8,212,500	$ 10,950,000	$ 13,687,500
Overnight Parking			$ 6,205,000	$ 6,205,000	$ 6,205,000	$ 6,205,000
Food, Showers, etc.			$ 9,125,000	$ 9,125,000	$ 9,125,000	$ 9,125,000
Warehouses			$ 1,920,000	$ 1,920,000	$ 1,920,000	$ 1,920,000
Total Truck Stop Revenue			$ 22,725,000	$ 25,462,500	$ 28,200,000	$ 30,937,500
Total Revenue			$ 316,550,000	$ 370,387,500	$ 424,225,000	$ 478,062,500
Expenses:						
Train:						
Operations			$ 1,600,000	$ 1,600,000	$ 1,600,000	$ 1,600,000
Administration	2.0%		$ 5,876,500	$ 6,898,500	$ 7,920,500	$ 8,942,500
Labor	2.0%		$ 5,876,500	$ 6,898,500	$ 7,920,500	$ 8,942,500
Total Train Expense			$ 13,353,000	$ 15,397,000	$ 17,441,000	$ 19,485,000
Truck Stop:						
Fuel	$ 3.75	per trk	$ 2,737,500	$ 4,106,250	$ 5,475,000	$ 6,843,750
Overnight Parking			$ 620,500	$ 620,500	$ 620,500	$ 620,500
Food, Showers, etc.			$ 6,387,500	$ 6,387,500	$ 6,387,500	$ 6,387,500
Warehouses			$ 192,000	$ 192,000	$ 192,000	$ 192,000
Total Truck Stop Expense			$ 9,937,500	$ 11,306,250	$ 12,675,000	$ 14,043,750
Total Expenses			$ 23,290,500	$ 26,703,250	$ 30,116,000	$ 33,528,750
Operating Profit			**$ 293,259,500**	**$ 343,684,250**	**$ 394,109,000**	**$ 444,533,750**

Grapevine Hill
Tunnel Project
Cash Flow Analysis $US

			Utilization of Truck Traffic			
			10%	15%	20%	25%
Traffic Assumptions:						
Truck Traffic (number of trucks per year)	7,300,000		730,000	1,095,000	1,460,000	1,825,000
Passenger Trains			27,375	27,375	27,375	27,375
Revenue Assumptions:						
Revenue per Truck			$ 120	$ 120	$ 120	$ 120
Revenue per Passenger Train			$ 6,000	$ 6,000	$ 6,000	$ 6,000
Revenue:						
Trains:						
Intermodal Trains			$ 87,600,000	$ 131,400,000	$ 175,200,000	$ 219,000,000
Passenger Trains			$ 164,250,000	$ 164,250,000	$ 164,250,000	$ 164,250,000
Total Train Revenue			$ 251,850,000	$ 295,650,000	$ 339,450,000	$ 383,250,000
Truck Stop:						
Fuel	$ 7.50	per trk	$ 5,475,000	$ 8,212,500	$ 10,950,000	$ 13,687,500
Overnight Parking			$ 6,205,000	$ 6,205,000	$ 6,205,000	$ 6,205,000
Food, Showers, etc.			$ 9,125,000	$ 9,125,000	$ 9,125,000	$ 9,125,000
Warehouses			$ 1,920,000	$ 1,920,000	$ 1,920,000	$ 1,920,000
Total Truck Stop Revenue			$ 22,725,000	$ 25,462,500	$ 28,200,000	$ 30,937,500
Total Revenue			$ 274,575,000	$ 321,112,500	$ 367,650,000	$ 414,187,500
Expenses:						
Train:						
Operations			$ 1,600,000	$ 1,600,000	$ 1,600,000	$ 1,600,000
Administration	2.0%		$ 5,037,000	$ 5,913,000	$ 6,789,000	$ 7,665,000
Labor	2.0%		$ 5,037,000	$ 5,913,000	$ 6,789,000	$ 7,665,000
Total Train Expense			$ 11,674,000	$ 13,426,000	$ 15,178,000	$ 16,930,000
Truck Stop:						
Fuel	$ 3.75	per trk	$ 2,737,500	$ 4,106,250	$ 5,475,000	$ 6,843,750
Overnight Parking			$ 620,500	$ 620,500	$ 620,500	$ 620,500
Food, Showers, etc.			$ 6,387,500	$ 6,387,500	$ 6,387,500	$ 6,387,500
Warehouses			$ 192,000	$ 192,000	$ 192,000	$ 192,000
Total Truck Stop Expense			$ 9,937,500	$ 11,306,250	$ 12,675,000	$ 14,043,750
Total Expenses			$ 21,611,500	$ 24,732,250	$ 27,853,000	$ 30,973,750
Operating Profit			**$ 252,963,500**	**$ 296,380,250**	**$ 339,797,000**	**$ 383,213,750**

Grapevine Hill
Tunnel Project
Cash Flow Analysis $US

		Utilization of Truck Traffic			
		10%	15%	20%	25%
Alternative A - Subsidized Loan at 3% Interest Rate					
Operating Profit		$ 252,963,500	$ 296,380,250	$ 339,797,000	$ 383,213,750
Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Interest Expense (1st Year)		$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009
Profit Before Tax		$ 84,313,491	$ 127,730,241	$ 171,146,991	$ 214,563,741
Income Tax	30%	$ 25,294,047	$ 38,319,072	$ 51,344,097	$ 64,369,122
Net Profit		$ 59,019,444	$ 89,411,169	$ 119,802,894	$ 150,194,619
Add: Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Add: Interest Expense (1st Year)		$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009
Cash Flow Before Debt Service (1st Year)		$ 227,669,453	$ 258,061,178	$ 288,452,903	$ 318,844,628
Interest Expense (1st Year)		103,500,009	103,500,009	103,500,009	103,500,009
Principal Payment (1st Year)		$ 72,685,091	$ 72,685,091	$ 72,685,091	$ 72,685,091
Total Debt Service		176,185,100	176,185,100	176,185,100	176,185,100
Debt Coverage		1.29	1.46	1.64	1.81
Alternative B - Subsidized Loan at 6% Interest Rate					
Operating Profit		$ 252,963,500	$ 296,380,250	$ 339,797,000	$ 383,213,750
Depreciation		65,150,000	65,150,000	65,150,000	65,150,000
Interest Expense (1st Year)		$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845
Profit Before Tax		(34,346,345)	9,070,405	52,487,155	95,903,905
Income Tax	30%	-	-	-	$ 28,771,172
Net Profit		$ (34,346,345)	$ 9,070,405	$ 52,487,155	$ 67,132,734
Add: Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Add: Interest Expense (1st Year)		$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845
Cash Flow Before Debt Service (1st Year)		$ 252,963,500	$ 296,380,250	$ 339,797,000	$ 354,442,578
Interest Expense (1st Year)		222,159,845	222,159,845	222,159,845	222,159,845
Principal Payment (1st Year)		$ 45,932,307	$ 45,932,307	$ 45,932,307	$ 45,932,307
Total Debt Service		268,092,152	268,092,152	268,092,152	268,092,152
Debt Coverage		0.94	1.11	1.27	1.32

Grapevine Grade
Tunnel Project
Cash Flow Analysis $US

			10%	15%	20%	25%	50%	75%
			Utilization of Truck Traffic					
Traffic Assumptions:								
Truck Traffic (number of trucks per year)	7,300,000		730,000	1,095,000	1,460,000	1,825,000	3,650,000	5,475,000
Passenger Trains	100 /day		36,500	36,500	36,500	36,500	36,500	36,500
Revenue Assumptions:								
Revenue per Truck			$ 140	$ 140	$ 140	$ 140	$ 140	$ 140
Revenue per Passenger Train			$ 7,000	$ 7,000	$ 7,000	$ 7,000	$ 7,000	$ 7,000
Revenue:								
Trains:								
Intermodal Trains			$ 102,200,000	$ 153,300,000	$ 204,400,000	$ 255,500,000	$ 511,000,000	$ 766,500,000
Passenger Trains			$ 255,500,000	$ 255,500,000	$ 255,500,000	$ 255,500,000	$ 255,500,000	$ 255,500,000
Total Train Revenue			$ 357,700,000	$ 408,800,000	$ 459,900,000	$ 511,000,000	$ 766,500,000	$ 1,022,000,000
Truck Stop:								
Fuel	$ 7.50	per trk	$ 5,475,000	$ 8,212,500	$ 10,950,000	$ 13,687,500	$ 27,375,000	$ 41,062,500
Overnight Parking			$ 6,205,000	$ 6,205,000	$ 6,205,000	$ 6,205,000	$ 6,205,000	$ 6,205,000
Food, Showers, etc.			$ 9,125,000	$ 9,125,000	$ 9,125,000	$ 9,125,000	$ 9,125,000	$ 9,125,000
Warehouses			$ 1,920,000	$ 1,920,000	$ 1,920,000	$ 1,920,000	$ 1,920,000	$ 1,920,000
Total Truck Stop Revenue			$ 22,725,000	$ 25,462,500	$ 28,200,000	$ 30,937,500	$ 44,625,000	$ 58,312,500
Total Revenue			$ 380,425,000	$ 434,262,500	$ 488,100,000	$ 541,937,500	$ 811,125,000	$ 1,080,312,500
Expenses:								
Train:								
Operations			$ 1,600,000	$ 1,600,000	$ 1,600,000	$ 1,600,000	$ 1,600,000	$ 1,600,000
Administration	2.0%		$ 7,154,000	$ 8,176,000	$ 9,198,000	$ 10,220,000	$ 15,330,000	$ 20,440,000
Labor	2.0%		$ 7,154,000	$ 8,176,000	$ 9,198,000	$ 10,220,000	$ 15,330,000	$ 20,440,000
Total Train Expense			$ 15,908,000	$ 17,952,000	$ 19,996,000	$ 22,040,000	$ 32,260,000	$ 42,480,000
Truck Stop:								
Fuel	$ 3.75	per trk	$ 2,737,500	$ 4,106,250	$ 5,475,000	$ 6,843,750	$ 13,687,500	$ 20,531,250
Overnight Parking			$ 620,500	$ 620,500	$ 620,500	$ 620,500	$ 620,500	$ 620,500
Food, Showers, etc.			$ 6,387,500	$ 6,387,500	$ 6,387,500	$ 6,387,500	$ 6,387,500	$ 6,387,500
Warehouses			$ 192,000	$ 192,000	$ 192,000	$ 192,000	$ 192,000	$ 192,000
Total Truck Stop Expense			$ 9,937,500	$ 11,306,250	$ 12,675,000	$ 14,043,750	$ 20,887,500	$ 27,731,250
Total Expenses			$ 25,845,500	$ 29,258,250	$ 32,671,000	$ 36,083,750	$ 53,147,500	$ 70,211,250
Operating Profit			**$ 354,579,500**	**$ 405,004,250**	**$ 455,429,000**	**$ 505,853,750**	**$ 757,977,500**	**$ 1,010,101,250**

		Utilization of Truck Traffic					
		10%	15%	20%	25%	50%	75%
Alternative A - Subsidized Loan at 3% Interest Rate							
Operating Profit		$ 354,579,500	$ 405,004,250	$ 455,429,000	$ 505,853,750	$ 757,977,500	$ 1,010,101,250
Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Interest Expense (1st Year)		$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009
Profit Before Tax		$ 185,929,491	$ 236,354,241	$ 286,778,991	$ 337,203,741	$ 589,327,491	$ 841,451,241
Income Tax	30%	$ 55,778,847	$ 70,906,272	$ 86,033,697	$ 101,161,122	$ 176,798,247	$ 252,435,372
Net Profit		$ 130,150,644	$ 165,447,969	$ 200,745,294	$ 236,042,619	$ 412,529,244	$ 589,015,869
Add: Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Add: Interest Expense (1st Year)		$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009
Cash Flow Before Debt Service (1st Year)		$ 298,800,653	$ 334,097,978	$ 369,395,303	$ 404,692,628	$ 581,179,253	$ 757,665,878
Interest Expense (1st Year)		103,500,009	103,500,009	103,500,009	103,500,009	103,500,009	103,500,009
Principal Payment (1st Year)		$ 72,685,091	$ 72,685,091	$ 72,685,091	$ 72,685,091	$ 72,685,091	$ 72,685,091
Total Debt Service		176,185,100	176,185,100	176,185,100	176,185,100	176,185,100	176,185,100
Debt Coverage		1.70	1.90	2.10	2.30	3.30	4.30
Alternative B - Subsidized Loan at 6% Interest Rate							
Operating Profit		$ 354,579,500	$ 405,004,250	$ 455,429,000	$ 505,853,750	$ 757,977,500	$ 1,010,101,250
Depreciation		65,150,000	65,150,000	65,150,000	65,150,000	65,150,000	65,150,000
Interest Expense (1st Year)		$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845
Profit Before Tax		67,269,655	117,694,405	168,119,155	218,543,905	470,667,655	722,791,405
Income Tax	30%	-	-	-	$ 65,563,172	$ 141,200,297	$ 216,837,422
Net Profit		$ 67,269,655	$ 117,694,405	$ 168,119,155	$ 152,980,734	$ 329,467,359	$ 505,953,984
Add: Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Add: Interest Expense (1st Year)		$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845
Cash Flow Before Debt Service (1st Year)		$ 354,579,500	$ 405,004,250	$ 455,429,000	$ 440,290,578	$ 616,777,203	$ 793,263,828
Interest Expense (1st Year)		222,159,845	222,159,845	222,159,845	222,159,845	222,159,845	222,159,845
Principal Payment (1st Year)		$ 45,932,307	$ 45,932,307	$ 45,932,307	$ 45,932,307	$ 45,932,307	$ 45,932,307
Total Debt Service		268,092,152	268,092,152	268,092,152	268,092,152	268,092,152	268,092,152
Debt Coverage		1.32	1.51	1.70	1.64	2.30	2.96

Grapevine Hill
Tunnel Project
Cash Flow Analysis $US

			Utilization of Truck Traffic			
			10%	15%	20%	25%
Traffic Assumptions:						
Truck Traffic (number of trucks per year)	7,300,000		730,000	1,095,000	1,460,000	1,825,000
Passenger Trains			27,375	27,375	27,375	27,375
Revenue Assumptions:						
Revenue per Truck			$ 100	$ 100	$ 100	$ 100
Revenue per Passenger Train			$ 5,000	$ 5,000	$ 5,000	$ 5,000
Revenue:						
Trains:						
Intermodal Trains			$ 73,000,000	$ 109,500,000	$ 146,000,000	$ 182,500,000
Passenger Trains			$ 136,875,000	$ 136,875,000	$ 136,875,000	$ 136,875,000
Total Train Revenue			$ 209,875,000	$ 246,375,000	$ 282,875,000	$ 319,375,000
Truck Stop:						
Fuel	$ 7.50	per trk	$ 5,475,000	$ 8,212,500	$ 10,950,000	$ 13,687,500
Overnight Parking			$ 6,205,000	$ 6,205,000	$ 6,205,000	$ 6,205,000
Food, Showers, etc.			$ 9,125,000	$ 9,125,000	$ 9,125,000	$ 9,125,000
Warehouses			$ 1,920,000	$ 1,920,000	$ 1,920,000	$ 1,920,000
Total Truck Stop Revenue			$ 22,725,000	$ 25,462,500	$ 28,200,000	$ 30,937,500
Total Revenue			$ 232,600,000	$ 271,837,500	$ 311,075,000	$ 350,312,500
Expenses:						
Train:						
Operations			$ 1,600,000	$ 1,600,000	$ 1,600,000	$ 1,600,000
Administration	2.0%		$ 4,197,500	$ 4,927,500	$ 5,657,500	$ 6,387,500
Labor	2.0%		$ 4,197,500	$ 4,927,500	$ 5,657,500	$ 6,387,500
Total Train Expense			$ 9,995,000	$ 11,455,000	$ 12,915,000	$ 14,375,000
Truck Stop:						
Fuel	$ 3.75	per trk	$ 2,737,500	$ 4,106,250	$ 5,475,000	$ 6,843,750
Overnight Parking			$ 620,500	$ 620,500	$ 620,500	$ 620,500
Food, Showers, etc.			$ 6,387,500	$ 6,387,500	$ 6,387,500	$ 6,387,500
Warehouses			$ 192,000	$ 192,000	$ 192,000	$ 192,000
Total Truck Stop Expense			$ 9,937,500	$ 11,306,250	$ 12,675,000	$ 14,043,750
Total Expenses			$ 19,932,500	$ 22,761,250	$ 25,590,000	$ 28,418,750
Operating Profit			**$ 212,667,500**	**$ 249,076,250**	**$ 285,485,000**	**$ 321,893,750**

Grapevine Hill
Tunnel Project
Cash Flow Analysis $US

Alternative A - Subsidized Loan at 3% Interest Rate

		Utilization of Truck Traffic 10%	15%	20%	25%
Operating Profit		**$ 212,667,500**	**$ 249,076,250**	**$ 285,485,000**	**$ 321,893,750**
Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Interest Expense (1st Year)		$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009
Profit Before Tax		$ 44,017,491	$ 80,426,241	$ 116,834,991	$ 153,243,741
Income Tax	30%	$ 13,205,247	$ 24,127,872	$ 35,050,497	$ 45,973,122
Net Profit		$ 30,812,244	$ 56,298,369	$ 81,784,494	$ 107,270,619
Add: Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Add: Interest Expense (1st Year)		$ 103,500,009	$ 103,500,009	$ 103,500,009	$ 103,500,009
Cash Flow Before Debt Service (1st Year)		$ 199,462,253	$ 224,948,378	$ 250,434,503	$ 275,920,628
Interest Expense (1st Year)		103,500,009	103,500,009	103,500,009	103,500,009
Principal Payment (1st Year)		$ 72,685,091	$ 72,685,091	$ 72,685,091	$ 72,685,091
Total Debt Service		176,185,100	176,185,100	176,185,100	176,185,100
Debt Coverage		1.13	1.28	1.42	1.57

Alternative B - Subsidized Loan at 6% Interest Rate

		10%	15%	20%	25%
Operating Profit		**$ 212,667,500**	**$ 249,076,250**	**$ 285,485,000**	**$ 321,893,750**
Depreciation		65,150,000	65,150,000	65,150,000	65,150,000
Interest Expense (1st Year)		$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845
Profit Before Tax		(74,642,345)	(38,233,595)	(1,824,845)	34,583,905
Income Tax	30%	-	-	-	$ 10,375,172
Net Profit		$ (74,642,345)	$ (38,233,595)	$ (1,824,845)	$ 24,208,734
Add: Depreciation		$ 65,150,000	$ 65,150,000	$ 65,150,000	$ 65,150,000
Add: Interest Expense (1st Year)		$ 222,159,845	$ 222,159,845	$ 222,159,845	$ 222,159,845
Cash Flow Before Debt Service (1st Year)		$ 212,667,500	$ 249,076,250	$ 285,485,000	$ 311,518,578
Interest Expense (1st Year)		222,159,845	222,159,845	222,159,845	222,159,845
Principal Payment (1st Year)		$ 45,932,307	$ 45,932,307	$ 45,932,307	$ 45,932,307
Total Debt Service		268,092,152	268,092,152	268,092,152	268,092,152
Debt Coverage		0.79	0.93	1.06	1.16

Grapevine Hill
Tunnel Project
Loan Amortization

Loan Amount	$ 3,234,500,000
Amortization	30 years
Interest Rate	**3%**
Payments	Quarterly
Number of payments	120

Payment	Interest	Principal	Total Payment	Principal Balance
				$ 3,234,500,000
Capitalized Construction Interest				$ 242,587,500
Amortized Loan Amount				$ 3,477,087,500
1	$ 26,078,156	$ 17,968,119	$ 44,046,275	$ 3,459,119,381
2	$ 25,943,395	$ 18,102,880	$ 44,046,275	$ 3,441,016,502
3	$ 25,807,624	$ 18,238,651	$ 44,046,275	$ 3,422,777,851
4	$ 25,670,834	$ 18,375,441	$ 44,046,275	$ 3,404,402,409
1st Year	$ 103,500,009	$ 72,685,091	$ 176,185,100	
5	$ 25,533,018	$ 18,513,257	$ 44,046,275	$ 3,385,889,153
6	$ 25,394,169	$ 18,652,106	$ 44,046,275	$ 3,367,237,046
7	$ 25,254,278	$ 18,791,997	$ 44,046,275	$ 3,348,445,049
8	$ 25,113,338	$ 18,932,937	$ 44,046,275	$ 3,329,512,112
2nd Year	$ 101,294,802	$ 74,890,297	$ 176,185,100	
9	$ 24,971,341	$ 19,074,934	$ 44,046,275	$ 3,310,437,178
10	$ 24,828,279	$ 19,217,996	$ 44,046,275	$ 3,291,219,182
11	$ 24,684,144	$ 19,362,131	$ 44,046,275	$ 3,271,857,051
12	$ 24,538,928	$ 19,507,347	$ 44,046,275	$ 3,252,349,704
3rd Year	$ 99,022,691	$ 77,162,408	$ 176,185,100	
13	$ 24,392,623	$ 19,653,652	$ 44,046,275	$ 3,232,696,052
14	$ 24,245,220	$ 19,801,055	$ 44,046,275	$ 3,212,894,997
15	$ 24,096,712	$ 19,949,562	$ 44,046,275	$ 3,192,945,434
16	$ 23,947,091	$ 20,099,184	$ 44,046,275	$ 3,172,846,250
4th Year	$ 96,681,646	$ 79,503,453	$ 176,185,100	
17	$ 23,796,347	$ 20,249,928	$ 44,046,275	$ 3,152,596,322
18	$ 23,644,472	$ 20,401,803	$ 44,046,275	$ 3,132,194,520
19	$ 23,491,459	$ 20,554,816	$ 44,046,275	$ 3,111,639,704
20	$ 23,337,298	$ 20,708,977	$ 44,046,275	$ 3,090,930,726
5th Year	$ 94,269,576	$ 81,915,524	$ 176,185,100	
21	$ 23,181,980	$ 20,864,295	$ 44,046,275	$ 3,070,066,432
22	$ 23,025,498	$ 21,020,777	$ 44,046,275	$ 3,049,045,655
23	$ 22,867,842	$ 21,178,433	$ 44,046,275	$ 3,027,867,223
24	$ 22,709,004	$ 21,337,271	$ 44,046,275	$ 3,006,529,952
6th Year	$ 91,784,325	$ 84,400,775	$ 176,185,100	

Payment	Interest	Principal	Total Payment	Principal Balance
25	$ 22,548,975	$ 21,497,300	$ 44,046,275	$ 2,985,032,652
26	$ 22,387,745	$ 21,658,530	$ 44,046,275	$ 2,963,374,122
27	$ 22,225,306	$ 21,820,969	$ 44,046,275	$ 2,941,553,153
28	$ 22,061,649	$ 21,984,626	$ 44,046,275	$ 2,919,568,526
7th Year	$ 89,223,674	$ 86,961,426	$ 176,185,100	
29	$ 21,896,764	$ 22,149,511	$ 44,046,275	$ 2,897,419,015
30	$ 21,730,643	$ 22,315,632	$ 44,046,275	$ 2,875,103,383
31	$ 21,563,275	$ 22,483,000	$ 44,046,275	$ 2,852,620,383
32	$ 21,394,653	$ 22,651,622	$ 44,046,275	$ 2,829,968,761
8th Year	$ 86,585,335	$ 89,599,765	$ 176,185,100	
33	$ 21,224,766	$ 22,821,509	$ 44,046,275	$ 2,807,147,252
34	$ 21,053,604	$ 22,992,671	$ 44,046,275	$ 2,784,154,581
35	$ 20,881,159	$ 23,165,116	$ 44,046,275	$ 2,760,989,466
36	$ 20,707,421	$ 23,338,854	$ 44,046,275	$ 2,737,650,612
9th Year	$ 83,866,950	$ 92,318,149	$ 176,185,100	
37	$ 20,532,380	$ 23,513,895	$ 44,046,275	$ 2,714,136,717
38	$ 20,356,025	$ 23,690,250	$ 44,046,275	$ 2,690,446,467
39	$ 20,178,349	$ 23,867,926	$ 44,046,275	$ 2,666,578,541
40	$ 19,999,339	$ 24,046,936	$ 44,046,275	$ 2,642,531,605
10th Year	$ 81,066,093	$ 95,119,007	$ 176,185,100	
41	$ 19,818,987	$ 24,227,288	$ 44,046,275	$ 2,618,304,317
42	$ 19,637,282	$ 24,408,993	$ 44,046,275	$ 2,593,895,324
43	$ 19,454,215	$ 24,592,060	$ 44,046,275	$ 2,569,303,264
44	$ 19,269,774	$ 24,776,500	$ 44,046,275	$ 2,544,526,764
11th Year	$ 78,180,259	$ 98,004,841	$ 176,185,100	
45	$ 19,083,951	$ 24,962,324	$ 44,046,275	$ 2,519,564,439
46	$ 18,896,733	$ 25,149,542	$ 44,046,275	$ 2,494,414,898
47	$ 18,708,112	$ 25,338,163	$ 44,046,275	$ 2,469,076,735
48	$ 18,518,076	$ 25,528,199	$ 44,046,275	$ 2,443,548,535
12th Year	$ 75,206,871	$ 100,978,229	$ 176,185,100	
49	$ 18,326,614	$ 25,719,661	$ 44,046,275	$ 2,417,828,874
50	$ 18,133,717	$ 25,912,558	$ 44,046,275	$ 2,391,916,316
51	$ 17,939,372	$ 26,106,903	$ 44,046,275	$ 2,365,809,413
52	$ 17,743,571	$ 26,302,704	$ 44,046,275	$ 2,339,506,709
13th Year	$ 72,143,274	$ 104,041,826	$ 176,185,100	
53	$ 17,546,300	$ 26,499,975	$ 44,046,275	$ 2,313,006,734
54	$ 17,347,551	$ 26,698,724	$ 44,046,275	$ 2,286,308,010
55	$ 17,147,310	$ 26,898,965	$ 44,046,275	$ 2,259,409,045
56	$ 16,945,568	$ 27,100,707	$ 44,046,275	$ 2,232,308,338
14th Year	$ 68,986,729	$ 107,198,371	$ 176,185,100	
57	$ 16,742,313	$ 27,303,962	$ 44,046,275	$ 2,205,004,375
58	$ 16,537,533	$ 27,508,742	$ 44,046,275	$ 2,177,495,633
59	$ 16,331,217	$ 27,715,058	$ 44,046,275	$ 2,149,780,576
60	$ 16,123,354	$ 27,922,921	$ 44,046,275	$ 2,121,857,655
15th Year	$ 65,734,417	$ 110,450,683	$ 176,185,100	

Payment	Interest	Principal	Total Payment	Principal Balance
61	$ 15,913,932	$ 28,132,343	$ 44,046,275	$ 2,093,725,312
62	$ 15,702,940	$ 28,343,335	$ 44,046,275	$ 2,065,381,977
63	$ 15,490,365	$ 28,555,910	$ 44,046,275	$ 2,036,826,067
64	$ 15,276,196	$ 28,770,079	$ 44,046,275	$ 2,008,055,988
16th Year	$ 62,383,433	$ 113,801,667	$ 176,185,100	
65	$ 15,060,420	$ 28,985,855	$ 44,046,275	$ 1,979,070,133
66	$ 14,843,026	$ 29,203,249	$ 44,046,275	$ 1,949,866,884
67	$ 14,624,002	$ 29,422,273	$ 44,046,275	$ 1,920,444,610
68	$ 14,403,335	$ 29,642,940	$ 44,046,275	$ 1,890,801,670
17th Year	$ 58,930,782	$ 117,254,318	$ 176,185,100	
69	$ 14,181,013	$ 29,865,262	$ 44,046,275	$ 1,860,936,408
70	$ 13,957,023	$ 30,089,252	$ 44,046,275	$ 1,830,847,156
71	$ 13,731,354	$ 30,314,921	$ 44,046,275	$ 1,800,532,234
72	$ 13,503,992	$ 30,542,283	$ 44,046,275	$ 1,769,989,951
18th Year	$ 55,373,381	$ 120,811,719	$ 176,185,100	
73	$ 13,274,925	$ 30,771,350	$ 44,046,275	$ 1,739,218,601
74	$ 13,044,140	$ 31,002,135	$ 44,046,275	$ 1,708,216,465
75	$ 12,811,623	$ 31,234,651	$ 44,046,275	$ 1,676,981,814
76	$ 12,577,364	$ 31,468,911	$ 44,046,275	$ 1,645,512,903
19th Year	$ 51,708,051	$ 124,477,049	$ 176,185,100	
77	$ 12,341,347	$ 31,704,928	$ 44,046,275	$ 1,613,807,974
78	$ 12,103,560	$ 31,942,715	$ 44,046,275	$ 1,581,865,259
79	$ 11,863,989	$ 32,182,286	$ 44,046,275	$ 1,549,682,974
80	$ 11,622,622	$ 32,423,653	$ 44,046,275	$ 1,517,259,321
20th year	$ 47,931,518	$ 128,253,581	$ 176,185,100	
81	$ 11,379,445	$ 32,666,830	$ 44,046,275	$ 1,484,592,491
82	$ 11,134,444	$ 32,911,831	$ 44,046,275	$ 1,451,680,660
83	$ 10,887,605	$ 33,158,670	$ 44,046,275	$ 1,418,521,990
84	$ 10,638,915	$ 33,407,360	$ 44,046,275	$ 1,385,114,630
21st Year	$ 44,040,408	$ 132,144,691	$ 176,185,100	
85	$ 10,388,360	$ 33,657,915	$ 44,046,275	$ 1,351,456,715
86	$ 10,135,925	$ 33,910,350	$ 44,046,275	$ 1,317,546,365
87	$ 9,881,598	$ 34,164,677	$ 44,046,275	$ 1,283,381,688
88	$ 9,625,363	$ 34,420,912	$ 44,046,275	$ 1,248,960,775
22nd Year	$ 40,031,245	$ 136,153,854	$ 176,185,100	
89	$ 9,367,206	$ 34,679,069	$ 44,046,275	$ 1,214,281,706
90	$ 9,107,113	$ 34,939,162	$ 44,046,275	$ 1,179,342,544
91	$ 8,845,069	$ 35,201,206	$ 44,046,275	$ 1,144,141,338
92	$ 8,581,060	$ 35,465,215	$ 44,046,275	$ 1,108,676,123
23rd Year	$ 35,900,448	$ 140,284,652	$ 176,185,100	
93	$ 8,315,071	$ 35,731,204	$ 44,046,275	$ 1,072,944,919
94	$ 8,047,087	$ 35,999,188	$ 44,046,275	$ 1,036,945,731
95	$ 7,777,093	$ 36,269,182	$ 44,046,275	$ 1,000,676,549
96	$ 7,505,074	$ 36,541,201	$ 44,046,275	$ 964,135,349
24th Year	$ 31,644,325	$ 144,540,775	$ 176,185,100	

Payment	Interest	Principal	Total Payment	Principal Balance
97	$ 7,231,015	$ 36,815,260	$ 44,046,275	$ 927,320,089
98	$ 6,954,901	$ 37,091,374	$ 44,046,275	$ 890,228,714
99	$ 6,676,715	$ 37,369,560	$ 44,046,275	$ 852,859,155
100	$ 6,396,444	$ 37,649,831	$ 44,046,275	$ 815,209,324
25th Year	$ 27,259,075	$ 148,926,025	$ 176,185,100	
101	$ 6,114,070	$ 37,932,205	$ 44,046,275	$ 777,277,119
102	$ 5,829,578	$ 38,216,697	$ 44,046,275	$ 739,060,422
103	$ 5,542,953	$ 38,503,322	$ 44,046,275	$ 700,557,100
104	$ 5,254,178	$ 38,792,097	$ 44,046,275	$ 661,765,003
26th Year	$ 22,740,780	$ 153,444,320	$ 176,185,100	
105	$ 4,963,238	$ 39,083,037	$ 44,046,275	$ 622,681,966
106	$ 4,670,115	$ 39,376,160	$ 44,046,275	$ 583,305,806
107	$ 4,374,794	$ 39,671,481	$ 44,046,275	$ 543,634,324
108	$ 4,077,257	$ 39,969,018	$ 44,046,275	$ 503,665,307
27th Year	$ 18,085,403	$ 158,099,697	$ 176,185,100	
109	$ 3,777,490	$ 40,268,785	$ 44,046,275	$ 463,396,522
110	$ 3,475,474	$ 40,570,801	$ 44,046,275	$ 422,825,721
111	$ 3,171,193	$ 40,875,082	$ 44,046,275	$ 381,950,639
112	$ 2,864,630	$ 41,181,645	$ 44,046,275	$ 340,768,994
28th Year	$ 13,288,786	$ 162,896,313	$ 176,185,100	
113	$ 2,555,767	$ 41,490,507	$ 44,046,275	$ 299,278,486
114	$ 2,244,589	$ 41,801,686	$ 44,046,275	$ 257,476,800
115	$ 1,931,076	$ 42,115,199	$ 44,046,275	$ 215,361,601
116	$ 1,615,212	$ 42,431,063	$ 44,046,275	$ 172,930,538
29th Year	$ 8,346,644	$ 167,838,456	$ 176,185,100	
117	$ 1,296,979	$ 42,749,296	$ 44,046,275	$ 130,181,242
118	$ 976,359	$ 43,069,916	$ 44,046,275	$ 87,111,326
119	$ 653,335	$ 43,392,940	$ 44,046,275	$ 43,718,386
120	$ 327,888	$ 43,718,387	$ 44,046,275	$ (1)
30th Year	$ 3,254,561	$ 172,930,539	$ 176,185,100	

Grapevine Hill
Tunnel Project
Loan Amortization

Loan Amount	$ 3,234,500,000
Amortization	30 years
Interest Rate	**6%**
Payments	Quarterly
Number of payments	120

Payment	Interest	Principal	Total Payment	Principal Balance
				$ 3,234,500,000
Capitalized Construction Interest				$ 485,175,000
Amortized Loan Amount				$ 3,719,675,000
1	$ 55,795,125	$ 11,227,913	$ 67,023,038	$ 3,708,447,087
2	$ 55,626,706	$ 11,396,332	$ 67,023,038	$ 3,697,050,755
3	$ 55,455,761	$ 11,567,277	$ 67,023,038	$ 3,685,483,479
4	$ 55,282,252	$ 11,740,786	$ 67,023,038	$ 3,673,742,693
1st Year	$ 222,159,845	$ 45,932,307	$ 268,092,152	
5	$ 55,106,140	$ 11,916,898	$ 67,023,038	$ 3,661,825,795
6	$ 54,927,387	$ 12,095,651	$ 67,023,038	$ 3,649,730,144
7	$ 54,745,952	$ 12,277,086	$ 67,023,038	$ 3,637,453,058
8	$ 54,561,796	$ 12,461,242	$ 67,023,038	$ 3,624,991,816
2nd Year	$ 219,341,275	$ 48,750,877	$ 268,092,152	
9	$ 54,374,877	$ 12,648,161	$ 67,023,038	$ 3,612,343,655
10	$ 54,185,155	$ 12,837,883	$ 67,023,038	$ 3,599,505,772
11	$ 53,992,587	$ 13,030,451	$ 67,023,038	$ 3,586,475,321
12	$ 53,797,130	$ 13,225,908	$ 67,023,038	$ 3,573,249,412
3rd Year	$ 216,349,748	$ 51,742,404	$ 268,092,152	
13	$ 53,598,741	$ 13,424,297	$ 67,023,038	$ 3,559,825,116
14	$ 53,397,377	$ 13,625,661	$ 67,023,038	$ 3,546,199,454
15	$ 53,192,992	$ 13,830,046	$ 67,023,038	$ 3,532,369,408
16	$ 52,985,541	$ 14,037,497	$ 67,023,038	$ 3,518,331,911
4th Year	$ 213,174,651	$ 54,917,501	$ 268,092,152	
17	$ 52,774,979	$ 14,248,059	$ 67,023,038	$ 3,504,083,852
18	$ 52,561,258	$ 14,461,780	$ 67,023,038	$ 3,489,622,072
19	$ 52,344,331	$ 14,678,707	$ 67,023,038	$ 3,474,943,365
20	$ 52,124,150	$ 14,898,888	$ 67,023,038	$ 3,460,044,477
5th Year	$ 209,804,718	$ 58,287,434	$ 268,092,152	
21	$ 51,900,667	$ 15,122,371	$ 67,023,038	$ 3,444,922,106
22	$ 51,673,832	$ 15,349,206	$ 67,023,038	$ 3,429,572,900
23	$ 51,443,593	$ 15,579,445	$ 67,023,038	$ 3,413,993,455
24	$ 51,209,902	$ 15,813,136	$ 67,023,038	$ 3,398,180,319
6th Year	$ 206,227,994	$ 61,864,158	$ 268,092,152	

Payment	Interest	Principal	Total Payment	Principal Balance
25	$ 50,972,705	$ 16,050,333	$ 67,023,038	$ 3,382,129,986
26	$ 50,731,950	$ 16,291,088	$ 67,023,038	$ 3,365,838,898
27	$ 50,487,583	$ 16,535,455	$ 67,023,038	$ 3,349,303,443
28	$ 50,239,552	$ 16,783,486	$ 67,023,038	$ 3,332,519,957
7th Year	$ 202,431,790	$ 65,660,362	$ 268,092,152	
29	$ 49,987,799	$ 17,035,239	$ 67,023,038	$ 3,315,484,718
30	$ 49,732,271	$ 17,290,767	$ 67,023,038	$ 3,298,193,951
31	$ 49,472,909	$ 17,550,129	$ 67,023,038	$ 3,280,643,822
32	$ 49,209,657	$ 17,813,381	$ 67,023,038	$ 3,262,830,441
8th Year	$ 198,402,637	$ 69,689,515	$ 268,092,152	
33	$ 48,942,457	$ 18,080,581	$ 67,023,038	$ 3,244,749,860
34	$ 48,671,248	$ 18,351,790	$ 67,023,038	$ 3,226,398,070
35	$ 48,395,971	$ 18,627,067	$ 67,023,038	$ 3,207,771,003
36	$ 48,116,565	$ 18,906,473	$ 67,023,038	$ 3,188,864,530
9th Year	$ 194,126,241	$ 73,965,911	$ 268,092,152	
37	$ 47,832,968	$ 19,190,070	$ 67,023,038	$ 3,169,674,460
38	$ 47,545,117	$ 19,477,921	$ 67,023,038	$ 3,150,196,539
39	$ 47,252,948	$ 19,770,090	$ 67,023,038	$ 3,130,426,449
40	$ 46,956,397	$ 20,066,641	$ 67,023,038	$ 3,110,359,807
10th Year	$ 189,587,430	$ 78,504,722	$ 268,092,152	
41	$ 46,655,397	$ 20,367,641	$ 67,023,038	$ 3,089,992,166
42	$ 46,349,882	$ 20,673,156	$ 67,023,038	$ 3,069,319,011
43	$ 46,039,785	$ 20,983,253	$ 67,023,038	$ 3,048,335,758
44	$ 45,725,036	$ 21,298,002	$ 67,023,038	$ 3,027,037,756
11th Year	$ 184,770,101	$ 83,322,051	$ 268,092,152	
45	$ 45,405,566	$ 21,617,472	$ 67,023,038	$ 3,005,420,285
46	$ 45,081,304	$ 21,941,734	$ 67,023,038	$ 2,983,478,551
47	$ 44,752,178	$ 22,270,860	$ 67,023,038	$ 2,961,207,691
48	$ 44,418,115	$ 22,604,923	$ 67,023,038	$ 2,938,602,769
12th Year	$ 179,657,164	$ 88,434,988	$ 268,092,152	
49	$ 44,079,042	$ 22,943,996	$ 67,023,038	$ 2,915,658,772
50	$ 43,734,882	$ 23,288,156	$ 67,023,038	$ 2,892,370,616
51	$ 43,385,559	$ 23,637,479	$ 67,023,038	$ 2,868,733,137
52	$ 43,030,997	$ 23,992,041	$ 67,023,038	$ 2,844,741,096
13th Year	$ 174,230,479	$ 93,861,673	$ 268,092,152	
53	$ 42,671,116	$ 24,351,922	$ 67,023,038	$ 2,820,389,174
54	$ 42,305,838	$ 24,717,200	$ 67,023,038	$ 2,795,671,974
55	$ 41,935,080	$ 25,087,958	$ 67,023,038	$ 2,770,584,016
56	$ 41,558,760	$ 25,464,278	$ 67,023,038	$ 2,745,119,738
14th Year	$ 168,470,794	$ 99,621,358	$ 268,092,152	
57	$ 41,176,796	$ 25,846,242	$ 67,023,038	$ 2,719,273,496
58	$ 40,789,102	$ 26,233,936	$ 67,023,038	$ 2,693,039,560
59	$ 40,395,593	$ 26,627,445	$ 67,023,038	$ 2,666,412,116
60	$ 39,996,182	$ 27,026,856	$ 67,023,038	$ 2,639,385,259
15th Year	$ 162,357,674	$ 105,734,478	$ 268,092,152	

Payment	Interest	Principal	Total Payment	Principal Balance
61	$ 39,590,779	$ 27,432,259	$ 67,023,038	$ 2,611,953,000
62	$ 39,179,295	$ 27,843,743	$ 67,023,038	$ 2,584,109,257
63	$ 38,761,639	$ 28,261,399	$ 67,023,038	$ 2,555,847,858
64	$ 38,337,718	$ 28,685,320	$ 67,023,038	$ 2,527,162,538
16th Year	$ 155,869,431	$ 112,222,721	$ 268,092,152	
65	$ 37,907,438	$ 29,115,600	$ 67,023,038	$ 2,498,046,938
66	$ 37,470,704	$ 29,552,334	$ 67,023,038	$ 2,468,494,604
67	$ 37,027,419	$ 29,995,619	$ 67,023,038	$ 2,438,498,985
68	$ 36,577,485	$ 30,445,553	$ 67,023,038	$ 2,408,053,432
17th Year	$ 148,983,046	$ 119,109,106	$ 268,092,152	
69	$ 36,120,801	$ 30,902,237	$ 67,023,038	$ 2,377,151,195
70	$ 35,657,268	$ 31,365,770	$ 67,023,038	$ 2,345,785,425
71	$ 35,186,781	$ 31,836,257	$ 67,023,038	$ 2,313,949,168
72	$ 34,709,238	$ 32,313,800	$ 67,023,038	$ 2,281,635,368
18th Year	$ 141,674,088	$ 126,418,064	$ 268,092,152	
73	$ 34,224,531	$ 32,798,508	$ 67,023,038	$ 2,248,836,860
74	$ 33,732,553	$ 33,290,485	$ 67,023,038	$ 2,215,546,375
75	$ 33,233,196	$ 33,789,842	$ 67,023,038	$ 2,181,756,533
76	$ 32,726,348	$ 34,296,690	$ 67,023,038	$ 2,147,459,843
19th Year	$ 133,916,627	$ 134,175,525	$ 268,092,152	
77	$ 32,211,898	$ 34,811,140	$ 67,023,038	$ 2,112,648,703
78	$ 31,689,731	$ 35,333,307	$ 67,023,038	$ 2,077,315,395
79	$ 31,159,731	$ 35,863,307	$ 67,023,038	$ 2,041,452,088
80	$ 30,621,781	$ 36,401,257	$ 67,023,038	$ 2,005,050,831
20th year	$ 125,683,140	$ 142,409,012	$ 268,092,152	
81	$ 30,075,762	$ 36,947,276	$ 67,023,038	$ 1,968,103,556
82	$ 29,521,553	$ 37,501,485	$ 67,023,038	$ 1,930,602,071
83	$ 28,959,031	$ 38,064,007	$ 67,023,038	$ 1,892,538,064
84	$ 28,388,071	$ 38,634,967	$ 67,023,038	$ 1,853,903,097
21st Year	$ 116,944,418	$ 151,147,734	$ 268,092,152	
85	$ 27,808,546	$ 39,214,492	$ 67,023,038	$ 1,814,688,605
86	$ 27,220,329	$ 39,802,709	$ 67,023,038	$ 1,774,885,897
87	$ 26,623,288	$ 40,399,750	$ 67,023,038	$ 1,734,486,147
88	$ 26,017,292	$ 41,005,746	$ 67,023,038	$ 1,693,480,401
22nd Year	$ 107,669,456	$ 160,422,696	$ 268,092,152	
89	$ 25,402,206	$ 41,620,832	$ 67,023,038	$ 1,651,859,569
90	$ 24,777,894	$ 42,245,144	$ 67,023,038	$ 1,609,614,425
91	$ 24,144,216	$ 42,878,822	$ 67,023,038	$ 1,566,735,603
92	$ 23,501,034	$ 43,522,004	$ 67,023,038	$ 1,523,213,599
23rd Year	$ 97,825,350	$ 170,266,802	$ 268,092,152	
93	$ 22,848,204	$ 44,174,834	$ 67,023,038	$ 1,479,038,765
94	$ 22,185,581	$ 44,837,457	$ 67,023,038	$ 1,434,201,308
95	$ 21,513,020	$ 45,510,018	$ 67,023,038	$ 1,388,691,290
96	$ 20,830,369	$ 46,192,669	$ 67,023,038	$ 1,342,498,621
24th Year	$ 87,377,174	$ 180,714,978	$ 268,092,152	

Payment	Interest	Principal	Total Payment	Principal Balance
97	$ 20,137,479	$ 46,885,559	$ 67,023,038	$ 1,295,613,063
98	$ 19,434,196	$ 47,588,842	$ 67,023,038	$ 1,248,024,221
99	$ 18,720,363	$ 48,302,675	$ 67,023,038	$ 1,199,721,546
100	$ 17,995,823	$ 49,027,215	$ 67,023,038	$ 1,150,694,331
25th Year	$ 76,287,862	$ 191,804,290	$ 268,092,152	
101	$ 17,260,415	$ 49,762,623	$ 67,023,038	$ 1,100,931,708
102	$ 16,513,976	$ 50,509,062	$ 67,023,038	$ 1,050,422,646
103	$ 15,756,340	$ 51,266,698	$ 67,023,038	$ 999,155,947
104	$ 14,987,339	$ 52,035,699	$ 67,023,038	$ 947,120,248
26th Year	$ 64,518,069	$ 203,574,083	$ 268,092,152	
105	$ 14,206,804	$ 52,816,234	$ 67,023,038	$ 894,304,014
106	$ 13,414,560	$ 53,608,478	$ 67,023,038	$ 840,695,536
107	$ 12,610,433	$ 54,412,605	$ 67,023,038	$ 786,282,931
108	$ 11,794,244	$ 55,228,794	$ 67,023,038	$ 731,054,137
27th Year	$ 52,026,041	$ 216,066,111	$ 268,092,152	
109	$ 10,965,812	$ 56,057,226	$ 67,023,038	$ 674,996,911
110	$ 10,124,954	$ 56,898,084	$ 67,023,038	$ 618,098,827
111	$ 9,271,482	$ 57,751,556	$ 67,023,038	$ 560,347,271
112	$ 8,405,209	$ 58,617,829	$ 67,023,038	$ 501,729,443
28th Year	$ 38,767,457	$ 229,324,695	$ 268,092,152	
113	$ 7,525,942	$ 59,497,096	$ 67,023,038	$ 442,232,346
114	$ 6,633,485	$ 60,389,553	$ 67,023,038	$ 381,842,793
115	$ 5,727,642	$ 61,295,396	$ 67,023,038	$ 320,547,397
116	$ 4,808,211	$ 62,214,827	$ 67,023,038	$ 258,332,570
29th Year	$ 24,695,280	$ 243,396,872	$ 268,092,152	
117	$ 3,874,989	$ 63,148,049	$ 67,023,038	$ 195,184,521
118	$ 2,927,768	$ 64,095,270	$ 67,023,038	$ 131,089,250
119	$ 1,966,339	$ 65,056,699	$ 67,023,038	$ 66,032,551
120	$ 990,488	$ 66,032,550	$ 67,023,038	$ 1
30th Year	$ 9,759,583	$ 258,332,569	$ 268,092,152	

Grapevine Hill
Tunnel Project
Depreciation

Year 1	Cost	Depreciation Rate (years)	Annual Depreciation
Tunnel	$3,200,000,000	50	$ 64,000,000
Two Intermodals	$ 34,500,000	30	$ 1,150,000
Total	$3,234,500,000		$ 65,150,000

O008
Attachment 4

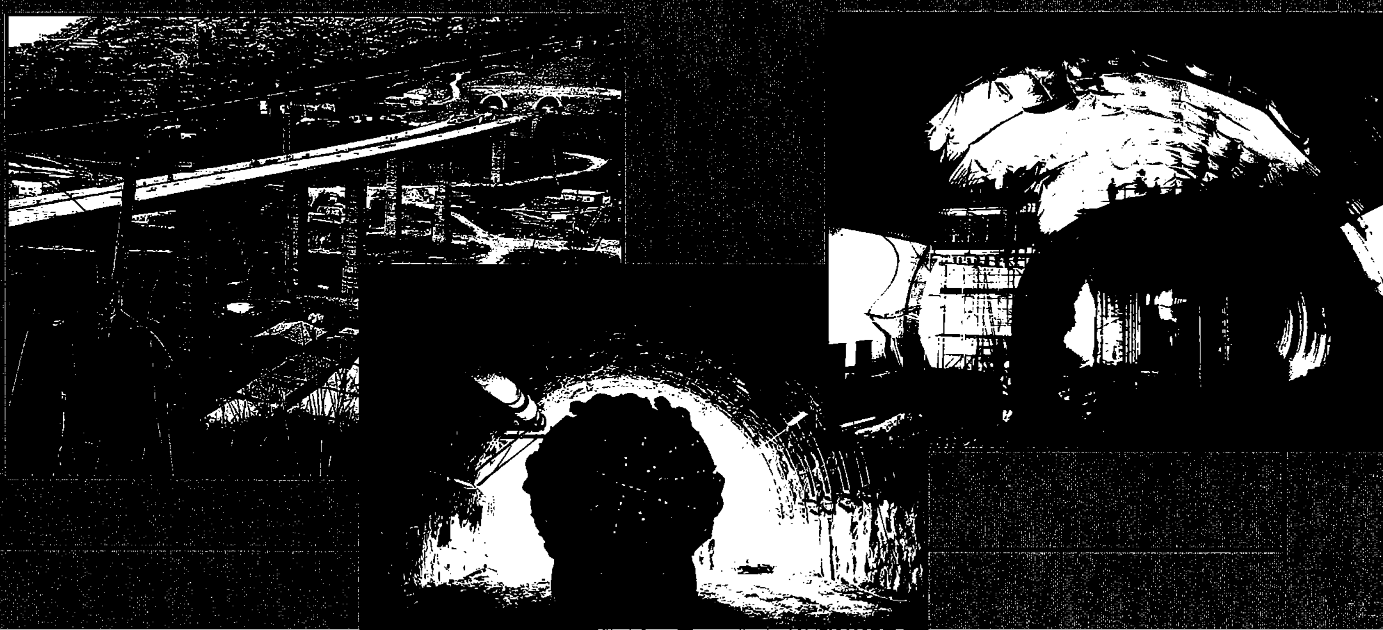
FINAL REPORT

A Comparative Analysis of Tunnel Construction Times, Costs and Risks Associated with the Choice of High Speed Rail Tunneling Alignment between Los Angeles and Bakersfield

Submitted to the City of Palmdale — January 31, 2003

TRANSMETRICS
Engineering & Construction Management

GEODATA



TRANSMETRICS, INC. is a civil engineering firm providing engineering, transportation planning, and construction management services to public and private sector clients. In business since 1982, TRANSMETRICS primarily serves the transportation industry. However, in the past ten years, TRANSMETRICS has expanded its services to include major private and public projects such as educational, medical, and municipal facilities, and the design and relocation of interstate utilities.

TRANSMETRICS offers a wide range of construction management services. Our engineers have the experience to lead a project from the planning and design stage to construction in an efficient and cost effective manner.

Because of its diversified workload and clientele, TRANSMETRICS actively participates in a variety of industry organizations which include:

- American Railway Engineering and Maintenance Association (AREMA)
- American Public Transportation Association (APTA)
- American Society of Civil Engineers (ASCE)
- International Association of Public Transport (UITP)
- American Public Works Association (APWA)
- National Society of Professional Engineers (NSPE)

TRANSMETRICS
Engineering & Construction Management

Transforming ideas into projects and monitoring them until completion: this is our daily task. During more than 16 years activity in the field of geo-engineering we have intensified and diversified our competence, following a strategy of multi-disciplinary growth.

Geodata is an independent geo-engineering company which, since it was founded in 1984, has grown and developed in Italy and throughout the world. Geodata employs more than one hundred professionals who specialize in geo-engineering and subsurface projects. Their skills and extensive experience has made Geodata S.p.A. one of the most respected names in the tunneling industry worldwide.

Geodata works with construction companies and public or private authorities in planning subsurface works and in various sectors of ground engineering. Geo-engineering is our core business; it is our specialization and our strength. Geodata is in a position to supervise this work throughout the specific stages: from preliminary surveys and territorial planning to design and from the optimization of the conventional and mechanized construction techniques to monitoring of the construction progress.

Geodata management has been an active participant in the International Tunneling Association where they present various reports and lead workshop discussions. Its key advisor, *Sebastiano Pelizza* served as President of the International Tunneling Association from 1995-1998.

GEODATA

TRANSMETRICS
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Campbell, California 95008
Phone: 408.371.6800 / Fax: 408.371.6900

January 31, 2003

Mr. Stephen H. Williams, Director
City of Palmdale, Department of Public Works
38250 Sierra Highway
Palmdale, CA 93550

Subject: Final Report: Comparative Analysis of the Tunnel Construction Times, Costs, and Risks associated with two alignments for the High Speed Rail crossing of the Tehachapi Mountain Range between Los Angeles to Bakersfield

Dear Mr. Williams:

Transmetrics/Geodata having completed the subject analysis, is pleased to submit its final report to the City of Palmdale.

This report outlines the geologic challenges involved in the two tunneling options under consideration by the California High Speed Rail Authority. It is intended to assist everyone involved in a decision making role, to consider all the risks and costs inherent in the selection of one alignment over the other.

Prior to the start of the analysis, the study team members made a site visit, obtained extensive mapping and documentation from the U.S. Geological Survey and the California Geologic Survey, and held a teleconference with the program manager retained by the California High Speed Rail Authority.

On behalf of the study team, I would like to thank you and your staff, all the individuals and agencies contacted, and the consultants and staff of the California High Speed Rail Authority for your cooperation and assistance during the conduct of our work.

We look forward to working with you and your staff in the weeks to come and will respond to any questions regarding the analysis.

Very truly yours,

TRANSMETRICS, INC.

Jack Ybarra
President

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

Final Report

Prepared for the

City of Palmdale

by

TRANSMETRICS Inc.
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and

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Corso Duca Degli Abruzzi 48/E
10129 Turin, ITALY

January 31, 2003

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EXECUTIVE SUMMARY

The California High-Speed Rail Authority (HSRA) is making a comparative evaluation of two alignment alternatives, I-5 (Grapevine) and AV (Antelope Valley), for the high-speed rail connection between Sylmar and Bakersfield.

The earlier studies of the Authority have focused on minimizing tunnel requirements and cost (Corridor Evaluation study of 1999 and QUANTM study of 2002) and minimizing potential environmental impacts (the Screening Evaluation) by avoiding sensitive zones in identifying the potentially suitable routes. However, there is a limit to these reductions due to the constraints imposed by the specific topography and tectonic setting of the region as well as the high-speed train technology. Furthermore, for the limited number of potentially suitable routes identified by the previous screening studies, and subsequently confirmed by the QUANTM analysis, the various categories of risks, especially the geological and construction risks, were not considered. In the opinion of Transmetrics and Geodata, these other risks are as important as those already considered by the Authority and its consultants; they are also critical in the final choice of the optimum alignment/route for the mega tunneling project.

The potential, typical risks that may be encountered in a mega tunneling project include risk of encountering adverse geologic conditions, constructions risks, such as choice of a wrong type of TBM, ground-squeezing behavior, and face collapses. Financial risks, such as delay in completion of the contract or cost overruns, and contractual risks such as time delays and disputes are also a typical problem.

The city of Palmdale believes that specific uncertainties in tunneling should be adequately integrated into the various studies commissioned by the Authority. Risks associated with the I-5 alignment should be adequately examined with those associated with the Antelope Valley alignment. This study is intended to continue the concept development process to an all encompassing conclusion.

Consequently, the City of Palmdale retained Transmetrics/Geodata to provide a complementary risk assessment to assist in the project development process.

The purpose of this risk analysis study is to identify the optimum alignment with respect to minimizing the capital investment and the risk of construction-cost overruns and delays, and to review specific uncertainties in the tunneling that should be adequately incorporated into the overall decision making effort.

Sufficient site-specific data was not available. Experience judgment, was used for the study model and USGS data and reports were utilized in lieu of precise, in-situ explorations and measurements. Full use was made of the information contained in the 1994 Preliminary Engineering Feasibility Study conducted for Caltrans. Relevant reports and maps were obtained from the USGS to study the geomorphological, geological, hydrogeological, and geotechnical conditions of the two alternative alignment-corridors, establishing foreseeable ground models. A preliminary model of both alignments was made to define the corresponding construction schemes based on Geodata's experience for similar projects in Europe.

The number of tunnel segments (or tunnel zones, TZ) in the I-5 and AV alternatives are 4 and 7, respectively, with the maximum anticipated grade of 2.5% or 3.5%. The geologic horizons crossed by the various tunnel zones will vary from metamorphic and igneous rocks to sedimentary rocks and gravel deposits. Numerous faults intersect the two alignments. Some of these faults have a tectonically active character and a potential for plastic slippage of the fault faces.

The construction methodology selected for the two alignments is the use of tunnel boring machines (TBMs) except in some instances, such as excavation of portals, where conventional drill and blast techniques is selected. In addition to the main, twin tunnels of 9.5m diameter, a service tunnel of 6.5m diameter and seismic chambers (in major fault zones) are the principal components of underground excavation.

The comparative analyses of the two alternative alignments were performed using the tool called DAT, or Decision Aids in Tunneling.

A unique feature of DAT is its capability for a comparative evaluation of the performance of various project alternatives. Construction schemes, alignments and methods of construction are incorporated parameters. The potential of these alternatives in managing geotechnical and construction uncertainties within prescribed, or acceptable values of time and cost is also incorporated.

A DAT run is essentially a computer simulation of several random processes. The idea of using computer simulations derives from the fact that it is not possible to find analytically resulting random functions when processes are too complicated, like the construction of tunnels. So simulating a construction process is the only solution to obtain statistical information about the total time and cost. This information gives a good estimate of the average, minimum and maximum expected values. By definition the simulation of a random process uses a random number generator.

DAT and the associated computer SIMSUPER have been developed over a period of 20 years by MIT (Massachusetts Institute of Technology) and EPFL (Ecole Polytechnique Federale de Lausanne), with the participation of Geodata for practical application of the code in various international tunneling projects.

DAT simulates the tunnel construction process cycle for TBM, with its various rounds of drilling and blasting. A simulated, probabilistically ground class profile is assembled. For each cycle or round, the program selects a cost-time pair from the cost and time distributions and the ground class associated with the particular location.

The ground class assigned to a location (or a given tunnel segment) is a function of the following parameters: behavioral category, potential instability conditions, potential problematic water, possible presence of gas, and (anomalous) abrasivity of the rock mass. The behavioral category is defined by combining the strength index of the ground with its deformation index.

The total cost and time for a particular tunnel-simulation run represents a single point in the cost-versus-time plot. By conducting a statistically significant number of runs, many points are obtained and a scattergram (or cloud) is formed, expressing explicitly the inherent variability in the estimated construction cost and time.

The construction simulation requires input regarding advance rates and costs (for various elements of construction) for different behavioral categories. Costs and advance rates are influenced by geo-events such as water inflow, and consequences related to occurrence of instability phenomena.

The results of DAT simulation for each alignment (at max grades of 2.5% and 3.5%) are given in Sec. 6 as histograms and statistics of the construction time and cost as well as the scattergram formed by 1000 points in the cost-time frame. A super-imposed comparative scattergram for the two alternative alignments, and a comparative construction time and cost table, are also provided.

Finally, the results exclude the construction risks and costs of surface structures such as bridges and surface railbed. These costs are included in the HLB Report.

The results of the analyses demonstrate the following:

- Although the amount of tunneling work involved in the I-5 and AV alignment are almost the same, be it the 2.5% grade or the 3.5% grade option, ground conditions along the AV alignments are relatively more favorable and hence involving less construction, financial or contractual risks.

- For the 3.5% max grade option, the mean construction time required for the I-5 alignment is almost twice as much as that required for the AV alignment (2218 working days against 1125 working days, see Table 6.9). Similar results were obtained for the 2.5% max grade option. A slight increase in the mean construction time for the AV alignment due to increased total length of tunneling was observed (see also Table 3.1).

- In terms of the mean construction cost for the 3.5% max grade option, the Antelope Valley alignment is about 40% less costly than the I-5 alignment. This advantage is reduced for the 2.5% maximum grade option. The 2.5% grade option is 15% less costly, due to increased total length of the tunnel. Furthermore, the increased tunnel length for the AV alignment at 2.5% max grade will reduce the costs for the corresponding external works and environmental impact.

<u>In summary, the ground conditions along the AV alignment involve lower risks regarding construction, financing, and contracts. For both max. grades (2.5% and 3.5%), the AV alignment is clearly less costly than the I-5 alignment. Note that the DAT analyses does not simulate the financial consequences of increased duration of construction. However, it is likely that a longer duration of construction will further increase the difference in the cost of the two alternatives.</u>

Generally speaking, the findings of this study quantifies to some extent the relative risks involved in the two alternative alignments. This should allow the Authority to make a more informed decision regarding the final alignment choice.

It is recommended that geologic uncertainties be reduced by pursuing a planned site investigations, eventually using a service tunnel as a pilot bore for an investigation. Innovative technological solutions should be incorporated in the strategy for managing the high-risk aspects of the project.

Study Team

The study Team was a joint effort of Transmetrics Inc., a civil engineering firm based in Campbell, California, and Geodata S.p.A. of Turin, Italy. Both firms have previously teamed together for work on projects of similar nature. Geodata is a geo-engineering company with particular expertise in the design of underground structures in complex and difficult ground conditions. Since its beginning in 1984, Geodata's activities have involved one or more of the various technical phases (lab and in-situ characterization, feasibility study, preliminary design, final design, performance monitoring, design optimization during construction, resident engineering, independent design checks) for over 1500 km of tunnels (for transportation, water supply, and sewage disposal).

Since 1990, Geodata has teamed with Professor H. E. Einstein of MIT in applying DAT to identify the optimum tunnel alignment relative to geologic and construction risks in various projects around the world. The more recent (1999-2002) applications of DAT involved the following projects:

1. **Guardarrama High Speed Rail Tunnel in Spain**. Geodata made an independent assessment of the basic design and the associated risks for the Minister of Public Works.

2. **PAJARAS High Speed Rail Tunnel in Spain**. Geodata made an independent design check and risk analysis. The design was prepared by the joint venture, INECO S.A. and Geoconsult Ingeneieros Consultores S.A.

3. **Torino-Lyon High Speed Railway**. For the long and deep tunnels Geodata made a risk analysis for the Authority, ALPTUNNEL (a joint organization of the French and Italian Governments).

The team of experts contributing to the present study includes:

Dr. Shulin Xu (Ph.D. in Engineering Geology from Imperial College, London, England) has performed DAT applications for Geodata since 1990. Dr. Xu is Geodata's Technical Director and is the coordinator of this study.

Eng. Piergiorgio Grasso (a Civil Engineering graduate from the Technical University of Turin, Italy) is the President and Principal Engineer of Geodata. He has 27 years of experience in design of underground works.

Prof. Sabastiano Pelizza (a Mining Engineering graduate from the Technical University of Turin, Italy) was President of International Tunneling Association during 1995-1998. He has consulted for Geodata since 1984.

Dr. Ashraf Mahtab (Ph.D. in Civil Engineering from the University of California, Berkeley) is a consultant to Geodata with particular reference to the application of DAT.

Dr. Herbert E. Einstein (Professor of Civil Engineering at MIT) is the original developer of DAT. He is an expert advisor to Geodata for this type of study.

1. INTRODUCTION

1.1 HSRA Project Description and Background

The California High-Speed Rail Authority (HSRA) has undertaken a process to develop a high speed rail ground transportation system (HSGT) to connect the cities of San Diego, Los Angeles, San Francisco, and Sacramento. The proposed HSR system would be similar to the HSR systems currently in place in Germany, France, Italy, Spain and Japan. However, the HSGT must cross the Tehachapi Mountain Range north of Los Angeles. There are several active faults in this mountain range and will require a choice of route alignment which is safe and minimizes construction related issues.

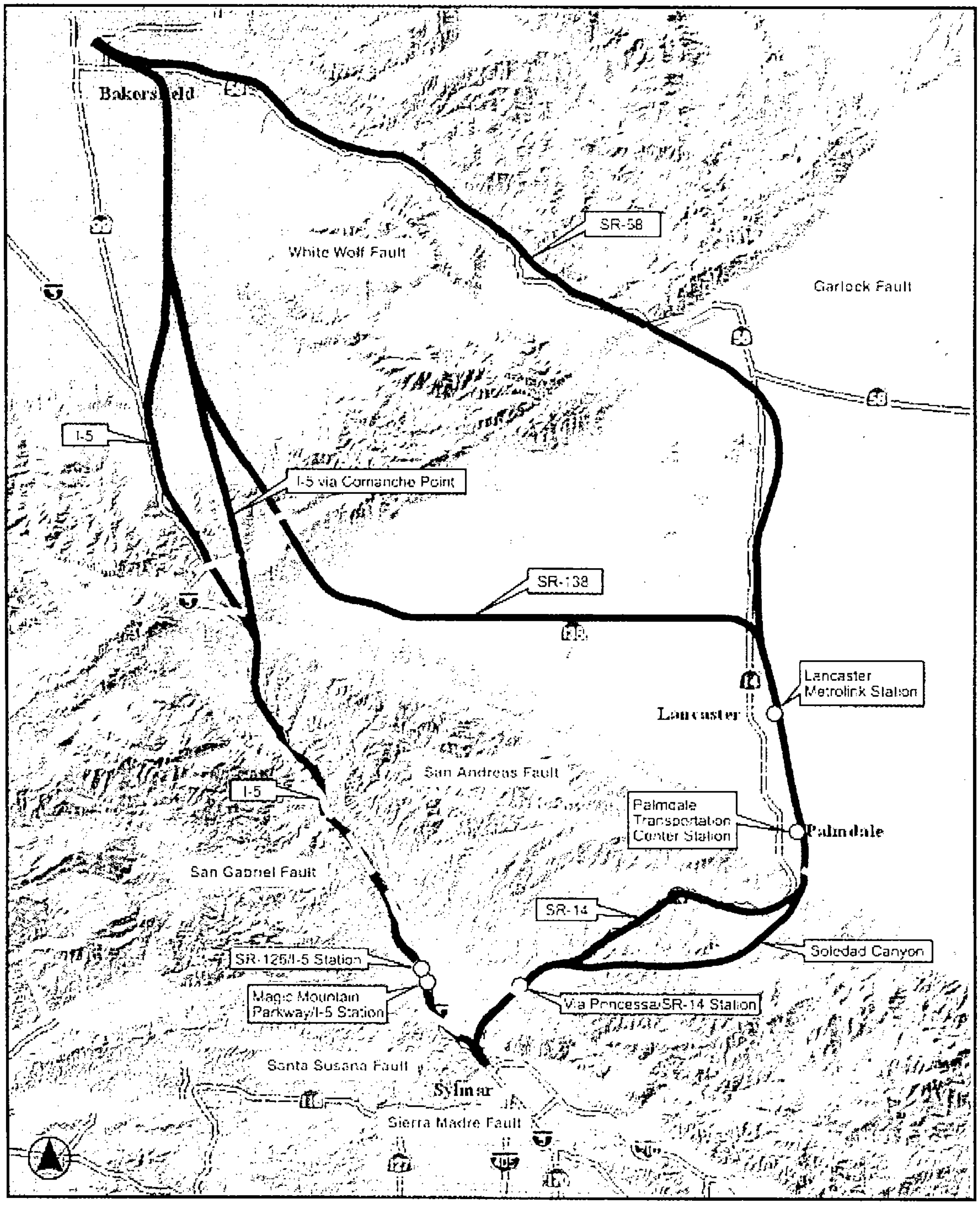
The two principal alignment options considered by the HSRA for crossing the Tehachapi Mountains between Los Angeles Union Station and Bakersfield are – the AV, or the Antelope Valley, alignment and the I-5, or the Grapevine, alignment. The two alignments differ principally in relation to length, accessibility, and construction complexity and risk (see Fig. 1.1).

For the tunnel study in this report, the tunnel portal positions have been established assuming that at least 20 meters of overburden are required above the tunnel base. This is due to the large dimension of the tunnels and the need to have a reasonable minimum cover thickness to start the excavation. This means that the position of the portals can be slightly different with respect to the position defined in the HSRA's documents (Orthophotos).

The I-5 alignment is some 65km shorter than the AV alignment and would, therefore, allow a 5 percent (6-9 minute) shorter non-stop travel time, depending on the final choice of the high speed rail technology and the train speed. In comparison, the AV alignment would offer high-speed rail service to at least 438,000 additional residents and 165,000 employees today, and to over 720,000 additional residents (and 270,000 employees) at the time of system startup in the 2015-20 period.

Finally, from a construction perspective, while the I-5 option would require the construction of a shorter track than the AV alignment, this advantage would come at the cost of more route miles of tunneling (the exact figure for the miles will depend on the choice of the grade) through a fault-ridden section of the Tehachapi Mountains, the costliest – and riskiest – type of civil construction that would be encountered in an attempt to cross the Tehachapi Mountain range.

Figure 1.1 Map of the Alternative Alignments



Legend

Alignments to be Evaluated

Station Locations to be Evaluated

Fault

1.2 Review of Available Information

1.2.1 Extent of available information

The analyses presented in this report have been developed by the Consultant using the available information (under the categories discussed below) and, in the absence of available information, using the appropriate assumptions based on experience.

Geology

The main source of information regarding the geology and geotechnical characteristics of the ground along the two alternative alignments was contained in the document on "Preliminary Engineering Feasibility Study – Final Geotechnical Summary Report" dated April 11, 1994, submitted to the California Department of Transportation, prepared for Parsons Brinkerhoff Quade & Douglas by MAA Engineering Consultants, Inc. of Los Angeles. On request, this document, and the maps and sections annexed to it, were supplied to Geodata by PBQD. Additional information was downloaded from the Authority's website.

Geodata also acquired relevant reports and maps from the United States Geological Survey to study the geomorphological, geological, hydrogeological, and geotechnical conditions of the two alternative alignment-corridors, aiming at identifying the corresponding risks. This information from the USGS came from their offices in Menlo Park, San Francisco and Denver.

Drawings

The only drawings available for the study where those produced for the Preliminary Engineering Feasibility Study in the period of 1993-1994 by MAA Engineering.

Boreholes

No borehole information was available to Geodata. It is understood that some boreholes were drilled recently to check the ground conditions of alternative alignments.

Tunnel Design

The Tunneling Feasibility Study made in the period of 1993-1994 for Caltrans was the only background information available on the design for either of the two alternative alignments. A judgment on certain design and construction parameters required for the analysis had to be made by the Consultant to complete the model for this study.

<u>Construction methodology</u>

A clear statement of the construction methodology is not found in any official documents made available to the Consultant, except in the Tunneling Conference Summary where it was mentioned that "Tunnel Boring Machines should be assumed as the excavation method for all tunnels with the exception of specific areas identified during the conference that have difficult geology."

1.2.2 Review of Previous studies

The project planning and feasibility studies, the environmental impact assessment, and the selection of the system's route alignment have been conducted primarily by the Authority's consultant, and the project development is currently at the stage of final screening evaluation of alignment options. The following two events in the long process of initial project development study should be noted.

1. During the period of 2001 to March 2002, the Authority conducted an alignment optimization and refinement study to further clarify screening decisions using the QUANTM system. The QUANTM system is a new automated alignment optimization system developed and applied in Australia. It was the intent of the authority to improve on the previous analyses based on "best practices" for conceptual engineering. The results were presented in a final report titled, "Alignment Refinement/Optimization and Evaluation of the QUANTM System" published in April 2002.

   In the beginning of December 2001, the Authority organized a two-day (December 3 and 4) Tunneling Conference to discuss major tunneling problems involved in the California HSR project. However, the documentation of this Conference is limited to only a few pages of summary placed on the Authority's website, and the proceedings of the Conference have not yet been published.

2. Great importance has been given by both the Authority and its consultant to the above two events.

   - Previous corridor evaluation studies have focused on minimizing tunnel requirements and cost;
   - Current screening evaluations focused on minimizing potential environmental impacts;
   - Influenced by the results of the Tunneling Conference, the QUANTM study attempted to minimize tunneling and capital costs. In this regard, it is more comparable to the earlier corridor evaluation study results.

The two often conflicting aspects of minimizing tunnel requirements and cost, and minimizing potential environmental impacts are interrelated. They should be treated following a systematic engineering approach.

The risks and/or critical considerations listed below have been identified in previous studies. Attempts have also been made to deal with these issues.

- Alignment crossing fault and shear zones of considerable length. The solution adopted, wherever possible, was to avoid these zones by either deviating the route or increasing the vertical grade to move the alignment to the surface.
- Alignment crossing water-saturated zones and/or zones with high groundwater pressure. The attempted solution was to deviate the route wherever possible.
- One longer versus many shorter tunnels. In general, shifting the problem of fault crossing from underground to surface may not be a an optimum choice. For the HSR project this problem will be complicated by the fact that the alignments run across active earthquake faults. The I-5 alignment is of concern because it is parallel to at least two faults. While the region is vulnerable to earthquakes, tunnels are generally more resistant to seismic events than equivalent superstructures as experienced in Kobe, Japan and in the Loma Prieta, California events. The region's faults are expected to produce large, lateral shear displacements during an earthquake and might endure a tunnel section closure.
- During operation. The time and cost involved in rehabilitating an earthquake-damaged tunnel section (compared to that of an equivalent superstructure) needs to be investigated.
- The addition of high embankments and deep trenches may also be a factor associated with vertical-grade options, considering the associated costs of trench support, embankment-slope protection, and maintenance.

However, there are also other risks which were not addressed in the previous studies. For example, the potential, typical risks to be encountered in a mega tunneling project like the California HSR project may include:

1) The risk of encountering adverse conditions due to the inherent uncertainties of ground and groundwater conditions – leading to significant cost overruns and project delay;

2) The potential for accidents during tunneling and post construction;

3) Construction risks, such as selecting the wrong type of TBM, human error, rock squeezing behavior, face collapses and production of materials causing hazardous environmental conditions;

4) Financial risks to the owner, such as delay in completion of the contract, cost overruns, or lower than projected rates of capital return;

5) Contractual risks, such as additional work not covered, time delays, disputes, claims and litigation.

It should be noted that the underground construction industry seems particularly prone to disputes – this is most likely because of the risks and uncertainties associated with subsurface conditions and costly plant and equipment required for tunneling.

It is believed that the costing (and timing) of the project would be quite different if the geological and construction risks, as well as the entailed financial risks, were included in all cost calculations.

Therefore, it is necessary to perform an alignment-specific risk analysis for each potentially suitable alignment, to complement the QUANTM analysis, considering at a minimum the following:

- the variation of construction time and cost as a function of the expected geologic conditions and the associated variations and uncertainties;
- the impact of construction duration on economic and financial issues.

The final choice of the optimum alignment can be enhanced on the basis of a multi-criteria analysis, taking into account the following key factors:

1) Environmental impacts,
2) Total construction cost and risk of cost over-runs,
3) Construction duration and the risk of delays,
4) Performance of the chosen alignment alternative in dealing with risks during operation,
5) Capital investment and the related financial risks.

Determining an optimal alignment for the HSR system is quite complex and requires a multidisciplinary approach supported by effective and efficient tools.

1.3 Purpose and Scope of the Analysis

The study presented in this report was commissioned for two main reasons, (1.) Specific uncertainties in the tunneling process were not adequately integrated into earlier studies commissioned by the Authority, and (2.) to identify the optimum alignment with respect to minimizing capitol investment and risk of construction cost overruns, and costly delays.

The objective of the study is to conduct a geo-engineering risk analysis and an economic risk analysis associated with the design and construction of tunnels for the high-speed rail project between Sylmar and Bakersfield, along two alternative alignments (see Figure 1.1):

1. *I-5 Alignment - Sylmar to Bakersfield following Interstate 5*

   ("Grapevine")

2. *Antelope Valley Alignment –*

   Segment 1 - Sylmar to Palmdale via SR-14 and Soledad Canyon

   Segment 2 - Palmdale to Mojave (level terrain)

   Segment 3 - Mojave to Bakersfield via SR-58

The tunneling duration and cost as well as the corresponding risk assessment of the two alternative alignments will be made to address the following two questions:

1. Which alignment requires the least capital investment; and
2. Which alignment presents the lowest risk of construction cost overruns and schedule delays?

[*Note that a unified benefit-cost analysis previously prepared by the Consultant, HLB Decision Economics, Inc., will be updated to include the results of the present tunneling risk analysis.*]

The specific tasks of Transmetrics Inc. and Geodata S.p.A. (to be referred to as the "CONSULTANT" will include:

1. Define Risk Assessment Model and establish the primary output paramenters such as:
   - Number, length, size, alignment, and location of tunnels, surface structures and the related surface structures;
   - General rock mass type and quality;
   - Proximity to favorable or adverse geotechnical conditions
   - Faults and fault zones (vulnerability to earthquake damage),
   - Water-saturated zones,
   - Surface instabilities,
   - Location/impact of surface facilities and structure (e.g., portals, ventilation facilities).
2. Analyze data provided by PBQD and the USGS
3. Prepare Quantitative Cost and Risk Outputs.

   Prepare central, upper, and lower values for costs and schedule impacts for each alignment and grade option.
4. Prepare General Discussion of Tunneling Risks and Risk-minimization.

   This will include a discussion of key tunneling design and cost parameters, risk factors, and other issues associated with alignment and design of long, deep tunnels based on the Consultant's international experience.
5. Prepare a Technical Working Paper.

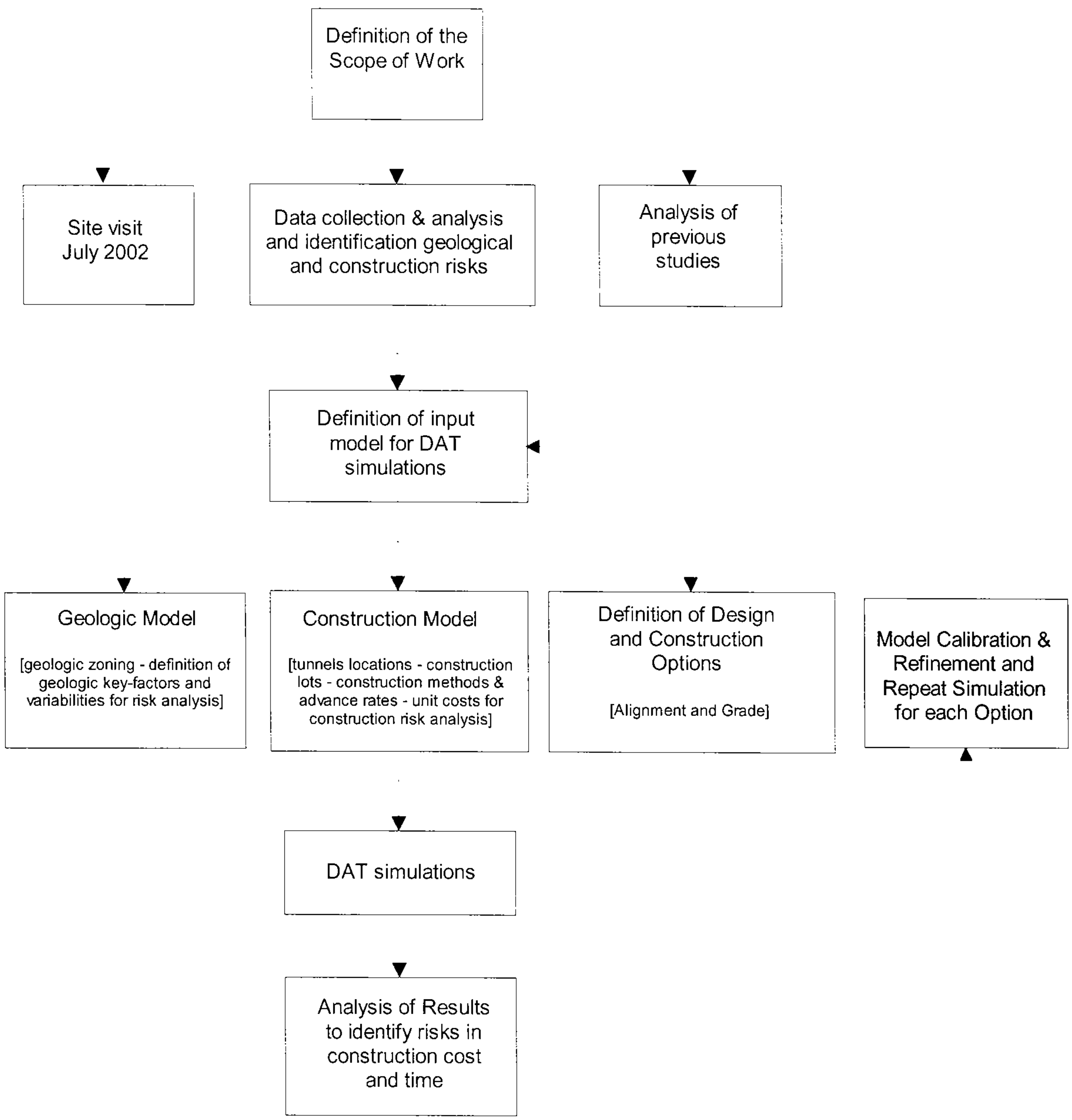
The process to fulfill the above tasks are illustrated in Figure 1.2.

1.4 List of Acronyms

CONSULTANT	Transmetrics Inc. and Geodata S.p.A.
CHSRA	California High-Speed Rail Authority
HSR	High-Speed Rail
DAT	Decision Aids in Tunneling
QUANTM	Automated Alignment Optimum System developed and applied in Australia
PBQD	Consultant to HSRA
AV	Antelope Valley (alignment)
I-5	Grapevine (alignment)
GSI	Geologic Strength Index
UCS	Unconfined Compressive Strength
TZ	Tunnel Zone
TBM	Tunnel Boring Machine

EPB Earth Pressure Balance
CONV Conventional Excavation (using drill-and-blast technique)

Figure 1.2 Flowchart illustrating the process for risk analysis conducted



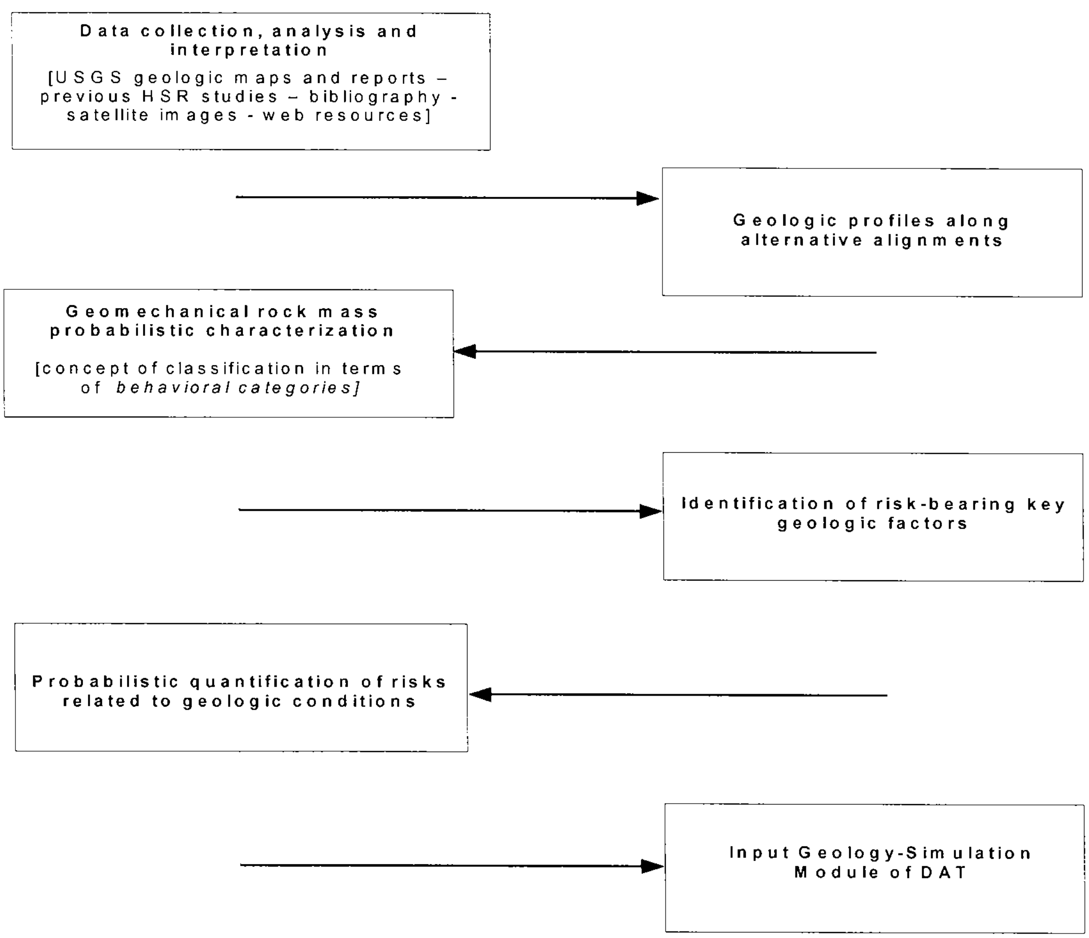
2. GEOLOGIC CONDITIONS ALONG ALTERNATIVE ALIGNMENTS

It is common experience in tunnelling that geologic conditions play an important, often critical role in determining the final success of a project in terms of meeting the planned schedule and budgeted costs. This is due to the inherent uncertainties about the prediction of the geologic key factors and their natural spatial variability, that can only be reduced but not eliminated through the execution of proper site investigations.

Bearing this in mind and considering the extent and complexity of the California HSR project, we have considered it necessary to establish an adequate geologic model aimed at defining the conditions to be encountered during tunnelling along the two alternative alignments. The model should be consistent with the current stage of development of the Project and with the available information.

The model-development process is illustrated in Figure 2.1.

Figure 2.1 Flowchart showing the geological-model development process



The following is a summary of the geologic conditions that are expected to be encountered along the I-5 and AV alignments. Details of the geologic conditions are provided in Appendix 2.

2.1 Geologic Units

The four broad geologic units expected to be crossed by the tunnel alignments are:

- (Pre-Tertiary) Metamorphic rocks, such as quartzite.
- (Pre-Tertiary) Intrusive rocks, such as granite.
- (Tertiary) Sedimentary rocks, such as sandstone, and volcanic rocks, such as basalt.
- Quaternary deposits, such as gravel.

2.2 Principal Faults

The characteristics of the principal faults that are considered to directly intersect the underground sections of the two tunnel alignments are summarized in Table 2.1. Two important aspects of the faults, which should be considered in the selection of a tunnel alignment are: the tectonically active character, and the slow, plastic slippage that may generate ground movements of several mm/year.

Table 2.1 Principal fault zones affecting the alternative alignments

Fault zone	Location (align., approx. chain.) (3)		Type	Attitude (dip/dip direction or strike direction)	Estimated width [m] (1)	Last seismic event year/magnitude] (2)	
S. Andreas	I-5	km 78+000	S, RH	Near vertical, NW-SE	800 - 1000	1857 (south branch)	8.0
Garlock	I-5 AV	km 70+250 km 79+350	S, LH	Near vertical, NE-SW	500 - 800	1992 (Mojave)	5.7
S. Gabriel	AV	km 177+950 km 178+200 km 178+850	S, RH	Near vertical, NW-SE	400 - 600	Quaternary	unknown
S. Susana	I-5 AV	? km 183+600 km 184+200	T	var., NW to NE	200 - 250	Late Quaternary 1971 (S. Fernando)	unknown. 6.5
Pleito	I-5	km 57+700	T	var., NNW	150 - 200	345-1465 years ago	unknown
Pastoria	I-5	km 67+000	R	var., SSE	300 - 400	unknown; probably non active	
Edison	AV	km 38+600 km 40+600	N	45-75°, NNW	100 - 200	unknown; probably non active	
Legend	S (strike-slip fault), T (thrust fault), N (normal fault), R (reverse fault); RH, LH (right-hand mov., left-hand mov.)						
Note	(1) The figures refer to the estimated width of the fault affected zone (2) From SCDEC (Southern California Earthquake Data Center http://www.scecdc.scec.org/faultmap.html) (3) Chainage onset is assumed in Bakersfield						

2.3 Groundwater Conditions

Groundwater in the study area is contained in three basin-fill aquifer systems: the Basin and Range aquifers, the Central Valley aquifers, and the Coastal Basins aquifers. Due to the lack of any detailed hydrogeological information, a qualitative hydrogeologic characterization was made to distinguish the potentially affected zones from the potentially unaffected zones with respect to the negative impacts of water inflow during tunneling.

2.4 Geomechanical Characterization of the Ground

The ground along the tunnel horizon was assigned "behavioral categories" **a** to **f** using the approach detailed in Appendix 2. The approach combines the Geologic Strength Index with the Deformation Index of the ground at the tunnel face and around the cavity, to define a behavioral category for the ground at a given section of the tunnel.

2.5 Anticipated Geologic Conditions Along Alternative Alignments

This section will outline the expected geologic conditions along the alternative alignments as recognized through the study of background literature (listed in Appendix 1) and visual inspection during the site visit of July 2002. Descriptions are presented for all the tunnel zones (TZ) of each alternative alignment option separately. For the sake of simplicity and completeness, reference will be made to deeper and longer, 2.5%-maximum-grade-alignment configuration. The descriptions are also valid for 3.5% max grade configuration.

I-5 (Grapevine) alignment

- TZ 1 (Grapevine to Castaic Lake)

Metamorphic to granitic rock types shall be encountered.

Tunneling shall intersect a very tectonically disturbed zone. Major regional faults are (i.e. Garlock and San Andreas systems) several hundred meterswide, while other important faults (e.g. Pleito thrust zone, Pastoria fault) and a certain number of minor shear zones will be crossed. Poor to very poor conditions can be anticipated through these zones, with a high potential for ground instability phenomena. Ground squeezing could occur in zones of low rock mass strength to lythostatic pressure ratio, while wedge-like instabilities could occur as a consequence of the blocky nature of the rock mass.

Zones bounded by successive fault zones are, on average, expected to be quite disturbed due to significant, though variable, fracture intensity. Also, the occurrence of associated potential water inflow phenomena seems to be quite probable in these zones.

The northern portal area (Grapevine) is a well recognized area subject to landsliding.

A particularly difficult geologic zone is represented by the section that extends between Garlock and San Andreas fault zones where, besides the expected very poor geomechanical conditions, groundwater can play a critical role in tunnel stability. The presence of a water body at the surface (tunneling shall be very close to Castaic lake) of this relatively low overburden zone, will constitute a very special environmental and geotechnical hazard.

- TZ 2 (Castaic Lake to Marple Canyon-Violin Canyon)

Here, sedimentary units of flysch-like character (interlayered sequence of sandstone, siltstone, claystone) are anticipated; rock properties are quite variable primarily as a consequence of the variability in rock types (reference can be made to the concept of *geotechnical complexity* or *complex rocks* as developed by the Italian Geotechnical Association since 1979).

In the northern area, intensely folded rock masses are anticipated. According to data from the USGS, the relative stiffness of the prevailing rock type (sandstone) folding could be associated with severe fracturing and blockyness of the rock mass, particularly in the fold hinge zones.

In the southern part of the tunnel zone not well lithified claystones may be encountered over a stretch of several hundred meters. Here instability phenomena is likely to occur during the excavation.

Similar to TZ1, the alignment will pass near a water body at surface (ZZZ artificial reservoir), this will be a matter of particular concern from the environmental and construction points of view.

From morphologic analysis (on both topographic maps and satellite image) the zone seems to be intersected by several minor faults that could be associated with their proximity to major fault zones (San Gabriel, San Andreas).

- TZ 3 (Santa Clara River to Lyon Canyon)

This narrow tunnel zone will intersect sedimentary units from Quaternary, unconsolidated coarse-grained grounds to Pliocene rocks. Tunneling shall be mainly in shallow conditions, except for a zone towards the center of the TZ where it will pass through a relief that appears quite densely urbanized.

While the potential for significant water inflows should not be important, the nature of the rocks could indicate the presence of gas.

- TZ 4 (Weldon Canyon to San Fernando-Sylmar)

Through this tunnel zone the alignment finally arrives at the San Fernando-Sylmar node. Again, clastic sedimentary rocks, of both marine and continental origins, will be encountered.

The entire zone, and particularly the second half towards Sylmar, is directly affected by important fault structures linked to the Santa Susana thrust system. Severe tectonization due to compressive shearing and, consequently, poor geomechanical conditions can be anticipated. Both water and gas could be present.

The tunnel will underpass a very low overburden near the I-5 freeway as well as the L.A. aqueduct.

Antelope Valley (Soledad Canyon) alignment

- TZ 1 (El Tejon to SR58-SR223-Bena Road junction)

This is the first tunnel zone that is between Bakersfield and the Tehachapi mountains.

Separated by the Edison fault, this tunnel zone encounters coarse sedimentary rocks in the first section of the tunnel, and granitic rocks until the eastern limit. With regard to the former, some uncertainty is represented by the very nature of the unit, i.e. whether it behaves more like a soil or a rock. For purposes of this study, it has been assumed that the unit is characterized by having a cohesive strength due to the presence of inter-particle bondage.

Due to its spatially variable altitude, the Edison fault could be actually intersected in different locations and possibly also in very unfavorable conditions (subparallel to the tunnel axis).

- TZ 2 (Clear Creek to Rowen)

This quite narrow tunnel zone is expected to be entirely excavated through good granitic rocks. Only minor tectonic structures have been hypothesized based on morphologic analysis.

A mainly elastic response to excavation can be anticipated.

- TZ 3 (West of Keene to West of Summit - Tehachapi)

This long tunnel zone will intersect a staggered series of dioritic and quartz-monzonitic and metamorphic rocks of probable sedimentary origin.

Through morphologic analysis and interpretation, some narrow fault zones have been introduced in the geologic model.

From the geomechanical perspective, potential instability phenomena are more likely to be associated with metamorphic rocks under high overburden and/or where rocks have been subjected to shearing.

- TZ 4 (from Proctor Lake zone to Mojave Desert)

Tehachapi mountains crossing will be carried out through this tunnel zone. The most evident feature is represented by the Garlock fault zone, which combines quartz-monzonitic rocks and Paleozoic gneiss. The latter represents a sort of tectonic slice bounded at both limits by a fault structure, and is expected to be mostly tectonically disturbed and weathered.

At the southern boundary (Mojave), quartz-monzonitic rocks disappear giving place to Quaternary coarse continental sedimentary units that progressively thicken towards the Mojave plain. For older deposits a certain cohesive strength can be hypothesized, but for more recent deposits a prevailing frictional behavior is anticipated.

Challenging geotechnical conditions shall be encountered when boring through the wide Garlock fault zone and the neighboring gneissic rocks, and particularly where the rocks are loose as a consequence of tectonic events.

- TZ 5 (from Soledad to Apple Canyon)

This long tunnel zone is south of the San Andreas Fault relief, through the Soledad Canyon region, and will intersect a variety of geologic units.

Hard and massive granitic rocks are present in the eastern border. The central portion is occupied mostly by heterogeneous rocks of the Vasquez volcano-sedimentary complex, and a tectonically bounded volume of Precambrian deeply weathered anorthosites. Finally, in the western zone, clastic sedimentary rocks appear.

On average, fair geotechnical conditions can be anticipated, with the exception of the area where anorthosites are present. Also across fault zones, most of which have also been recognized on geologic maps (e.g. the Pole Canyon fault), worse conditions are expected. Unfavorable groundwater conditions should characterize the section where the Soledad Canyon valley will be crossed with a reduced overburden.

- TZ 6 (South of SR 14 to Placerita Canyon)

This tunnel zone crosses, under relatively low overburden, sedimentary clastic rocks of various type: sandstones, siltstones, mudstones and, to a lesser extent, conglomerates (in the form of quite isolated levels or lenses). In addition, some tuff layers will be encountered in the eastern portion.

This zone also crosses in different locations some branches of the San Gabriel fault zone, which will provide a series of sub-zones with very poor geotechnical conditions. Groundwater is not expected to be a problematic issue because of the prevailing shallow conditions in which the TZ exists.

- TZ 7 (from Elsemere Canyon to San Fernando-Sylmar)

Through this tunnel zone the corridor enters the San Fernando Valley. It follows at a short distance TZ6 and shall encounter similar geologic units of sedimentary origin.

Non-marine facies, encountered at the northern margin, are described as quite loosely consolidated to poorly cemented, while marine facies in the central portion, appear as rock masses.

At the southern margin, the corridor is repeatedly crossed by different branches of the Santa Barbara thrust system, giving rise to a significant length of rock masses of very poor geotechnical condition.

Oil fields are present in the area and the potential of encountering some gas volumes particularly in the deepest sections of the TZ has to be considered.

2.6 Evaluation of Risk Arising from Adverse Geologic Conditions (Events)

For the purpose of the present study, only potentially adverse geologic conditions are considered. Other event categories, which might negatively affect the construction process, such as mechanical failures, socio-economic events, natural extreme phenomena (e.g. earthquakes, inundations, etc.) are not taken into account.

It should also be mentioned, that other factors not considered in the present study shall play an important role when a comprehensive risk analysis is implemented to help decision makers in selecting the more reliable project solution.

For example, when dealing with an alignment that passes through an area subject to landslides, one has to consider that more lengthy and costly tunneling could be a more reliable solution than increasing the grade or aerial sections. This reasoning holds true when considering the same alignment with respect to potential earthquake induced structural or functional failures.

Another important issue is represented by environmental factors. Temporary as well as permanent works or facilities above ground have different impacts on the perceived environmental value of certain areas. In this respect, a more general public consensus could be reached regarding the feasibility of some solutions instead of others. For instance, the increased costs of a longer tunnel in a territory of environmental value could represent an acceptable trade-off.

Adverse geologic conditions that can be experienced in tunnel construction have the potential of causing time delays and costs overruns. This is of particular relevance when such adverse conditions have not been sufficiently investigated before starting the construction phase.

Although the principal types of potentially adverse geologic features can be reasonably anticipated through detailed studies, uncertainties about the location still remain as an inherent risky aspect of underground construction.

The best way to effectively manage such uncertainties is to treat them in a probabilistic manner, describing the possible occurrence of each category of accident with specific probabilistic parameters as will be depicted in the description of DAT (Section 4).

For the purpose of this study, starting from the referenced geologic model, four categories of potentially adverse conditions (geo-events) have been recognized, namely:

- Tunnel instability phenomena (from local collapse to severe ground squeezing)
- Water inflows
- Presence of hazardous gas (explosive or toxic hydrocarbons)
- Anomalous abrasivity

Conceptually, the risk for each event can be defined as a function of uncertainty and damage; that is,

Risk = *f (event uncertainty, event damage)*

Through DAT simulations, a zoning of the geologic adverse conditions has been performed emphasizing for each *geo-event* two or three levels of significance. This is done combining the estimated likelihood of occurrence and the potential impact on the construction phase.

3. SCHEMES FOR CONSTRUCTION OF THE TWO ALIGNMENTS

In order to perform the proposed alignment specific risk analysis, the Consultant had to make a conceptual construction of each design construction option, making relevant assumptions for those aspects not yet defined in previous studies. This conceptual design is summarized in the following subsections.

3.1 Definition of the Alignment Alternatives

As anticipated in Section 1 - Introduction, the two alternative alignments considered by the HSRA for crossing the Tehachapi Mountains between Los Angeles Union Station and Bakersfield are:

- The AV, or the Antelope Valley Alignment, and
- The I-5, or the Grapevine Alignment.

These two alignments differ principally in relation to (1) length, (2) accessibility, and (3) construction complexity and risk.

The position of the so called "Tunnel Zones" is defined based on the position indicated in the Authority's documents (Orthophotos).

The position of each single tunnel is fixed using the following procedure:

1) Get the approximate position from the Orthophotos.
2) On the basis of Step 1, evaluate if the maximum vertical grade of the tunnel in question is consistent with the specified maximum grade option (be it 2,5% or 3,5%). If not, move the position of one or both portals, changing as a consequence slightly the length of the tunnel in order to be consistent with the maximum-grade option to be analyzed.
3) In order to have 20M of overburden above a tunnel base, portals can be adjusted to insure a reasonable cover thickness before the start of construction.
4) For those long tunnels whose lengths are greater than 6 miles (see forward to Section 3.3) a third service tunnel is required for ventilation, evacuation and construction access. In this case the portal positions are fixed in accordance with those of the corresponding main tunnels.

Applying the above procedure, the positions of the portals and the lengths of the tunnels analyzed can be slightly different with respect to those defined in the Authority's documents.

The construction scheme for each tunnel is defined according to the Consultant's experience and knowledge. The schemes adopted are detailed in the subsection 3.5 (Tables 3.3 to 3.6). Each alignment grade option has been studied independently with the intent of reducing construction risks in terms of time and cost, without neglecting the technical feasibility.

The main tunnels are configured with twin bores, each bore housing a single rail track. The distance between the two bores and therefore the length of the crosspassages, should be determined properly in a successive design phase to ensure the stability of the pillar between the twin bores.

3.2 Choice of an Excavation Technique

As technical literature and excavation experiences all over the world have shown in the last decade, long tunnel excavation by TBM is nowadays a must, not only to ensure financial return of the investment, but also to manage labor conditions and environmental impacts. When rock mass conditions exist in a wider range, TBM excavation minimizes the construction time due to the high advance rates of this technology. This technological benefit is complemented often with an almost immediate installation of the final lining in the tunnel without incurring delays.

A particular family of TBM machines, i.e., the Double Shield TBM, is known for its wide application range and high performance. This is made possible by the feature that allows the machine to advance both as an open TBM when rock conditions are good to medium and as a single shield TBM when rock conditions are poor to extremely poor. In both excavation modes, the working site is kept in a safe condition by the protection of the telescopic shield and the consequent pre-cast concrete segmental lining which is installed simultaneously with the advance of the excavation. The result is a high performance rate in both good and poor rock conditions. The main disadvantages are the high initial investment and a long period of procurement and assembly.

For the both the I-5 and the AV alignment alternative, Double Shield TBMs have been selected for the tunnel excavation.

TBM excavation is applied for all long tunnels in order to make each machine excavate as long as technically feasible, thus amortizing the initial high cost of the machine.

For short tunnels, the first option is to use a TBM previously employed to excavate a similar small section in another tunnel, taking into account the related costs of disassembling and reassembling as well as transportation from one site to the other. If the transfer of a TBM from another excavation site impacts too negatively on overall construction time, a dedicated TBM should be adopted.

Conventional excavation may be selected for all those situations where its application will significantly reduce overall construction duration.

3.3 Service Tunnel

As discussed in the Tunneling Conference (December 3-4, 2001), a service tunnel is required for tunnel lengths over 6 miles, with the aim of providing a safety access way. It is assumed that the excavation of the service tunnels will start as early as possible before to the excavation of main tunnels.

The horizontal position of the service tunnel is assumed to be central to the main twin bore tunnels, in order to provide the best geological information for the excavation of the main tunnels and thus optimize its safety role. The service tunnel also provides drainage for groundwater to avoid inflow into the main tunnels.

It should also be pointed out that the service tunnel requires a thicker pillar between the main tunnels. Therefore, the length of each cross passage must take into account this increase in the separation distance between the twin bores of the main tunnel.

3.4 Seismic Chamber

As mentioned previously in Section 1.2.2, in case the tunnel crosses a major potential earthquake inducing fault zone (the San Andreas Fault and the Garlock Fault), the construction of a 1000m long large cross-section chamber, will allow for the realignment of the rail tracks in case of a major seismic event. The basis of this conceptual design choice is that these faults are expected to produce sufficiently large, lateral shear displacements during an earthquake capable of cutting and closing the tunnel section. It should be noted that so far the enlargement of a normal tunnel section to form the required seismic chamber has been considered only in the direction of the assumed potential lateral movement, which is predicted based on the past movement records of the fault concerned. However, a very recent science discovery has revealed that "faults go backwards". This discovery was reported first in the September 2002 issue of "Science" and then in the November 2002 issue of "Geoscientist" the magazine of the Geological Society of London. The following paragraphs are extracted from the article published in "Geoscientist".

> *"The earthquake known as the Hector Mine Event (1999) has enabled seismologists to identify new forms of earthquake-related deformation.*
>
> *On October 16 1999, approximately 37 miles from Palm Springs, California, a magnitude 7.1 earthquake ripped through 28 miles of faults in the Mojave Desert. Because of the area's sparse population and development, the massive quake caused virtually no major measurable injuries or destruction.*
>
> *Yet the Hector Mine event, named after a long-abandoned mine in the area, has indeed created a mine of information about earthquakes, faults, and ruptures for scientists at Scripps Institution of Oceanography at the University of California, San Diego.*
>
> *Writing in Science (September 13), the scientists, along with a colleague at the California Institute of Technology (Caltech), reveal how they used satellite and radar technologies to uncover characteristics of faults previously unknown to science. These include the first evidence that faults move backwards, contrary to conventional observations, and indications that the material within faults is significantly different from that in its surroundings."*

This new discovery suggests there is a risk that the seismic chamber solution may not serve its intended purpose. Clearly, this is not just a design risk. On the other hand, an alternative design of the seismic chamber is out the scope of work of the Consultant.

For the proposed analysis, the seismic chamber conceived by the HSRA is analyzed, also in terms of its potential for optimization of the construction of the tunnel crossing through a fault zone. Possible scenarios have been defined and analyzed to check if construction of a seismic chamber beforehand may help to reduce the overall time of constructing the main tunnel, and to minimize at the same time, the risk exposure of the main tunnel construction.

In any case, as a design choice an at grade fault crossing is preferred for each alignment option wherever the allowable maximum grade permits in order to limit construction costs and reduce risks.

In the case of the I-5 Alignment, the excavation of the seismic chambers through the Garlock Fault, is assumed to start from the service tunnel for both the 2.5% and the 3.5% maximum grade options. Consequently, when the 9.5m diameter TBMs reach the fault zone, they can simply be pulled or pushed through the already constructed seismic chamber, and thus avoid the risks of instability and blocking of the TBM. Only for the 2.5% maximum grade option, the seismic chamber required for crossing the San Andreas Fault Zone is assumed to be realized before the arrival of the 9.5m diameter TBM excavating the main tunnel. In this case it is also assumed that the seismic chamber will be constructed during the long period of procurement and assembly of the large TBM.

In the same manner, the 2.5% maximum grade option of the AV Alignment requires the construction of a couple of seismic chambers in the Tunnel Zone no. 4 to cross the Garlock Fault. To reduce general scheduling risks and to avoid ground instabilities when constructing the main tunnels, it is assumed that these seismic chambers will be constructed *a priori* from an access shaft.

3.5 Construction Scheme of Alignment Grade Option

Given the choice of two alternative alignments (I-5 or AV) and two maximum grade (2.5% or 3.5%) options, there are in total four combined options. The construction schemes adopted for these 4 alignment maximum grade options are defined on the basis of the criteria presented in Sections 3.1 to 3.4 and are illustrated in Figures 3.1 to 3.6. In these figures the realization scheme for each portal is not represented in order to keep the figure readable.

Table 3.1 gives a legend to the graphic symbols used in Figures 3.1 to 3.6, while Table 3.2 contains a summary of the construction features of various options, detailed also separately in Tables 3.3 to 3.6.

Table 3.1 Legend to Figures 3.1 to 3.6

Tunnel Zone n° 1	Name of the Tunnel Zone considered
	Profile of the area
	Approximate position of tunnels
SHAFT	Excavation of shafts, with conventional method, is represented with black vertical arrows
Seismic Chamber	Excavation of the seismic chambers for major fault crossings (San Andreas Fault and Garlock Fault), by conventional methods, is represented with green straight arrows
TBM 9.5m EPB 9.5m	Excavation of the main tunnels is represented by black straight arrows to show the direction of advance, and with a "9.5m TBM" label if the excavation is realized by means of a 9.5m diameter TBM, or a "EPB 9.5m" label if it is realized by means of an Earth Pressure Balance Shield
TBM 5.0m	Excavation of the service tunnels (by means of a 5.0m-diameter TBM) is represented with red straight arrows
CONV	Excavation of the main tunnels using conventional methods (such as Drill & Blast or NATM) is represented with blue straight arrows
	A curved arrow represents the transportation of the same TBM in a different tunnel or in the second tube of the same twin bore tunnel
50000 60000	Chainage (i.e. Station) is given in the bottom of every figure. The chainage distance increases from Bakersfield to Los Angeles.

Fig. 3.1 I-5 Alignment with 3.5% maximum grade – Tunnel profile and construction scheme

Alignment Alternative I-5 Maximum grade 3.5%

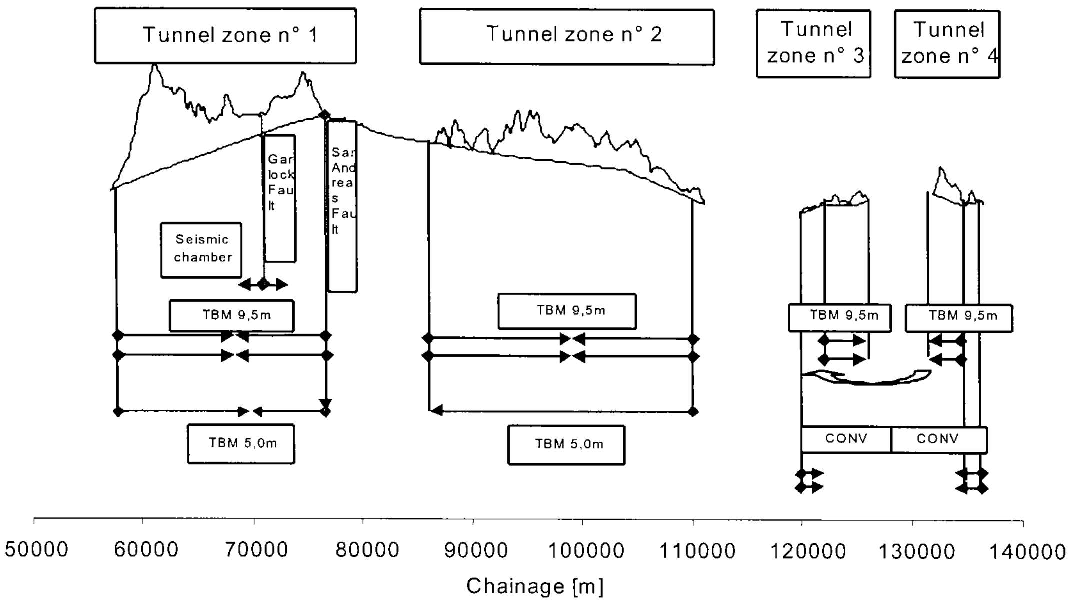


Fig. 3.2 I-5 Alignment with 2.5% maximum grade – Tunnel profile and construction scheme

Alignment Alternative I-5 - Maximum grade 2.5%

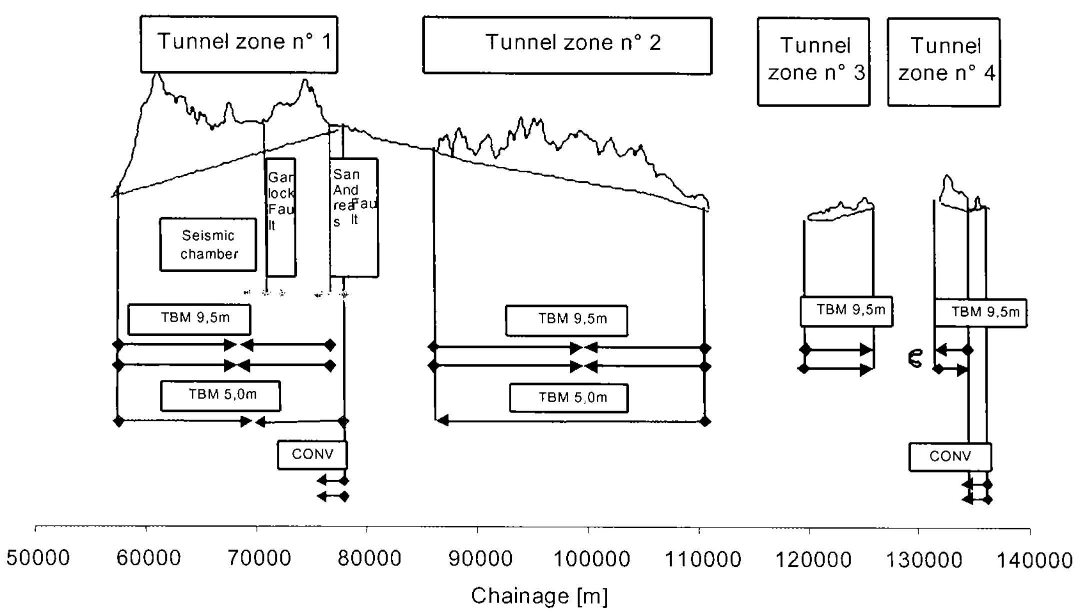


Fig. 3.3 AV Alignment with 3.5% maximum grade – Tunnel profile and construction scheme

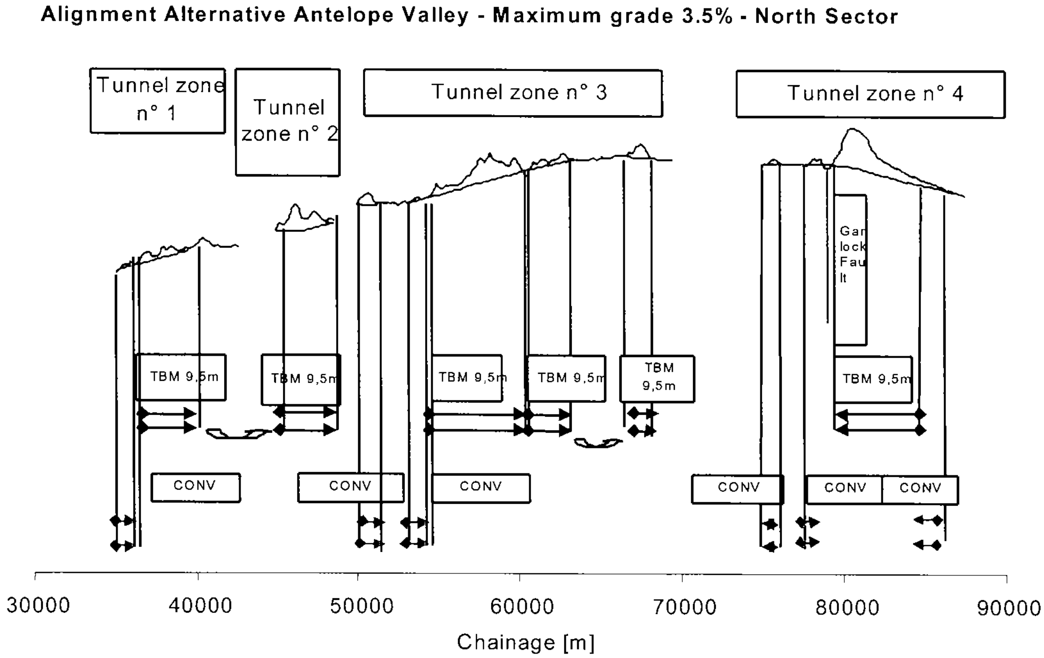


Fig. 3.4 AV Alignment with 3.5% maximum grade – Tunnel profile and construction scheme.

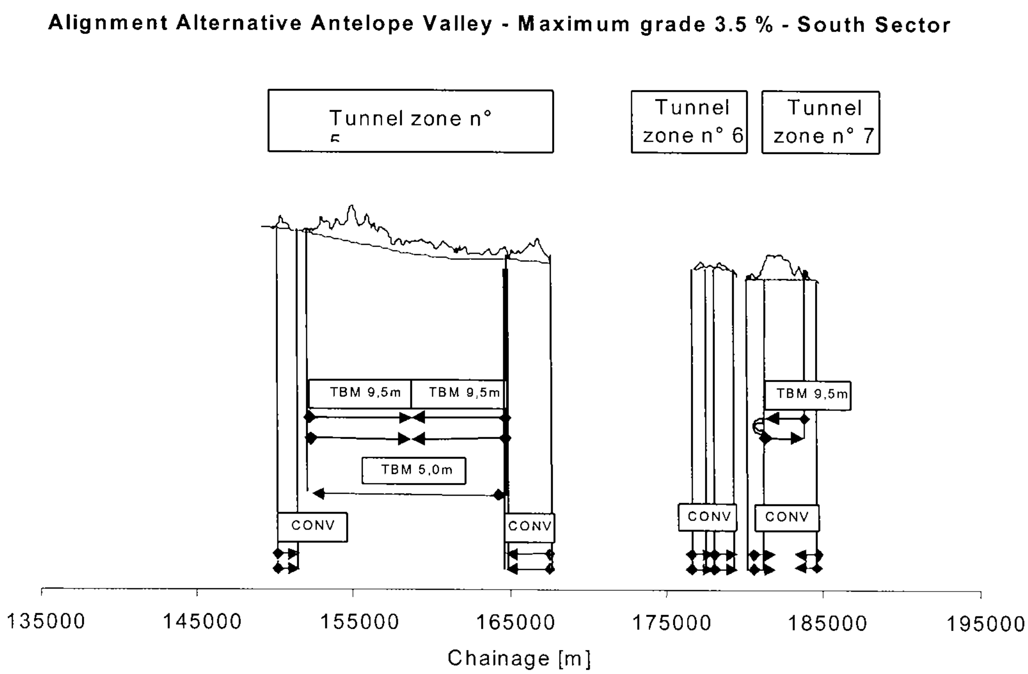


Fig. 3.5 AV Alignment with 2.5% maximum grade – Tunnel profile and construction scheme

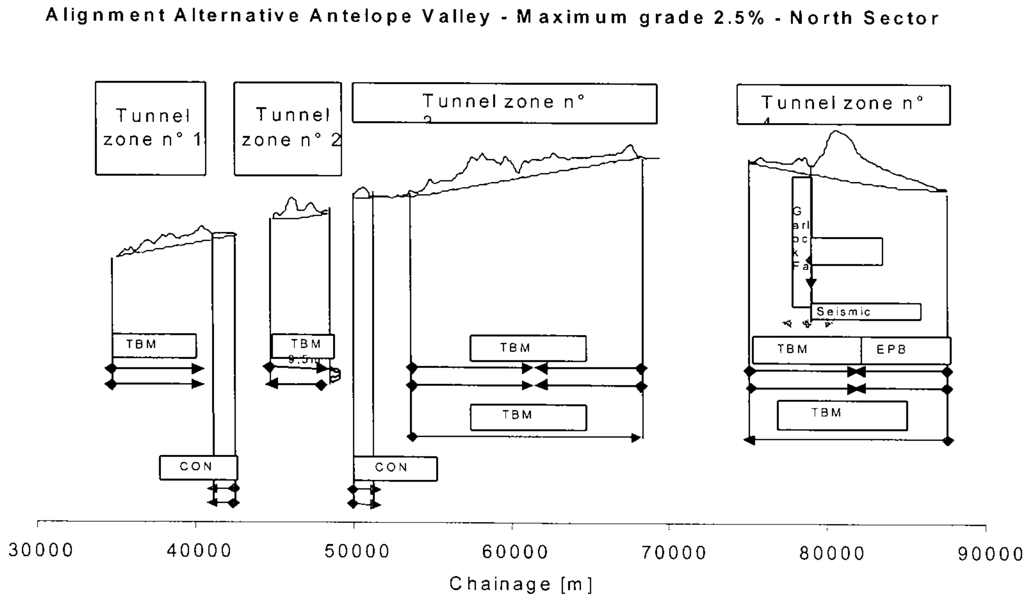


Fig. 3.6 AV Alignment with 2.5% maximum grade – Tunnel profile and construction scheme

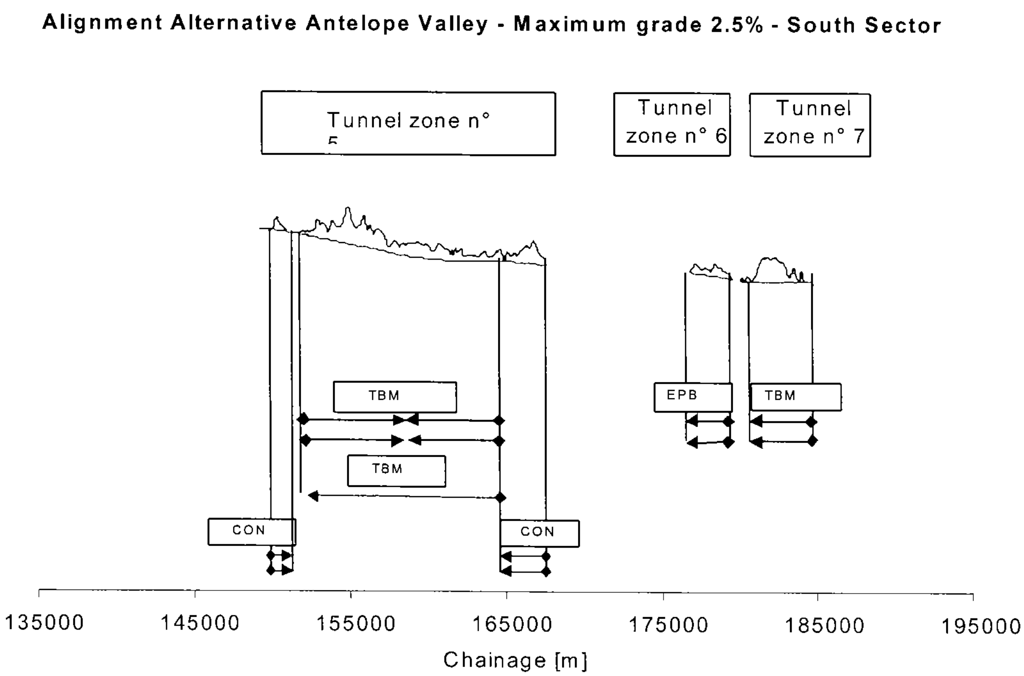


Table 3.2 Summary of construction phases

Summary of construction phases		Alignment Alternative I-5		Alignment Alternative AV	
		Max grade 3.5%	Max grade 2.5%	Max grade 3.5%	Max grade 2.5%
1) Main tunnels					
Number of Main Tunnels	[-]	8	8	36	14
Number of 9.5 m TBMs	[-]	*	*	*	*
Number of 9.5 m EPBSs	[-]	*	*	*	*
Cumulative Tunnel Length (Twin-Tunnel)	[km]	52.5	54.0	50.0	64.2
	[miles]	32.6	33.5	31.1	39.9
Total Tunneling length (counting both tubes)	[km]	104.9	107.9	99.9	128.3
	[miles]	65.2	67.0	62.1	79.7
Breakdown of Total Tunneling length according to Tunneling methods					
by TBM	[km]	100.8	103.8	78.9	114.0
	[miles]	62.6	64.5	49.0	70.8
by Cut & Cover	[km]	2.1	2.1	10.0	4.5
	[miles]	1.3	1.3	6.2	2.8
by Conventional method	[km]	2.0	2.0	11.0	9.8
	[miles]	1.2	1.2	6.8	6.1
2) Service Tunnels					
Number of Service Tunnels	[-]	2	2	1	3
Number of 5.0 m TBMs	[-]	*	*	*	*
Total length of Service Tunnels	[km]	43.5	43.5	13.0	24.9
	[miles]	27.0	27.0	8.1	15.5
3) Trenches					
Total length of Trenches due to adjustment of the Tunnels profiles	[km]	2.7	0.0	4.0	1.4
	[miles]	1.7	0.0	2.5	0.9
4) Other works					
Excavation sites/Portals	[-]	23	23	50	41
Number of shafts	[-]	1	1	0	1
Number of Major Fault Crossing Seismic Chambers	[-]	2	4	0	2
* To be defined					

Table 3.3 Construction scheme for the I-5 Alternative Alignment, 3.5% max. grade

	Alignment Alternative	I-5				
	Maximum grade	3.5%				
Tunnel zone number	Construction features	From chainage [m]	To chainage [m]	9.5m TBM	5.0m TBM	Traditional Excavation Sites
		[m]	[m]	[-]	[-]	[-]
1	Twin main tunnels	57300	76600	4		
	Service tunnel	57300	76600		2	
	Seismic chambers (from Service tunnel)	71325	70825			2
	Seismic chambers (from Service tunnel)	71325	71825			2
2	Twin main tunnels	86600	111200	4		
	Service tunnel	86600	111200		1	
3	Conventional excav.	120000	121500			2
	Twin main tunnels	121550	126000	2*		
4	Twin main tunnels	131950	134600	2*		
	Shaft (h=50m)	134600				1
	Conventional excav.	134600	135000			2
	Conventional excav.	135000	136200			2

Table 3.4 Construction scheme for the I-5 Alternative Alignment, max. 2.5% grade

	Alignment Alternative	I-5				
	Maximum grade	2.5%				
Tunnel zone number	Construction features	From chainage [m]	To chainage [m]	9.5m TBM	5.0m TBM	Traditional Excavation Sites
		[m]	[m]	[-]	[-]	[-]
1	Twin main tunnels	57300	76600	4		
	Service tunnel	57300	76600		2	
	Seismic chambers in Garlock Fault crossing (from Service tunnel)	71325	70825			2
	Seismic chambers in Garlock Fault crossing (from Service tunnel)	71325	71825			2
	Shaft (h=60m)	76200				1
	Seismic chambers in San Andrea Fault crossing (from Shaft)	75800	76200			2
	Seismic chambers in San Andrea Fault crossing (from Shaft)	76200	76800			2
2	Twin main tunnels	86600	111200	4		
	Service tunnel	86600	111200		1	
3	Twin main tunnels	120000	126000	2		
4	Twin main tunnels	131950	134600	1		
	Shaft (h=50m)	134600				1
	Conventional excavation	134600	135000			2
	Conventional excavation	135000	136400			2

Table 3.5 Construction scheme for the AV Alternative Alignment, max. 3.5% grade

	Alignment Alternative	AV				
	Maximum grade	3.5%				
Tunnel zone number	Construction features	From chainage [m]	To chainage [m]	9.5m TBM	5.0m TBM	Traditional Excavation Sites
		[m]	[m]	[-]	[-]	[-]
1	Conventional excav.	35000	36200			2
	Twin main tunnels	36250	39300	2*		
2	Twin main tunnels	44900	47850	2*		
3	Conventional excav.	50000	51350			2
	Conventional excav.	53000	54300			2
	Twin main tunnels	54300	60400	2		
	Twin main tunnels	60450	63150	2*		
	Twin main tunnels	66550	68250	2*		
4	Conventional excav.	75350	76250			2
	Conventional excav.	77750	78850			2
	Twin main tunnels	79150	85200	2		
	Conventional excav.	85200	85700			2
5	Conventional excav.	150150	151150			2
	Twin main tunnels	151950	165050	4		
	Service tunnel	151950	165050		1	
	Conventional excav.	165050	167750			2
6	Conventional excav.	176800	177600			2
	Conventional excav.	178500	179350			2
7	Conventional excav.	180600	180850			2
	Conventional excav.	181050	181650			2
	Twin main tunnels	181650	184000	1		
	Conventional excav.	184000	184700			2

Table 3.6 Construction scheme for the AV Alternative Alignment, max. 2.5% grade

	Alignment Alternative	AV				
	Maximum grade	2.5%				
Tunnel zone number	Construction features	From chainage [m]	To chainage [m]	9.5m TBM	5.0m TBM	Traditional Excavation Sites
		[m]	[m]	[-]	[-]	[-]
1	Twin main tunnels	35000	41500	2		
	Conventional excav.	41500	42950			2
2	Twin main tunnels	44900	48600	1		
3	Conventional excav.	50000	51350			2
	Twin main tunnels	53000	68200	4		
	Service tunnel	53000	68200		1	
4	Twin main tunnels	75000	87100	2+2**		
	Service tunnel	75000	87100		1	
	Shaft (h=50m)	78500				1
	Seismic chambers in Garlock Fault crossing (from Shaft)	78200	78500			2
	Seismic chambers in Garlock Fault crossing (from Shaft)	78500	79200			2
	*** EPB machine					
5	Conventional excav.	150150	151150			2
	Twin main tunnels	151950	165050	4		
	Service tunnel	151950	165050		1	
	Conventional excav.	165050	167750			2
6	Twin main tunnels	176800	179600	2**		
	** EPB machine					
7	Twin main tunnels	180000	184800	2		

4 DESCRIPTION OF DAT (DECISION AIDS IN TUNNELING)

In view of the number of alternatives under analysis and the potential for considerable risks associated with the selection of one alignment over the other, the use of the software /system DAT (Decision Aids in Tunneling) was used by the project study team. DAT is a tool for making probabilistic estimates of the time and cost of constructing a tunnel, or network of tunnels, taking into account the uncertainties in the geologic and construction variables. DAT also functions as a value adding tool for making an assessment of the risk of exceeding the thresholds of cost and time for projects.

A DAT run is essentially a computer simulation of several random processes. The idea of using computer simulations comes with the fact it is not possible to find analytically resulting random functions when processes are too complicated like the construction of tunnels. So simulating a construction process is the only solution to obtain statistical information about the total time and cost. This information gives a good idea on the average, minimum and maximum expected values. By definition, the simulation of a random process uses a random number generator.

DAT and the associated computer code SIMSUPER have been developed over a period of 20 years by MIT (Massachusetts Institute of Technology) and EPFL (École Polytéchnique Fédérale de Lausanne), with the participation of the US National Science Foundation, the Swiss Federal Office for Transportation, the Swiss Science Foundation, and Geodata SpA.

A unique feature of DAT is its capability for a comparative evaluation of the performance of project alternatives with respect to the potential of these alternatives in managing geotechnical and construction uncertainties within prescribed or acceptable values of time and cost.

DAT consists of two interrelated simulation modules: Geology and Construction.

In the Geology module the geotechnical conditions are organized in the various input matrices following an approach similar to that of defining a geotechnical profile, i.e., defining, chainage by chainage, all the geological and geomechanical conditions that have an impact on the tunnel construction practice. The user's task is to identify and define which are those parameters and what are their possible states. Uncertainty in this definition is either entered by indicating the variability in the assigned value of the parameter, and/or in its state probability (e.g., see Table 5.3). In addition, variability of conditions along a segment is modeled using a Markov process. In a manner similar to defining the geomechanics classification, different parameter states are combined to define homogeneous ground classes that are subsequently associated with the construction methods. For example, if problematic water inflows and squeezing conditions are identified as impacting parameters, their possible states have to be defined, as well as the influence of their possible state combinations on every excavation phase modeled in the subsequent construction module.

The Construction module consists of two principal components:

- The first refers to the construction methods where the construction cycle can be simulated activity by activity. In this case variability is introduced into the model by statistical distributions of basic construction indices, e.g., advance rate and unit cost, usually derived practical case histories and price analysis.
- The second module, which is referred to as *tunnel network,* permits the definition of the sequence of realization of a tunnel and a project, e.g., two opposite fronts for a tunnel, or excavation of a pilot bore by a TBM, followed by the enlargement by traditional (or conventional) methods.

In both the geology and the construction modules, variability of the parameters is described through a user-defined distribution function that can be chosen from among Uniform, Triangular, and Bounded Triangular distributions. In the Uniform distribution, the variable always has the same probability of taking on any value. In the Triangular distribution, a minimum value, a most likely value (the mode), and a maximum value have to be provided, recognizing that the total area under the triangle must equal one (as the total probability of occurrence of the parameter must be 100%). In the Bounded Triangular distribution, the probabilities on the minimum and maximum boundaries of the triangle are greater than zero. Where this last distribution has been used in this study, the minimum and maximum probabilities are indicated in the input tables.

5 DAT SIMULATIONS INPUT

5.1 Determination of the Geomechanical Parameters

As part of the input to the DAT analysis, geological and geomechanical longitudinal profiles were defined based on maps of the USGS. Also, based on USGS reports, the essential geomechanical parameters were defined for each homogeneous geological zone.

In addition to the behavioral categories, the range of "geo-events" (see Sec. 2.6) that could cause delays and extra costs were considered, particularly when a tunnel was to be excavated by a TBM. A TBM is a relatively rigid method of excavation that cannot easily be adapted to changing ground conditions. The events that have been considered are:

- Potential instability conditions (excavation face, cavity, or both);
- Potential problematic water inflows (large quantities in short time);
- Possible presence of gas
- Anomalous abrasivity of the rocks to be excavated.

The combination of the behavioral categories and the first three of the above mentioned geo-events determines in an unambiguous way the so-called "Ground Parameter Set". A Ground Parameter Set includes the probability of occurrence of each parameter state and is not yet associated with a segment of tunnel. In other words, a few combinations of the parameters can be applied to a zone characterized by a unique Ground Parameter Set, as each parameter state is still expressed as a probability of occurrence. The univocal association of the unit segment to a homogeneous set of parameters brings it to the following stages: (a) combination of the Ground Parameter Set and the Anomalous Abrasivity parameter to define a Combined Ground Class, and (b) the Geological simulation that is repeated at every global simulation. The combination of the parameters that determine the values of cost and average advance rates, and/or the cost and duration of interventions in case of "accidents" associated with each meter of tunnel or each unit segment is the output of the Geological simulation. This output in turn becomes an input to the Construction simulation. This feature, which can be considered as the simulation of the geological uncertainty, makes one simulation different from another with respect to the geological aspect. It is not possible to show the detailed zoning of each parameter as it is different for each of the 1000 simulations. Instead, the following sections will define the meaning and the determination process of each Ground Parameter Set, as well as its zoning and the formation of the Anomalous Abrasivity zones that constitute the highest detail information that can be given without entering into each simulation run. Further details are given in Section 5.2.

Table 5.1 Schematic generation of the Ground Parameter Set corresponding to each homogeneous zone in DAT's Geo Module, results from the combination of behavioral categories and "geo-events". Colors refer to different states and/or combination of the parameter and express the importance of this combination. Values and combinations are given as an example of the method of determination of any Ground Parameter Set. For a detailed screening of possible parameter states, see Sections 5.1.1 to 5.1.5. The significance of brackets around the parameter "Anomalous abrasivity" is explained in paragraph 5.1.5.

Zone number / **Parameter name**		1	2	3	etc.
Behavioral category		90% a/b 10% c	50% c 50% d	100% fault	...
Potential instability conditions	+	100% no	1% yes 99% no	[redacted]	...
Potential problematic water	+	1% yes 99% no	100% no	[redacted]	...
Possible presence of gas	+	1% yes 99% no	100% no	100% no	...
(Anomalous abrasivity)	+	*100% no*	*100% yes*	*100% no*	...
Ground parameter set	=	GPS X	GPS Y	GPS Z	...

The following sections show the details of each parameter, and the resulting Ground Parameter Set for each homogeneous zone.

5.1.1 Behavioral categories

For a description of the assumed classification, reference may be made to Section 2.4 Geomechanical characterization of the ground. In the present analysis, behavioral classes have been grouped in a slightly different way to fit the specific conditions of the specific project area characterized by an important number of major fault zones. In order to associate the most suitable construction parameters to those very special zones, a behavioral category named "fault" has been created because its characteristics actually duplicate those of the "f" category discussed in Section 2.4. The possible states of the "Behavioral category" parameter are shown in Table 5.2.

Table 5.2 The possible states of the "Behavioral category" parameter

Parameter	Possible states
Behavioral category	a/b
	c
	d
	e/f
	fault

In the definition of the Ground Parameter Sets, assignment of the parameter state is obtained with probabilistic assumptions, for example, a particular zone may be defined with a 50% probability of state "c" and a 50% probability of state "d". Several combinations have been assumed, presenting ratios of 10/90, 50/50 and 90/10 between two contiguous classes. The result is a probabilistic distribution of the behavioral classes, modeled in every simulation-run.

5.1.2 Potential instability conditions

Instability conditions have been grouped into three main categories: No Instability Zones, Minor Instability Zones and Major Instability Zones.

The three possible states of the parameter are associated with a probability of occurrence that allows the program to create the parameter zoning in a probabilistic way. The possible states of the "Potential Instability Condition" parameter, with their associated probabilities, are shown in Table 5.3.

Table 5.3 "Potential Instability Condition" parameter possible states and assumed probabilities of occurrence

Parameter	Possible states	Probability of occurrence Instability	Probability of occurrence No Instability
Potential Instability Condition	No instability zones	0%	100%
	Minor instability zones	1%	99%
	Major instability zones	10%	90%

5.1.3 Potential problematic water inflow

Two principal scenarios have been hypothesized. In the first, no significant water inflows or minor water inflows (that do not impact on the construction process) can be anticipated. In the second, the water inflow phenomenon is severe enough to cause a construction delay (the excavation must be stopped in order to adopt the necessary countermeasures).
The two possible states of the parameter, are associated with a probability of occurrence that allows the program to create the parameter zoning in a probabilistic way. The possible states of the "Potential Problematic Water Inflow" parameter, with their associated probabilities, are shown in Table 5.4.

Table 5.4 "Potential Problematic Water Inflow" parameter possible states and assumed probabilities of occurrence in fault-free zones

Parameter	Possible states	Probability of occurrence	Probability of occurrence
		Water Inflow	No Water Inflow
Problematic Water Inflow	No/Minor Water Inflow	0%	100%
	Severe Water Inflow	1%	99%

When associated to Fault Zones, the probabilities of occurrence have been modified in order to consider the particular conditions and the higher risks of encountering problematic water inflows. In those particular zones, the two states of the parameter are shown in Table 5.5.

Table 5.5 The possible states of the "Potential Problematic Water Inflow" parameter and assumed probabilities of occurrence in Fault zones

Parameter	Possible states	Probability of occurrence	Probability of occurrence
		Water Inflow	No Water Inflow
Problematic Water Inflow	Minor Water Inflow	10%	90%
	Severe Water Inflow	20%	80%

5.1.4 Possible presence of gas

Two principal scenarios have been hypothesized. In the first case, no gas (mainly potentially explosive hydrocarbon-type) shall be encountered during construction, while in the second case it will be encountered without prior warning and thus force the excavation to be stopped in order to allow the gas to dissipate.

The two possible states of the parameter are associated with a probability of occurrence that allows the program to create the parameter zoning in a probabilistic way. The possible states of the "Possible presence of gas" parameter, with their associated probabilities, are shown in Table 5.6.

Table 5.6 The possible states of the "Possible presence of gas" parameter and assumed probabilities of occurrence.

Parameter	Possible states	Probability of occurrence	Probability of occurrence
		Gas detected	No Gas detected
Possible presence of gas	No Gas zone	0%	100%
	Probable Gas zone	1%	99%

As for the "Potential Problematic Water Inflow" parameter, in Fault zones characterized by a high risk of gas presence, the probability of occurrence has been raised as showed in Table 5.7.

Table 5.7 The possible states of the "Possible presence of gas" parameter and assumed probabilities of occurrence in Fault zones

Parameter	Possible states	Probability of occurrence	Probability of occurrence
		Gas detected	No Gas detected
Possible presence of gas	Minor Gas zone	10%	90%
	Probable Gas zone	20%	80%

5.1.5 Anomalous abrasivity

Two conditions are anticipated. In the first, normal abrasion conditions can be anticipated, while in the second, the presence of quartz-feldspar-rich massive rocks can cause delays during the TBM construction phase due to abrasivity. This condition will lead to additional costs because excavation tools are changed more often. Like the other parameters, the "Anomalous abrasivity" parameter has also two states with different assumed probabilities of occurrence that permit the creation of the parameter state distribution profile along a tunnel alignment in a probabilistic way. Unlike the other parameters, the abrasivity doesn't really take part in the definition of the Ground Parameter Set (that is why its name has been enclosed in brackets in Table 5.1), but acts at the same level as the Ground Parameter Set. This increases the cost and reduces the advance rate in the successive construction phase. This option, especially included in the DAT program, allows for the number of Ground Parameter Sets to be kept relatively low otherwise it would be doubled by the presence of this double state additional parameter, thus increasing the data-input time and the possibility of errors. The combination of Ground Parameter Set and Abrasivity class leads to the definition of the so-called "Combined Ground Class" that is finally used to define the most appropriate method of construction for each of the Combined Ground Classes. By the way, the effect of this device over the simulation results is minimal as it works as a mere user facility.

For this reason abrasivity will henceforth be considered as a "normal" parameter in order to maintain a higher readability of the report.

Table 5.8 The possible states of the "Anomalous abrasivity" parameter and assumed probabilities of occurrence

Parameter	Possible states	Probability of occurrence Anomalous abrasivity	Probability of occurrence Normal abrasivity
Anomalous abrasivity	Non abrasive	0%	100%
	Abrasive	100%	0%

5.1.6 Ground parameter set

The result of the combination of considered parameters is the subdivision of both the Alignment Alternative corridors in homogeneous zones, defined either position wise or length wise and characterized by an assigned Ground Parameter Set. In Table 5.9a an example of a particular tunnel zone is given (Tunnel zone n°2 of the I-5 Alternative Alignment), with reference to the univocal determination of the Ground Parameter Set in each homogeneous zone. In Table 5.9b a detailed example is given for a typical Ground Parameter Set in order to show how the concepts shown previously are realized in the geomechanical input phase.

Note that a zone can be considered as homogeneous only when the key geologic factors, characteristic of that particular zone, can be reasonably assumed to be constant or variable in accordance with a certain "probabilistic rule" (the concept of Markov process).

Furthermore, the zoning of an alignment according to the established geologic conditions is modeled in DAT allowing the boundaries between adjacent homogeneous zones to vary in each simulation run with a predefined range. For example, the position of a fault zone at the tunnel level cannot be defined precisely until construction approaches the approximate position and the variability can be considered in the geological model and modeled statistically by DAT. This method of simulating geological parameter variations or uncertainties represents actually a sensitivity analysis.

Finally, it should be noted that the negative effects of tunnel instability on construction time and cost are generally greater with increasingly worse ground conditions or when the ground falls in unfavorable behavioral categories (e, f and fault zones).

Table 5.9a Example of the zoning of Tunnel zone n°2 in the I-5 Alternative with reference to the determination of the Ground Parameter Set (GPS)

			BEHAVIORAL CATEGORIES					POTENTIAL INSTABILITY CONDITIONS		POTENTIAL PROBLEMATIC WATER INFLOW		POSSIBLE PRESENCE OF GAS		GPS
Zone number	Mode start position	Mode end position	a/b	c	d	e/f	Fault	Instability	No instability	Water inflow	No water inflow	Gas detected	No gas detected	
T2_1	86600	86700			50%	50%		1%	99%		100%	0%	100%	41
T2_2	86700	87900	10%	90%					100%		100%	10%	90%	21
T2_3 f	87900	87950					100%	1%	99%	10%	90%	10%	90%	4
T2_4	87950	90100	10%	90%					100%		100%	10%	90%	21
T2_5 f	90100	90150					100%	1%	99%	10%	90%	10%	90%	4
T2_6	90150	91900		90%	10%			1%	99%		100%	10%	90%	27
T2_7 f	91900	91950					100%	1%	99%	10%	90%	10%	90%	4
T2_8	91950	93600		50%	50%			1%	99%	1%	99%	10%	90%	34
T2_9 f	93600	93650					100%	1%	99%	10%	90%	10%	90%	4
T2_10	93650	94600		50%	50%			1%	99%	1%	99%	10%	90%	34
T2_11 f	94600	94650					100%	1%	99%	10%	90%	10%	90%	4
T2_12	94650	97400		50%	50%			1%	99%	1%	99%	10%	90%	34
T2_13 f	97400	97450					100%	1%	99%	10%	90%	10%	90%	4
T2_14	97450	101300		90%	10%			1%	99%	1%	99%	10%	90%	26
T2_15 f	101300	101350					100%	1%	99%	10%	90%	10%	90%	4
T2_16	101350	103200		90%	10%			1%	99%	1%	99%	10%	90%	26
T2_17 f	103200	103250					100%	1%	99%	10%	90%	10%	90%	4
T2_18	103250	104550		50%	50%			1%	99%	1%	99%	10%	90%	34
T2_19	104550	106350			50%	50%		1%	99%		100%	10%	90%	43
T2_20 f	106350	106400					100%	1%	99%	10%	90%	10%	90%	4
T2_21	106400	109850			50%	50%		1%	99%		100%	10%	90%	43
T2_22 f	109850	109900					100%	1%	99%	10%	90%	10%	90%	4
T2_23	109900	120000			50%	50%		1%	99%		100%	10%	90%	43

As can be seen in Table 5.9a, each homogeneous zone of Tunnel n°2 is defined by a particular set of parameters and its code is given in the last column. That particular value is the result of the combination of behavioral category and the range of "geo-events". For example, the Ground Parameter Set n°26 can be found in Table 4.9a at Chainage 97450-101300 and 101350-103200, with the corresponding parameter probabilities. As it is shown in that table, those two zones contain a Fault zone (Chainage 101300–101350, characterized by an "f" suffix in the zone name, Ground Parameter Set 4), that is characterized by a 100% probability of "fault" behavioral category, a 1% probability of instability conditions, 10% probability of problematic water inflow and 10% of gas presence. Other fault zones can be found in the same tunnel zone, as well as in poor condition zones.

Table 5.9b Example of characterization of a Ground Parameter Set for a given zone

<table>
<tr><td colspan="3" rowspan="2">Ground Parameter Set number</td><td colspan="2" rowspan="2">26</td><td colspan="4">Zones in which the GPS is present in Alignment Alternative AV</td><td colspan="2">T5_16, T5_20</td></tr>
<tr><td colspan="4">Zones in which the GPS is present in Alignment Alternative I-5</td><td colspan="2">T2_14, T2_16, T4_6</td></tr>
<tr><td colspan="5">BEHAVIORAL CATEGORIES</td><td colspan="2">POTENTIAL INSTABILITY CONDITIONS</td><td colspan="2">POTENTIAL PROBLEMATIC WATER INFLOW</td><td colspan="2">POSSIBLE PRESENCE OF GAS</td></tr>
<tr><td>a/b</td><td>c</td><td>d</td><td>e/f</td><td>Fault</td><td>Instability</td><td>No instability</td><td>Water inflow</td><td>No water inflow</td><td>Gas detected</td><td>No gas detected</td></tr>
<tr><td></td><td>90%</td><td>10%</td><td></td><td></td><td>1%</td><td>99%</td><td>1%</td><td>99%</td><td>10%</td><td>90%</td></tr>
<tr><td colspan="5">Notes</td><td colspan="2">Notes</td><td colspan="2">Notes</td><td colspan="2">Notes</td></tr>
<tr><td colspan="5">In the zones characterized by the GPS 26, DAT assigns to each unit length a behavioral category that is determined with the Monte Carlo method assuming a probabilistic distribution of 90% of "c" group and a 10% of "d" group.</td><td colspan="2">In the same zones, the presence of instability conditions has a probabilistic distribution of 1% of occurrence, and 99% of no occurrence</td><td colspan="2">The presence of problematic water inflows has a probabilistic distribution of 1% of occurrence, and 99% of no occurrence</td><td colspan="2">In the same manner, the presence of gas has a probabilistic distribution of 10% of occurrence, and 90% of no occurrence</td></tr>
</table>

The Ground Parameter Set n°26 is shown with its characteristics in Table 5.9b; the meaning of the given probabilities is expressed in the last-row notes. For each unit length (whose value gives the distance between two successive parameters typically 10 m), the Monte Carlo method is applied to determine the state of each parameter following the distribution of probabilities defined in the corresponding Ground Parameter Set. With reference to the same Ground Parameter Set n°26, shown as an example, it can be pointed out that each unit segment can be assigned a "c" or a "d" behavioral category following respective probabilities of 90% and 10%. In the same way, instability or no instability can be assigned with a 1%/99% ratio, as well as water inflow or no water inflow and gas detected and no gas detected with their relative probabilities. This leads to the fact that each unit segment characterized with a Ground Parameter Set n°26 may be assigned to a combination of parameters that is different in every simulation run. (See Table 5.9c):

Table 5.9c Example of the combinations of Behavioral category, Instability conditions, Problematic water inflow and Presence of Gas that can be assigned to a unit segment characterized by a defined Ground Parameter Set (in this example, set n° 26).

GROUND PARAMETER SET N° 26			
BEHAVIORAL CATEGORIES	POTENTIAL INSTABILITY CONDITIONS	POTENTIAL PROBLEMATIC WATER INFLOW	POSSIBLE PRESENCE OF GAS
c (90%)	Instability (1%)	Water inflow (1%)	Gas detected (10%)
			No gas detected (90%)
		No water inflow (99%)	Gas detected (10%)
			No gas detected (90%)
	No instability (99%)	Water inflow (1%)	Gas detected (10%)
			No gas detected (90%)
		No water inflow (99%)	Gas detected (10%)
			No gas detected (90%)
d (10%)	Instability (1%)	Water inflow (1%)	Gas detected (10%)
			No gas detected (90%)
		No water inflow (99%)	Gas detected (10%)
			No gas detected (90%)
	No instability (99%)	Water inflow (1%)	Gas detected (10%)
			No gas detected (90%)
		No water inflow (99%)	Gas detected (10%)
			No gas detected (90%)

As explained in Section 5.1, it is not possible to show the detailed zoning of each segment, as it varies in each simulation run and its single run report would not bring any further useful information. The zoning of both the Alignment Alternatives is thus given in Tables 5.10 to 5.17, showing both the probabilistic positioning of zones and the probabilistic assignment of the parameters by means of the Ground Parameter Set zoning. In Tables 5.18 and 5.19 the zoning of the parameter "Anomalous abrasivity" is shown. The zonings with little error are valid for both max grade options 2.5% and 3.5%.

Finally, it should be pointed out that the estimation of the probability of occurrence of adverse geologic conditions is partly based on engineering judgement and past experiences gained from tunneling in similar geologic environments, in addition to maximizing the usage of the available information. This approach is appropriate considering the limited quality and the extent of the available geologic knowledge about the specific area of interest, as mentioned earlier in Section 1.2.1. In the future when additional new information (from direct investigations and from records of past tunneling experiences in the project region) becomes available one can use the new information to check the adequacy of currently assumed figures and to re-calibrate the occurrence assumptions of adverse conditions, thus arriving at a more objective model.

Table 5.10 Alignment Alternative I-5 - Subdivision in homogeneous zones and Ground Parameter Set of each zone (1 of 4).

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16
Name	T1_0	T1_1	T1_2	T1_3 Pleito	T1_4	T1_5	T1_6	T1_7	T1_8 f	T1_9	T1_10 f	T1_11	T1_12 f	T1_13	T1_14 f	T1_15
Generation mode	1	1	2	1	1	1	1	2	1	2	1	2	1	2	1	2
Min length	57000	150	--	100	50	700	400	--	50	--	50	--	50	--	50	--
Mode length	57000	200	--	200	100	800	500	--	100	--	100	--	100	--	100	--
Max length	57000	250	--	300	150	900	600	--	150	--	150	--	150	--	150	--
Prob. Min length	0	0.1	--	0.1	0.1	0.1	0	--	0	--	0	--	0	--	0	--
Prob. Max length	0	0.1	--	0.1	0.1	0.1	0	--	0	--	0	--	0	--	0	--
Min end position	--	--	57550	--	--	--	--	62300	--	62900	--	63800	--	64500	--	66700
Mode end position	57000	--	57600	--	--	--	--	62400	--	63000	--	63900	--	64600	--	66850
Max end position	--	--	57650	--	--	--	--	62500	--	63100	--	64000	--	64700	--	67000
Prob. Min position	--	--	0	--	--	--	--	0	--	0	--	0	--	0	--	0
Prob. Max pos	--	--	0	--	--	--	--	0	--	0	--	0	--	0	--	0
Ground parameter set	41	41	24	5	24	17	19	24	3	24	3	24	3	20	3	41

	Zone 17	Zone 18	Zone 19	Zone 20	Zone 21	Zone 22	Zone 23	Zone 24	Zone 25	Zone 26	Zone 27	Zone 28	Zone 29	Zone 30	Zone 31	Zone 32
Name	T1_16 Pastoria	T1_17	T1_18	T1_19 Garlock	T1_20	T1_21	T1_22	T1_23 S Andreas	T2_1	T2_2	T2_3 f	T2_4	T2_5 f	T2_6	T2_7 f	T2_8
Generation mode	1	2	1	1	1	2	2	2	1	2	1	2	1	2	1	2
Min length	200	--	150	600	150	--	--	--	50	--	25	--	25	--	25	--
Mode length	500	--	200	800	200	--	--	--	100	--	50	--	50	--	50	--
Max length	800	--	250	1000	250	--	--	--	150	--	75	--	75	--	75	--
Prob. Min length	0	--	0	0	0	--	--	--	0	--	0.5	--	0.5	--	0.5	--
Prob. Max length	0	--	0	0	0	--	--	--	0	--	0	--	0	--	0	--
Min end position	--	69500	--	--	--	75600	76700	86600	--	87800	--	90000	--	91800	--	93500
Mode end position	--	69650	--	--	--	75800	76800	86600	--	87900	--	90100	--	91900	--	93600
Max end position	--	69800	--	--	--	76000	76700	86600	--	88000	--	90200	--	92000	--	93700
Prob. Min position	--	0	--	--	--	0	0	0	--	0	--	0	--	0	--	0
Prob. Max pos	--	0	--	--	--	0	0	0	--	0	--	0	--	0	--	0
Ground parameter set	5	22	24	5	24	22	36	5	41	21	4	21	4	27	4	34

Table 5.11 Alignment Alternative I-5 - Subdivision in homogeneous zones and Ground Parameter Set of each zone (2 of 4)

	Zone 33	Zone 34	Zone 35	Zone 36	Zone 37	Zone 38	Zone 39	Zone 40	Zone 41	Zone 42	Zone 43	Zone 44	Zone 45	Zone 46	Zone 47	Zone 48
Name	T2_9 f	T2_10	T2_11 f	T2_12	T2_13 f	T2_14	T2_15 f	T2_16	T2_17 f	T2_18	T2_19	T2_20 f	T2_21	T2_22 f	T2_23	T3_1
Generation mode	1	2	1	2	1	2	1	2	1	2	2	1	2	1	2	1
Min length	25	--	25	--	25	--	25	--	25	--	--	25	--	25	--	1900
Mode length	50	--	50	--	50	--	50	--	50	--	--	50	--	50	--	2100
Max length	75	--	100	--	75	--	75	--	75	--	--	75	--	75	--	2300
Prob. Min length	0.5	--	0	--	0.5	--	0.5	--	0.5	--	--	0.5	--	0.5	--	0
Prob. Max length	0	--	0	--	0	--	0	--	0	--	--	0	--	0	--	0
Min end position	--	94500	--	97300	--	101200	--	103100	--	104350	106250	--	109750	--	120000	--
Mode end position	--	94600	--	97400	--	101300	--	103200	--	104550	106350	--	109850	--	120000	--
Max end position	--	94700	--	97500	--	101400	--	103300	--	104750	106450	--	109950	--	120000	--
Prob. Min position	--	0	--	0	--	0	--	0	--	0	0	--	0	--	0	--
Prob. Max pos	--	0	--	0	--	0	--	0	--	0	0	--	0	--	0	--
Ground parameter set	4	34	4	34	4	26	4	26	4	34	43	4	43	4	43	36

	Zone 49	Zone 50	Zone 51	Zone 52	Zone 53	Zone 54	Zone 55	Zone 56	Zone 57	Zone 58	Zone 59	Zone 60	Zone 61	Zone 62	Zone 63	
Name	T3_2	T3_3 f	T3_4	T3_5 f	T3_6	T3_7 f	T3_8	T4_1	T4_2	T4_3 f	T4_4	T4_5 f	T4_6	T4_7 f	T4_8	
Generation mode	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
Min length	--	25	--	100	--	25	--	50	--	25	--	25	--	25	--	
Mode length	--	50	--	150	--	50	--	100	--	50	--	50	--	50	--	
Max length	--	75	--	250	--	75	--	150	--	75	--	75	--	75	--	
Prob. Min length	--	0.5	--	0	--	0.5	--	0	--	0.5	--	0.5	--	0.5	--	
Prob. Max length	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--	
Min end position	123200	--	124100	--	125500	--	132000	--	134200	--	134600	--	135200	--	200000	
Mode end position	123300	--	124200	--	125600	--	132000	--	134300	--	134700	--	135300	--	200000	
Max end position	123400	--	124300	--	125700	--	132000	--	134400	--	134800	--	135400	--	200000	
Prob. Min position	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	
Prob. Max pos	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	
Ground parameter set	36	4	36	6	36	4	36	41	27	4	27	4	26	4	41	

Table 5.12 Alignment Alternative I-5 - Subdivision in homogeneous zones and Ground Parameter Set of each zone (3 of 4)

				BEHAVIORAL CATEGORIES					POTENTIAL INSTABILITY CONDITIONS		POTENTIAL PROBLEMATIC WATER INFLOW		POSSIBLE PRESENCE OF GAS		Ground Parameter Set
Zone number	Zone name	Mode start position	Mode end position	a/b	c	d	e/f	Fault	Instability	No instability	Water inflow	No water inflow	Gas detected	No gas detected	
Zone 1	T1_0	57000	57000	0%	0%	50%	50%	0%	1%	99%	0%	100%	0%	100%	41
Zone 2	T1_1	57000	57200	0%	0%	50%	50%	0%	1%	99%	0%	100%	0%	100%	41
Zone 3	T1_2	57200	57600	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 4	T1_3 Pleito	57600	57800	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
Zone 5	T1_4	57800	57900	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 6	T1_5	57900	58700	90%	10%	0%	0%	0%	0%	100%	0%	100%	0%	100%	17
Zone 7	T1_6	58700	59200	90%	10%	0%	0%	0%	0%	100%	0%	100%	10%	90%	19
Zone 8	T1_7	59200	62400	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 9	T1_8 f	62400	62500	0%	0%	0%	0%	100%	1%	99%	10%	90%	0%	100%	3
Zone 10	T1_9	62500	63000	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 11	T1_10 f	63000	63100	0%	0%	0%	0%	100%	1%	99%	10%	90%	0%	100%	3
Zone 12	T1_11	63100	63900	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 13	T1_12 f	63900	64000	0%	0%	0%	0%	100%	1%	99%	10%	90%	0%	100%	3
Zone 14	T1_13	64000	64600	10%	90%	0%	0%	0%	0%	100%	0%	100%	0%	100%	20
Zone 15	T1_14 f	64600	64700	0%	0%	0%	0%	100%	1%	99%	10%	90%	0%	100%	3
Zone 16	T1_15	64700	66850	0%	0%	50%	50%	0%	1%	99%	0%	100%	0%	100%	41
Zone 17	T1_16 Pastoria	66850	67350	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
Zone 18	T1_17	67350	69650	50%	50%	0%	0%	0%	0%	100%	0%	100%	0%	100%	22
Zone 19	T1_18	69650	69850	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 20	T1_19 Garlock	69850	70650	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
Zone 21	T1_20	70650	70850	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 22	T1_21	70850	75800	50%	50%	0%	0%	0%	0%	100%	0%	100%	0%	100%	22
Zone 23	T1_22	75800	76800	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
Zone 24	T1_23 S Andreas	76800	86600	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
Zone 25	T2_1	86600	86700	0%	0%	50%	50%	0%	1%	99%	0%	100%	0%	100%	41
Zone 26	T2_2	86700	87900	10%	90%	0%	0%	0%	0%	100%	0%	100%	10%	90%	21
Zone 27	T2_3 f	87900	87950	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 28	T2_4	87950	90100	10%	90%	0%	0%	0%	0%	100%	0%	100%	10%	90%	21
Zone 29	T2_5 f	90100	90150	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 30	T2_6	90150	91900	0%	90%	10%	0%	0%	1%	99%	0%	100%	10%	90%	27
Zone 31	T2_7 f	91900	91950	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 32	T2_8	91950	93600	0%	50%	50%	0%	0%	1%	99%	1%	99%	10%	90%	34
Zone 33	T2_9 f	93600	93650	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 34	T2_10	93650	94600	0%	50%	50%	0%	0%	1%	99%	1%	99%	10%	90%	34
Zone 35	T2_11 f	94600	94650	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 36	T2_12	94650	97400	0%	50%	50%	0%	0%	1%	99%	1%	99%	10%	90%	34
Zone 37	T2_13 f	97400	97450	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 38	T2_14	97450	101300	0%	90%	10%	0%	0%	1%	99%	1%	99%	10%	90%	26
Zone 39	T2_15 f	101300	101350	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 40	T2_16	101350	103200	0%	90%	10%	0%	0%	1%	99%	1%	99%	10%	90%	26
Zone 41	T2_17 f	103200	103250	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 42	T2_18	103250	104550	0%	50%	50%	0%	0%	1%	99%	1%	99%	10%	90%	34

Table 5.13 Alignment Alternative I-5 - Subdivision in homogeneous zones and Ground Parameter Set of each zone (4 of 4)

				BEHAVIORAL CATEGORIES					POTENTIAL INSTABILITY CONDITIONS		POTENTIAL PROBLEMATIC WATER INFLOW		POSSIBLE PRESENCE OF GAS		Ground Parameter Set
Zone number	Zone name	Mode start position	Mode end position	a/b	c	d	e/f	Fault	Instability	No instability	Water inflow	No water inflow	Gas detected	No gas detected	
Zone 43	T2_19	104550	106350	0%	0%	50%	50%	0%	1%	99%	0%	100%	10%	90%	43
Zone 44	T2_20 f	106350	106400	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 45	T2_21	106400	109850	0%	0%	50%	50%	0%	1%	99%	0%	100%	10%	90%	43
Zone 46	T2_22 f	109850	109900	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 47	T2_23	109900	120000	0%	0%	50%	50%	0%	1%	99%	0%	100%	10%	90%	43
Zone 48	T3_1	120000	122100	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
Zone 49	T3_2	122100	123300	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
Zone 50	T3_3 f	123300	123350	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 51	T3_4	123350	124200	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
Zone 52	T3_5 f	124200	124350	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
Zone 53	T3_6	124350	125600	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
Zone 54	T3_7 f	125600	125650	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 55	T3_8	125650	132000	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
Zone 56	T4_1	132000	132100	0%	0%	50%	50%	0%	1%	99%	0%	100%	0%	100%	41
Zone 57	T4_2	132100	134300	0%	90%	10%	0%	0%	1%	99%	0%	100%	10%	90%	27
Zone 58	T4_3 f	134300	134350	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 59	T4_4	134350	134700	0%	90%	10%	0%	0%	1%	99%	0%	100%	10%	90%	27
Zone 60	T4_5 f	134700	134750	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 61	T4_6	134750	135300	0%	90%	10%	0%	0%	1%	99%	1%	99%	10%	90%	26
Zone 62	T4_7 f	135300	135350	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 63	T4_8	135350	200000	0%	0%	50%	50%	0%	1%	99%	0%	100%	0%	100%	41

Table 5.14 Alignment Alternative AV - Subdivision in homogeneous zones and Ground Parameter Set of each zone (1 of 4)

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16	Zone 17
Name	T1_0	T1_1	T1_2	T1_3 f	T1_4	T1_5	T1_6	T1_7	T1_8 Edison	T1_9	T1_10 Edison	T1_11	T2_1	T2_2 f	T2_3	T2_4 f	T2_5
Generation mode	1	2	2	1	2	2	1	2	1	2	2	2	1	1	2	1	2
Min length	35000	--	--	25	--	--	450	--	150	--	--	--	50	50	--	25	--
Mode length	35000	--	--	50	--	--	550	--	200	--	--	--	100	100	--	50	--
Max length	35000	--	--	75	--	--	650	--	250	--	--	--	150	150	--	75	--
Prob. Min length	0	--	--	0	--	--	0	--	0	--	--	--	0	0	--	0	--
Prob. Max length	0	--	--	0	--	--	0	--	0	--	--	--	0	0	--	0	--
Min end position	--	35050	35900	--	36500	37100	--	38300	--	39600	40400	45000	--	--	47950	--	50000
Mode end position	--	35100	36000	--	36600	37200	--	38400	--	39800	40600	45000	--	--	48050	--	50000
Max end position	--	35150	36100	--	36700	37300	--	38500	--	40000	40800	45000	--	--	48150	--	50000
Prob. Min position	--	0	0	--	0	0	--	0	--	0	0	0	--	--	0	--	0
Prob. Max pos	--	0	0	--	0	0	--	0	--	0	0	0	--	--	0	--	0
Ground parameter set	29	29	33	4	33	29	33	29	5	32	36	40	33	5	22	3	33

	Zone 18	Zone 19	Zone 20	Zone 21	Zone 22	Zone 23	Zone 24	Zone 25	Zone 26	Zone 27	Zone 28	Zone 29	Zone 30	Zone 31	Zone 32	Zone 33	Zone 34
Name	T3_1	T3_2	T3_3	T3_4	T3_5 f	T3_6	T3_7	T3_8	T3_9	T3_10 f	T3_11	T3_12 f	T3_13	T3_14	T3_15	T3_16 f	T3_17
Generation mode	1	2	1	1	1	1	2	1	2	1	2	1	2	2	2	1	2
Min length	50	--	25	4600	25	150	--	600	--	100	--	25	--	--	--	25	--
Mode length	75	--	50	4800	50	200	--	650	--	150	--	50	--	--	--	50	--
Max length	100	--	75	5000	75	250	--	700	--	200	--	75	--	--	--	75	--
Prob. Min length	0	--	0	0	0	0	--	0	--	0	--	0	--	--	--	0	--
Prob. Max length	0	--	0	0	0	0	--	0	--	0	--	0	--	--	--	0	--
Min end position	--	50800	--	--	--	--	58800	--	59900	--	61450	--	64500	66900	67700	--	69200
Mode end position	--	51000	--	--	--	--	59000	--	60100	--	61550	--	64600	67000	67800	--	69300
Max end position	--	51200	--	--	--	--	59200	--	60250	--	61650	--	64700	67100	67900	--	69400
Prob. Min position	--	0	--	--	--	--	0	--	0	--	0	--	0	0	0	--	0
Prob. Max pos	--	0	--	--	--	--	0	--	0	--	0	--	0	0	0	--	0
Ground parameter set	40	28	5	44	5	32	25	32	37	5	32	5	37	40	44	5	44

	Zone 35	Zone 36	Zone 37	Zone 38	Zone 39	Zone 40	Zone 41	Zone 42	Zone 43	Zone 44	Zone 45	Zone 46	Zone 47	Zone 48	Zone 49	Zone 50	Zone 51
Name	T3_18	T4_1	T4_2 f	T4_3	T4_4 Garlock	T4_5	T4_6 f	T4_7	T4_8 f	T4_9	T4_10	T4_11	T5_1	T5_2 f	T5_3	T5_4	T5_5 f
Generation mode	2	2	1	2	1	2	1	2	1	1	2	2	2	1	2	2	1
Min length	--	--	100	--	400	--	25	--	25	500	--	--	--	25	--	--	25
Mode length	--	--	150	--	500	--	50	--	50	600	--	--	--	50	--	--	50
Max length	--	--	200	--	600	--	75	--	75	700	--	--	--	75	--	--	75
Prob. Min length	--	-	0	--	0	--	0 5	--	0 5	0	--	--	--	0 5	--	--	0 5
Prob. Max length	--	--	0	--	0	--	0	--	0	0	--	--	--	0	--	--	0
Min end position	75000	77400	--	78750	--	82150	--	83400	--	--	84300	149400	150900	--	151650	152550	--
Mode end position	75000	77500	--	78850	--	82250	--	83500	--	--	84400	149400	151000	--	151750	152650	--
Max end position	75000	77600	--	78950	--	82350	--	83600	--	--	84500	149400	151100	--	151850	152750	--
Prob. Min position	0	0	--	0	--	0	--	0	--	--	0	0	0	--	0	0	--
Prob. Max pos	0	0	--	0	--	0	--	0	--	--	0	0	0	--	0	0	--
Ground parameter set	40	44	5	36	5	40	3	17	3	17	22	48	17	3	22	17	3

Table 5.15 Alignment Alternative AV - Subdivision in homogeneous zones and Ground Parameter Set of each zone (2 of 4)

	Zone 52	Zone 53	Zone 54	Zone 55	Zone 56	Zone 57	Zone 58	Zone 59	Zone 60	Zone 61	Zone 62	Zone 63	Zone 64	Zone 65	Zone 66	Zone 67	Zone 68
Name	T5_6	T5_7	T5_8	T5_9 f	T5_10	T5_11	T5_12	T5_13 f	T5_14	T5_15 f	T5_16	T5_17 f	T5_18	T5_19 f	T5_20	T6_1	T6_2 S Gabriel
Generation mode	1	2	2	1	2	1	2	1	2	1	2	1	2	1	2	2	1
Min length	1100	--	--	25	--	600	--	100	--	100	--	25	--	25	--	--	100
Mode length	1200	--	--	50	--	700	--	150	--	150	--	50	--	50	--	--	150
Max length	1300	--	--	75	--	800	--	200	--	200	--	75	--	75	--	--	200
Prob. Min length	0	--	--	0 5	--	0	--	0	--	0	--	0.5	--	0.5	--	--	0
Prob. Max length	0	--	--	0	--	0	--	0	--	0	--	0	--	0	--	--	0
Min end position	--	155400	156150	--	156650	--	159050	--	161350	--	163900	--	164900	--	176800	177700	--
Mode end position	--	155500	156250	--	156750	--	159150	--	161450	--	164000	--	165000	--	176800	177800	--
Max end position	--	155600	156350	--	156850	--	159250	--	161550	--	164100	--	165100	--	176800	177900	--
Prob. Min position	--	0	0	--	0	--	0	--	0	--	0	--	0	--	0	0	--
Prob. Max pos	--	0	0	--	0	--	0	--	0	--	0	--	0	--	0	0	--
Ground parameter set	17	23	28	4	28	23	21	6	40	6	26	4	34	4	26	48	6

	Zone 69	Zone 70	Zone 71	Zone 72	Zone 73	Zone 74	Zone 75	Zone 76	Zone 77	Zone 78	Zone 79	Zone 80	Zone 81	Zone 82	Zone 83	Zone 84	
Name	T6_3	T6_4 S Gabriel	T6_5	T6_6 S Gabriel	T6_7	T6_8	T7_1	T7_2	T7_3 f	T7_4	T7_5	T7_6	T7_7 S Susana	T7_8	T7_9 S Susana	T7_10	
Generation mode	2	1	2	1	2	2	2	2	1	2	1	2	1	2	2	2	
Min length	--	100	--	100	--	--	--	--	25	--	200	--	50	--	--	--	
Mode length	--	150	--	150	--	--	--	--	50	--	300	--	100	--	--	--	
Max length	--	200	--	200	--	--	--	--	75	--	400	--	150	--	--	--	
Prob. Min length	--	0	--	0	--	--	--	--	0 5	--	0	--	0	--	--	--	
Prob. Max length	--	0	--	0	--	--	--	--	0	--	0	--	0	--	--	--	
Min end position	178000	--	178650	--	178900	180000	180250	180900	--	182000	--	183400	--	183900	184100	200000	
Mode end position	178050	--	178700	--	179200	180000	180350	181000	--	182600	--	183500	--	184050	184200	200000	
Max end position	178100	--	178750	--	179300	180000	180450	181100	--	183200	--	183800	--	184150	184400	200000	
Prob. Min position	0	--	0	--	0	0	0	0	--	0	--	0	--	0	0	0	
Prob. Max pos	0	--	0	--	0	0	0	0	--	0	--	0	--	0	0	0	
Ground parameter set	48	6	48	6	48	48	43	21	4	21	43	43	6	38	6	42	

Table 5.16 Alignment Alternative AV- Subdivision in homogeneous zones and Ground Parameter Set of each zone (3 of 4)

				BEHAVIORAL CATEGORIES					POTENTIAL INSTABILITY CONDITIONS		POTENTIAL PROBLEMATIC WATER INFLOW		POSSIBLE PRESENCE OF GAS		Ground Parameter Set
Zone number	Zone name	Mode start position	Mode end position	a/b	c	d	e/f	Fault	Instability	No instability	Water inflow	No water inflow	Gas detected	No gas detected	
T1_0	Zone 1	35000	35000	0%	10%	90%	0%	0%	1%	99%	0%	100%	0%	100%	29
T1_1	Zone 2	35000	35100	0%	10%	90%	0%	0%	1%	99%	0%	100%	0%	100%	29
T1_2	Zone 3	35100	36000	0%	50%	50%	0%	0%	1%	99%	0%	100%	0%	100%	33
T1_3 f	Zone 4	36000	36050	0%	0%	0%	0%	100%	5%	95%	10%	90%	10%	90%	4
T1_4	Zone 5	36050	36600	0%	50%	50%	0%	0%	1%	99%	0%	100%	0%	100%	33
T1_5	Zone 6	36600	37200	0%	10%	90%	0%	0%	1%	99%	0%	100%	0%	100%	29
T1_6	Zone 7	37200	37750	0%	50%	50%	0%	0%	1%	99%	0%	100%	0%	100%	33
T1_7	Zone 8	37750	38400	0%	10%	90%	0%	0%	1%	99%	0%	100%	0%	100%	29
T1_8 Edison	Zone 9	38400	38600	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T1_9	Zone 10	38600	39800	0%	50%	50%	0%	0%	1%	99%	1%	99%	0%	100%	32
T1_10 Edison	Zone 11	39800	40600	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
T1_11	Zone 12	40600	45000	0%	0%	50%	50%	0%	1%	99%	1%	99%	0%	100%	40
T2_1	Zone 13	45000	45100	0%	50%	50%	0%	0%	1%	99%	0%	100%	0%	100%	33
T2_2 f	Zone 14	45100	45200	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T2_3	Zone 15	45200	48050	50%	50%	0%	0%	0%	0%	100%	0%	100%	0%	100%	22
T2_4 f	Zone 16	48050	48100	0%	0%	0%	0%	100%	5%	95%	10%	90%	0%	100%	3
T2_5	Zone 17	48100	50000	0%	50%	50%	0%	0%	1%	99%	0%	100%	0%	100%	33
T3_1	Zone 18	50000	50075	0%	0%	50%	50%	0%	1%	99%	1%	99%	0%	100%	40
T3_2	Zone 19	50075	51000	0%	10%	90%	0%	0%	1%	99%	1%	99%	0%	100%	28
T3_3	Zone 20	51000	51050	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T3_4	Zone 21	51050	55850	0%	0%	90%	10%	0%	1%	99%	1%	99%	0%	100%	44
T3_5 f	Zone 22	55850	55900	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T3_6	Zone 23	55900	56100	0%	50%	50%	0%	0%	1%	99%	1%	99%	0%	100%	32
T3_7	Zone 24	56100	59000	0%	90%	10%	0%	0%	1%	99%	0%	100%	0%	100%	25
T3_8	Zone 25	59000	59650	0%	50%	50%	0%	0%	1%	99%	1%	99%	0%	100%	32
T3_9	Zone 26	59650	60100	0%	0%	10%	90%	0%	1%	99%	0%	100%	0%	100%	37
T3_10 f	Zone 27	60100	60250	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T3_11	Zone 28	60250	61550	0%	50%	50%	0%	0%	1%	99%	1%	99%	0%	100%	32
T3_12 f	Zone 29	61550	61600	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T3_13	Zone 30	61600	64600	0%	0%	10%	90%	0%	1%	99%	0%	100%	0%	100%	37
T3_14	Zone 31	64600	67000	0%	0%	50%	50%	0%	1%	99%	1%	99%	0%	100%	40
T3_15	Zone 32	67000	67800	0%	0%	90%	10%	0%	1%	99%	1%	99%	0%	100%	44
T3_16 f	Zone 33	67800	67850	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T3_17	Zone 34	67850	69300	0%	0%	90%	10%	0%	1%	99%	1%	99%	0%	100%	44
T3_18	Zone 35	69300	75000	0%	0%	50%	50%	0%	1%	99%	1%	99%	0%	100%	40
T4_1	Zone 36	75000	77500	0%	0%	90%	10%	0%	1%	99%	1%	99%	0%	100%	44
T4_2 f	Zone 37	77500	77650	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T4_3	Zone 38	77650	78850	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
T4_4 Garlock	Zone 39	78850	79350	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T4_5	Zone 40	79350	82250	0%	0%	50%	50%	0%	1%	99%	1%	99%	0%	100%	40
T4_6 f	Zone 41	82250	82300	0%	0%	0%	0%	100%	5%	95%	10%	90%	0%	100%	3
T4_7	Zone 42	82300	83500	90%	10%	0%	0%	0%	0%	100%	0%	100%	0%	100%	17

Table 5.17 Alignment Alternative AV- Subdivision in homogeneous zones and Ground Parameter Set of each zone (4 of 4)

Zone number	Zone name	Mode start position	Mode end position	BEHAVIORAL CATEGORIES					POTENTIAL INSTABILITY CONDITIONS		POTENTIAL PROBLEMATIC WATER INFLOW		POSSIBLE PRESENCE OF GAS		Ground Parameter Set
				a/b	c	d	e/f	Fault	Instability	No instability	Water inflow	No water inflow	Gas detected	No gas detected	
T4_8 f	Zone 43	83500	83550	0%	0%	0%	0%	100%	5%	95%	10%	90%	0%	100%	3
T4_9	Zone 44	83550	84150	90%	10%	0%	0%	0%	0%	100%	0%	100%	0%	100%	17
T4_10	Zone 45	84150	84400	50%	50%	0%	0%	0%	0%	100%	0%	100%	0%	100%	22
T4_11	Zone 46	84400	149400	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	48
T5_1	Zone 47	149400	151000	90%	10%	0%	0%	0%	0%	100%	0%	100%	0%	100%	17
T5_2 f	Zone 48	151000	151050	0%	0%	0%	0%	100%	5%	95%	10%	90%	0%	100%	3
T5_3	Zone 49	151050	151750	50%	50%	0%	0%	0%	0%	100%	0%	100%	0%	100%	22
T5_4	Zone 50	151750	152650	90%	10%	0%	0%	0%	0%	100%	0%	100%	0%	100%	17
T5_5 f	Zone 51	152650	152700	0%	0%	0%	0%	100%	5%	95%	10%	90%	0%	100%	3
T5_6	Zone 52	152700	153900	90%	10%	0%	0%	0%	0%	100%	0%	100%	0%	100%	17
T5_7	Zone 53	153900	155500	50%	50%	0%	0%	0%	0%	100%	0%	100%	10%	90%	23
T5_8	Zone 54	155500	156250	0%	10%	90%	0%	0%	1%	99%	1%	99%	0%	100%	28
T5_9 f	Zone 55	156250	156300	0%	0%	0%	0%	100%	5%	95%	10%	90%	10%	90%	4
T5_10	Zone 56	156300	156750	0%	10%	90%	0%	0%	1%	99%	1%	99%	0%	100%	28
T5_11	Zone 57	156750	157450	50%	50%	0%	0%	0%	0%	100%	0%	100%	10%	90%	23
T5_12	Zone 58	157450	159150	10%	90%	0%	0%	0%	0%	100%	0%	100%	10%	90%	21
T5_13 f	Zone 59	159150	159300	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T5_14	Zone 60	159300	161450	0%	0%	50%	50%	0%	1%	99%	1%	99%	0%	100%	40
T5_15 f	Zone 61	161450	161600	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T5_16	Zone 62	161600	164000	0%	90%	10%	0%	0%	1%	99%	1%	99%	10%	90%	26
T5_17 f	Zone 63	164000	164050	0%	0%	0%	0%	100%	5%	95%	10%	90%	10%	90%	4
T5_18	Zone 64	164050	165000	0%	50%	50%	0%	0%	1%	99%	1%	99%	10%	90%	34
T5_19 f	Zone 65	165000	165050	0%	0%	0%	0%	100%	5%	95%	10%	90%	10%	90%	4
T5_20	Zone 66	165050	176800	0%	90%	10%	0%	0%	1%	99%	1%	99%	10%	90%	26
T6_1	Zone 67	176800	177800	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	48
T6_2 S. Gabrie	Zone 68	177800	177950	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T6_3	Zone 69	177950	178050	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	48
T6_4 S. Gabrie	Zone 70	178050	178200	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T6_5	Zone 71	178200	178700	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	48
T6_6 S. Gabrie	Zone 72	178700	178850	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T6_7	Zone 73	178850	179200	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	48
T6_8	Zone 74	179200	180000	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	48
T7_1	Zone 75	180000	180350	0%	0%	50%	50%	0%	1%	99%	0%	100%	10%	90%	43
T7_2	Zone 76	180350	181000	10%	90%	0%	0%	0%	0%	100%	0%	100%	10%	90%	21
T7_3 f	Zone 77	181000	181050	0%	0%	0%	0%	100%	5%	95%	10%	90%	10%	90%	4
T7_4	Zone 78	181050	182600	10%	90%	0%	0%	0%	0%	100%	0%	100%	10%	90%	21
T7_5	Zone 79	182600	182900	0%	0%	50%	50%	0%	1%	99%	0%	100%	10%	90%	43
T7_6	Zone 80	182900	183500	0%	0%	50%	50%	0%	1%	99%	0%	100%	10%	90%	43
T7_7 S. Susan	Zone 81	183500	183600	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T7_8	Zone 82	183600	184050	0%	0%	10%	90%	0%	1%	99%	1%	99%	10%	90%	38
T7_9 S Susan	Zone 83	184050	184200	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T7_10	Zone 84	184200	200000	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	42

Table 5.18 Alignment Alternative I-5 - Zoning of the parameter "Anomalous abrasivity"

Abrasive zone n°	Parameter State	Generation Mode	Min. End Position	Mode End Position	Max. End Position	Prob Min.	Prob Max.	Mean End Position
1	Non abrasive zone	Position	57000	57000	57000	0	0	57000
2	Non abrasive zone	Position	57000	57100	57200	0.1	0.1	57000
3	Abrasive zone	Position	62100	62100	62300	0.1	0.1	62100
4	Non abrasive zone	Position	64800	64900	65000	0.1	0.1	64900
5	Abrasive zone	Position	66700	66800	66900	0.1	0.1	66800
6	Non abrasive zone	Position	67100	67200	67300	0.1	0.1	67200
7	Abrasive zone	Position	68900	69000	69100	0.1	0.1	69000
8	Non abrasive zone	Position	70600	70700	70800	0.1	0.1	70700
9	Abrasive zone	Position	86400	86500	86600	0.1	0.1	86500
10	Non abrasive zone	Position	96200	96300	96400	0.1	0.1	96300
11	Abrasive zone	Position	100200	100300	100400	0.1	0.1	100300
12	Non abrasive zone	Position	101200	101300	101400	0.1	0.1	101300
13	Abrasive zone	Position	104500	104600	104700	0.1	0.1	104600
14	Non abrasive zone	Position	136200	136200	136200	0.1	0.1	136200

Table 5.19 Alignment Alternative AV - Zoning of the parameter "Anomalous abrasivity"

Abrasive zone n°	Parameter State	Generation Mode	Min. End Position	Mode End Position	Max. End Position	Prob Min.	Prob Max.	Mean End Position
1	Non abrasive zone	Position	35000	35000	35000	0	0	35000
2	Non abrasive zone	Position	38400	38500	38600	0.1	0.1	38500
3	Abrasive zone	Position	56300	56400	56500	0.1	0.1	56400
4	Non abrasive zone	Position	56500	56600	56700	0.1	0.1	56600
5	Abrasive zone	Position	57900	58000	58100	0.1	0.1	58000
6	Non abrasive zone	Position	58600	58700	58800	0.1	0.1	58700
7	Abrasive zone	Position	59200	59300	59400	0.1	0.1	59300
8	Non abrasive zone	Position	60500	60600	60700	0.1	0.1	60600
9	Abrasive zone	Position	63600	63700	63800	0.1	0.1	63700
10	Non abrasive zone	Position	65300	65400	65500	0.1	0.1	65400
11	Abrasive zone	Position	79100	79200	79300	0.1	0.1	79200
12	Non abrasive zone	Position	84300	84400	84500	0.1	0.1	84400
13	Abrasive zone	Position	155200	155300	155400	0.1	0.1	155300
14	Non abrasive zone	Position	184800	184800	184800	0.1	0.1	184800

5.2 Construction Related Input

The construction related input has been modeled using the following scheme:

a) The basic average advance rates and costs per linear meter of tunnel have been defined for each construction method as follows:
   - Tunnel excavated by 9.5m diameter TBM;
   - Service tunnel excavated by 5.0m diameter TBM;
   - Tunnel excavated by Earth Pressure Balanced Shield;
   - Tunnel excavated by conventional method such as Drill and Blast or NATM;
   - Shaft excavated by conventional methods;
   - Seismic chamber excavated by conventional methods;
   - Portal zone realization.

   For each Behavioral Category (a/b, c, d, e/f and Fault), the definition is with a probabilistic min-mode-max range.
   The advance rates for excavation by TBMs have been defined based on the Colorado School of Mines Model (Clark, 1987 and Howart, 1987). The Model represents a well-known boring-speed prediction method that calculates the penetration rate per revolution of the TBM cutterhead on the basis of the rock mass characteristics (like the uniaxial compression strength and the tensile strength of the rocks), the characteristics of the cutters and the layout of the cutters of the cutterhead, as well as the machine-specific data (like maximum thrust on each cutter and rotation speed of the cutterhead). The Model gave a range of penetration rates for each rock formation. These predicated values together with the practical experiences gained from boring in similar geomechanical conditions, allowed for the definition of a realistic range of basic, average, advance rates for each Behavioral Category. The values of costs per meter for excavation by TBMs have been determined taking into account the various aspects involved such as the depreciation of the machine, assembly and disassembly as well as any transfer of the machine, the labor costs, the consumables including cutters, energy consumption, the segmental lining and/or grouting, etc. For the other excavation methods, costs and advance rates have been assumed mainly on the basis of relevant experiences gained from similar European projects, especially when no such data about U.S. projects are available.

b) In the DAT analysis, "Geo-event" related formulas have been defined in order to consider the influence of the occurrence of the unfavorable conditions on construction time and cost. Consequently, for each unit zone analyzed, if none of the unfavorable geo-events (like water inflow, anomalous abrasivity, etc.) is forecasted (or simulated by the geology module of DAT), the formulas defined for the corresponding, normal condition (in terms of the behavioral class and the associated construction method) will be used to calculate the time and cost for constructing the tunnel in this zone. If a problematic water inflow has been forecasted in a unit zone, the formulas defined for the specific type of geo-event will be used to determine the construction time and cost of this unit zone. The net influences of each unfavorable geo-event is the increase in the construction cost and the lowering of the advance rate, reflecting the impact of the specific interventions and/or downtime periods required to overcome the event.

c) If as a result of forecasting minor and major instability conditions there is an occurrence of an instability phenomena, an increasing law that considers the effect of successive and reiterated events has been adopted. In this manner, it is possible to take into account the effect of the socio-political-economic conditions that arise as a consequence of a repetitious accident. The cost of overcoming the problem is no longer stated in terms of time and cost but would depend on other aspects such as contracts, safety, social impact, etc.

5.2.1 Modeled activities and construction techniques

The construction of the various structures has been modeled in the DAT simulation as follows:

a) Main tunnels (diameter 9.5 m, single track twin tunnels) are mostly realized by means of fully mechanized excavation. Due to the anticipated geologic conditions and the related hazards, double shielded TBMs have been chosen in order to allow excavation and lining activities in medium to fair conditions. In poor conditions, excavation is slowed by the necessity of alternating lining installation and face advancing, while insufficient gripping conditions force the machine to act as a single shield TBM. While advance rates are significantly reduced, costs per meter are not affected to the same degree, which implies that the construction time of a tunnel in poor ground conditions may vary in a wider range than its final cost. As expressed previously, financial costs are not considered in this analysis.

b) In particular conditions, it is assumed the capability of the TBMs can be modified in order to exert a counter pressure to support the face during excavation. For those excavation methods, for which the construction schemes are referred to as EPB-Shields, the advance rates have a smaller range due to the very special features of the excavation technique itself and the particular field of application.

c) A service/safety tunnel (in this case, a single bore of 5.0 m in diameter) is required for those main, twin-bore tunnels longer than 6 miles (9.6 km) and this service/safety tunnel is assumed to be in a central position between the twin bores. Usually, the relatively small, service/safety tunnel will be constructed ahead of the main tunnel as the so-called pilot tunnel to probe the ground conditions and, hence, to reduce the geological uncertainties for the subsequent construction of the main tunnel. The excavation method assumed for the service/safety tunnels is the same as that assumed for the corresponding main tunnel, but with considerably higher advance rates when tunnelling in medium to fair conditions. However, the presence of very poor ground conditions will reduce the advance rates significantly since it has been assumed that the encounter of a critical zone will require the TBM excavating the service/safety tunnel to adopt wide inspection measures to exclude the possibility of having the machine blocked, while the TBMs for excavation of the main tunnel will subsequently use the information acquired.

d) Conventional techniques (NATM and others) have been applied to the construction of structures such as seismic chambers, shafts, portals and specific sectors of the main tunnels, where conditions and/or reduced lengths make the fully mechanized

d) Conventional techniques (NATM and others) have been applied to the construction of structures such as seismic chambers, shafts, portals and specific sectors of the main tunnels, where conditions and/or reduced lengths make the fully mechanized method uneconomic and/or unfeasible. In this last case, both advance rates and cost per meters may vary within a wider range than for the TBM methods. In very poor conditions it could be necessary to partialize the excavation section and/or realize wide consolidation interventions.

e) The by-pass to connect the parallel, twin bores of a main tunnel have not been considered in calculating the total construction time and cost of the main tunnel. However, it is important to define time and cost for constructing the bypasses in the global analysis. Besides their intended purpose, service/safety tunnels can help to keep the twin bores of a long, main tunnel at a distance which is approximately twice the separation distance between the twin bores of a relatively short main tunnel (i.e., less than 6 miles long), thus helping to avoid the stress-strain interferences between the twin bores of the main tunnel upon excavation. The only negative effect is that the number of bypasses under the triple-bore configuration will be twice that of the simple, twin-bore configuration.

5.2.2 Advance rates and costs per meter in "normal" conditions

The advance rates and costs per meter for the various technical classes and the various excavation techniques modeled are shown in Tables 5.20 to 5.29. Unit costs of some European tunnel projects are given in Appendix 3 for reference purpose. As mentioned previously, those values are applied directly in case no unfavorable events such as

water inflows, instabilities, anomalous abrasivity and presence of gas are detected, while they are employed in specific formulas if those "accidents" or "geo events" are encountered. The details of those aspects are shown in the following paragraphs.

Table 5.20 Distributions of advance rates for 9.5 m diameter TBMs

9.5 diameter TBMs: advance rates							
Parameter	**Parameter states**	**Min [m/d]**	**Mode [m/d]**	**Max [m/d]**	**Prob. min**	**Prob. max**	**Mean [m/d]**
Behavioral category	**a/b**	8.5	11.5	15	0.1	0.1	11.7
	c	11.5	14.6	18.7	0.1	0.1	15.0
	d	12	14.9	21.8	0.1	0.1	16.4
	e/f	8.2	9.5	11.9	0.1	0.1	9.9
	fault	8.2	9.5	11.9	0.1	0.1	9.9

Table 5.21 Distributions of excavation costs for 9.5 m diameter TBMs

9.5 diameter TBMs: costs per meter							
Parameter	**Parameter states**	**Min [US$/m]**	**Mode [US$/m]**	**Max [US$/m]**	**Prob. min**	**Prob. max**	**Mean [US$/m]**
	a/b	7850	8440	9180	0.1	0.1	8495

Behavioral category	a/b	7850	8440	9180	0.1	0.1	8495
	d	7260	8000	8470	0.1	0.1	7908
	e/f	8800	9500	10200	0.1	0.1	9500
	fault	8800	9500	10200	0.1	0.1	9500

Table 5.22 Distributions of advance rates for 5.0 m diameter TBMs

5.0 diameter TBMs: advance rates							
Parameter	Parameter states	Min [m/d]	Mode [m/d]	Max [m/d]	Prob. min	Prob. max	Mean [m/d]
Behavioral category	a/b	17	23	30	0.1	0.1	23.4
	c	23	29.2	37.4	0.1	0.1	29.9
	d	24	29.8	43.6	0.1	0.1	32.7
	e/f	12.5	13.9	16.3	0.1	0.1	14.3
	fault	12.5	13.9	16.3	0.1	0.1	14.3

Table 5.23 Distributions of excavation costs for 5.0 m diameter TBMs

5.0 diameter TBMs: costs per meter							
Parameter	Parameter states	Min [US$/m]	Mode [US$/m]	Max [US$/m]	Prob. min	Prob. max	Mean [US$/m]
	a/b	4690	4960	5350	0.1	0.1	5004
	c	4670	4850	5070	0.1	0.1	4864
	d	4430	4710	4940	0.1	0.1	4691
	e/f	5800	6100	6450	0.1	0.1	6118
	fault	5800	6100	6450	0.1	0.1	6118

Table 5.24 Distributions of advance rates for EPB machines

9.5 diameter EPBs: advance rates							
Parameter	Parameter states	Min [m/d]	Mode [m/d]	Max [m/d]	Prob. min	Prob. max	Mean [m/d]
Behavioral category	used mainly in e/f and fault	6	7.5	8	0.1	0.1	7.1

Table 5.25 Distributions of excavation costs for EPB machines

9.5 diameter EPBs: costs per meter							
Parameter	Parameter states	Min [US$/m]	Mode [US$/m]	Max [US$/m]	Prob. min	Prob. max	Mean [US$/m]
Behavioral category	used mainly in e/f and fault	10000	10500	11000	0.1	0.1	10500

Table 5.26 Distributions of advance rates for conventional methods excavation

Conventional methods excavation: advance rates							
Parameter	Parameter states	Min [m/d]	Mode [m/d]	Max [m/d]	Prob. min	Prob. max	Mean [m/d]
Behavioral category	a/b	5	5.5	6	0.1	0.1	5.5
	c	5	5.5	6	0.1	0.1	5.5
	d	2.5	2.75	3	0.1	0.1	2.8
	e/f	1.5	1.75	2	0.1	0.1	1.8
	fault	1.5	1.75	2	0.1	0.1	1.8

Table 5.27 Distributions of excavation costs for conventional methods excavation

Conventional methods excavation: costs per meter							
Parameter	Parameter states	Min [US$/m]	Mode [US$/m]	Max [US$/m]	Prob. min	Prob. max	Mean [US$/m]
Behavioral category	a/b	9000	9500	10000	0.1	0.1	9500
	c	9000	9500	10000	0.1	0.1	9500
	d	14000	14500	15000	0.1	0.1	14500
	e/f	20000	21000	22000	0.1	0.1	21000
	fault	20000	21000	22000	0.1	0.1	21000

Table 5.28 Distributions of advance rates for other conventional methods excavation

Other conventional methods excavation: advance rates						
Excavation activity	Min [m/d]	Mode [m/d]	Max [m/d]	Prob. min	Prob. max	Mean [m/d]
Shaft	2	3	4	0.1	0.1	3.0
Seismic chamber	1.75	2	2.5	0.1	0.1	2.1
Portals	4.5	6	7.5	0.1	0.1	6.0

Table 5.29 Distributions of excavation costs for other conventional methods excavation

Other conventional methods excavation: costs per meter						
Excavation activity	Min [US$/m]	Mode [US$/m]	Max [US$/m]	Prob. min	Prob. max	Mean [US$/m]
Shaft	13200	13400	13900	0.1	0.1	13510
Seismic chamber	45000	50000	55000	0.1	0.1	50000
Portals	12500	15000	17500	0.1	0.1	15000

5.2.3 Advance rates and costs per meter in instability zones

When unstable conditions are associated to a unit zone, two instability phenomena (parameter states) are simulated: Minor Instability Phenomenon and Major Instability Phenomenon.

In the first case, the simulation considers a minor event such as the temporary blockage of the cutterhead due to either detachments of rock wedges/blocks from the face or minor squeezing conditions. In the latter case, severe squeezing around the shield or face collapse is considered, resulting in important delays and a major intervention cost. In this latter case, the phenomenon has been considered as the result of coupled hydro-mechanical effects, and includes in itself the influence of the presence of water in terms of costs and delays.

In both cases, the costs and delays are not independent from previous instability phenomena, but follow an incremental law that amplifies the effect of successive and reiterated events.

- *Time*

Time necessary to overcome the unfavorable event unit zone is expressed with the following formula:

$$t_{instability} = (\text{delay\_time} + \frac{\text{unit\_length}}{\text{advance\_rate}}) \cdot F$$

where advance_rate = is the corresponding advance rate of the behavioral class, as seen in Tables 5.20 and 5.22.

delay_time = is the estimated duration of the intervention required to overcome the "accident", with different distributions in Minor and Major Instability Phenomena, as shown in the following table:

Table 5.30 Distribution of the delay time parameter

Instability Phenomena: delay times						
Instability Phenomenon	Min [w-days]	Mode [w-days]	Max [w-days]	Prob. min	Prob. max	Mean [w-days]
Minor (9.5 m TBM)	2.5	3.5	5	0.1	0.1	3.7
Major (9.5 m TBM)	7	15	30	0.1	0.1	17.6
Minor (5.0 m TBM)	1	1.5	2	0.1	0.1	1.5
Major (5.0 m TBM)	7	15	30	0.1	0.1	17.6

$F = F(A) = (1 + n \cdot A)$

n = number of repetition of the same "accident" in the same simulation

A = is an empirical factor characterizing the degree of impact of repeating accidents, whose value depends on the type of the Instability Phenomenon, as shown in the following table.

Table 5.31 Distribution of the values of the empirical factor A

Instability Phenomena: value of empirical factor A						
Instability Phenomenon	**Min**	**Mode**	**Max**	**Prob. min**	**Prob. max**	**Mean**
Minor	0.1	0.2	0.3	0.1	0.1	0.2
Major	0.25	0.5	0.8	0.1	0.1	0.5

As shown, the effect of reiterative events has been simulated with a relatively small amplitude in case of Minor Instability Phenomenon, while it may induce important and greater delays when Major Instability Phenomena occur.

- *Cost*

The total cost required to overcome the instability zone results from the association of two subcosts:

- a time dependent cost, consequence of the forced downtime and labor costs, based on an average cost per site stopped day whose average value is assumed to be $30,000 per day.
- direct additional cost of the remedial measures, which is a function of the particular type of intervention required to overcome the accident zone such as the protection of the crown level with forepoling, grouting with special materials as polyurethanes, or other ground treatments. These interventions have a higher cost in Major Instability Phenomena than in Minor ones, also the service tunnels require a lower intervention due to the minor diameter of the TBMs.

Both subcosts are subject to the factor that increases the amplitude of the event in case of reiterated events. The formula used to determine the cost of overcoming the unfavorable event zone is given:

$$cost_{instability} = (\$30{,}000 \cdot delay\_time + delay\_cost) \cdot F + unit\_length \cdot cost\_per\_meter$$

where cost_per_meter = is the corresponding cost per meter of the behavioral class, as shown in Tables 5.21 and 5.23.

delay_time = is the same parameter shown previously in the time equation.

delay_cost = is the estimated cost of the intervention, assumed on similar experiences, with different values in Minor and Major Instability Phenomena, as shown in the following table:

Table 5.32 Distribution of the delay cost parameter

Instability Phenomena: intervention costs	
Instability Phenomena	**Delay_cost [US$]**
Minor (9.5 m TBM)	100,000
Major (9.5 m TBM)	300,000
Minor (5.0 m TBM)	70,000
Major (5.0 m TBM)	200,000

F = F(A) = (1 + n · A) is the same parameter used previously in the time equation.

5.2.4 Advance rates and costs per meter in problematic water inflow zones

- *Time*

When severe water inflow zones are to be encountered, a "delay time" parameter is defined to account for the delay imposed by pumping out the water from the excavation face. The equation that expresses the time necessary to overcome a unit zone characterized by the water inflow event is given:

$$t_{water\ inflow} = delay\_time + \frac{unit\_length}{advance\_rate}$$

where the parameters are the same as those used to represent the instability case, except for the "delay_time" whose values are the following:

Table 5.33 Distribution of the values of the "delay_time" parameter characterizing severe water inflows.

Problematic water inflows: delay_time						
Water Inflow Phenomena	**Min [w-days]**	**Mode [w-days]**	**Max [w-days]**	**Prob. min**	**Prob. max**	**Mean [w-days]**
Severe water inflow	1	1.5	2	0.1	0.1	1.5

- *Cost*

The cost of overcoming the event has been modeled as time dependent, since it depends on the downtime period and on the energy consumption of the pumping system. The average cost per day is slightly higher than that of the production stop cost, because it includes the energy cost, i.e. $31,000 per day.

$$\text{cost}_{\text{water inflow}} = (\$31{,}000 \cdot \text{delay\_time}) + \text{unit\_length} \cdot \text{cost\_per\_meter}$$

5.2.5 Advance rates and costs per meter in gas-bearing zones

It is assumed gas detection devices will be employed during the excavation, thus avoiding unexpected gas ignitions. It is common to do this where there is risk of encountering gas pockets.

- *Time*

When gas bearing zones are to be encountered, a "delay time" parameter is used to account for the delay imposed by the necessity to de-gas the tunneling environment. The equation that expresses the time necessary to overcome a unit zone characterized by this event is given:

$$t_{\text{gas bearing}} = \text{delay\_time} + \frac{\text{unit\_length}}{\text{advance\_rate}}$$

where the parameters are the same as those used in the instability case, except for the "delay_time" whose values are the following:

Table 5.34 Distribution of the delay time parameter in presence of gas

Gas bearing zones: delay times						
Gas Phenomena	**Min [w-days]**	**Mode [w-days]**	**Max [w-days]**	**Prob. min**	**Prob. max**	**Mean [w-days]**
Present	1	1.5	2	0.1	0.1	1.5

- *Cost*

The cost of overcoming the gas bearing zone has been modeled as time dependent, as it depends both on the downtime period and on the energy consumption of the airing system. The average cost per day is slightly higher than the production stop cost to include the energy cost, i.e. $31,000 per day.

$$\text{cost}_{\text{gas detected}} = (\$31{,}000 \cdot \text{delay\_time}) + \text{unit\_length} \cdot \text{cost\_per\_meter}$$

5.2.6 Advance rates and costs per meter in anomalous-abrasivity zones

- *Time*

When anomalous-abrasivity zones are assigned, the equation that expresses the time necessary to overcome a unit zone characterized by this event considers a 10% increase of advance time due to more frequent change of the excavation tools, as given in the formula below:

$$t_{\text{anom.abrasivity}} = 1.10 \cdot \frac{\text{unit\_length}}{\text{advance\_rate}}$$

- *Cost*

In the same way, the cost necessary to overcome the same unit zone is also assumed to be 10% higher:

$$\text{cost}_{\text{anom.abrasivity}} = 1.10 \cdot \text{unit\_length} \cdot \text{cost\_per\_meter}$$

5.2.7 Other assumptions

All time related values are given in working days. Holidays, vacations and possible downtimes generated outside the construction process have not been taken into account.

Cost related values are given in US dollars and are inclusive of overhead and profit (10%) rates. All the conditions that could negatively affect the tunnel construction such as poor geomechanical conditions, "geo-events", etc. have been quantified in terms of their economic impact. Financial costs are not included in the DAT analysis.

A maximum number of simultaneous working sites has not been fixed. No limitations about the TBM's market have been considered, assuming generally a delivery time of approximately 12 months (range between 300 and 325 working days, with 6 working days per week and 26 working days per month) for the 9.5 m TBMs, and 8 months (range between 205 and 230 working days) for the 5.0 m TBMs. The on site assembly of each TBM will take approximately another two months (modal value 52, range between 45 and 60 working days). During the long period of TBM procurement and assembly, other working activities can be started or even completed, but each activity like excavation of shaft or advance a short tunnel by conventional method will also need to have a lead time of two months to prepare the site.

6. DAT SIMULATION RESULTS

6.1 Summary Description of the Pre-DAT-Simulation Analysis

With reference to the flowchart illustrating the process of risk analysis (see figure 1.2), the following preparatory tasks for the DAT simulations were accomplished:

- Definition of the design and construction-options in Section 3;
- Definition of input data to the Geological Model for each design and construction option in Section 5.1;
- Definition of input data to the Construction Model for each design and construction option in Section 5.2; and
- A summary of the principles of the DAT simulation process in Section 4.

However, to make sure that the DAT system ran correctly and yielded meaningful results, we also conducted the following pre-analyses:

1) Used minimum values defined for all geological and construction parameters to make a deterministic estimate of the minimum and total construction cost and duration for each alignment and maximum grade option. The minimum construction cost and time values obtained served as a guide for checking the output of the DAT simulations;
2) Conducted a limited number of DAT simulation runs for each alignment and maximum grade option and compared the output with the deterministic estimates, thus calibrating the DAT process;
3) Tested the sensitivity of the DAT simulation results to the number of simulation runs considering the huge number of geological and construction variables involved. For this purpose, the number of test simulation runs for each option was progressively increased from 100, to 300, to 500, to 750, and finally to 1000. The results obtained from each step were compared with those from the previous one. It was noted that for all the options studied, there was practically no further benefit to increase the number of simulation-runs to more than 1000. Therefore, for the final, production analysis, the number of simulation runs was fixed at 1000.

6.2 Post-Processing of the DAT-Simulation Results

The post processing of the simulation results for each combined alignment maximum grade option mainly involves the application of standard statistical procedures including:

- simple statistical summary of the construction time and cost to yield the minimum, maximum, and the mean at 95% probability, and standard deviation values for the total construction cost and time of each option.
- frequency counting and histogram representation of the variation in the total time and cost.
- fitting of a normal distribution curve to the frequency of total time and cost.
- production of cost versus time scatter plots for comparison.

6.3 The Results of the DAT Analysis

With reference to the procedures given in Section 6.2, the presentation of the post-processed results of the DAT analysis is done using consistently standardized formats.

Step 1 – Separate presentation of the results for each combined alignment maximum grade option (see forward to Sections 6.3.1 to 6.3.4 for the 4 options analyzed, respectively), in the order given below.

1. A scatter plot showing the direct output from DAT in terms of the total construction time and cost of the 1000 simulation-runs for each option;
2. A time-frequency histogram, fitted with a cumulative normal distribution curve;
3. A table presenting the summary statistics of the construction time including its minimum, maximum, mean, at-95%-probability, and standard deviation values for the total construction cost and time of each option
4. The cost-frequency histogram, fitted with a cumulative normal distribution curve;
5. A table presenting the summary statistics of the construction cost including its minimum, maximum, and the mean at 95% probability and standard deviation values for the total construction cost and time of each option.

Specifically,

Section 6.3.1 presents the results of the I-5 Alignment with 3.5% maximum grade option (Figure 6.1, Figure 6.2, Table 6.1, Figure 6.3, and Table 6.2).

Section 6.3.2 presents the results of the I-5 Alignment with 2.5% maximum grade option (Figure 6.4, Figure 6.5, Table 6.3, Figure 6.6, and Table 6.4).

Section 6.3.3 presents the results of the AV Alignment with 3.5% maximum grade option (Figure 6.7, Figure 6.8, Table 6.5, Figure 6.9, and Table 6.6).

Section 6.3.2 presents the results of the AV Alignment with 2.5% maximum grade option (Figure 6.10, Figure 6.11, Table 6.7, Figure 6.12, and Table 6.8).

Step 2 – Comparative presentation of all the results for the four combined alignment maximum grade options (see forward to **Sections 6.3.5**), in the order given below.

1. A superimposed, scatter plot (Figure 6.13) showing the direct output from DAT in terms of the total construction time and cost of the 1000 simulation-runs;
2. A summary table presenting the global statistics of the construction time and cost including the minimum, the maximum, and the mean, at 95% probability and standard deviation values for the total construction cost and time of all options (Table 6.9).

6.3.1 The results of the I-5 Alignment with 3.5% maximum grade option

Figure 6.1 Total Construction Time vs. Cost scatter plot of the option of I-5 Alignment with 3.5% maximum grade

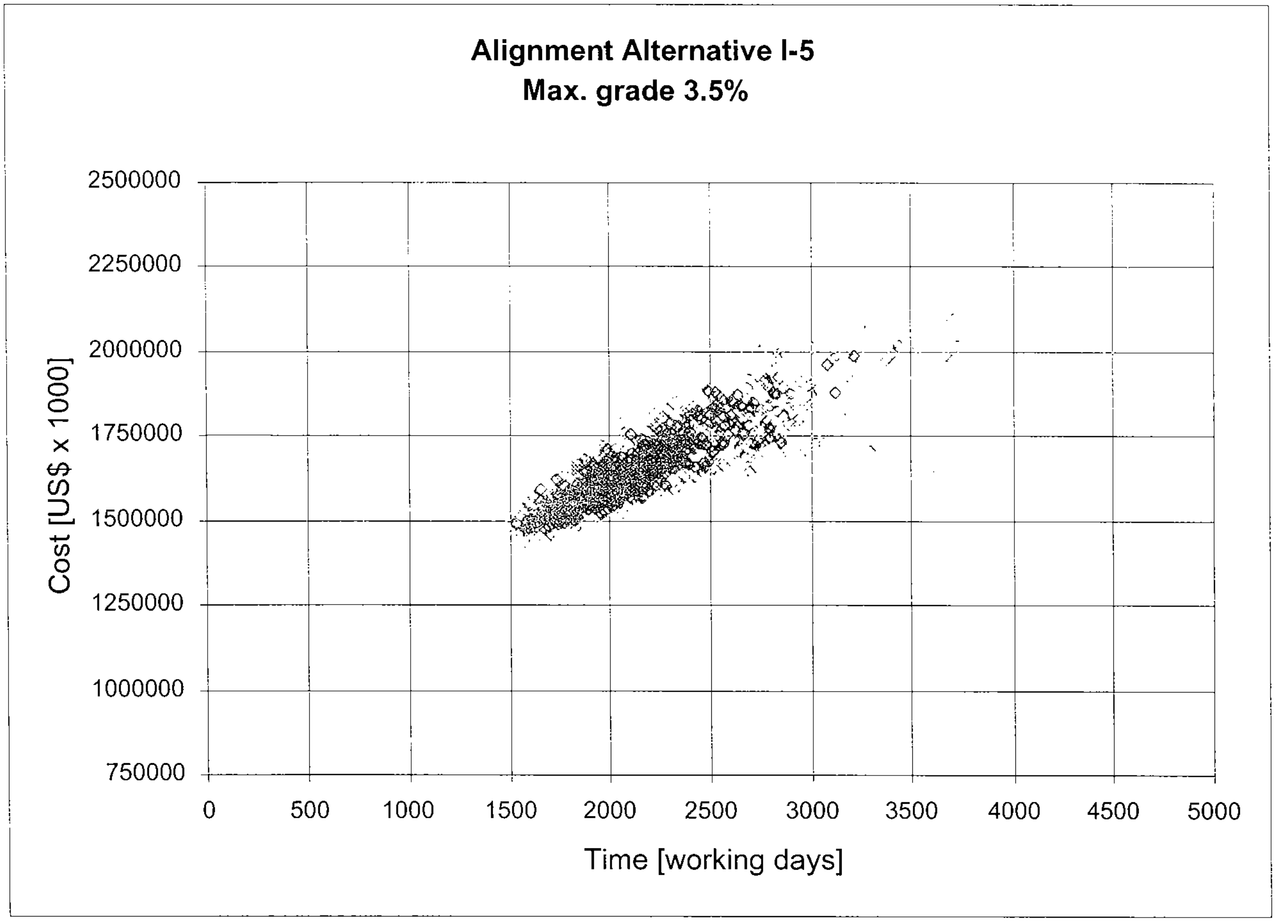


Figure 6.2 Total Construction Time histogram of the option of I-5 Alignment with 3.5% maximum grade

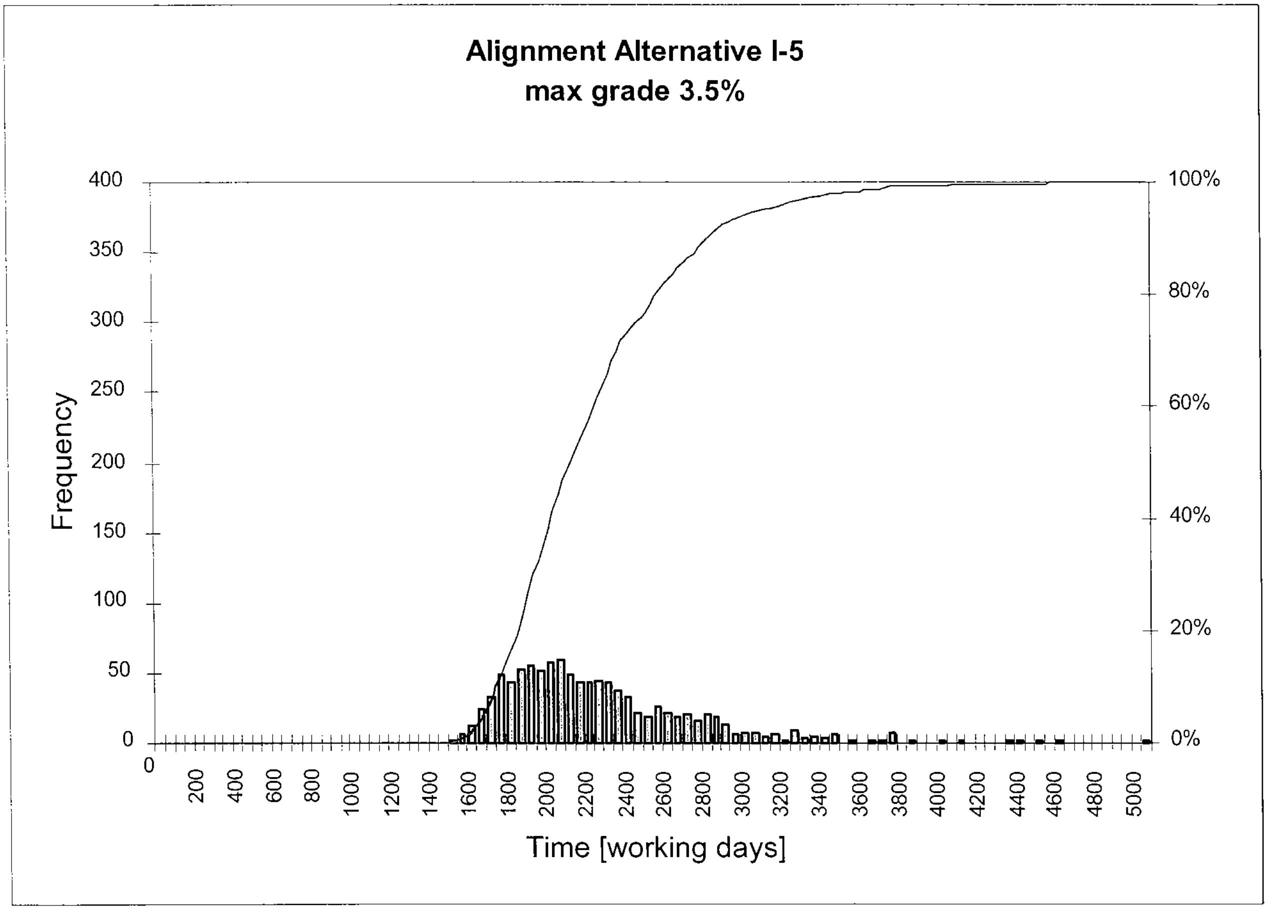


Table 6.1 Statistical data about the Total Construction Time of the option of I-5 Alignment with 3.5% maximum grade

Alignment Alternative I-5 Max grade 3.5%	Construction time	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[working days]	2218
Median value	[working days]	2111
St. Deviation	[working days]	471
Minimum value	[working days]	1492
Value at 95%	[working days]	3100
Difference between 95% value and mean value	[working days]	882
Difference between 95% value and min value	[working days]	1608

Figure 6.3 Total Construction Cost histogram of the option of I-5 Alignment with 3.5% maximum grade

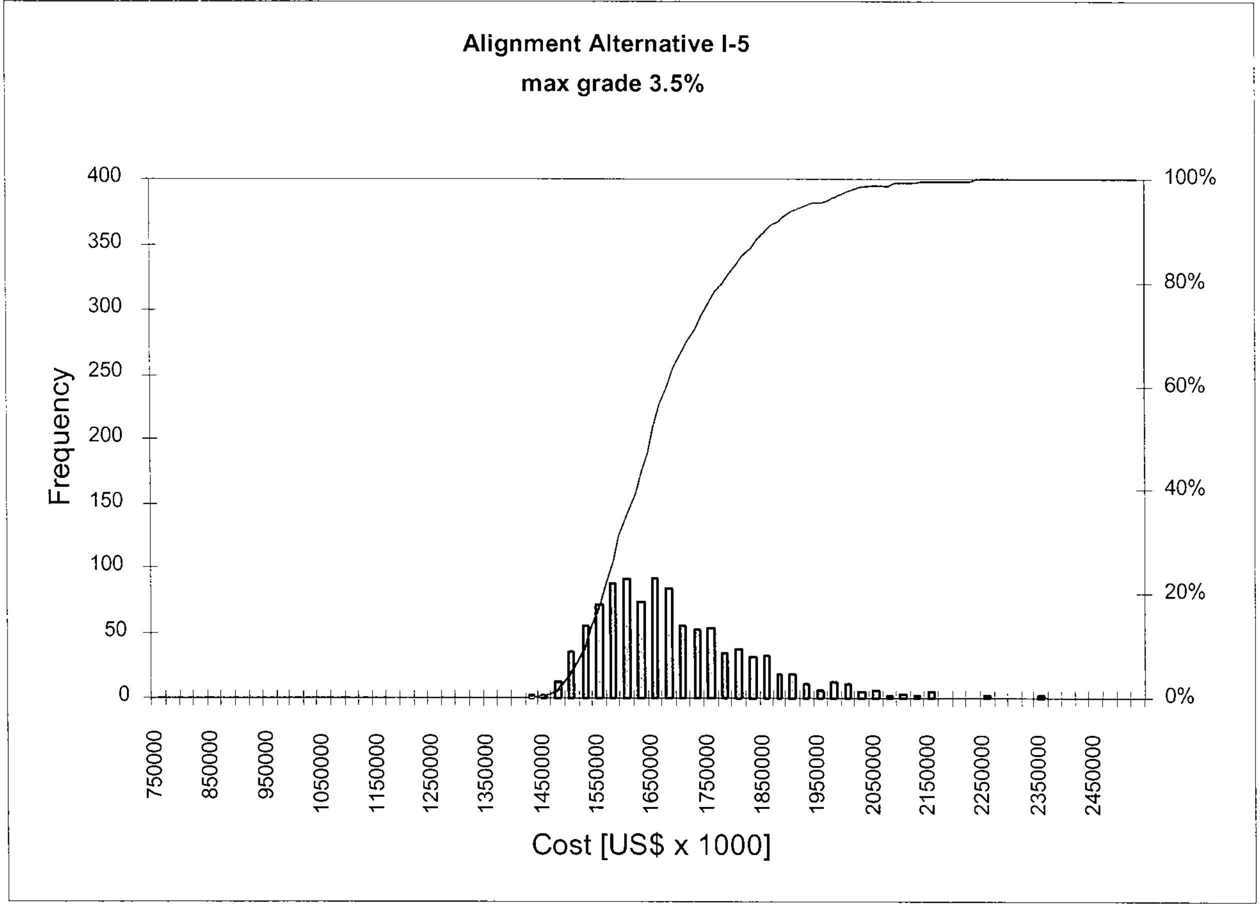


Table 6.2 Statistical data about the Total Construction Cost of the option of I-5 Alignment with 3.5% maximum grade

Alignment Alternative I-5 Max grade 3.5%	Construction cost	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[US$ x 1000]	1670080
Median value	[US$ x 1000]	1643417
St. Deviation	[US$ x 1000]	133507
Minimum value	[US$ x 1000]	1420421
Value at 95%	[US$ x 1000]	1925000
Difference between 95% value and mean value	[US$ x 1000]	254920
Difference between 95% value and min value	[US$ x 1000]	504579

6.3.2 The results of the I-5 Alignment with 2.5% maximum grade option

Figure 6.4 Total Construction Time vs. Cost scatter plot of the option of I-5 Alignment with 2.5% maximum grade

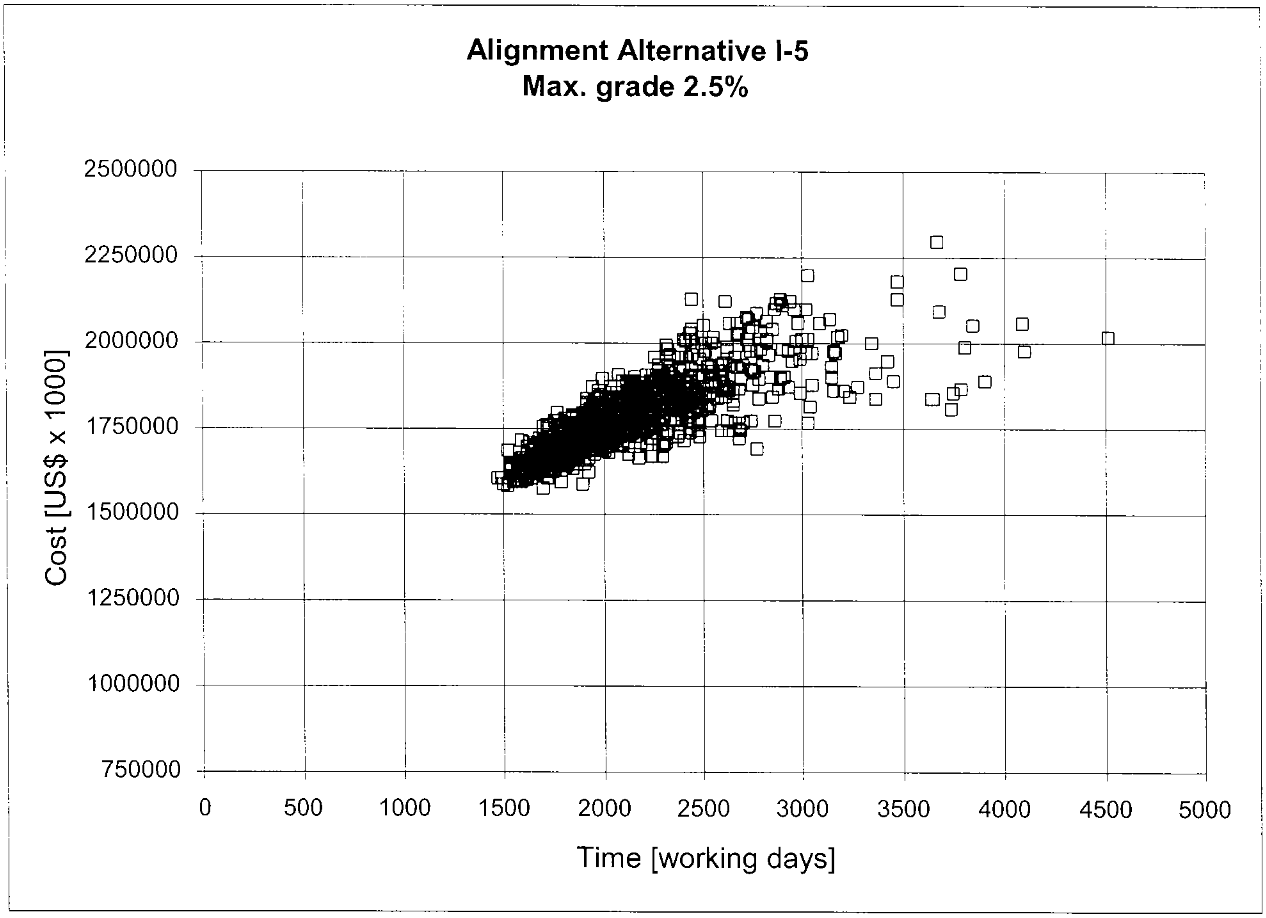


Figure 6.5 Total Construction Time histogram of the option of I-5 Alignment with 2.5% maximum grade

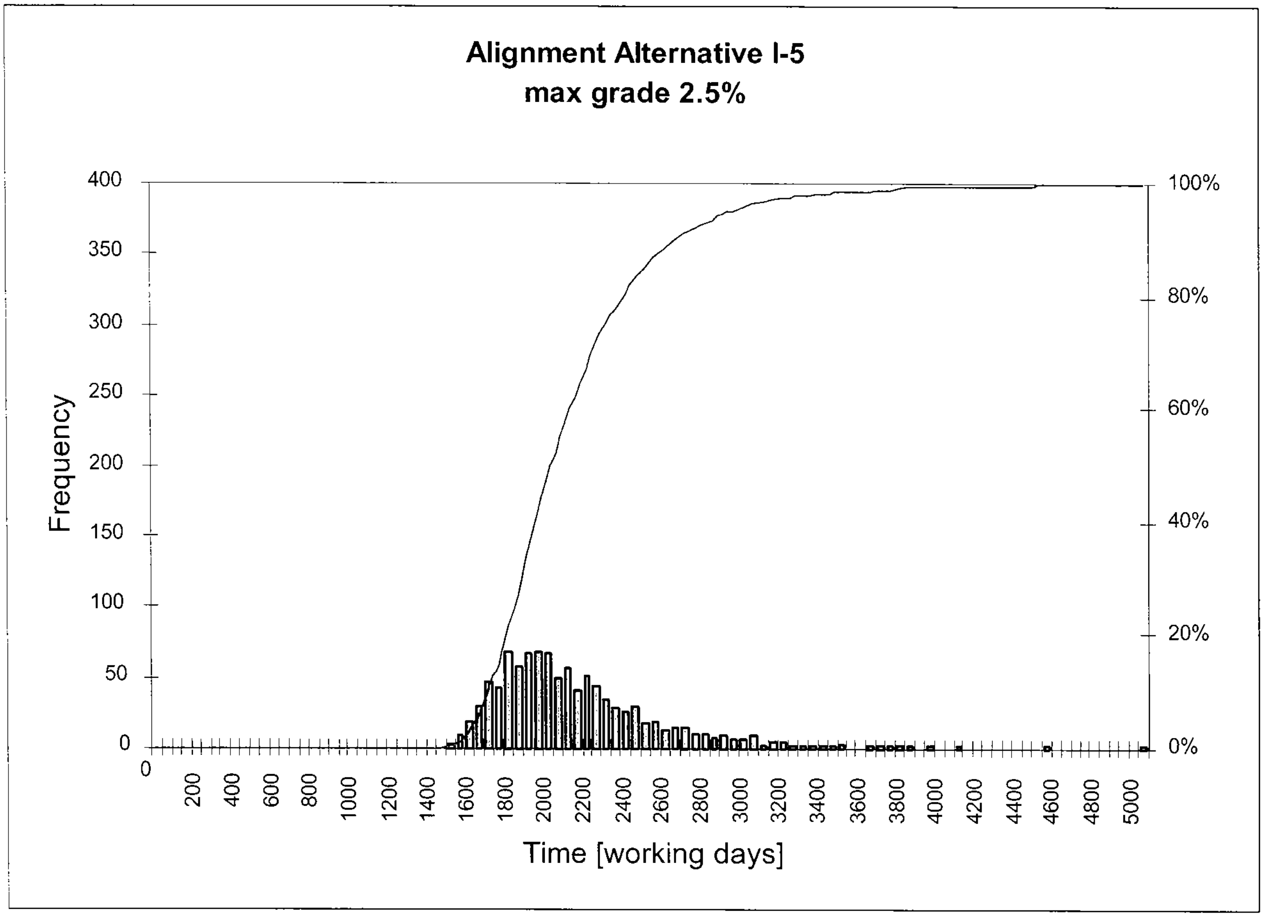


Table 6.3 Statistical data about the Total Construction Time of the option of I-5 Alignment with 2.5% maximum grade

Alignment Alternative I-5 Max grade 2.5%	Construction time	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[working days]	2124
Median value	[working days]	2027
St. Deviation	[working days]	431
Minimum value	[working days]	1470
Value at 95%	[working days]	2900
Difference between 95% value and mean value	[working days]	776
Difference between 95% value and min value	[working days]	1430

Figure 6.6 Total Construction Cost histogram of the option of I-5 Alignment with 2.5% maximum grade

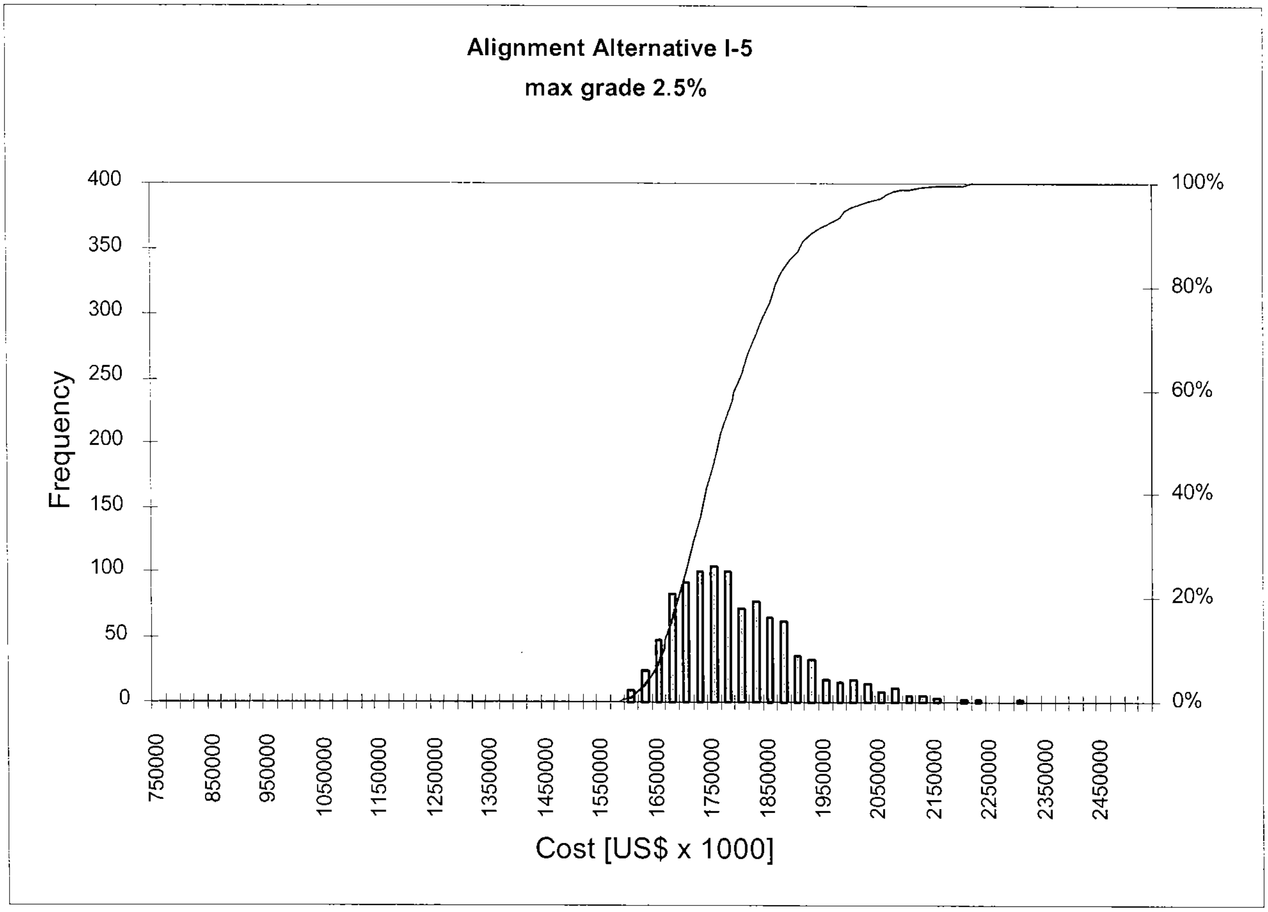


Table 6.4 Statistical data about the Total Construction Cost of the option of I-5 Alignment with 2.5% maximum grade

Alignment Alternative I-5 Max grade 2.5%	Construction cost	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[US$ x 1000]	1779101
Median value	[US$ x 1000]	1758361
St. Deviation	[US$ x 1000]	110232
Minimum value	[US$ x 1000]	1576264
Value at 95%	[US$ x 1000]	1975000
Difference between 95% value and mean value	[US$ x 1000]	195899
Difference between 95% value and min value	[US$ x 1000]	398736

6.3.3 The results of the AV Alignment with 3.5% maximum grade option

Figure 6.7 Total Construction Time vs. Cost scatter plot of the option of AV Alignment with 3.5% maximum grade

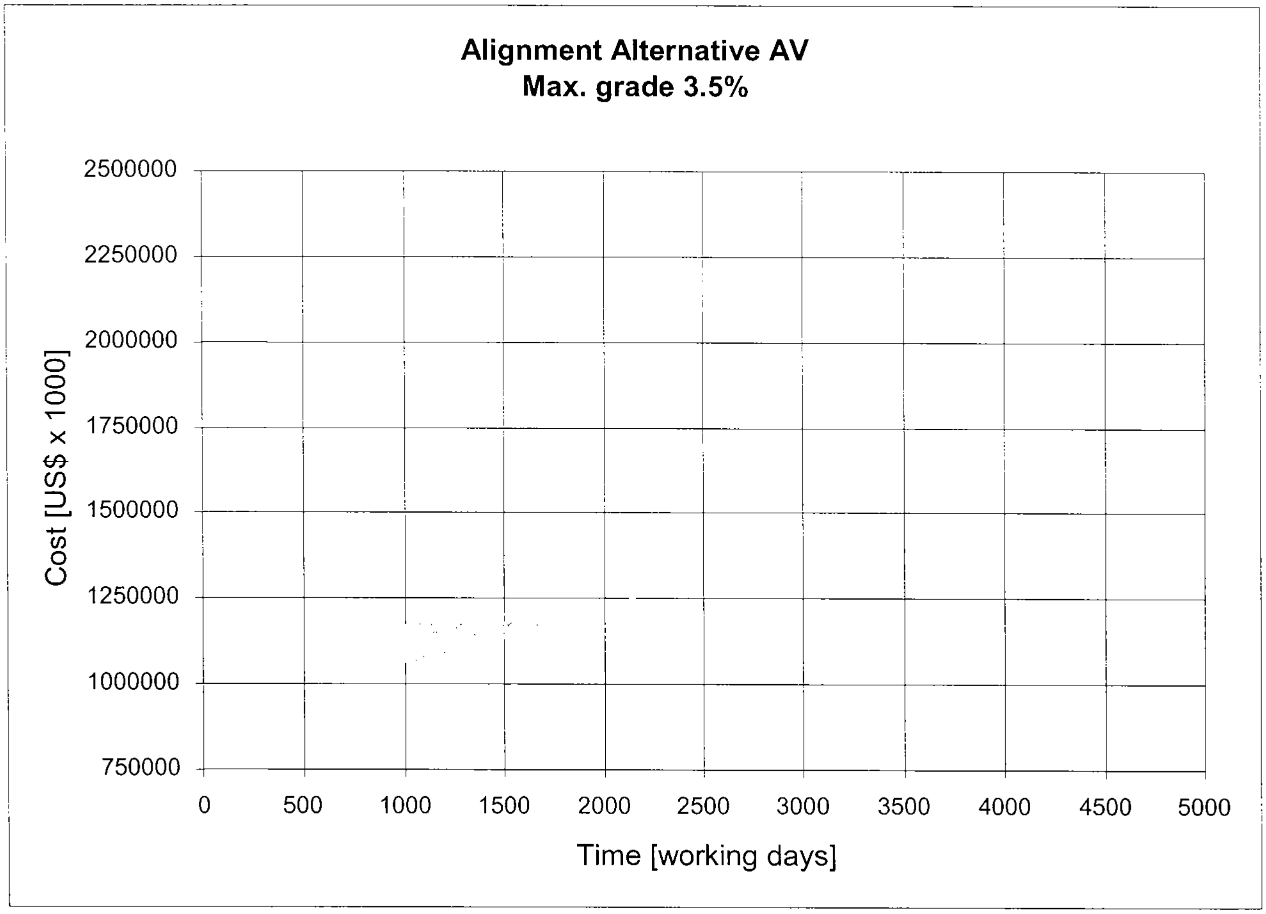


Figure 6.8 Total Construction Time histogram of the option of AV Alignment with 3.5% maximum grade

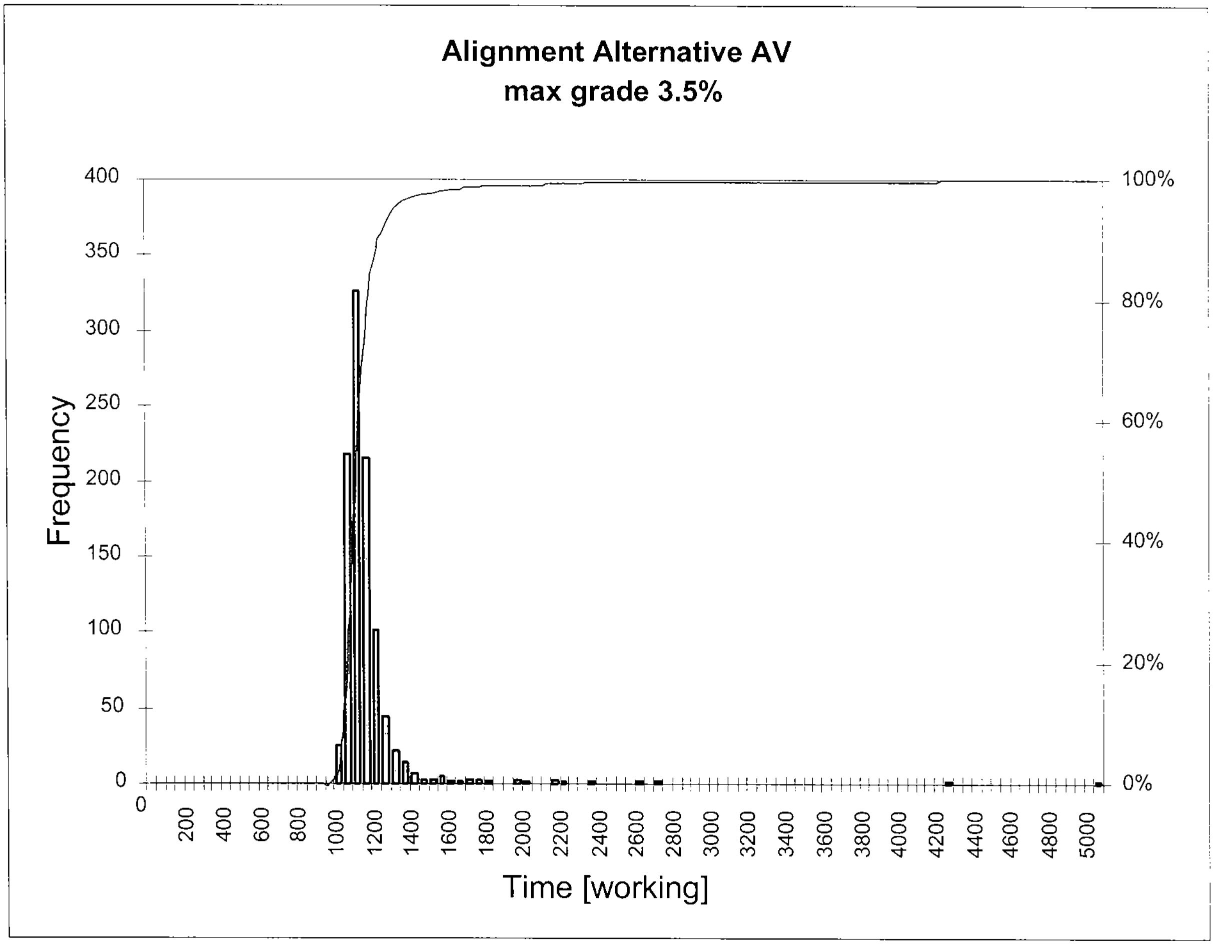


Table 6.5 Statistical data about the Total Construction Time of the option of AV Alignment with 3.5% maximum grade

Alignment Alternative AV Max grade 3.5%	Construction time	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[working days]	1125
Median value	[working days]	1089
St. Deviation	[working days]	217
Minimum value	[working days]	962
Value at 95%	[working days]	1250
Difference between 95% value and mean value	[working days]	125
Difference between 95% value and min value	[working days]	288

Figure 6.9 Total Construction Cost histogram of the option of AV Alignment with 3.5% maximum grade

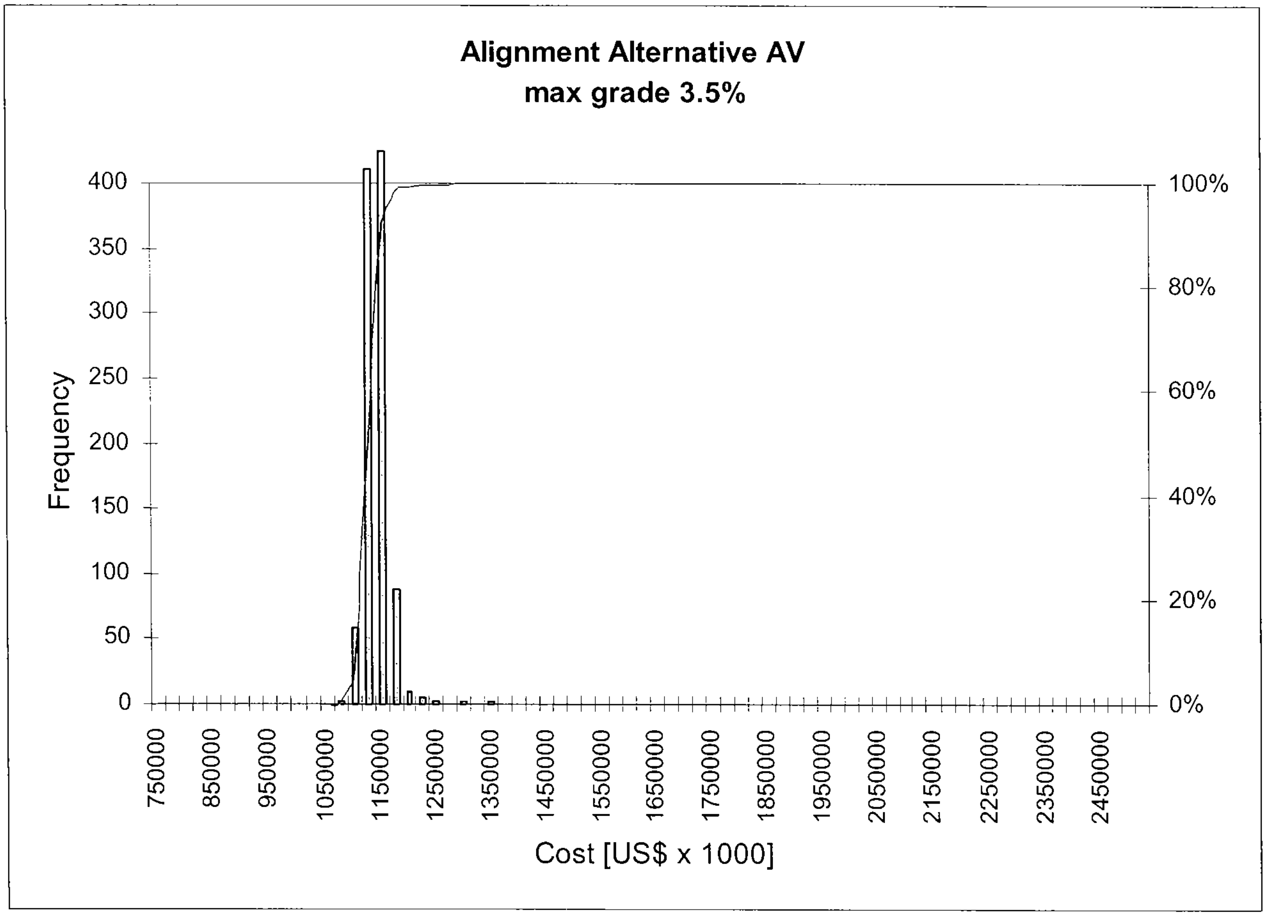


Table 6.6 Statistical data about the Total Construction Cost of the option of AV Alignment with 3.5% maximum grade

Alignment Alternative AV Max grade 3.5%	Construction cost	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[US$ x 1000]	1127511
Median value	[US$ x 1000]	1125936
St. Deviation	[US$ x 1000]	21023
Minimum value	[US$ x 1000]	1073210
Value at 95%	[US$ x 1000]	1150000
Difference between 95% value and mean value	[US$ x 1000]	22489
Difference between 95% value and min value	[US$ x 1000]	76790

6.3.4 The results of the AV Alignment with 2.5% maximum grade option

Figure 6.10 Total Construction Time vs. Cost scatter plot of the option of AV Alignment with 2.5% maximum grade

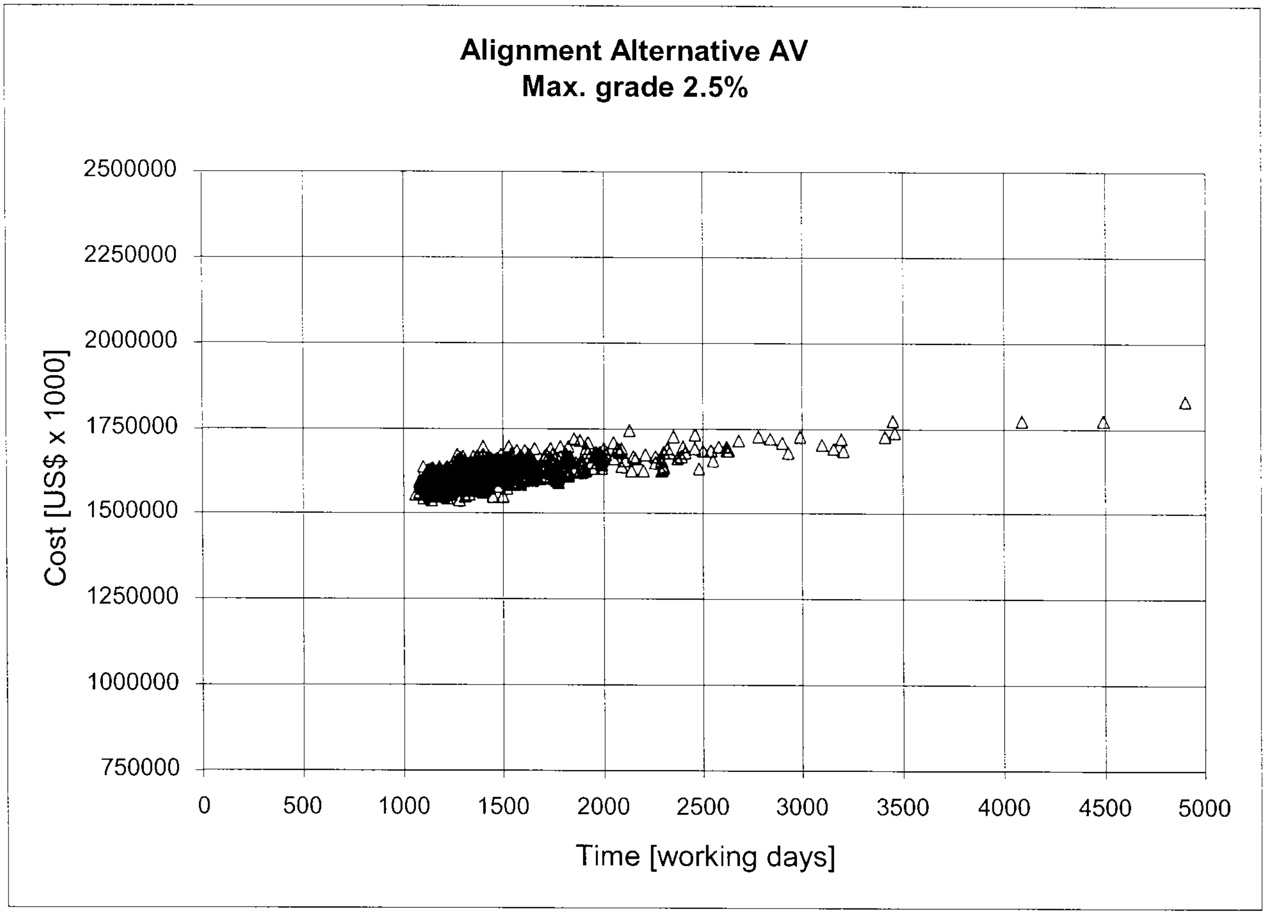


Figure 6.11 Total Construction Time histogram of the option of AV Alignment with 2.5% maximum grade

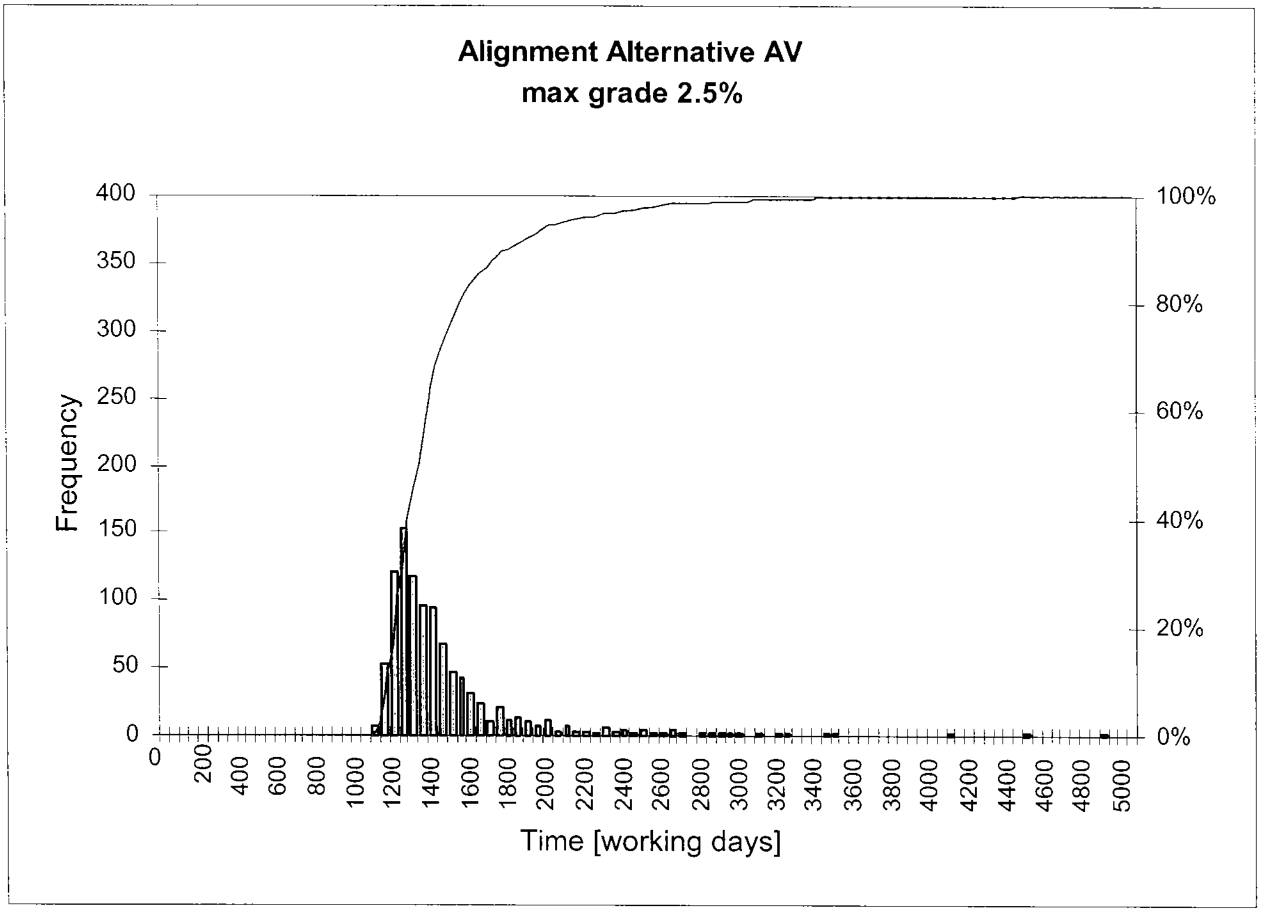


Table 6.7 Statistical data about the Total Construction Time of the option of AV Alignment with 2.5% maximum grade

Alignment Alternative I-5AV Max grade 2.5%	Construction time	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[working days]	1430
Median value	[working days]	1321
St. Deviation	[working days]	370
Minimum value	[working days]	1060
Value at 95%	[working days]	2050
Difference between 95% value and mean value	[working days]	620
Difference between 95% value and min value	[working days]	990

Figure 6.12 Total Construction Cost histogram of the option of AV Alignment with 2.5% maximum grade

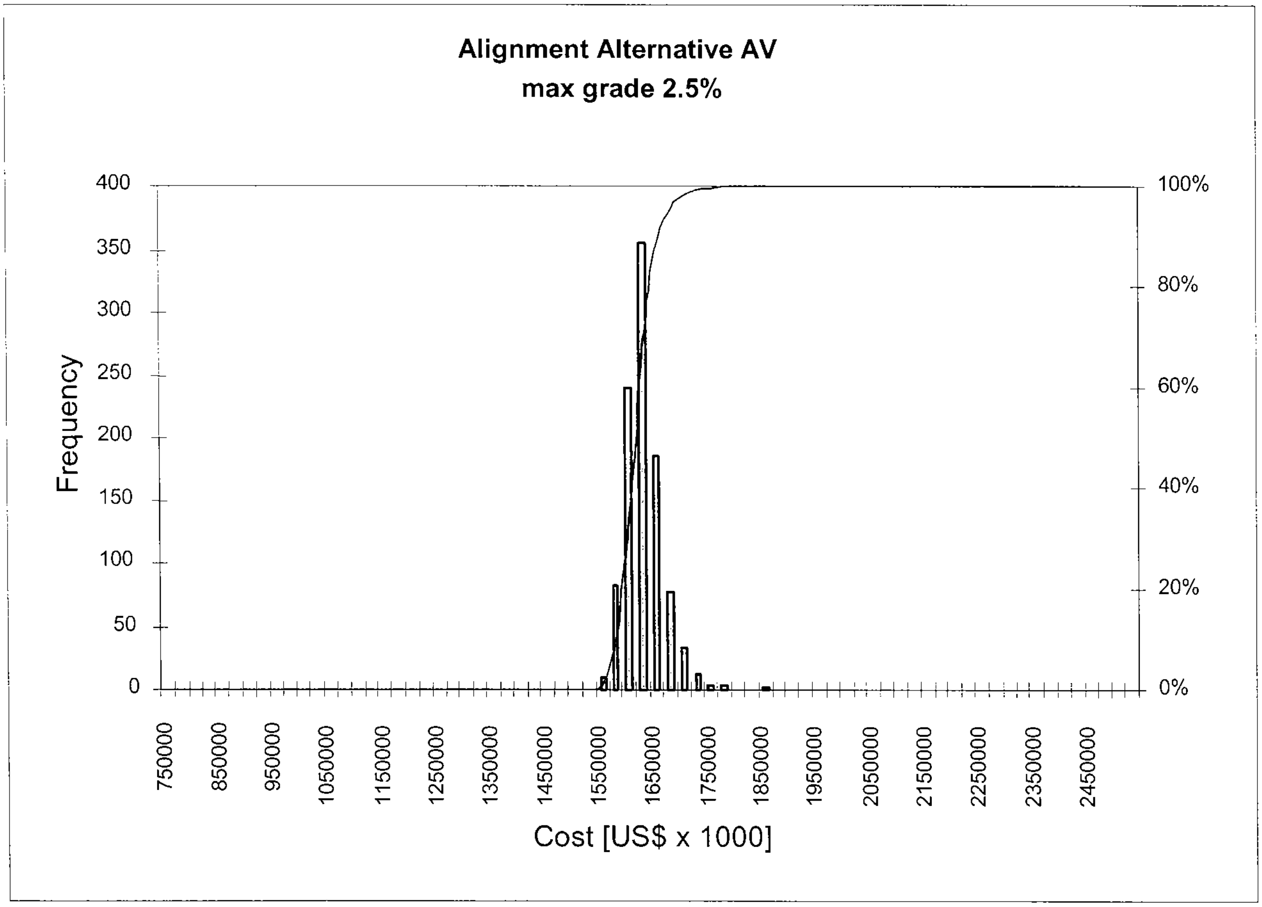


Table 6.8 Statistical data about the Total Construction Cost of the option of AV Alignment with 2.5% maximum grade

Alignment Alternative AV Max grade 2.5%	Construction cost	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[US$ x 1000]	1614790
Median value	[US$ x 1000]	1610143
St. Deviation	[US$ x 1000]	34021
Minimum value	[US$ x 1000]	1537212
Value at 95%	[US$ x 1000]	1675000
Difference between 95% value and mean value	[US$ x 1000]	60210
Difference between 95% value and min value	[US$ x 1000]	137788

6.3.5 Comparative presentation of all the results

Figure 6.13 Scatter plot showing the results of all 4 options for comparison

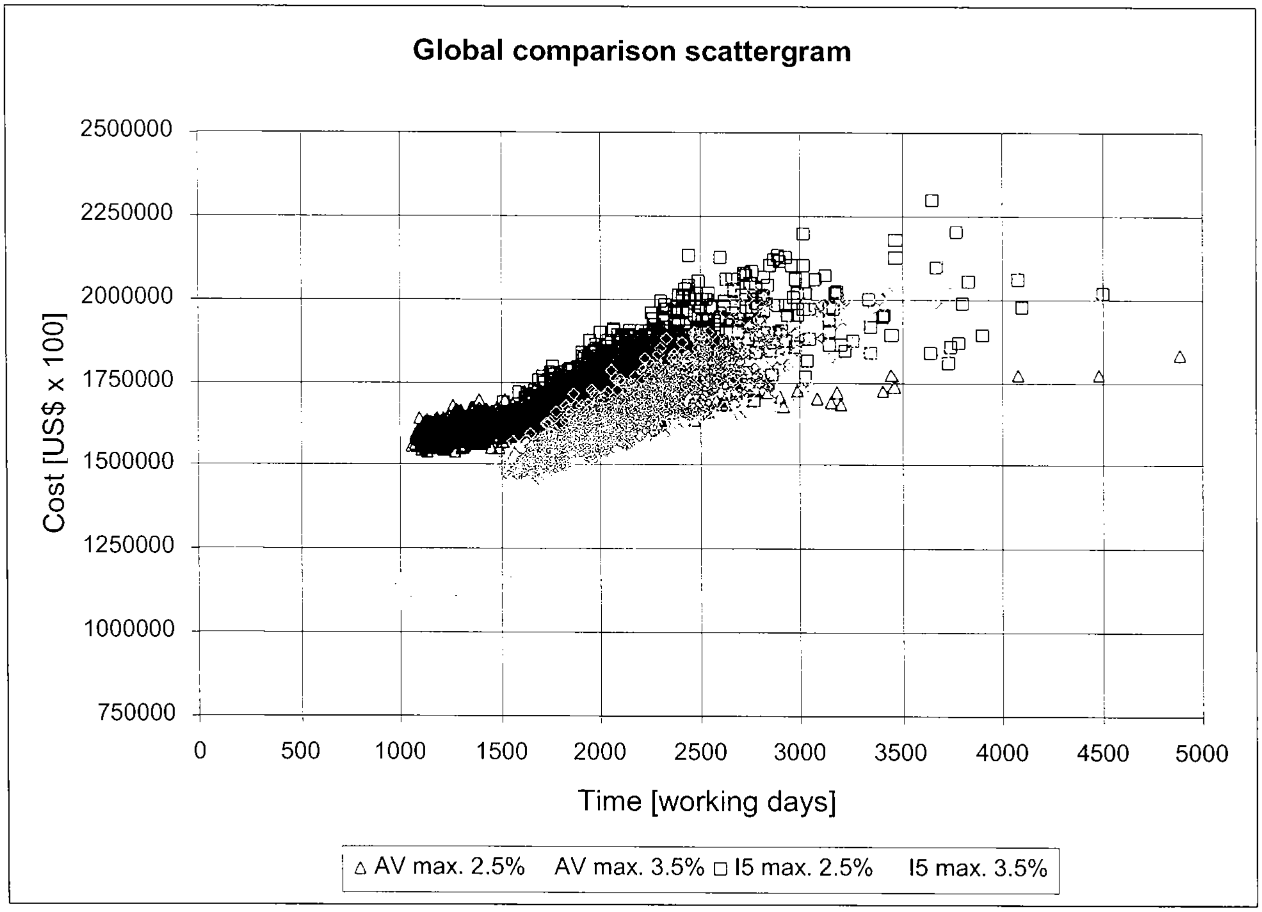


Table 6.9 Global statistics of all 4 options for comparison

		Alignment Alternative I-5		Alignment Alternative AV	
		Max. grade 3.5%	Max. grade 2.5%	Max. grade 3.5%	Max. grade 2.5%
Construction time analysis	**Unit**	**Value**	**Value**	**Value**	**Value**
Number of simulations	[-]	1000	1000	1000	1000
Mean value	[working days]	2218	2124	1125	1430
Median value	[working days]	2111	2027	1089	1321
St. Deviation	[working days]	471	431	217	370
Minimum value	[working days]	1492	1470	962	1060
Value at 95%	[working days]	3100	2900	1250	2050
Difference between 95% value and mean value	[working days]	882	776	125	620
Difference between 95% value and min value	[working days]	1608	1430	288	990
Coefficient of Variation	[%]	21.2	20.3	19.3	25.9
Construction cost analysis	**Unit**	**Value**	**Value**	**Value**	**Value**
Number of simulations	[-]	1000	1000	1000	1000
Mean value	[US$ x 1000]	1670080	1779101	1127511	1614790
Median value	[US$ x 1000]	1643417	1758361	1125936	1610143
St. Deviation	[US$ x 1000]	133507	110232	21023	34021
Minimum value	[US$ x 1000]	1420421	1576264	1073210	1537212
Value at 95%	[US$ x 1000]	1925000	1975000	1150000	1675000
Difference between 95% value and mean value	[US$ x 1000]	254920	195899	22489	60210
Difference between 95% value and min value	[US$ x 1000]	504579	398736	76790	137788
Coefficient of Variation	[%]	8.0	6.2	1.9	2.1

6.4 Discussion of the Results

The results obtained from the DAT simulations must be correctly interpreted in the light of the underlining assumptions.

Considering the variation in the total construction costs (see Figure 6.13 and Table 6.9), it can be observed that, for both Alignment alternatives there is a clear positive relationship between the increase in the average cost and the total length of tunneling (when changing from the 3.5%-max-grade to the 2.5%-maximum grade), as one would normally expect.

Considering the uncertainty about costs which can be measured by the Coefficients of Variation, see Table 6.9), both maximum grade options of the I-5 alignment show higher dispersion than those of the corresponding AV alignment which can be attributed to the more adverse, geologic conditions found along the I-5 alignment.

Additionally, the augmented tunneling length for the AV alignment implies an increase in the spread of results (COV from 1.9% to 2.1%), which is consistent with the increased uncertainties associated with more tunnel stretches running through geologically difficult zones. [Considering the actual tunnel configurations which do not differ from the 2.5% to the 3.5% maximum grade option, the opposite trend of COV, from 8.0% to 6.2%, is evident for the I-5 alignment.]

Similar considerations can be made about the total construction times, especially for the I-5 alignment. The reduced average total construction time for the 2.5% maximum grade configuration, which has approximately 1.5 miles of more tunneling than the 3.5% configuration, derives from the different construction schemes adopted, where one more TBM had to be introduced to optimize the whole construction scheme.

In addition to the above general comments, the following specific observations can be made:

1) The shape of the clouds for the AV alignment (both 3.5% and 2.5% grade options), as shown in the comparative scatter plot of Figure 6.13, is quite different from those of the I-5 alignment (both grade options).

   In the case of the AV Alignment, the cloud tends to close down towards the high ends (of time and cost) with increasingly fewer number of points, while that of the I-5 Alignment is not only wider but also open, with a lower concentration of results in the desired lower range of total construction cost and duration.

   Without entering into the statistical data and the absolute values, the discrepancy above means that the uncertainty of the result in the I-5 alignment is much higher than in the AV alignment.

2) For all four options studied, the dispersion of results is always wider in the time direction than in the cost direction. This is because a linear correspondence between an increase of time and an increase of costs is not foreseen. For tunnel excavation by TBM, supported by pre-cast concrete lining, there is a wide variation in the advance rate due to variations in ground conditions. However, there is no significant variation in the construction cost per linear meter of tunnel. For the HSR Project, the combination of TBM excavation with pre-cast concrete lining is the construction method adopted for almost all tunnels involved in each option.

3) The scattering aspect revealed in Item 1) above is shown clearly by the histograms, especially in the area of costs. Both grade options of the AV Alignment have an extremely "slim" distribution (see Figures 6.9 and 6.12) of cost, with quite small differences between the 95% value and the minimum value (being 76 millions of USD for the 3.5% maximum grade option and 137 millions of USD for the 2.5% maximum grade option, respectively, see Table 6.6 and Table 6.8). The same results are much more uncertain for the I-5 Alignment, with very large differences between the 95% value and the minimum value (being 500 millions of USD and 400 millions of USD for the 3.5%, see Table 6.2, and the 2.5% maximum grade option, see Table 6.4, respectively.)

4) In terms of the mean construction cost, the 3.5% maximum grade option of the AV alignment is about 40% cheaper than that of the corresponding I-5 alignment, while this advantage is reduced for the 2.5% maximum grade option, being about 15% cheaper, due to the increased total length of tunnelling works involved. Furthermore, it should be noted that the increased tunnel length for the AV alignment at the 2.5% maximum grade means savings in costs for construction of the external works and for the mitigation of the environmental impact in the stretches replaced by tunnels.

5) The time histograms of both maximum grade options of the I-5 alignment have similar distributions (see Figure 6.2 and Figure 6.5), due to the fact that the differences in the construction schemes do not affect the final construction time. The main difference consists in the existence of a second set of seismic chambers to cross the San Andrea Fault Zone. This feature introduces additional, costs, but not time because the construction of the second couple of seismic chambers was foreseen to be done mainly during the long period of procurement and assembly of the TBMs. The TBMS will start their tunnel excavation from the chambers and, thus will not affect the final construction time.

6) The 2.5% maximum grade option of the AV alignment has a consistently lower range of variation in the total construction time (with a difference of 990 working days between the 95% value and the minimum value, see Table 6.7), and the 3.5% maximum grade option has an even lower range (being only 288 working days, see Table 6.5). However, the corresponding differences for the I-5 alignment are 1608 and 1430 working days respectively for the 3.5% (see Table 6.1) and the 2.5% maximum grade option (see Table 6.3). These differences between the AV and the I-5 alignment derive mainly from the differences in the geological conditions involved: the relatively shorter and shallower tunnels on the AV alignment are associated with less geological difficulties and thus a lower degree of uncertainty, compared with the long and deep tunnels on the I-5 Alignment.

7) For the 3.5% maximum grade option, the mean construction time required for the I-5 alignment is almost twice as much as that required for the AV alignment (2218 working days against 1125 working days, see Table 6.9). The same trend is basically true also for the 2.5% maximum grade option, with a slight increase in the mean construction time for the AV alignment, due to increased total length of tunneling (see also Table 3.1).

8) It should be pointed out that our DAT analysis does not simulate the financial consequences associated with increased construction duration which could change significantly the forecast of the total investment cost. This financial impact of

construction duration will definitely further magnify the current differences in the construction costs between the I-5 options and the AV options.

Finally, with reference to all the histograms fitted with a cumulative normal distribution curve, the risk of exceeding certain cost or time limits can be easily evaluated if such limits or targets are known.

The conclusions derived from the DAT-simulation results are presented in Section 7.

7. CONCLUSIONS AND RECOMMENDATIONS

Given the large amount of tunneling works involved (see Table 3.1), the Bakersfield to Los Angeles Corridor itself, be it the I-5 alignment or the Antelope Valley alignment, is a mega project.

The potential, typical risks that may be encountered in a mega tunneling project are:

1) Risk of encountering adverse conditions due to the inherent uncertainties of ground and groundwater conditions – leading to significant cost overruns and project delay;
2) The potential for accidents during tunneling work and, later on, during operation;
3) Risk to the health and safety of workers and third party individuals, including personal injury and, in extreme cases, loss of life;
4) Construction risks, such as choice of a wrong type of TBM, ground-squeezing behavior, face collapses; and production of materials causing hazardous environmental conditions;
5) Financial risks to the owner, such as delay in completion of the contract or cost overruns;
6) Contractual risks, such as additional work not covered, time delays, disputes, claims and litigation.

The underground construction industry seems particularly prone to disputes. This is most likely because of the risks and uncertainties associated with subsurface conditions and the costly plant and equipment required (for example, the TBM and its associated back up gear).

Traditionally, the potential risks listed above have been managed indirectly through the engineering decisions taken during project development. This approach is often found to be inadequate during construction. Many recent case histories have demonstrated that risk management can be significantly improved by using systematic risk management techniques throughout the tunneling project development. The use of these techniques can ensure that most potential problems are identified and addressed in a timely fashion so that appropriate and cost effective risk reducing measures can be implemented. The use of risk management in the early stages of a tunnel project is essential, particularly at the beginning of the planning process where major decisions, such as choice of alignment and selection of construction methods, can be influenced.

The study presented in this report was commissioned for two main reasons, (1.) Specific uncertainties in the tunneling process were not adequately integrated in earlier studies commissioned by the Authority, and (2.) to identify the optimum alignment with respect to minimizing capitol investment and risk of construction cost overruns and costly delays.

As pointed out in Section 1.2.2, the earlier studies of the Authority have focused on minimizing tunnel requirements and cost (Corridor Evaluation study and QUANTM study) and minimizing potential environmental impacts (the Screening Evaluation) by avoiding sensitive zones in identifying the potentially suitable routes. However, there is a limit to these reductions due to the constraints imposed by the specific topography and tectonic setting of the region as well as the high speed train technology. Furthermore, for the limited number of potentially suitable routes identified by the previous screening studies, and subsequently confirmed by the QUANTM analysis, the various categories of risks, especially the geological and construction risks, were not considered. In the opinion of Transmetrics/Geodata, these other risks are as important as those already considered by the Authority. They are also critical in the final choice of the optimum alignment/route for the mega tunneling project.

Consequently, the study commissioned by the City of Palmdale and undertaken by Transmetrics/Geodata represents a complementary, step forward in the development process of the Project.

It is understood from the beginning of this report that, to perform an alignment specific risk analysis, focusing on the geological and constructional aspects, requires specific information about the ground conditions of each potentially suitable alignment. However, most of the required information is not directly available because no preliminary site-specific investigations have been made.

To overcome this problem, we adopted the common practice of utilizing our tunneling experience and judgment as well as USGS data and reports in lieu of precise, in situ explorations and measurements. In addition, full use was made of the information contained in the Preliminary Engineering Feasibility Study of PBQD. We acquired relevant reports and maps from the USGS to study the geomorphological, geological, hydrogeological, and geotechnical conditions of the two alternative alignment corridors, establishing foreseeable ground models. We also made a preliminary design of both alignments, defining the corresponding construction schemes based on our European experience for similar projects.

To facilitate the comparison of the geological and construction risks involved in the two alternative alignments and also to further overcome the problem of limited data, we adopted a probabilistic model that incorporates the impact of different geological factors on the risks and productivity. The specific model adopted was developed at the Massachusetts Institute of Technology and is called Decision Aids in Tunneling (DAT). The model allows for the comparison, in terms of construction time and cost, of various, feasible, design and construction solutions for a tunneling project, and for quantification of risks related to each solution.

The various analyses presented in this report have demonstrated the following:

- Although the amount of tunneling work involved in the I-5 and the AV alignment are almost the same, be it the 2.5% grade or the 3.5% grade option, the ground conditions along the AV are relatively more favorable and hence involve less construction risks, financial risks, and contractual risks.
- For the 3.5% max grade option, the mean construction time required for the I-5 alignment is almost twice as much as that required for the AV alignment (2218 working days against 1125 working days, see Table 6.9). The same trend is basically true for the 2.5% max grade option, with a slight increase in the mean construction time for the AV alignment due to increased total length of tunneling (see also Table 3.1).

- In terms of the mean construction cost, for the 3.5% max grade option, the Antelope Valley alignment is about 40% cheaper than the I-5 alignment, while this advantage is reduced for the 2.5% max grade option. The 2.5% grade option is 15% cheaper, again due to increased total length of the tunnel. Furthermore, the increased tunnel length for the AV alignment at 2.5% max grade will reduce the costs for the corresponding external works and environmental impact.
- It should be pointed out that the DAT analyses presented in this report do not simulate the financial consequences associated with increased construction duration. If the financial impact due to longer construction duration is taken into consideration, the final results will not only change significantly the forecast of the total investment required for each alignment option, but will also magnify the construction cost differences between the I-5 and the Antelope Valley alignment.

Generally speaking, the findings of this study have confirmed the concerns of the City of Palmdale over the relative risks involved in the two alternative alignments. These findings should also permit the Authority to make more informed decisions regarding the final choice of the best alignment, including the process to be followed before making the final choice.

On the basis of the analysis conducted, we offer the following three specific recommendations:

In general, the construction experience gained by Geodata from similar, International, mega projects is directly useful as information to assist consideration of new alternatives – management, contracting and new technologies – for the current mega project.

1) Reducing uncertainties

Reducing uncertainties through site investigations, especially the preliminary investigation, for mechanized tunneling, is a key investment strategy for project owners because it will directly reduce risks with short, medium and long term benefits.

To facilitate the final choice of the optimum alignment, site investigations should be designed to reduce the geological uncertainties, thus either confirming or negating the geological and construction risks identified in the analyses presented in this report. For this purpose, a proper balance of effort should be maintained between investigating the I-5 alignment and exploring the Antelope Valley alignment.

Once the optimum alignment is selected, it is strongly recommended that critical sections (if not all sections) of the service tunnels should be constructed first, since they can be used as pilot tunnels to investigate the ground conditions and to experiment with the construction techniques to be employed for the construction of the main tunnels later.

2) Development of Innovation – New Technologies

The greatest payoff can be realized by the use of innovation in complex underground projects, especially long and deep tunnels, with difficult or unexplored geology, as in the California High Speed Rail project. In addition to the risks listed previously, there are still potential technological risks. For example, the technical feasibility of realizing the huge, seismic chambers in very wide fault zones, and the technical capacity of the tunneling market to supply the great number of large-diameter TBM's required for realizing this mega tunneling project will be a challenging task.

Innovation means that the new concepts are competently developed, consistent with the limits of current knowledge and experience, and carefully matched to the specific conditions of the project. For this purpose, it is suggested that the Authority work closely with engineers, contractors and manufacturers, as early as possible, to develop innovative solutions to the high risk aspects of the project, bearing in mind that innovation takes time.

3) Contracting Practices

It is now almost universally accepted that "the ground belongs to the Owner" – including the sometimes unknown difficult geologic conditions which will be encountered. Wise Owners recognize this and seek ways to equitably mitigate the risks, sharing and allocating risk to the best entity that can foresee or control that particular risk. Passing risk along without a strategic and equitable approach will often lead to disputes which will eventually have a great impact on the project and the Owner.

It is now accepted by many Owners that the contracting practice of accepting a fixed-cost low bidder from a group of "qualified" contractors, should not be adopted when the jobs are large, the geology uncertain, and potential for extremely high cost overruns escalate. It has been the experience of some Owners that the low-bid contracting system can result in delays, cost overruns, problems with project completion and a long process of claims and litigation. Negotiated contracts with fair allocation of risks among the parties involved could be more cost effective and equitable.

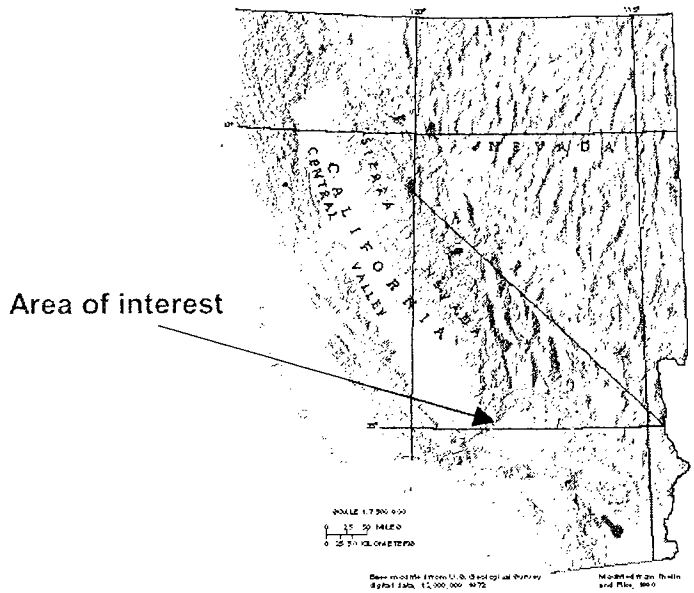
Appendix 1 List of reference geological documents

Type	Title	Year of publ.	Other
Map	Geologic map of the Warm Springs Mountain Quadrangle	1997	scale 1:24,000
Map	Geologic map of the Whitaker Peak Quadrangle	1997	scale 1:24,000
Map	Geologic map of California. Los Angeles sheet	1969	scale 1:250,000
Map	Geologic map of California Bakersfield sheet	1965	scale 1:250,000
Map	Geologic map of California	1977	scale 1:750,000
Map	Geologic map and cross sections of the southeastern margin of the San Joaquin Valley, California	1984	scale 1:125,000 (contains Bakersfield area)
Map+Paper	Geologic map of the Tehachapi Quadrangle, Kern County, California	1970	scale 1:65,000 (with accompaining explanatory paper)
Map	Geologic map of the San Andreas Fault Zone, Leona Valley, California	1976 (repr. 1984)	scale 1:10,000
Paper+Maps	Geology of the Willow Springs and Rosamond Quadrangles, California	1963	scale 1:62,500
Map+Paper	Geologic map of the Cummings Mountain Quadrangle, Kern County, California	1970	scale 1:65,000 (with accompaining explanatory paper)
Map	Geologic map of the Pearland Quadrangle, California	1953	scale 1:24,000 relevant descriptive notes on the map
Map	Geologic map of the Black Mountain Quadrangle, California	2002	scale 1:24,000
Map	Geologic map of the Liebre Mountain Quadrangle, California	2002	scale 1:24,000
Map	Geologic map of the Pacifico Mountain and Palmdale (south half) Quadrangle, California	2001	scale 1:24,000
Map	Geologic map of the Sleepy Valley and Ritter Ridge Quadrangles, California	1997	scale 1:24,000
Paper+Map	Postcrystalline Deformation of the Pelona Schist Bordering Leona Valley, Southern California	1978	Geological Survey Professional Paper 1039 with annexed geologic map at 1:10,000
Paper+Map	Basement-Rock Correlations Across the White Wolf-Breckenridge-Southern Kern Canyon Falut Zone, Southern Sierra Nevada, California	1986	U.S. Geological Survey Bull. 1651, with annexed geologic map at 1:25,000
Paper+Map	Stratigraphy and Sedimentology of the Eocene Tejon Formation, Western Tehachapi and San Emigdio Mountains, California	1987	U.S. Geological Survey Bull. 1268, with annexed geologic non colour map at 1:62,500
Paper+Map	The Metamorphic and Plutonic Rocks of the Southermost Sierra Nevada, California, and their Tectonic Framework	1989	U.S. Geological Survey Professional Paper 1381, with annexed geologic map at 1:125,000
Map	Geologic map of the Grapevine Quadrangle, California	1973	U.S. Geological Survey open file map, preliminary non colour Scale 1:24,000
Map	Geologic map of the Pastoria Creek Quadrangle, California	1973	U.S. Geological Survey open file map, preliminary non colour. Scale 1:24,000
Map	Geologic map of the Eagle Rest Peak Quadrangle, California	1973	U.S. Geological Survey open file map, preliminary non colour. Scale 1:24,000
Map	Geologic map of the Santiago Creek Quadrangle, California	1973	U.S. Geological Survey open file map, preliminary non colour. Scale 1:24,000
Map	Geologic map of the Pleito Hills Quadrangle, California	1973	U.S. Geological Survey open file map, preliminary non colour. Scale 1:24,000
Maps (4)+Table	Geologic maps of the Knob Hill, Pine Mountain, Oil Center and Bena Quadrangles, California	1986	U.S. Geological Survey open-file report 86-188, preliminary non colour. Scale 1:24,000
Map+Notes	Preliminary Geologic map of the Val Verde 7.5' Quadrangle, Southern California	1995	U.S. Geological Survey open-file report 95-504, preliminary non colour. Scale 1:24,000
Map+Notes	Preliminary Geologic map of the Oat Mountain 7.5' Quadrangle, Southern California	1995	U.S. Geological Survey open-file report 95-89, preliminary colour. Scale 1:24,000
Map+Notes	Preliminary Geologic map of the Mint Canyon 7.5' Quadrangle, Southern California	1996	U.S. Geological Survey open-file report 96-89, preliminary colour. Scale 1:24,000
Map+Notes	Preliminary Geologic map of the Newhall 7.5' Quadrangle, Southern California	1995	U.S. Geological Survey open-file report 95-503, preliminary non colour. Scale 1:24,000
Notes	Geologic map and Digital Database of the Apache Canyon 7.5' Quadrangle, Ventura and Kern Counties, California	2000	U.S. Geological Survey open-file report 00-359. Stratigraphy, structure and units description NO MAP
Notes	Preliminary Geologic map of the San Fernando 7.5' Quadrangle, Southern California: a Digital Database	1997	U.S. Geological Survey open-file report 97-163. Just a description of the adopted GIS system
Map	Preliminary Geologic map of the Mojave Quadrangle, California	1959	scale 1:62,500
Map	Geologic map of the Lancaster Quadrangle, Los Angeles County, California	1960	scale 1:62,500
Map	State of California - Special Studies Zones Palmdale Quadrangle	1979	scale 1:24,000 topographic map with tectonic lineaments (potentially active faults)
Map	State of California - Special Studies Zones. Ritter Ridge Quadrangle	1979	scale 1:24,000 topographic map with tectonic lineaments (potentially active faults)
Maps (13)	Topographic maps along I-5 route	-	scale 1:24,000
Maps (24)	Topographic maps along SR-14 (via Palmdale) route	-	scale 1:24,000

APPENDIX 2 GEOLOGIC SETTING

2.1 Physiography of the region

The physiography of the region is a product of the geologic history of the area. Several coastal mountain ranges underlain by severely folded, faulted, mostly metamorphosed marine and continental sediments, forming the Pacific Border and the Lower Californian Physiographic Provinces.



Thelin, G.P., and Pike, R.J., 1990, Digital shaded relief map of the conterminous United States: Menlo Park, California, U.S. Geological Survey digital image processing, scale 1:3,500,000

Figure A2.1 Digital, shaded relief map showing the high rugged California mountain ranges surrounding the low lying Central Valley (modified after USGS Groundwater Atlas of United States; California, Nevada)

In the interior, the granitic rocks that underlie the fault blocks of the Sierra Nevada and the volcanic rocks of the southern Cascade Mountains join to form the eastern border of the low lying California Trough, which contains the Central Valley.

East of the Sierra Nevada, the landscape is characterized by a series of low, north-south trending mountain ranges and intervening valleys; the ranges and valleys were created by faulting that resulted in the horst and graben structures which in turn formed the Basin and Range Physiographic Province.

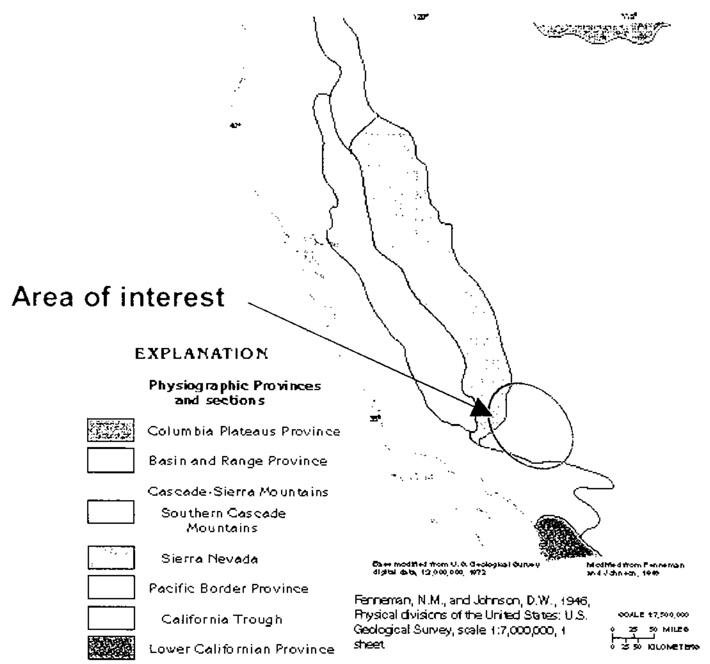


Figure A2.2 California Physiographic provinces (modified after USGS Groundwater Atlas of United States; California, Nevada).

The alternative alignment options intersect three physiographic provinces, namely: Central Valley (California Trough), Basin and Range (Mojave desert), and Pacific Border (Transverse Ranges; south of San Andreas fault alignment).

2.2 Regional structural outline

The California geographic region is situated along the active geodynamic margin between North America and North Pacific tectonic plates. The main boundary between the two plates coincides with the NNW-SSE San Andreas active fault system which separates the southern California from the rest of the north America continent.

Many other important regional active faults are present in California which determine and control the geologic development of distinct zones. The principal faults include: the NE-SW trending Garlock fault and the associated Tehachapi mountains separate the Sierra Nevada batholithic region from the Mojave desert, the complex system of San Gabriel-Santa Susana Sierra Madre faults which bound the Transverse Ranges north of Los Angeles, the San Gabriel NW-SE trending fault system which limits westward the San Gabriel mountains region, the White Wolf fault zone which intersects the southern part of the Sierra Nevada batholite.

The main faults are associated with a lateral strike slip character (San Andreas, Garlock, San Gabriel), while the minor faults are considered as compressive thrust faults (e.g., Santa Susana Sierra Madre, Pleito, and Pastoria systems) or normal type (e.g., Raymond Fault).

Practically all the above-mentioned main faults, and a significant number of minor associated faults will be crossed by the alternative alignment options. Depending on the geometric characteristics of the alignment such faults will be crossed either underground or at grade.

For the choice of the final alignment, one crucial aspect is represented by the active character of the faults. In fact, most of these faults are considered tectonically active or potentially active and seismogenetic in historic or recent (< 10,000 years B.P.) times. In this respect, California is well recognized as one of the most seismically active areas in the world. Besides, the anticipated lateral offset that could occur along major faults during earthquakes of exceptional magnitude, the design of underground structures will also have to take into consideration another important phenomenon associated with active fault zones, namely, the slow plastic slippage by which tectonic stresses are accommodated. Such movements can amount to several mm/year.

For the present study, the identification of fault zones is based on evidence from available maps (see reference documents list, Appendix 1) and on interpretation of satellite images coupled with morphologic analysis carried out on topographic maps (1:24,000 scale).

Because of their complex and long geologic history that presumably caused several lateral migrations of the principal fault plane, as well as the possible existence of multiple associated shear zones that might have been activated in different times, no attempt has been made to distinguish between the true fault planes and the associated fault affected zones, in terms of their geomechanical properties. It seems that this task might only be accomplished with the support of detailed studies and proper investigations.

Table A2.1 summarizes some characteristics of the principal faults that are considered to directly interfere with the underground sections of the studied alignments.

Table A2.1 Principal fault zones affecting the tunnels on the alternative alignments

Fault zone	Location (align., approx. chain.) (3)		Type	Attitude (dip/dip direction or strike direction)	Estimated width [m] (1)	Last seismic event year/magnitude] (2)	
S. Andreas	I-5	km 78+000	S, RH	Near vertical, NW-SE	800 - 1000	1857 (south branch)	8.0
Garlock	I-5 AV	km 70+250 km 79+350	S, LH	Near vertical, NE-SW	500 - 800	1992 (Mojave)	5.7
S. Gabriel	AV	km 177+950 km 178+200 km 178+850	S, RH	Near vertical, NW-SE	400 - 600	Quaternary	unknown
S. Susana	I-5 AV	? km 183+600 km 184+200	T	var., NW to NE	200 - 250	Late Quaternary 1971 (S. Fernando)	unknown. 6.5
Pleito	I-5	km 57+700	T	var., NNW	150 - 200	345-1465 years ago	unknown
Pastoria	I-5	km 67+000	R	var., SSE	300 - 400	unknown; probably non active	
Edison	AV	km 38+600 km 40+600	N	45-75°, NNW	100 - 200	unknown; probably non active	
Legend	S (strike-slip fault), T (thrust fault), N (normal fault), R (reverse fault); RH, LH (right-hand mov., left-hand mov.)						
Note	(1) The figures refer to the estimated width of the fault affected zone (2) From SCDEC (Southern California Earthquake Data Center http://www.scecdc.scec.org/faultmap.html) (3) Chainage onset is assumed in Bakersfield						

2.3 Lithologic and lithostratigraphic outline

The alternative, analyzed alignments traverse a variety of geologic units which can be broadly divided in three principal groups separated by unconformities: pre-Tertiary crystalline rocks; Tertiary volcanic, volcano clastic and sedimentary rocks; Quaternary sedimentary deposits.

Pre-Tertiary crystalline rocks are composed of plutonic igneous Mesozoic rocks (ranging in composition from hornblende diorite to quartz monzonite to granite) and metamorphic Paleozoic to Precambrian rocks which generally occur as isolated bodies or as interbedded layers within plutonic rocks. The two rock groups together constitute the crystalline basement upon which all later units were deposited.

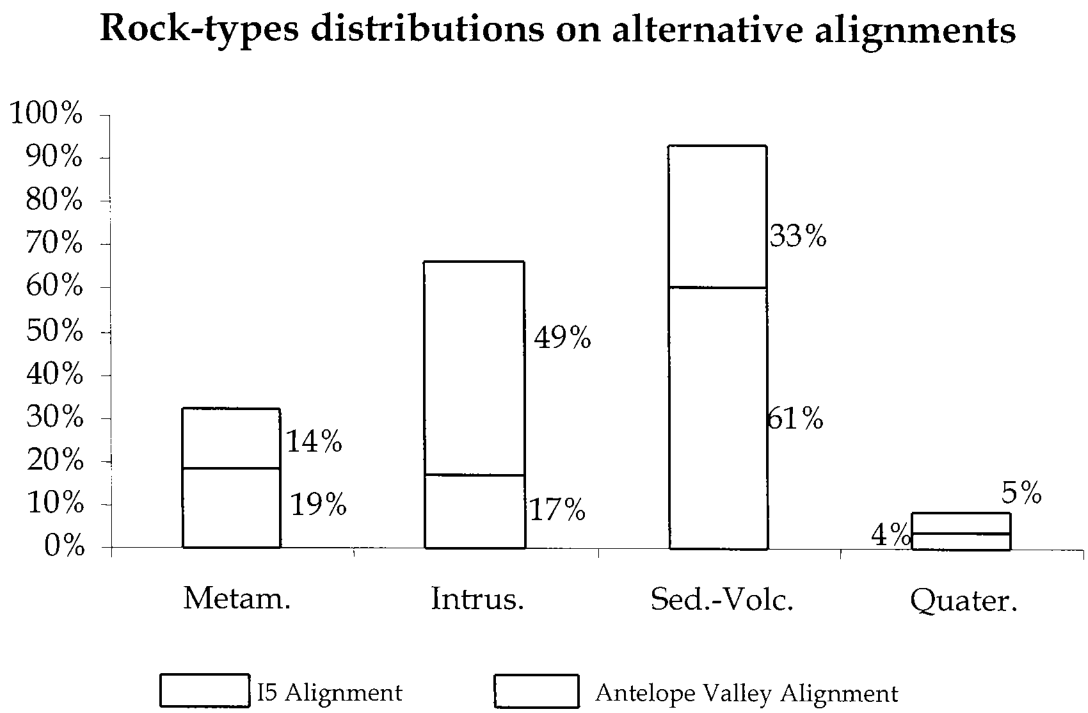
The Tertiary complex is composed of volcanic to sub-volcanic Eocene to Miocene units (rhyolite, andesite, basalt, pyroclastic rocks) and clastic flysch-like and non-marine sedimentary units (variably interbedded sandstones, siltstones, claystones and to a minor extent conglomerates).

The Quaternary deposits range from Pleistocene marine and non marine clastic deposits to fanglomeratic (i.e. sedimentary rock composed of heterogeneous unrelated materials that were originally deposited in an alluvial fan) and unlithified coarse piedmont deposits (gravel to boulder sized).

A more detailed description of the different rock-type occurrence along the alternative alignments is presented in Section 6 (Anticipated geologic conditions along alternative routes).

Figure A2.3 shows the relative distributions of different rock-types (pre-Tertiary metamorphic and intrusive rocks, Tertiary sedimentary-volcanic rocks, Quaternary deposits).

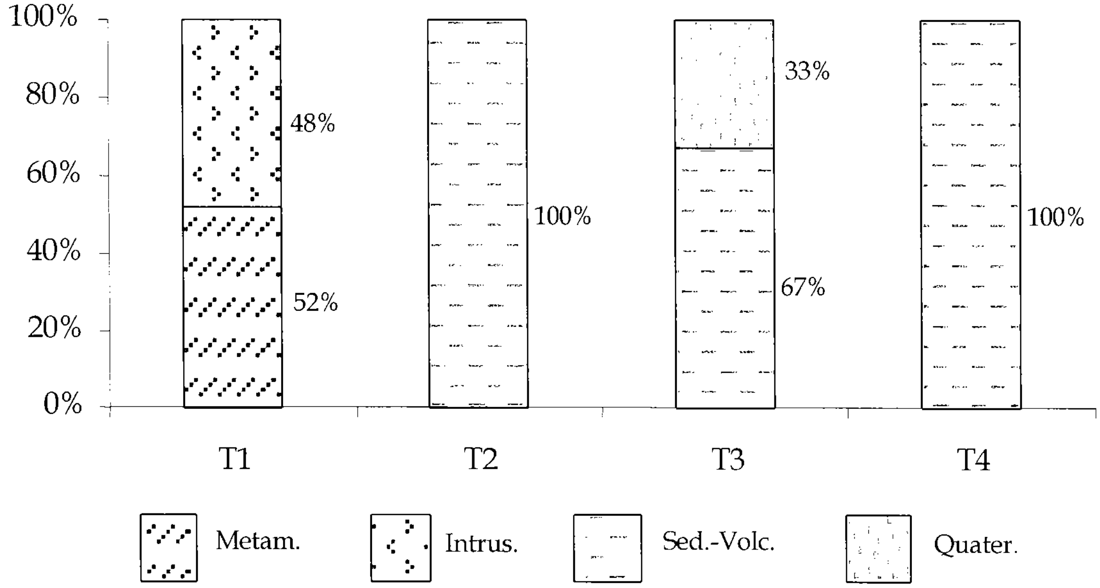
Figure A2.3 Distribution of the various rock types for the alignment options with reference to 2.5% max. grade (Metam. = metamorphic rocks, Intrus.= intrusive rocks, Sed.-Volc.= sedimentary-volcanic rocks, and Quarter.= Quaternary deposits)



Figures A2.4 gives the distribution the various rock types, in terms of both their percentage and accumulative length, on each tunnel along the I-5 alignment.

Figures A2.5 gives the distribution the various rock types, in terms of both their percentage and accumulative length, on each tunnel along the Antelope Valley alignment.

Figure A2.4 Rock type distribution in percentge and by length for each tunnel on the I-5 alternative alignment (with reference to the 2.5% max grade)



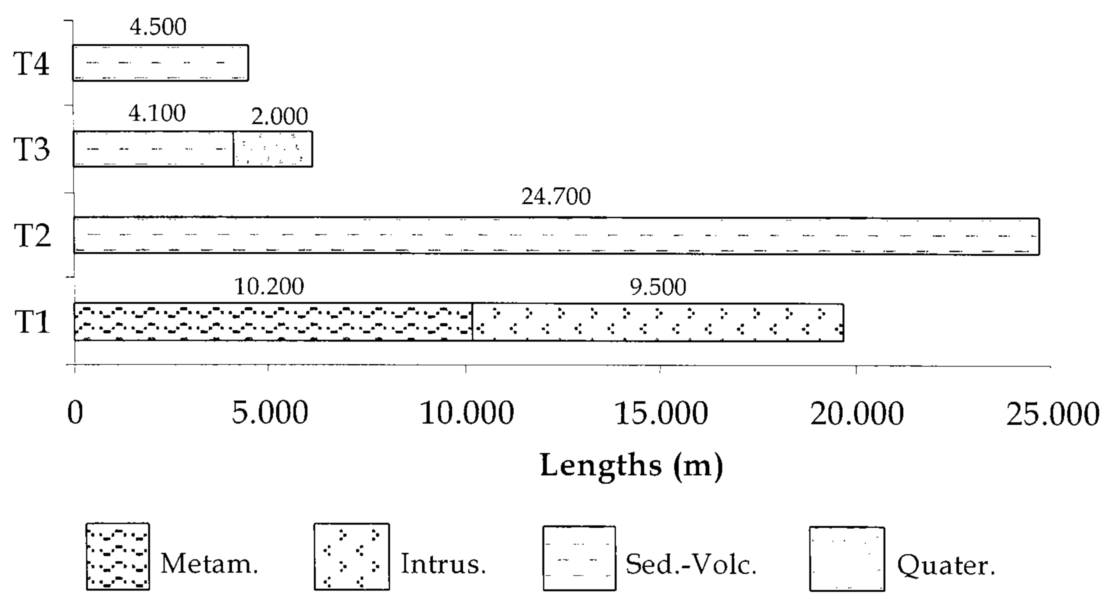
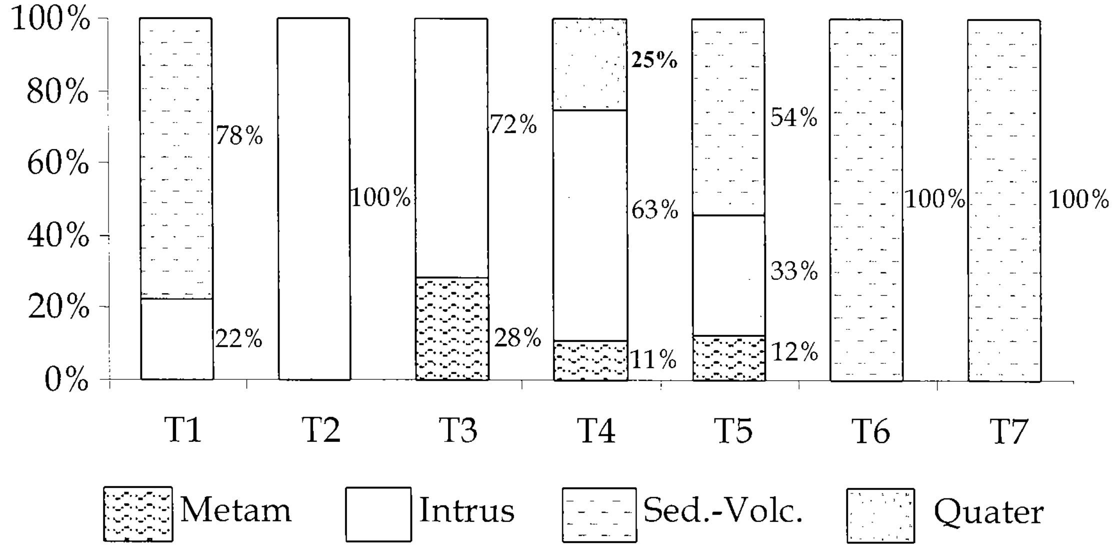
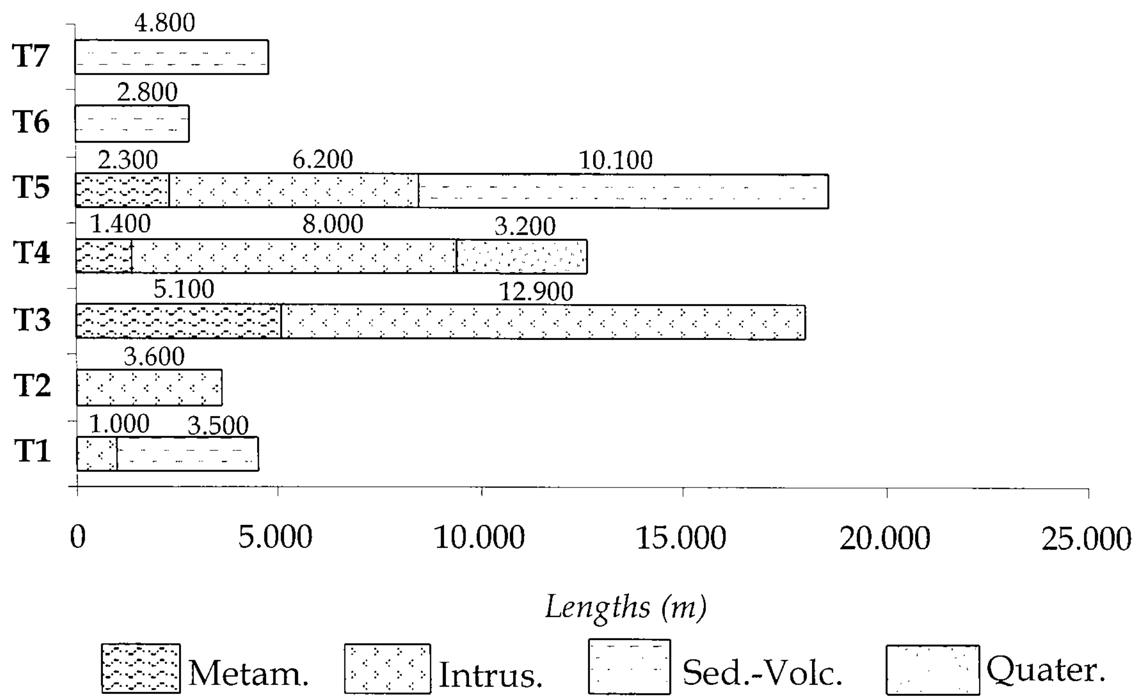


Figure A2.4 Rock type distribution in percentge and by length for each tunnel on the Antelope Valley alternative alignment (with reference to the 2.5% max grade)





The characteristics of the principal geological formations that are expected to be encountered in tunneling, for both alignment options, are described in the following sections.

Pre-Cenozoic crystalline rocks

- Precambrian anorthosites

Medium to very coarse-grained hornblende plagioclase rock; it outcrops in the San Gabriel Mountains area. It could be deeply weathered, broken and shattered with local, hard, slightly weathered to unweathered remnants. In the Soledad Canyon zone it appears to be in tectonic contact with more recent sedimentary units (Vasquez Fm).
Antelope Valley(AV) alignment (Soledad Canyon section)

- Paleozoic to Cretaceous metamorphic rocks

Moderately-foliated, fine-grained phyllites (Paleozoic) with interbedded marble and quartzite layers; this metamorphic complex is abundant towards North of Tehachapi Mountains where it is associated with younger intrusive rocks.
AV alignment

Probably of Paleozoic age highly foliated, sheared and faulted biotitic schists rich in quartz feldspar lenses are found along the Tehachapi Mountain chain where they are strictly associated with and bounded by main regional tectonic structures (Garlock fault zone).
AV alignment (Tehachapi Mountains section)
Cretaceous gneiss, amphibolite and granulite metamorphic complex is present in the northern side of the San Emigdio mountains; the complex is expected to be intensely fractured and weathered also at considerable depths. A Mesozoic to Paleozoic interlayered pile of calcareous, siliceous and pelitic rocks (Keene unit) is present along the tectonic contact between the previous metamorphic complex and the granitic rocks to the South.
I-5 alignment (Grapevine peak)

- Cretaceous intrusive rocks

In terms of relative abundance, they represent the second lithologic group as shown in Figure A2.5; they range in composition from granites, granodiorites, tonalites to quartz diorites and quartz monzonites and are known in the literature under various names. Their geomechanical properties are expected to cover the entire range (from good to very poor) of conditions in relation to specific topographic and tectonic settings.
Both I-5 and AV alignments

Tertiary sedimentary and volcanic rocks

- Vasquez Formation

It consists of coarse clastics, deposited upon volcanic rocks released as the North American tectonic plate initially collided with the Pacific Plate.

Figure A2.6 gives a typical appearance of Vasquez rock formation. The sediments at Vasquez formation were deposited above and with numerous basalt flows that constitute a major portion of the lower sequence; repeated episodes of uplift to quiescence produced several distinctive sequences called megacycles. These megacycles are characterized by coarse clastic sand and gravel deposits at the base of the sequence (as uplift became strong) with an upward fining progression (as tectonic activity slowed down) into the siltstones and shales of a distal alluvial fan playa depositional environment.

Figure A2.6 Typical appearance of Vasquez rocks

AV alignment (Soledad Canyon section)

- Saugus Formation (Pliocene to lower Pleistocene)

Clastic sedimentary unit composed of two principal facies.
A marine Pliocene facies, composed of sandstones, mudstones, red conglomerates beds and thin limestone beds. A fluvial Pliocene Pleistocene facies, consisting of sandstones, conglomerates and siltstones, described as loosely consolidated to poorly cemented.
In the San Gabriel Mountains region, it underwent intense folding by north south directed compressional forces that were associated with the mid-Pleistocene major orogenetic event of San Gabriel Mountains building.
Both *I-5 and AV alignments*

- Ridge Basin Group (Miocene to Pliocene)

Clastic sedimentary units composed of interlayered and interfingered sandstones, siltstones and claystones; each singular lithotype can locally constitute the prevailing rock unit. The sandstone unit is highly folded, fractured and jointed in the vicinity of the major tectonic structures.
I-5 alignment

- Castaic Formation (Miocene)

Shallow marine clastic, moderately lithified unit. Prevailing facies is composed of a thin bedded claystone (crumbly where weathered) with minor, thin sandstone layers. A secondary interlayered facies is composed of fine to medium grained arkosic cohesive sandstones interbedded claystone levels.
I-5 alignment

- Towsley Formation (upper Miocene to lower Pliocene)

Fairly well indurated with lightly, well cemented interbeds of siltstones to sandstones, with local well cemented pebble conglomerate and beds of breccia. They outcrop in the Santa Susana Mountains range where they are expected to be tectonically quite disturbed. Squeezing behavior of claystone layers was reported during the 60's when the 8m-diameter Newhall tunnel was constructed.
Both *I-5 and AV alignments*

- Pico Formation (Pliocene to Pleistocene)

Marine siltstones, sandstones and red conglomerate beds, fairly well indurated with lightly well-cemented interbeds
I-5 alignment

Quaternary deposits
Mainly alluvial type sedimentary deposits ranging form more recent, unconsolidated, undisected valley fill (gravels to silt grained) to older slightly-consolidated deposits. The deposits can reach considerable thickness also along the piedmont areas (300 to 350 ft. exposed thickness in the Mojave zone).
Both *I-5 and AV alignments*

2.4 Groundwater conditions

Groundwater in the considered area is contained in three major aquifer systems which consist primarily of basin fill deposits that occupy structural depressions caused by crustal deformations. The basin-fill aquifer systems are the Basin and Range aquifers, the Central Valley aquifer system, and the Coastal Basins aquifers.

The principal water yielding units are unconsolidated, continental, clastic deposits of Tertiary age that partly fill structural basins created by faulting. Volcanic rocks, which are principally lava and pyroclastic flows of Tertiary age, are important aquifers in some sparse, non contiguous areas.

The recharge of aquifers, which occurs mainly through runoff from precipitation in the surrounding mountains, infiltrates the permeable sediments of the valley floor either at the basin margins or through streambeds.

Confined or semi-confined aquifers are also known to exist in some places, particularly where interlayering and overlapping of fine and coarse sediments do occur (e.g. in the sediment-filled tectonic depression of Antelope Valley where a deeper artesian aquifer is separated from the upper freatic aquifer through fine lacustrine clays).

For the present study no detailed hydrogeologic information was available concerning hydrogeologic regional setting in the mountainous zones: i.e., no data on the hydraulic heads, permeability distributions, flow nets, hydraulic tests. Consequently, a very qualitative hydrogeological characterization has been carried out that allowed the distinguishing of the zones in which tunneling operations could be negatively affected by potential water inflows from the zones where hydrogeologic occurrences, if any, should not cause significant impacts.

Basement rocks (granite-like and metamorphic units) which build up the lower and lateral bound of the basin fill deposits can be normally considered as relatively impervious.

Groundwater flow through rock-like materials is basically controlled by discontinuities in rock masses; intact rocks can be considered practically impervious to water flow (due to very low primary porosity and low degree of pore interconnectivity), whereas water circulation in open fissures, joints, solution cavities is strongly facilitated.

Localized water bearing geologic structures, connected to and recharged from basin fill aquifers and from lakes and streams, are represented by areas of intense rock deformation and rupture such as folds and faults. Where the permeability of the rock material has been strongly enhanced due to tectonization, crushed basement rocks are also important water bearing features with enough effective storage and sufficient permeability to act as a local groundwater reservoir.

Anomalous hydraulic differential heads (in both vertical and horizontal directions) can develop through shear zones due to the presence of impermeable barriers made up of finegrained and weathered fault gouges. Such a condition is of particular relevance for all the numerous underground fault crossings.

2.5 Geomechanical characterization methodology

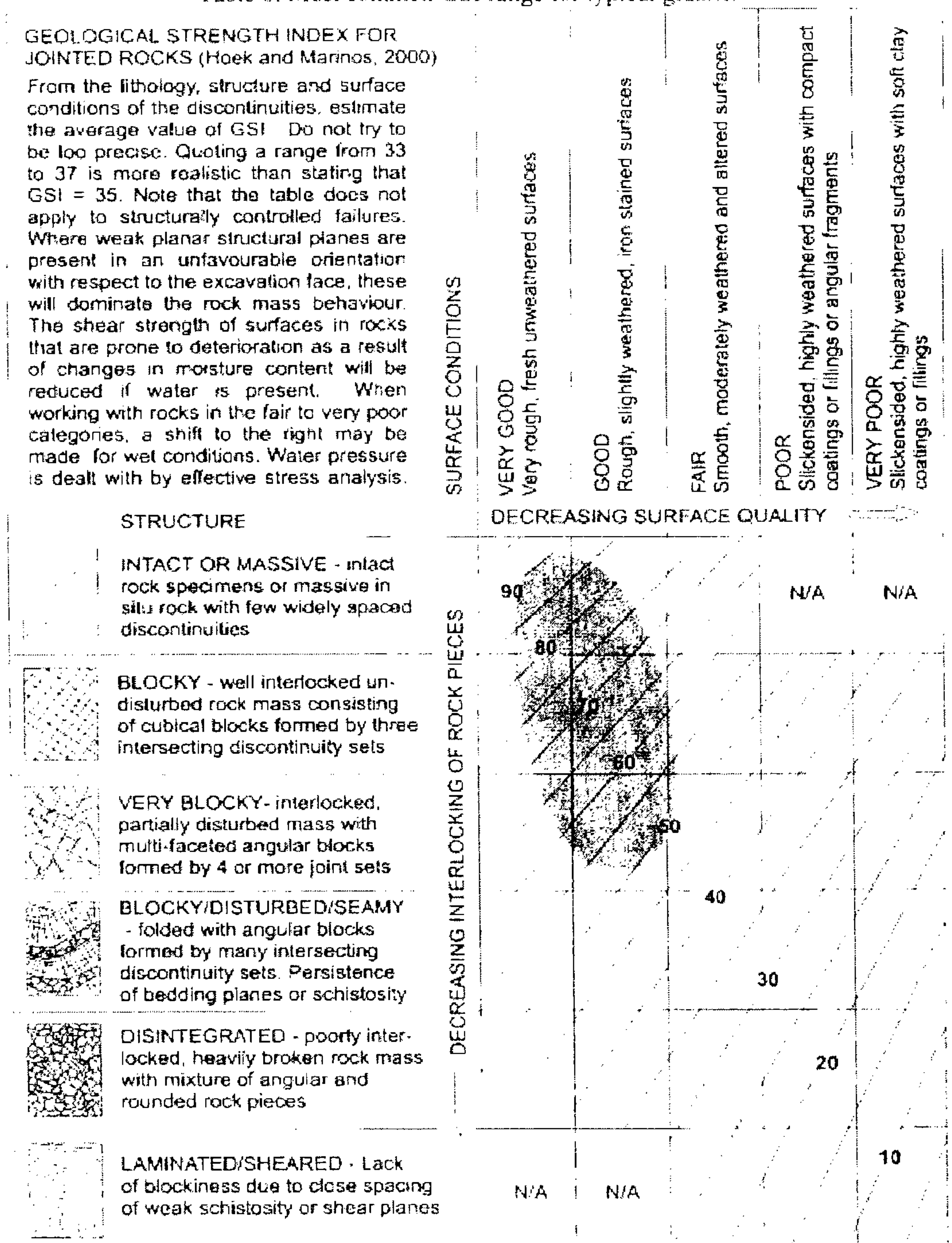
At the present stage of the study, geotechnical and geomechanical data about the geologic units that will be encountered in tunneling are not available.
In order to establish a reference geomechanical frame that permits the describing and classifying of the excavation conditions for tunneling, a simplified approach has been adopted which involves a two-step process:

- First, classify all the geologic units involved in each tunnel alignment into Geomechanical Groups according to the GSI (Geological Strength Index) system proposed by Hoek et al. (1995-2002), that is, assigning characteristic GSI-values to each unit present at the tunnel elevation and subsequently to the right Geomechanical Group;
- Then, determine the behavior class of each geologic unit according to the system proposed by Russo et al. (1998), considering not only the possible geomechanical characteristics of the unit (represented GSI) but also the corresponding in-situ stress conditions (generally, assumed to be geostatic, i.e. only proportional to the thickness of the overburden).

Practically, for Step 1 a characteristic range of GSI is attributed to each geological unit through visual comparison of its “imagined” characteristics with those shown on the special, standard charts by an experienced engineering geologist. As a result, the average, best and worst conditions are obtained. Figures A2.7 and A2.8 present two examples of such GSI charts, comparing two rock types with the standard chart (granite on Figure A2.7, and siltstones and claystones on Figure A2.8, respectively).

Figure A2.7 GSI chart for granites (after Marinos and Hoek, 2000)

Table 8: Most common GSI range for typical granite.*

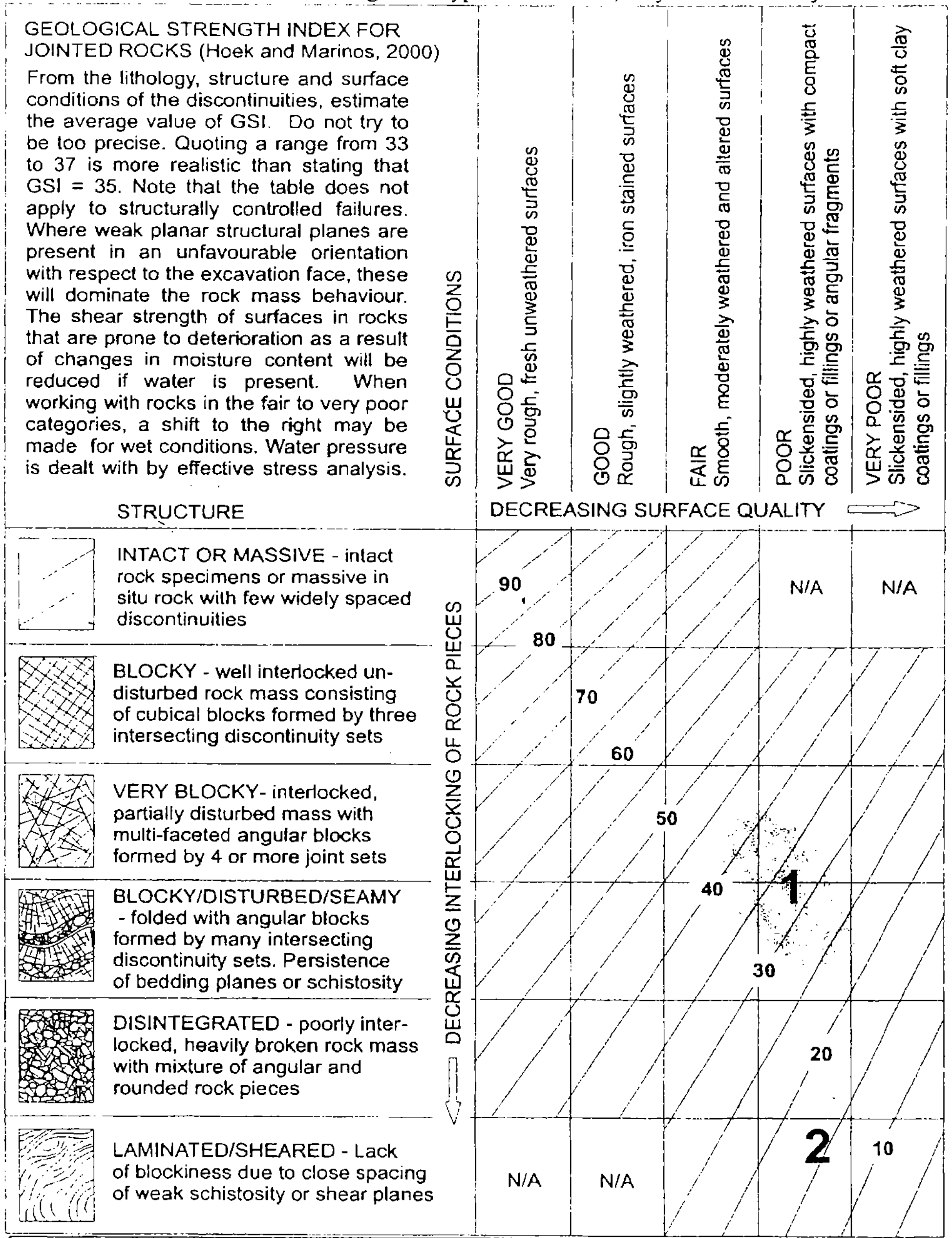


*WARNING:
The shaded areas are indicative and may not be appropriate for site specific design purposes.
Mean values are not suggested for indicative characterisation; the use of ranges is recommended

Only fresh rock masses are shown. Weathered granite may be irregularly illustrated on the GSI chart, since it can be assigned greatly varying GSI values or even behave as an engineering soil.

Figure A2.8 GSI chart for siltstones and claystones (after Marinos & Hoek, 2000)

Table 6: Most common GSI ranges for typical siltstones, claystones and clay shales.*



*WARNING:
The shaded areas are indicative and may not be appropriate for site specific design purposes. Mean values are not suggested for indicative characterisation; the use of ranges is recommended

1. Bedded, foliated, fractured
2. Sheared, brecciated

These soft rocks are classified by GSI as associated with tectonic processes. Otherwise, GSI is not recommended. The same is true for typical marls.

After the definition of geomechanical groups, the analysis of the excavation behaviour of rock masses around the excavation has been carried out, taking into account the existing stress conditions at the assumed tunnel levels.

Analysis are performed by combining the "Convergence-confinement" method (solution of Brown et al., 1983) and the probabilistic approach, through a spreadsheet model developed by Geodata (SIGRES); typical ranges for intact rock parameters, which are the necessary input to carry out such analysis (i.e., UCS, unit weight, etc.) were attributed to each rock type based on data derived from available literature. The latter is considered particularly adequate for the examined cases, in order to incorporate the actual uncertainties and the inherent variability of the geomechanical parameters.

The results of the simulations are classified on the basis of deformation indexes of the face and of the cavity (Russo et al., 1998), distinguishing six possible categories of behavior: from the best (Category "a") to the worst condition (Category "f"). A short description of the categories follows (see also Figure A2.9).

Categories "a-b"

In the behaviour categories "a-b", the strength of the rock mass exceeds the stress level at the face and around the cavity. The ground behaves elastically and in general deformations are of negligible magnitude. Instability phenomena are associated with wedge failure and seldom occur in category "a", where the rock mass is considered as a continuum, but joints are relatively abundant in category "b", where the rock mass is usually considered as discontinuous.

Category "c"

The magnitude of stress concentrations at the face approaches the strength of the rock mass (strength-to-stress ratio, S, is approximately one). The behaviour is elastic-plastic, resulting in minor instabilities. Nevertheless, the deformability gradient at the face is low, and the radial deformation (δ_o), defined as the percentage ratio of radial displacement at the face (u_o) to the equivalent cavity radius, R_o, is less than 0.5%. On the periphery of the cavity the stresses exceed the strength of the rock mass, S<1, resulting in the formation of a plastic zone around the excavation, having a width less than R_o. The formation of the plastic zone results in significant convergence until a new condition of equilibrium is reached.

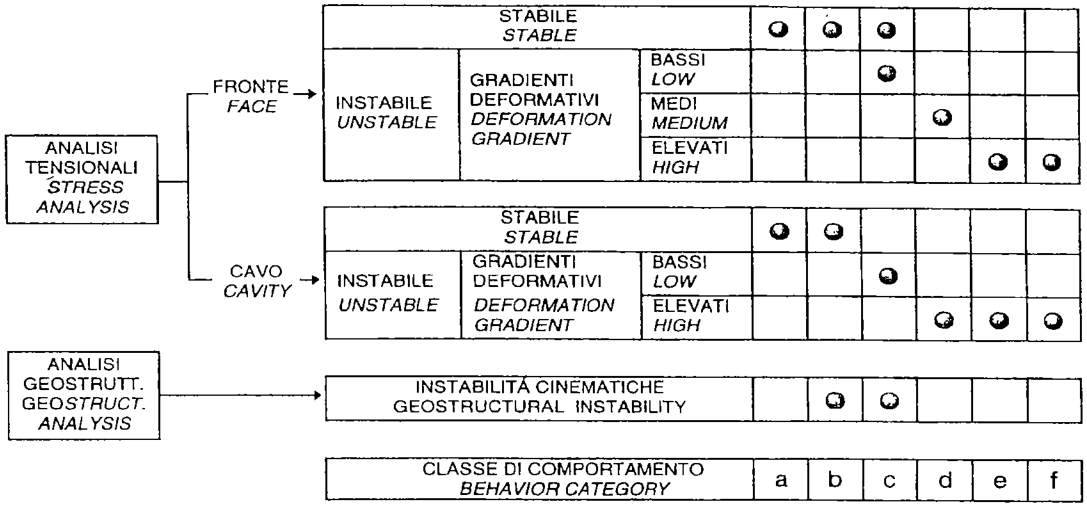
Category "d"

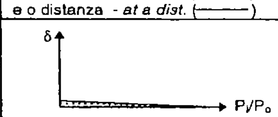
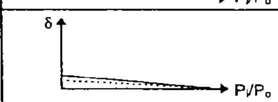
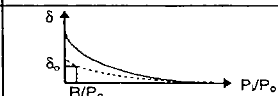
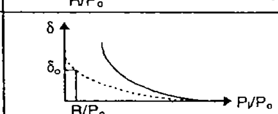
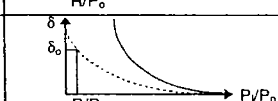
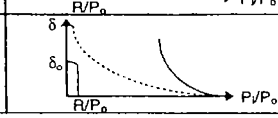
The magnitude of stress concentrations at the face exceeds the strength of the rock mass. The face is in a plastic state. The deformation gradient is low for typical excavation advance rates; therefore, immediate collapse of the face (δ_o<1.0%) is prevented. The plastic state at the face in conjunction with the development of the plastic zone around the cavity results in a worse overall stability condition than that of category "c".

Category "e"

Category "e" differs from category "d" with respect to the magnitude of deformation at the face and away from the face. At the face the stress-to-strength state results in high deformation gradient and critical conditions of face stability (δ_o>1.0%). The width of the plastic zone is greater than R_o. Therefore, in practical terms, this category includes the highly "squeezing" condition.

Figure A2.9 Definition of the behavioural categories (after Russo et al., 1998)



Classe *Category*	Fronte *Face*	Cavo *Cavity*	Curve caratteristiche *Characteristic curve* al fronte - at the *face* (········) e o distanza - *at a dist.* (———)	Interventi di stabilizzazione *Stabilization measures*: Funzione prev. *Primary function*	Interventi di stabilizzazione *Stabilization measures*: Tipologia *Type*
a	stabile *stable* S>1 (lievi instabilità di blocchi) (limited block instability)	Stabile *Stable* S>1 $R_p/R_o = 1$			
b	globalmente stabile *globally stable* S>1 (cinematisimi di blocchi) (wedge instability)	globalmente stabile *globally stable* S>1 (cinematisimi di blocchi) *(wedge instability)* $R_p/R_o = 1$		Confinamento *Confinement*	Radiale *Radial*
c	da stabile a leggermente instabile - *limit condition* S≅1 (bassi gradienti deformativi) *(low deformation gradient)* ($\delta_o \leq 0.5\%$)	instabile *unstable* S<1 (poco spingente) *(light squeezing)* $R_p/R_o \cong$ 1-2		>Confinamento *>Confinement*	Radiale *Radial*
d	instabile: fronte plasticizzato ma stabilità non critica *not critical face instability* (S<1) (medi gradienti deformativi) *(medium deformation gradient)* ($0.5\% < \delta_o < 1.0\%$)	instabile *unstable* S<1 (spingente) *(squeezing)* R_p/R_o ~ 2-4		Confinamento e/o miglioramento *Confinement and/or improvement*	Radiale ed eventualmente in avanzamento *Radial and eventually in advance*
e	instabile: condizioni critiche *critical instability* S<1 (elevati gradienti deformativi) *(high deformation gradient)* ($\delta_o \geq 1.0\%$)	instabile *unstable* S<1 (spingente) *(squeezing)* $R_p/R_o > 4$		Miglioramento e confinamento *Improvement and confinement*	In avanzamento e radiale *In advance and radial*
f	instabile a breve termine *short term stability* S<1 (immediate condizioni di colasso) *(immediate collapse)*	instabile *unstable* S<1		Miglioramento e/o confinamento *Improvement and/or confinement*	In avanzamento e radiale *In advance and radial*

Note:

S=Rapporto di mobilitazione (resistenza/sollecitazioni) *strength-to-stress ratio*

R=Resistenza mezzo nucleo - *strength of half nucleus*

δ=deformazione radiale (rapporto spostamento radiale /R_o) *radial deformation defined as the percent ratio of radial displacement (u_r) to R_o*

δ_o=deformazione radiale scontata al fronte - *radial deformation at the face*

R_p=Raggio plastico - *plastic zone radius*

R_o=Raggio equivalente galleria - *equivalent tunnel radius*

Confinamento: Intervento teso ad evitare la decompressione della roccia e quindi il suo decadimento

Confinement: Measures to avoid relaxation and preserve the inherent rock mass strength

Miglioramento: Intervento teso a migliorare le caratteristiche geomeccaniche della roccia all'estradosso

Improvement: Measures to enhance rock mass characteristics around the cavity

Definizione delle classi di comportamento - *Definition of behavior categories*
(Russo et al., 1998)

Category "f"

Category "f" is characterised by immediate collapse of the face during excavation (impossible to install support). This behaviour is associated with non cohesive soils and cataclastic rock masses such as those found in fault zones, especially under conditions of high, hydrostatic pressure and/or high in-situ stresses.

With specific reference to mechanized tunneling using TBMs, as in the present case, it can be observed that "a" to "d" categories are generally not associated with significant problems for the advancement of the boring machine, while the opposite situation is related to the category "e" (highly "squeezing" condition) and category "f" (immediate collapse of the cavity).

APPENDIX 3 UNIT COSTS OF SOME EUROPEAN TUNNEL PROJECTS

The range of cost values used in the DAT analysis derives from the Consultant's experience gained from similar international projects. Table A3.1 gives a summary of the unit costs (cost per linear meter of tunnel) for different excavation methods of some European high-speed rail projects. The unit costs include the cost of excavation, temporary support and permanent support.

Specifically, the tunnels listed in the table refer to the Gotthard and Lötschberg tunnels in Switzerland, the base tunnel (also known as the Alpetunnel) of the High-Capacity Railway between Turin and Lyon, the High-Speed Railway tunnel between Bologna and Florence, the Monginevro railway tunnel at the border of Italy and France, the Somport tunnel crossing the border of France/Spain, and the Guadarrama tunnel on the High-Speed Railway in Spain.

Table A3.1 Summary of unit costs of some European tunnel projects

Tunnel (Length)	Type of Work	Excavation Method	Rock Quality	Diameter /Section	Cost (US$/m)
Lötschberg (36km)	Railway Tunnel	TBM	Good	9.5m	7500
			Poor		19000
Gotthard (57km)	Railway Tunnel	TBM	Good	9.5m	7400
			Poor		24950
	Shaft (840m)	CONV	-	8.4m	43000
Lugano	Shaft (375m)	CONV	-	7.0m	30300
Alpetunnel (54km)	Railway Tunnel	TBM	Good	9.0m	12600
			Medium		15240
			Poor		30120
		CONV	Good	9.0m	13950
			Medium		18150
			Poor		40000
	Access Tunnel	CONV	-	$70m^2$	24800
Monginevro (23km)	Railway Tunnel	TBM	Good	9.0m	8000
			Medium		9850
			Poor		18100
		CONV	Good	9.0m	11200
			Medium		14000
			Poor		19800
	Access Tunnel	CONV	-	-	14200
Bologna-Firenze	Access Tunnel	CONV	Good	$60m^2$	8200
			Poor	$90m^2$	13000
Guadarrama	Railway Tunnel	TBM	Good	9.5m	10200
	Access Tunnel	CONV	Medium	$75\ m^2$	12000
Somport	Motorway Tunnel	CONV	-	10.0m	10700

APPENDIX 4 REFERENCES

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