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High-Speed Trains For California

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High-Speed Trains For California

Strategic Choice:
Comparison of Technologies and Choice of Route

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CALIFORNIA HIGH SPEED RAIL SERIES

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Definition of Terms

CalSpeed Train (CST):
refers to the VHST steel-wheel-on-rail technology assumed for the proposed mainlines linking Greater Los Angeles, the San Francisco Bay Area, and Sacramento. The CST is discussed in Chapter 3.

High-Speed Ground Transportation (HSGT):
includes HST or VHST steel wheel or Maglev technologies.

High-Speed Train (HST):
refers to steel-wheel-on-rail technology capable of top speeds in the neighborhood of 125-155 mph.

Maglev:
refers to magnetic-levitation-guided transport technologies.

Very High-Speed Train (VHST):
refers to steel-wheel-on-rail technology capable of over 155 mph top speeds.

PREFACE

This report represents the conclusion of the first year of IURD's study of the potential for a high-speed passenger train service in California. Seven previous studies have each dealt with a specific high-speed train technology; each attempted an evaluation, standardized so far as data permitted, of its technical and economic viability.

The present report first summarizes and synthesizes these seven studies, attempting a systematic point-by-point comparison. Then it goes on to develop a possible high-speed network for California in the light of known facts about the state's physical and economic geography. It develops physical profiles for such a route, and uses available cost data to produce an estimate of total construction cost. It gives simulations of timings between the major urban areas. These data will be used as basic inputs to the second stage of the work, now under way, which will analyze the market prospects for such a system and the ways in which it might be financed.

We gratefully acknowledge the support provided by the United States Department of Transportation and the California Department of Transportation [CALTRANS] through the University of California Transportation Center. Of course, any errors of fact or interpretation should be assigned to us and not to our sponsors.

During our study, after we concluded that we should recommend adoption of steel-wheel-on-steel-rail technology based on the French TGV, we approached M. André Huber of GEC-Alsthom for assistance in providing technical data about the performance of the TGV and in simulating its performance in California conditions. We want to acknowledge his help in this part of our study.

Our thanks go to the Caltrans Division of Rail, the San Francisco office of Morrison-Knudsen, Henry Johnson, and many other parties at numerous public agencies who were most helpful in providing information and offering helpful comments and criticism on the draft version of this report. Thanks also go to the University of California Transportation Center for funding this worl Finally, many thanks to the staff at I.U.R.D. for their help and support in producing this report.

EXECUTIVE SUMMARY

This report has two purposes:

(1) To evaluate candidate technologies for provision of a High-Speed Ground Transportation (HSGT) system for California.

(2) To survey and evaluate route options for such a system.

Comparison of Technologies

The candidate technologies have been evaluated in detail in separate working papers of the project, and are summarized here. Six are steel-wheel on steel-rail technologies: the Japanese *Shinkansen*, (SKS) the *French Train à Grande Vitesse* (TGV), the German *InterCity Express* (ICE), two *Tilt Trains* (the Italian ETR-450 and the Swedish X-2000), and the British *InterCity 125 and 225* (IC 125/225). Two are magnetic levitation technologies: the German *Transrapid* (TR) and the *Japanese Linear Motor Car (LMC)*. All the steel-wheel technologies except the British are classifiable as Very High-Speed Trains, currently capable of maximum speeds between 155 and 186 mph and potentially capable of 200-220 mph. The maximum speed of the Magnetic Levitation systems is still uncertain, but is likely to be in the range 250-300 mph.

The report summarizes the technical and commercial characteristics and performance of the systems, insofar as information is available. These are presented in a table with detailed explanatory notes.

A strategic assessment, the report argues, must depend on certain key elements. These are identified as feasibility, compatibility, cost, overall performance, and environmental impact.

Feasibility can only be demonstrated in regular, extended revenue service. Only four steel-wheel systems —the SKS, TGV, ETR-450, and IC 125/225 —so far meet this criterion, though the ICE and X-2000 may well do so during the next few years.

Compatibility with existing track systems allows trains to operate to and from any place served by such systems, and allows incremental upgrading of the level of service. All steel-wheel systems offer this feature except the Shinkansen; this last is, however, a result of its incompatibility with Japan's narrow-gauge rail system, and would not present such a disadvantage in American conditions. Maglev systems in contrast demand a separate dedicated track formation, which is not compatible with existing track systems.

Cost depends on a number of elements, especially track and train systems. The cost of the track depends on the amount of new construction and its technical parameters, especially gradients which determine the amount of cut and fill and of expensive bridge and tunnel construction. This is significant in mountain crossings. The IC 125/225, ETR 450, and X-2000 are the cheapest systems in terms of capital costs because of their minimal infrastructure costs, though maintenance costs for the tilt trains may be relatively high; however, none achieves highest possible speeds (as discussed later in this paper). The TGV appears the next most cost-effective system. TR also appears cost-effective (but with no revenue experience so far) and has superior gradient characteristics.

Overall performance depends especially on the capacity for sustained high-speed intercity service. Maglev offers the highest standards here, although so far untested in revenue service; it appears that the difference in maximum speed may prove to be on the order of 270 mph for Maglev versus 200-220 mph for VHST, while average start-to-stop speeds would of course be lower for both systems.

Environmental impacts include noise, emissions, visual intrusion, severance, and electromagnetic fields. These have so far been imperfectly evaluated and good comparative data are lacking. It appears that Maglev systems may be superior to VHST systems on emissions — this refers to all emissions, mainly generated by power generation, not by the trains themselves — and all might well be reduced by appropriate measures. Noise could and should be reduced by lower speeds in urban areas, probably 100-125 mph maximum, as well as by noise attenuation devices such as barriers.

Overall, VHST steel-wheel systems presently are to be preferred on the critical criterion of feasibility. A VHST steel-wheel technology presently seems to offer clear advantages in cost effectiveness combined with compatibility, performance, and proven reliability in revenue service. Maglev systems may eventually prove superior on performance, but the advantage is so far untested and may not be large. The evidence on environmental impact is so far unclear.

We conclude that a California HSGT system should be based on VHST technology, probably to be determined by competitive tendering. The design parameters should be based on the most advanced VHST technology available, effectively the advanced version of the TGV developed for the Australian Very Fast Train (VFT) and/or the forthcoming ICE-M system, which employ similar design parameters. These parameters are adopted in the next section of the report.

Choice of Route

The first priority for a California HSGT must be to provide for the fastest possible journey times between the state's two major urban areas and transportation markets, Greater Los Angeles and the San Francisco Bay Area. A second priority should be to provide the best possible level of service to the next level of urban areas, including San Diego, Sacramento, and the major cities of the Central Valley. Reconciling these objectives requires some degree of compromise.

Although these urban areas are connected through the Central Valley, with its relatively easy terrain, there are three major problems: the difficult mountain crossings at the southern end of the Valley and across the coast ranges in to the Bay Area; the very great extent of the urban areas and the resulting problem of environmental impact; and the fact that the existing rail infrastructure is of unacceptably low quality for high-speed operation without complete reconstruction. These suggest VHST service on new dedicated track between the major urban areas, plus HST on new tracks constructed on existing rail corridors within the urban areas.

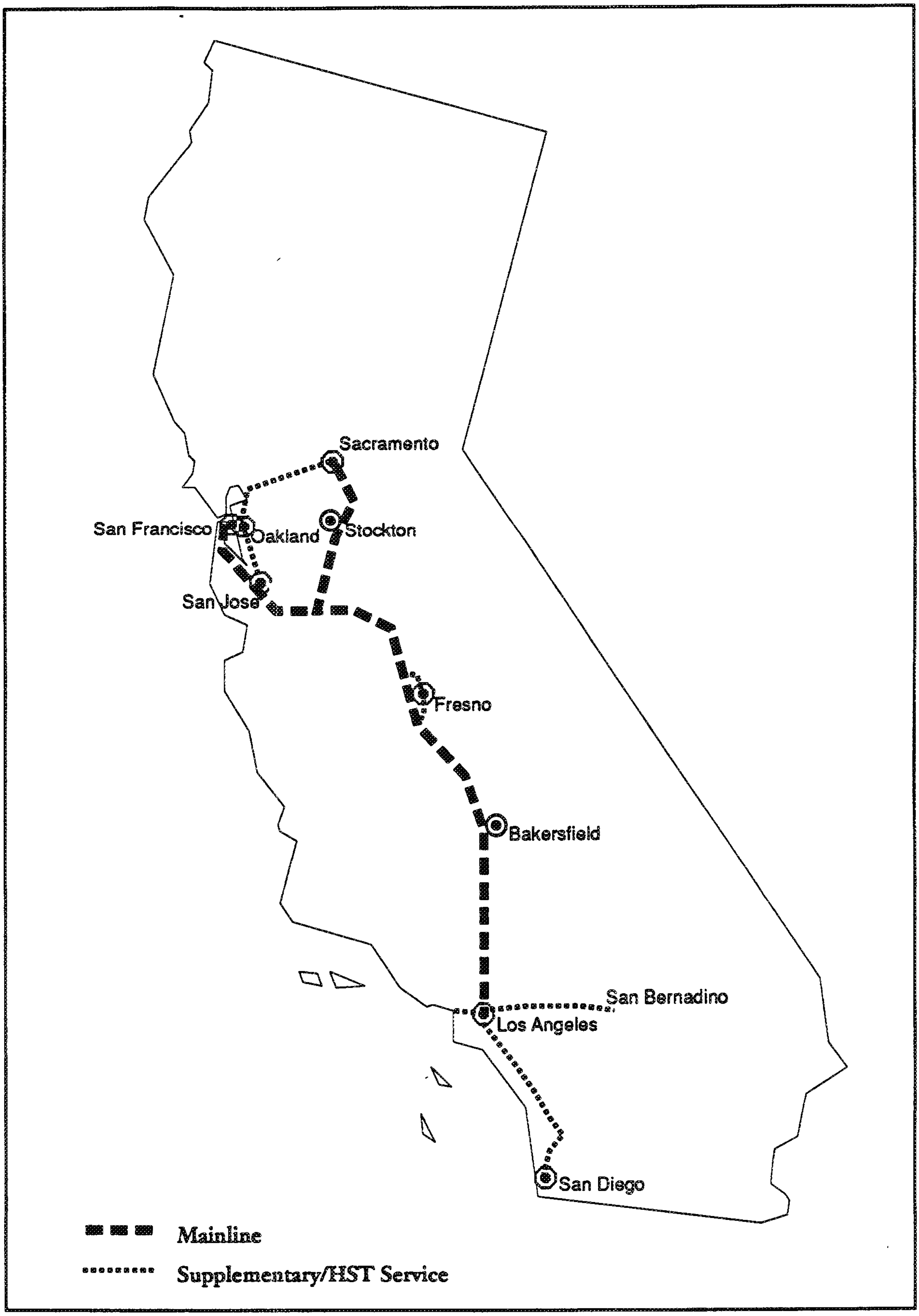
In order to serve the major markets competitively, a VHST spine connecting Greater Los Angeles and the San Francisco Bay Area would form the foundation of a California HSGT network. A branch serving Sacramento could be relatively easily added to this mainline and would offer a very attractive service between the state capital and Los Angeles (see Figure E.1).

The mainline begins at Los Angeles Union Station. After running on reconstructed right-of-way north to Newhall, the line would most likely cross the San Gabriel/Tehachapi Mountains via the Grapevine pass. Reaching the Central Valley, the line could follow one of two configurations: one following I-5 direct to the San Francisco area and the other serving Bakersfield and Fresno on a new dedicated right-of-way to the west of these cities. This latter appears the most promising alternative in terms of the tradeoff between the two objectives stated above.

Northwest of Fresno the mainline would split. One arm would follow the Pacheco Pass to Gilroy at the southern end of the Santa Clara Valley, and would then employ either the median of US-101 or the existing Southern Pacific right-of-way to San Jose. North of San Jose, this branch would use the Southern Pacific right-of-way up the peninsula to San Francisco, with a stop serving the San Francisco Airport. Another branch using an existing Southern Pacific right-of-way might serve a station in West Oakland.

The second branch of the mainline would continue on dedicated tracks to serve Modesto and Stockton en route to Sacramento. The preferred option to serve the Central Valley cities

FIGURE E.1: THE CALSPEED NETWORK



would be to construct new dedicated stations associated with major urban developments. However, loops to serve the existing downtowns would be an additional option.

A difficult geography, environmental constraints, and technical limits all conspire to make VHST service on the Los Angeles-to-San Diego and Bay Area-to-Sacramento routes presently infeasible. A more practical option is the upgrading of existing rail corridors to the best HST service possible, with electrification and tilt train technology playing important roles. Further study on new alignments for VHST service may take place as market demand warrants.

The Bay Area-to-Sacramento line would continue onward from San Jose via West Oakland, using upgraded Southern Pacific right-of-way, with the option of using some higher-speed diversions to Sacramento. Traffic on this sector could be expected to include a Bay Area-Sacramento shuttle and long-distance commute service as well as feeders to the VHST long-distance service. Because of severe curvatures in the existing alignment, this section might be a good candidate for use of tilt train technology. At Sacramento, this line would link with the VHST mainline down the Central Valley, offering the possibility of continuous circular service between West Oakland, Sacramento, Stockton, Modesto, and San Jose.

The Los Angeles to San Diego line would be an upgraded version of Amtrak's current intercity service, using the Santa Fe corridor from L.A. Union Station to downtown San Diego. Like the Bay Area-Sacramento line, traffic on this sector could be expected to include a San Diego-Los Angeles shuttle and long-distance commute service as well as feeders to the VHST long-distance service.

VHST intercity trainsets could be run on electrified and suitably upgraded commuter rail lines in the Los Angeles Basin to pick up and drop off long-distance passengers, thus making the whole system more accessible. Alternatively, commuter trains could provide the feeder service until demand justified the investment in upgrading the commuter lines.

Cost

The basis of the cost estimates is presented in Appendix B. Infrastructure costs for the VHST mainline connecting Los Angeles to San Francisco are estimated at $9.0 billion (see Table E.1). The VHST mainline branch providing service between Los Angeles and Sacramento would cost $1.3 billion. VHST trainsets would cost approximately $33 million each. Assuming a fleet of

TABLE E.1
CalSpeed Train Routing Summary
DISTANCES, EXPRESS TRAVEL TIMES AND COSTS

SEGMENT	DISTANCE TOTAL (MILES)	MAXIMUM SPEED (MPH)	AVERAGE SPEED (MPH)	TRAVEL TIME		TOTAL COST (DOLLARS)
				TOTAL (HOURS)	TOTAL (MINUTES)	
1. LOS ANGELES TO SAN FRANCISCO:						
L.A. BASIN	32	125	89.8	0.36	21.6	1,043,100,000
GRAPEVINE 5.0%	49	200	167.5	0.29	17.5	2,017,000,000
CENTRAL CORRIDOR	205	200	200.0	1.03	61.5	2,236,600,000
PACHECO PASS 5.0%	34	200	183.4	0.18	11.0	1,237,300,000
SCV: US-101	29	150	126.6	0.23	13.7	514,200,000
BAY AREA: SJ-SF	49	100	77.4	0.63	38.0	1,922,800,000
TOTAL:	398	200	146.1	2.72	163.3	$8,971,000,000
2. MAINLINE EXTENTION TO SACRAMENTO:						
PP-SAC NEW R/W	111	200	170.2	0.65	39.0	$1,258,000,000
3. SAN JOSE TO SACRAMENTO:						
	130	155	89.7	1.45	87.0	$2,858,000,000
4. LOS ANGELES TO SAN DIEGO						
	123	125	105.7	1.16	69.6	$3,239,000,000

ADDTIONAL COST:	
TRAINSETS	$33 MILLION EACH

20,[1] the total cost for rolling stock would be an additional $660 million for the Los Angeles to San Francisco mainline.

Infrastructure costs for electrifying and upgrading the San Jose to Sacramento corridor to HST level would be $2.9 billion. Similarly, to electrify and upgrade the Los Angeles-San Diego service to HST would cost $3.2 billion.

Strategy for Implementation

Following is a strategy based upon an intuitive assessment of the financial and institutional environment in California as well as the market for intercity travel:

The VHST mainline linking Greater Los Angeles with the Bay Area and Sacramento is a capital-intensive undertaking which will require private or joint public/private investment. This VHST mainline must be an "all at once proposition" if it is to be attractive to the private sector. Incremental upgrading of existing rail corridors will not attract private investment, since the resulting travel times could not compete with air or auto travel.

The costly new Southern California mountain crossing is not justifiable without the VHST link between Los Angeles and the Bay Area/Sacramento. If engineered to conventional train standards, the crossing would pose a severe impediment to competitive rail service between the major markets. Therefore, the pass should be engineered for a proven, VHST steel-wheel technology (approximately 5 percent grade and 19,680-foot horizontal curvature). The choice of these standards would not seriously impede performance in the eventuality that a Maglev technology were chosen.

In contrast to the VHST mainline, the HST candidate corridors (Los Angeles to San Diego and the Bay Area to Sacramento) and feeder services (the commuter lines) are suitable for incremental improvement and are thus more properly the province of the public sector, which has already committed substantial funds to upgrading them.

The overall strategy for implementing a HSGT network in California would rely on private sector investment in the VHST "trunk" with simultaneous public investment in upgrading the "branches." Prior to private sector commitment, the public sector might adopt the following strategy: plan rail corridor upgrade projects so as to facilitate the eventual linkage with the VHST lines,

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[1] A conservative figure synthesized from the TRB 1991 source and the Texas TGV franchise application estimates.

begin right-of-way preservation, and undertake a carefully thought-out preliminary engineering study on the Southern California mountain crossing, the most difficult engineering challenge.

A critical question will revolve around the use of shared right-of-way for intercity and commute services. A new formula for the sharing of costs and benefits between different systems will be required. This question will be the subject of further study along with market potential and other institutional and financial questions.

FIGURE E.2: FRENCH TRAIN À GRANDE VITESSE (TGV) *ATLANTIQUE*

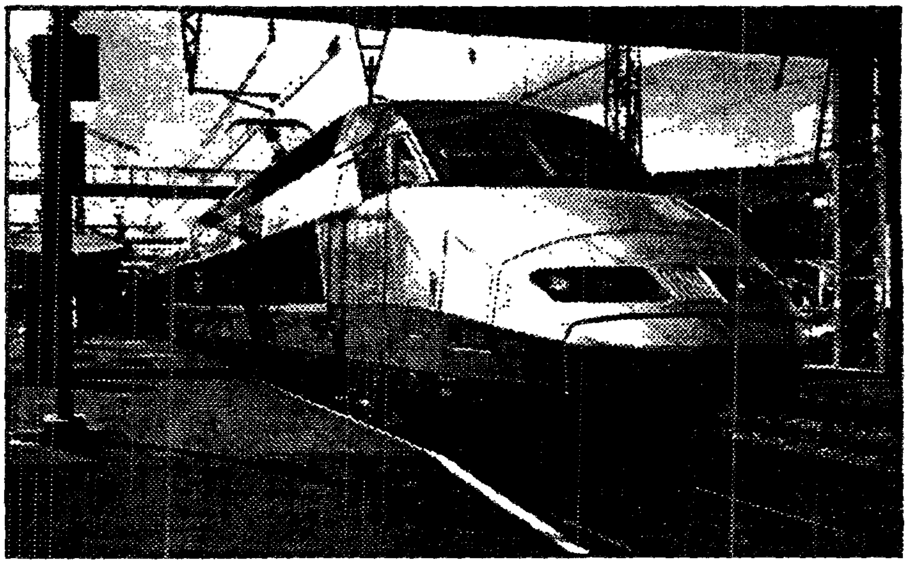
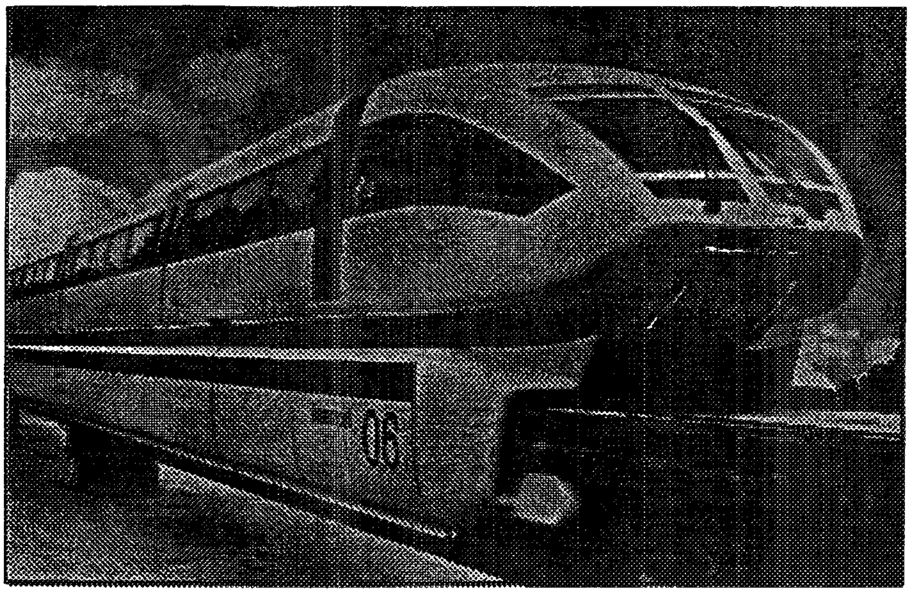
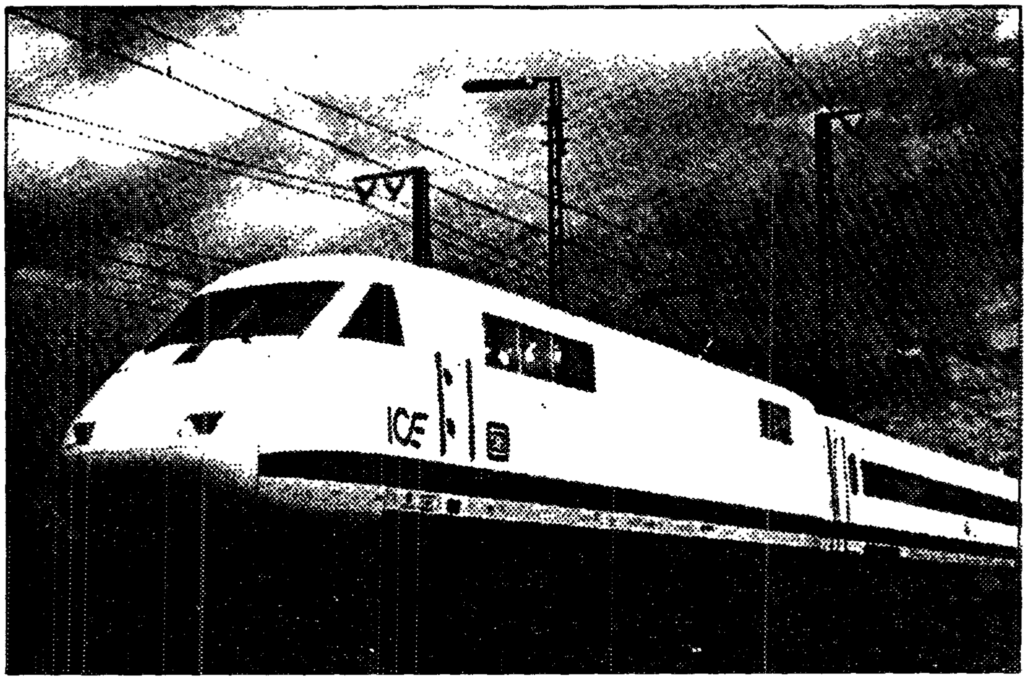


FIGURE E.3: THE MAGNETIC LEVITATION TRAIN



Source: Elwin Hennis, Super Speed Train Project

FIGURE E.4: INTERCITY EXPRESS (ICE)



Source: Bundesbahn-Zentralamt München. 1990. *Hochgeschwindigkeitszug ICE.* Munich: Deutche Bundesbahne (May).

1. INTRODUCTION

High-speed ground transportation is near the top of 1992's transportation policy agenda for California. The reasons are self-evident:

(1) Increasing gridlock on the state's highways, spreading from the cores of their metropolitan areas to their distant peripheries, and impeding intercity automobile trips.

(2) Increasing congestion in the state's leading airports, and extreme difficulty in expanding their capacity to meet projected demand, above all on the air corridor between Los Angeles and the San Francisco Bay Area — one of the most densely trafficked in the world.

(3) Growing concern about the environmental consequences of automobile emissions, which has already resulted in the adoption of policies by the Southern California Air Quality Control District, which will progressively phase out the gasoline-fueled internal combustion engine from 1997 onward.

(4) The release of substantial Federal funds through the Intermodal Surface Transportation Efficiency Act of 1991 — $151 billion, of which $31.5 billion is earmarked for transit over the next six years, with the strong possibility that states such as California will divert further allocations from highways to transit.

(5) The realization that other countries (Japan, France, Germany) and now other states (Texas) are drawing far ahead of California in adopting high-speed rail systems as an alternative to air and automobile intercity travel. CALTRANS has set up a Division of Rail with a specific remit to look at the technical and economic feasibility of high-speed rail in California, and substantial sums seem likely to be voted by the Assembly for studies during 1992-3.

Meanwhile, the U.S. Department of Transportation, through the University of California Transportation Center (UCTC), awarded a $101,741 one-year grant, August 1991-July 1992, to the Institute of Urban and Regional Development, UC Berkeley (IURD), for a preliminary survey of the potential for high-speed ground transportation in California (CalSpeed). In the first six months of the study, CalSpeed has evaluated seven major candidate technologies:

(1) *Shinkansen*: the Japanese "bullet train" (literally, "New Trunk Line").

(2) *TGV*: the French *Train à Grande Vitesse* (High-Speed Train).

(3) *ICE*: the German InterCity Express.

(4) *Tilt Trains*: the Italian *ETR-450* and the Swedish *X-2000*, which use tilting technology to allow trains to negotiate curves at much higher speeds than conventionally-engineered trains.

(5) *InterCity 125 and 225*: the British intercity expresses, which run exclusively on upgraded regular track.

(6) *Transrapid*: the German Magnetic Levitation system.

(7) *Linear Motor Car*: the Japanese Magnetic Levitation system.

Each of these forms the subject of a separate technological evaluation report.[1] Six of these are published simultaneously with this report; the seventh report is in press and will be published shortly. Results from all seven are included in this comparative report.

The evaluation of the separate systems has now reached a point where a comparative assessment of technical, economic, and environmental performance can be made. That is the first purpose of this report. The assessment is in Chapter 2.

Simultaneously, work has taken place on a preliminary assessment of the optimum configuration of a high-speed system for California. This has been based on an appreciation of the main markets for intercity travel, and of the technical constraints imposed by topography, existing urban development, the existing rail system, and the technical characteristics of each system. This work has now resulted in a proposed network, embodying some major strategic variants, for further assessment and testing. The second purpose of this report is to present the network. Chapter 3 is a discussion of the assumed technology and its impacts on the network. The very high-speed mainline linking the major California markets is presented in Chapter 4. Chapter 5 discusses the high-speed and conventional rail branches that would feed into the mainline. A summary of findings and conclusions can be found in Chapter 6.

To keep this report to a manageable length, the work is presented in two volumes. Volume I contains the main body of the report. Volume II contains detailed segment descriptions of the route, cost estimates, and travel time calculations.

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[1] See Appendix A.

2. THE COMPARISON OF TECHNOLOGIES

Classification and Description of Technologies

High-speed ground transportation (*HSGT*), as understood in countries where it is already in service or in advanced development, is basically and primarily an *intercity* transportation mode, characteristically connecting cities 100-500 miles apart, at maximum speeds of between 125 and 300 mph (200-500 km/hr). It may, however, also provide an intermediate level of service, in particular to suburban stations in larger metropolitan areas, where trains may stop to pick up or set down passengers; in some countries it may also carry longer-distance commuters, with station stops between 15 and 80 miles apart.

HSGT can be conveniently subdivided into the following categories in terms of overall speed:

- *HST* High-Speed Train: maximum speed 125-155 mph, on either dedicated new or upgraded track; e.g., Shinkansen, InterCity 125/225, Tilt Trains.
- *VHST* Very High-Speed Train: maximum speed 155-220 mph, on dedicated track; e.g., TGV-Atlantique, InterCity Express.
- Maglev: speed 200-300 mph+, either in German or Japanese versions.

Eight varieties of HSGT have been evaluated in terms of their technical specifications, performance characteristics, and operating performance. These evaluations are contained in CalSpeed reports 1-7, published simultaneously with this report.[2] The following paragraphs briefly describe each of them.

The *Shinkansen* (*SKS*) is the oldest-established HSGT system in the world, having begun service on the original Tokaido line between Tokyo and Osaka in 1964. This line was subsequently extended, and further lines were added in 1982-5; in addition, further extensions are being built or planned. It is an HST system, running at a maximum of 140 mph in the original configuration, and at 155 mph on later lines; speeds as high as 219 mph are envisaged. The trains run on international standard-gauge (4'8½") track which is 100 percent dedicated, since Japanese railways operate on 3'6" gauge tracks; an extension to open in 1992 will, however, operate over mixed-gauge track. The SKS has demonstrated an impressive performance and safety record over more than a quarter of a century; commercial results have been impressive, and the original line is near the limit of capacity.

The French *Train à Grande Vitesse* or *High-Speed Train* (*TGV*) began service over the Paris-Lyon line (*TGV Sud-Est*) in 1981; a second line, from Paris to west and southwest France (*TGV*

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[2] The seventh, on British Rail InterCity 125 and 225, is in press.

Atlantique), opened in 1989-90. It is a VHST system, running at a maximum speed of 168 mph on the original line and 186 mph on the *Atlantique*; the *TGV Nord*, to open in 1993, will operate at 196 mph, and speeds up to 217 mph are envisaged for the next generation of trains. Unlike the SKS, the TGV is a part-dedicated system; trains operate at very high speed on the dedicated sections, typically for distances of 120-300 miles from Paris, before returning to upgraded, older general-purpose tracks for the final part of their journey. The system is thus able to reach most major cities in a particular geographical sector at a relatively economical cost. The original *Sud-Est* line has recorded impressive performance and safety records and has been an outstanding commercial success, repaying its original costs after three years of service.

The German *InterCity Express* (*ICE*) began operation in summer 1991 between Hamburg, Hannover, Frankfurt, Stuttgart, and Munich. Like the TGV, it runs partly on dedicated and partly on upgraded tracks. It is a VHST system: trains achieve a maximum speed of 155 mph on the new dedicated stretches, although the next generation of trains will operate at 196 mph and the system is designed to operate eventually at speeds of over 200 mph. By the year 2000, specially-designed ICE and TGV trains will jointly operate international services between Frankfurt, Cologne, Brussels, Paris, and London. Since the system is still in its first year of operation, no firm technical or commercial results are yet available.

Two *Tilt Train* technologies, which use special tilting mechanisms to allow trains to run at high speeds over relatively sharp curves, are in operation in Europe: the Italian *ETR-450* (and its predecessor, the *Pendolino*), which has operated between Rome, Florence, and Milan since 1988; and the Swedish *X-2000*, which has run between Stockholm and Gothenburg since 1990. Both are VHST systems (maximum speed 155 mph, although the Swedish system presently operates at a maximum of 125 mph) designed to operate on conventional tracks, but in both stretches of new dedicated line are incorporated (in the Swedish case still under construction). In Italy the ETR-450 will eventually be phased out in favor of conventional VHST trains operating over mainly dedicated track, but will be cascaded down to operate over other routes with difficult characteristics.

British Rail's *InterCity 125 and 225* are in important respects anomalous. Both are non-dedicated HST systems with a maximum speed of 125 mph (to be upgraded to 140 mph on the 225 variant as soon as Automatic Train Protection is available), running over upgraded tracks; the 125 version is diesel-hauled, and the 225 hauled by electric locomotives. The 125 variant was introduced between London, Bristol, and South Wales in 1976 and between London, Leeds, Newcastle, and Edinburgh in 1978; the latter was electrified and upgraded to 225 service in 1989-91. The 125 service has shown excellent performance and commercial results in densely trafficked service. BR plan a further upgrade, the InterCity 250, operating at 155 mph maximum speed between London and Manchester within the next decade; this may involve some short stretches of dedicated new line.

The *Transrapid* (*TR*) is a German Maglev system, under intensive test for approximately 15 years but not so far introduced into revenue service; proposals to use it in Germany between Cologne-Bonn, Düsseldorf, and Essen, and in the United States between Los Angeles and Las Vegas, have been delayed, although it is now decided to employ it in high-speed service between Hamburg and Berlin. It is a totally dedicated system operating on its own guideway, which acts as the motor system for the train. It has achieved a maximum speed of 271 mph on test; the probable maximum usable speed is 250 mph.

The *Linear Motor Car* (*LMC*) is a Japanese Maglev system, developed by Japan Railways, and intensively tested since 1977. The train uses a dedicated guideway and is propelled by on-board superconducting magnets. An early prototype achieved a maximum speed of 323 mph on test. Revenue service is eventually planned over a 300-mile route between Tokyo and Osaka, but considerable further testing will be necessary before this can commence.

Basic Assumptions and Definitions

Table 2.1 sets out comparative data for these eight systems. For the six steel-wheel VHST and HST systems, Table 2.1 gives both basic technical data and operating data, so far as it is available; for the Maglev systems the table has no operating data, since neither system is yet commercially operational.

The data in these tables have been assembled from CalSpeed technical working papers 1-7, plus some additional analysis. In many cases they have involved making certain assumptions, which —in order to avoid unmanageably long footnotes— are set out in more detail below as a commentary on the tables themselves.

Miles in Service/High-Speed Percent: These are at the time of writing (May 1992). Total miles are all route miles served by high-speed trains, whether directly over high-speed lines or not; for the Maglev systems these are nil. High-speed mileage is dedicated, purpose-built, new high-speed track except for IC 125/225. In the case of the SKS, which is a 100 percent dedicated system, the two figures are identical. (In all these systems, trains operate at lower speeds in certain places, especially within urban areas.) Line 3 is a ratio of lines 1 and 2.

Table 2.1

Comparison of Key Data:
Steel Wheel/Steel Rail and Maglev Systems

1. NETWORK/FORMATION

	SKS	TGV	ICE	ETR-450	X-2000	IC 125/225	TR	LMC
Miles in Service (Total)	1140	2920	590	1367	283	1151	0	0
Miles in Service (High-Speed)	1140	436	265	161	283	1151	0	0
High-Speed % Total	100	15	45	12	100	100	100	100
Miles in Test							19.6	4
Ability to use Existing Track	Part	Yes	Yes	Yes	Yes	Yes	No	No
Incremental Upgrade	Part	Yes	Yes	Yes	Yes	Yes	No	No
Formation Width, feet*	35-38	45	45				40	35.4
Gauge*	4'8½"	4'8½"	4'8½"	4'8-½	4'8-½	4'8-½	NA	NA
Maximum Grade %*	2.0/1.5	3.5/2.5	3.0/4.0	1.8	1.81	0.5	10	4
Maximum Curve, thousand feet*	8.2/13.1	13.1	16.1/23.0				13.7	26.2
% Tunnel*	13/57	5	36					
% Viaduct/Bridge*	8/12	1	8					
Station Spacing, miles (Total)	20.0/18.6	42.3	49.2	61	94	27/131	12.6-32.8	62?
Station Spacing, miles (High-Spd)	20.0/18.6	72.7	53.0	61	94	27/131	12.6-32.8	62

2. TRAINS

	SKS	TGV	ICE	ETR-450	X-2000	IC 125/225	TR	LMC
No. of passenger cars	16/12	10x2	13	5/11	5	8/9	10	14
Train length, feet	1312/1148	779x2	1348	419/895	367	720/795	870	1033
Train capacity, passengers:								
1st	52	116x2	192	178/442	102	96/112		
2nd	805	369x2	462	None	152	360/444		
Other			39					
Total	857	485x2	693	178/442	254	456/556	1000	950
Train Control	ATC	ATC	ATC	Part ATC	Part ATC	CA/ATC	ATC	ATC
Speed, maximum potential, m.p.h.	216	320	253	155	155	140	300?	300?
Speed, maximum actual, m.p.h.	169/172	168/186	155	155	131	125	271	323
Speed, maximum planned, m.p.h.	219	196/217	196/217	155	131	140	250	300?
Speed, average, m.p.h.	125/140	132/147	91/100	74	83	97/109	146/171	
Acceleration,								
0-60 m.p.h., secs.			66					
0-125 m.p.h., secs.			200					
0-155 m.p.h., secs.			380					
Stopping from max speed, miles	1.9	2.2	3.0	1.6	0.9			
Headway, minutes, minimum	4	5	60**			5/10	12	
Trains/hour, peak	11	7	1			8/6	4-5	
Station Stop (Dwell Time), minutes	1-2	2-3	1-4	3		2/3		
On Time %	80	92						

	SKS	TGV	ICE	ETR-450	X-2000	IC 125/225	TR	LMC
3. TRAFFIC								
Passengers, million, latest	236	60	9+					
Passenger-miles	40998	9258						
Fares, cents/mile:								
1st	38	20-30	51-57			30		
2nd	29	13-19	33-38			20		
Total Population	68.1/47.3	14.1/13.2	14.6	58	4	10.6/15.5		
Ratio Populations at Ends	0.49/0.03	0.40/0.31	1.64/2.48		2	0.17/0.71		
4. SAFETY								
Accidents/million miles	None	None		None	None			
5. COSTS AND REVENUES								
Construction Costs, $m./mile	35.7-39.9	9.6	40.5		.7/2.8-3.5	2.3	11.0-24.8#	35.2#
Train costs, $000/seat			46.9	38.4	66.9	16.0		
Revenues/cost	2.4/0.5	2.3						11-31#
Years to Profit		3/10-11						
Share of Rail plus Air								
at approximately 300 miles	80-90	90			50			
at approximately 500 miles		51						
at approximately 700 miles	30							
6. ENVIRONMENT								
Primary Energy Consumption:								
125 mph, Watts/Seat/Mile							132	
155 mph, Watts/Seat/Mile							148	
186 mph, Watts/Seat/Mile							280	
250 mph, Watts/Seat/Mile							253	
Secondary Energy Consumption:								
125 mph, Watts/Seat/Mile							60	
155 mph, Watts/Seat/Mile							92	
186 mph, Watts/Seat/Mile							102	
250 mph, Watts/Seat/Mile							-	
Noise, 82 feet, 125 mph, Db(A)	70 hon	86	82~				79	
Noise, 82 feet, 155 mph, dB(A)		88	85~				82.5	
Noise, 82 feet, 186 mph, dB(A)		92	89~				86.5	
Noise, 82 feet, 250 mph, dB(A)			102				93/5	
Noise, 164 feet, 186 mph, dB(A)		92	87				81	

6. ENVIRONMENT (cont'd)	SKS	TGV	ICE	ETR-450	X-2000	IC 125/225	TR	LMC
Emissions, 125 mph:								
CO			2.6				2.0	
NOX			10.7				8.5	
SO2			8.9				17.1	
CH			0.25				0.20	
CO2			14,000				11,000	
Emissions, 186 mph:								
CO			4.6				2.8	
NOX			19.2				11.7	
SO2			15.9				9.7	
CH			0.44				k0.27	
CO2			25,000				21,000	
Land Take, acres/mile			12-14					
Electromagnetic Field:								
at seat							0.1	
by side							0.02	

SKS	Shinkansen (Japan)
TGV	Train à Grande Vitesse (France)
ICE	InterCity Express (Germany)
ETR-450	Tilt Train (Italy)
X-2000	Tilt Train (Sweden)
IC 125/225	Intercity 125/225 (Great Britain)
TR	Transrapid Maglev system (Germany)
LMC	Linear Motor Car Maglev system (Japan)
*	High-Speed Sections only
+	Projected from first 100 days of operation
#	Estimated; no actual figures available
**	Eventually, 3 minutes
~	Figures from Transrapid consultants are 1-3 Db(A) higher

Miles in Test: the length of the two Maglev test track facilities. A 27-mile facility is presently under construction in Japan, for completion in 1994; this will become part of the Tokyo-Osaka line, if and when built.

Ability to Use Existing Track/Incremental Upgrade: These are essentially the same. The first means the ability to use existing international standard-gauge (4'8½") rail tracks; the second refers to the possibility of upgrading or reconstructing such tracks for high-speed operation. SKS is a separate purpose-built system, since it is built at standard gauge while other lines in Japan are built on the narrow (3'6") gauge. As a consequence, neither through-running over existing track nor incremental upgrading was possible in the original configuration, but future extension plans provide for mixed gauge in places, and service begins in July 1992 on the Tohoku line from Sendai to Yamagata over mixed-gauge track. (In American conditions, of course, SKS could operate on ordinary rail tracks.) TGV, ICE, PL, and X-2000 consist of a mixture of new, upgraded, and standard track, offering through-running onto existing tracks and the potential for incremental upgrading or new stretches of line; the new 50-mile extension of the TGV-SE now under construction, via Lyon-Satolas to Valence, offers an example. IC 125/225 trains operate entirely over ordinary upgraded track, reflecting the very high basic quality of the inherited 19th-century British rail infrastructure. It appears that neither through-running onto existing rail track, nor incremental upgrade, will be possible with either Maglev system; theoretically, bivalent Maglev trains could operate over train tracks, but no experiments are taking place with such bivalent vehicles. Nonetheless, Maglev might be able to share existing right-of-way with conventional rail tracks, if enough space existed.

Formation Width: This is the width within the right-of-way on level ground. Actual width on bridges or in tunnels is usually less; in cuttings or on embankments it is more, depending on the mode of construction. For Maglev, the width is as indicated in test track specifications.

Gauge: In all six steel-wheel cases, this is the standard international railway gauge used in most of Europe: 4'8½".[3] For Maglev this is not applicable.

Maximum Grade/Maximum Curve: Where two figures are given, the first refers to the original standard (the Tokaido SKS and the TGV-SE), the second to the latest standard in use or planned for the immediate future (the Tohoku and Joetsu SKS, TGV-A, ICE-M). For the Maglev systems, TR shows design specifications; LMC shows specifications for the new test track.

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[3] International standard railway gauge is 4'-8½". American standard railway gauge is 4'8-3/8". Minor modifications would enable the equipment to operate on American-gauge tracks.

Percent Tunnel/Bridge: The first Japanese figure refers to the Tokaido SKS, the second to the Joetsu SKS, which was engineered through the Japanese Alps and contains the longest rail land tunnel in the world (the Daishimizu, 13.8 miles). The TGV figure is for the TGV-A. The ICE tunnel figure partly arises from the nature of the terrain, partly from environmental considerations. Configurations for the Maglev systems are insufficiently precise for details to be given.

Station Spacing: The first SKS figure refers to the Tokaido SKS, the second to the Joetsu. The TGV and ICE figures refer to the entire system. The close SKS spacing reflects the existence of two levels of service, the so-called *Hikari* super-express which skips many stations, and the all-station *Kodama* express. (In Spring 1992 a new top-level non-stop service is being introduced on the Tokaido line, the *Nozomi*, with a station spacing of 344 miles between Tokyo and Osaka.) Because the SKS is 100 percent dedicated, the figures for total and high-speed spacing are identical. For the TGV they diverge greatly, indicating that the system is based on prolonged longer-distance high-speed running coupled with denser station service over existing or upgraded tracks at the outer journey ends. For the ICE this characteristic is less pronounced because of the relatively even spacing of cities along the entire route from Hamburg to Munich. For the Maglev systems, figures are inferred from designs for the Essen-Bonn and Los Angeles-Las Vegas TR routes and the Tokyo-Osaka LMC route; the latter in particular is still imperfectly specified.

Number of passenger cars/length: The figure for length also includes power cars, typically two per train unit. The first SKS figure refers to the Tokaido/Sanyo, the second to the Tohoku/Joetsu lines. The TGV figures refer to the TGV-A; here, two units, each of two power cars and ten passenger cars, usually run together over the high-speed lines, being separated at intermediate stations to serve different branches. Maglev figures are from published specifications.

Train Capacity: SKS figures are for the Tohoku/Joetsu lines, TGV are TGV-A. Maglev systems show the latest designs proposed for revenue service; in the case of the LMC these must still be regarded as speculative.

Train Control: Automatic Train Control is used in all five systems for high-speed running, since color light signalling is regarded as hazardous at speeds above approximately 135 mph. Color light signalling is, however, used on both TGV and ICE on reconstructed or older track, although with supplemental ATC. So far IC 125/225 operate entirely with color aspect signalling; however, ATC is to be introduced throughout BR during the next three to four years.

Speed: Maximum potential speeds are obtained on test (TGV, ICE, Maglev systems) or estimated for the next generation of technology (SKS). Maximum actual speeds are those obtained in revenue service (steel-wheel systems). In case of the six steel-wheel systems, where two figures are given, the first figure is for the original technology (Tokaido SKS, TGV-SE, IC-125), and the second for the latest available (Tohoku/Joetsu SKS, TGV-A, IC-225). Maximum planned speeds are those planned or firmly expected to be operationally possible within the next ten years (steel-wheel systems); for SKS they refer to planned operational upgrade; for TGV to TGV-TM and the Australian VFT; and for ICE to ICE-M. Average speeds refer to regular revenue service, and have been obtained by taking best performance figures for representative journeys (Tokyo-Nagoya, Tokyo-Nagaoka, Paris-Lyon, Paris-Tours, Hamburg-Frankfurt, Hannover-Kassel, London-Bristol, London-York). For the Maglev systems, maximum potential is the target described in literature; maximum actual is the test track record; maximum planned is for revenue service, as quoted in the literature; average is the speed which is indicated from published plans for revenue service on Essen-Bonn and Los Angeles-Las Vegas.

Headway/Trains per hour: These are for the peak morning or evening hour. For Transrapid, they are those indicated for the planned Essen-Bonn service.

Station Stop (Dwell Time): These are obtained from published timetables and show the entire range over the system. Japanese dwell times are notably shorter than European, presumably because of the unusual crowd discipline of the Japanese.

On Time Percent: As obtained from official reports. No figures are yet available for ICE, which began revenue service in July 1991. Early on-time performance was reportedly poor because of equipment problems.

Passengers/Passenger Miles: The ICE figure is an annual estimate based on the first 100 days of operation, which may be unrepresentative.

Fares: Obtained from latest available fare tables and converted to U.S. dollars at the prevailing rate of exchange.

Total Population/Ratio Population at Ends: For SKS, the first figure refers to the Tokaido SKS, the second to the Joetsu; for TGV, the first refers to TGV-SE, the second to TGV-A. Total population is for Metropolitan Areas or their equivalents along the system, as estimated for Japan by Glickman (1979; figures refer to 1970) or for Europe by Cheshire and Hay (1989; figures refer to 1980). Ratios are between the population of the larger metro area at one end and all the rest; in the case of the ICE, because of its length, two figures are given, one based on Hamburg-Frankfurt, the other on Munich-Frankfurt.

Accidents/million miles: These are from official statistics. The SKS has never had an accident caused by operating error. Official figures include "obstructions" caused by natural disasters and the like. The TGV has never had an accident in high-speed operation; one accident occurred while running over ordinary tracks at a grade crossing, due to a truck driver's error.

Construction Costs: These have been based on costs at time of construction, converted to U.S. dollars at the prevailing rate of exchange. SKS figures refer to the Tohoku/Joetsu lines, completed in 1985; these were exceptionally expensive because of land costs and tunneling costs. The TGV figure is for TGV-A, which was built over gentle terrain with relatively few bridges or tunnels (see above); the ICE, in contrast, involved extensive tunneling. In addition, it appears that French civil engineering costs may be substantially lower than in other West European countries.[4] The figures reflect exchange rates at the time of comparison, though for European systems these should be roughly standardized because of the adoption of the European Community Exchange Rate Mechanism. Maglev figures are, of course, estimates, since the systems are not built.

Revenues/Cost: The entire stream of revenues against total cost, from latest estimates. This figure requires close further examination; almost certainly, figures for different systems are not fully comparable.

Years to Profit: Number of years from opening to the point where, according to official estimates, the line first yielded a surplus over construction and operating cost. Again, this figure requires closer examination. For the LMC, the figures must be regarded as largely a theoretical exercise at this stage.

Share of Rail plus Air: The share which high-speed rail has taken of the combined rail-air passengers between pairs of cities. For the SKS the cities are Osaka (346 miles from Tokyo) and Hakata (735 miles from Tokyo). For TGV they are Lyon (273 miles from Paris) and Marseille (470 miles from Paris). For X-2000 they are Göteborg (283 miles from Stockholm) and Stockholm.

Noise: Standardized measures of noise at 25 meters from the train. Generally, a 10 dB increase means an approximate doubling in perceived sound. Comparative figures: domestic ventilator fan 84 dB, domestic garbage disposal 90dB, diesel truck 92 dB, sports car 95 dB, punch press 105 dB, and circular saw 110 dB. The ICE and TR figures present problems in reconciliation

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[4] See "Race to the 1993 Rendevous" in *Railway Gazette International*, September 1991, which suggests that construction costs per mile for the TGV-Nord may be only one-tenth those of the equivalent British link from the Channel Tunnel to London.

because different sources give figures for ICE which disagree materially. Generally these figures can be taken only as approximations, and will require further checking as to their comparative validity.

Emissions: The ICE and TR figures are from a study by TR consultants. It is important to realize that they are indirectly produced through electricity generation, and therefore originate at the point of generation; they are not directly produced by the train itself.

Land Take: Numbers of acres per mile acquired for the right-of-way. Typically these German figures are only about one-third the land take for a typical inter-urban freeway.

Electromagnetic Field: These figures, from TR consultants, are contradicted by much higher figures from a Canadian source.

Key Criteria

Table 2.1 presented all the relevant data we could establish for comparison of the systems. However, in reaching a careful assessment of their technical and commercial capabilities in the specific circumstances of an HSGT system for California, we have concluded that certain elements are critically important.

(1) *Feasibility*. In investing very large sums of money in such a major facility as an HSGT system for California, the first essential is to choose a system that has shown its feasibility, not merely in test-track conditions, but in regular revenue service over an extended period of time. Only such experience can demonstrate performance standards in everyday running, including speed, traffic density, and reliability, as well as actual environmental impacts in real-life situations.[5] Further, only such a system can demonstrate actual commercial results. On this ground, only four systems —the Shinkansen, TGV, ETR-450, and IC 125 —so far qualify to be considered. The first can demonstrate 27 years of regular intensive revenue service over one line, and seven years over two others. The second can show some 11 years of intensive regular service over one line, and 1-2 years over a second. The third has some two years, and the fourth over fifteen years, of intensive revenue service. In all cases the density of traffic over the first-opened line is such as to offer abundant evidence of regular, dense, reliable, safe, everyday service; the systems have in effect been "tested to destruction" and have emerged as passing the most rigorous tests of technical performance and commercial return.

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[5] The early experience of BART neatly illustrates the perils of introducing a new technology without a previous record of revenue service.

(2) *Compatibility with existing systems.* A technology that is compatible with existing track systems can be operated over such systems, offering the possibility of through-running to any place those systems serve, and permitting incremental upgrading of the level of service. Two of the steel-wheel systems, the TGV and ICE, offer this feature and have been specifically designed to offer mixed running, partly over dedicated new high-speed line, partly over existing track upgraded for high-speed service, and partly over lower-speed, still-unreconstructed track. The third steel-wheel system, the Shinkansen, does not offer this feature for an idiosyncratic reason: it is built at standard European gauge and is therefore incompatible with the 1.067-meter-gauge system used on the rest of the Japanese railways. In American conditions, of course, the Shinkansen also could be run on ordinary tracks.[6]

The Magnetic Levitation systems, in contrast, are based on dedicated track formation which is not compatible with existing steel-wheel-on-steel-rail systems. Although the possibility of bivalent operation has been discussed in Germany, there are no present plans to achieve it. Consequently, Maglev systems must be judged as all-new systems. The choice between steel-wheel and Maglev therefore must turn in part on the contribution that existing rail formation, either upgraded or in its original state, could make to the effective performance of the entire system. As will emerge in Chapter 3, the basic California rail infrastructure is very much poorer than that available to European rail systems: most of it was built at much lower standards of grade and curvature than its European equivalents, and it has not been maintained and upgraded for dense or high-speed operation as most of them were. However, it does penetrate the urban areas to their very cores, and it generally offers generous rights-of-way, up to 100 feet in width, which offer the prospect of upgrading while maintaining the existing services in constant operation. Further, it does offer the possibility of providing local urban feeders and distributors to a high-speed operation, particularly now that upgrading is taking place to provide new commuter services in both the Bay Area and Los Angeles. As will emerge in Chapter 5, such local urban feeds are an integral part of the network proposed here. Although it might be possible in some cases to built new Maglev lines on the existing rail rights-of-way, using surplus space, even here the provision of a separate technology would appear inherently more expensive than duplicating an existing one. In others this would appear to be either technically impossible or extremely difficult and costly.

Nevertheless, steel-wheel trains offer another advantage: they can be run at lower speeds over an existing right-of-way to provide direct feeds to the high-speed part of the journey, without

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[6] In California, safe operation of TGV or ICE-type trainsets over tracks used by conventional passenger trains or freight trains would require installation of modern signalling, automatic train control, and high-quality track. A modification of trainset design standards might also be necessary as well.

the need to make a physical transfer. The ability to pick up and set down suburban travelers in this way could make a critical difference in the competitiveness of high-speed ground transportation as against air or automobile. For these reasons, a steel-wheel system is to be generally preferred to a Maglev one.

(3) *Cost*. To be successful in commercial service, a system has to be affordable. A number of elements enter into the comparative costs of systems, including the cost of construction of the system and the cost of the train sets. Since the width of the right-of-way is very similar for all systems under consideration, the construction costs chiefly reflect ruling gradients (which affect the amount of cut-and-fill, tunnel, and bridge costs) and the degree to which existing right-of-way and track can be employed. Magnetic levitation has an advantage in the first respect, steel-wheel systems on the second. In all cases, construction costs vary a great deal according to the type of terrain and the degree of urbanization, which affects land acquisition costs; conditions in Japan and Germany are more difficult in either or both respects than in France. Californian conditions vary greatly in both respects, with low costs in the Central Valley but high costs in the mountain crossings and in the urban areas. Additionally, international comparisons are affected by the prevailing exchange rates at the time of comparison; European costs against the dollar should, however, be approximately standardized since currencies are broadly aligned through the European Community Exchange Rate Mechanism (ERM).

Bearing these considerations in mind, it appears that the IC 125/225 is overall by far the cheapest system. This reflects the fact that it uses upgraded track. However, it is important to realize that this was only possible because of the very high basic quality of the inherited British 19th-century rail infrastructure; it is not a realistic option in California, where "upgrading" would in effect mean the construction of a completely new rail system. Given this fact, the correct comparison is between systems that contain this element of new construction. TGV is an exceptionally cost-effective system, although due to California conditions it would without doubt be more expensive than in the relatively favorable circumstances of France. The Transrapid system seems to be cost-effective also. Higher figures for the other systems are to be explained in part through physical circumstances of terrain.

(4) *Overall Performance*. Against these key considerations, it may well be argued that Maglev technology offers the prospect of greatly superior performance standards, particularly in speed, but also in comfort. Both the German and Japanese versions promise 300 mph maximum speeds, far in excess of the 186 mph currently achieved in regular revenue service by the fastest steel-wheel technology (the TGV-A). However, care should be taken in this comparison. First, the actual winner of the record for high-speed ground transportation under driver control is the TGV-

A, with 320 mph in test conditions, higher so far than either Maglev technology.[7] Second, the actual speed to be achieved by Maglev in revenue service may be less than suggested: the TR is planned for 271 mph service, while the Japanese LMC is in too early a stage of development to be able to predict. Third, conversely, the best speeds of steel-wheel technology are virtually certain to rise somewhat: the TGV-TM trains, designed to come into service in 1993, will achieve 196 mph, while the Australian VFT, based on fairly robust assumptions about the development of the next-generation TGV technology, is designed for 217 mph. Fourth, because of station stops, the average start-to-stop speed of any system will be lower: for the Los Angeles-Las Vegas Transrapid service, the best comparison was predicted to be 171 mph as compared to 147 mph for the current TGV-A generation in regular revenue service between Paris and Tours, and the certainty of 150-160 mph with TGV technology from 1993 onward.

(5) *Environmental Impacts*. This is the most difficult area of comparison. There appears to exist no systematic comparison of the environmental impacts of all candidate technologies; Table 2-1 presents such evidence as has been found. Some care should be used in interpreting this, since —as explained in the notes above —different sources quote materially different results; it is difficult in many cases to say whether the conditions of observation were standardized. According to GEC Alsthom,[8] the noise emitted by TGV-A motor cars is greater than the noise emitted by TR-07 motor cars at 186 mph, but the TGV-A trailers are quieter than the TR-07 trailers. The overall average noise level is claimed to be comparable and the differences to be within the margin of measurement error. Note, also, that at speeds greater than 217 mph, aerodynamic noise dominates and wheel-rail noise is a less significant component of total noise.

It also appears that total emissions for TR are lower— marginally at lower speeds but more notably at higher speeds —than for ICE; these, it must be stressed, are total emissions arising from power generation, and do not arise on the trains themselves. The TR figures are presumably simulated since actual operating experience was not available at the time they were made; we have been unable to test their reliability.

Both TGV and ICE reports have stressed the ability to reduce noise impacts considerably by noise attenuation devices, particularly in areas with denser populations; the TGV and SKS are also operated at lower speeds in urban areas. We assume that both practices would be followed in a California high-speed operation.

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[7] The Japanese LMC achieved an "instantaneous" speed of 323 mph in unmanned conditions on test. Its highest speed in conditions comparable to the TGV test was 249 mph.

[8] Letter dated April 24, 1992, from M. André Huber, GEC Alsthom.

Conclusion

We conclude that, on a careful weighing of the evidence, VHST steel-wheel-on-steel-rail technology is to be preferred on two critical grounds: it has been tested in regular revenue service over an extended period, and it is compatible with existing rail systems. On performance, Maglev systems may eventually show an advantage in speed, but at present the evidence is not clear: the TGV and ICE steel-wheel systems hold world ground speed records, and they also operate in regular revenue service at speeds which already closely approach those claimed for Maglev systems. We conclude that the distinctions here are too fine and ambiguous to counteract the undoubted advantages of steel-wheel on the first two key criteria. It is possible that in about a decade, with more evidence on actual commercial Maglev performance, this conclusion might have to be revised; but, on the basis of current performance, it appears quite sound. On environmental impact the evidence is somewhat fragmentary, although there are indications that Maglev may well be superior to any steel-wheel technology on grounds of noise, pollution, and resource consumption. Further, more rigorous, comparative work is undoubtedly needed on this question.

Because of the nature of the potential market and the distances in California, as already argued, the choice of technology should be based principally on speed, consistent with satisfactory performance on the criteria of safety, reliability, and commercial performance. Only a state-of-the-art VHST system will achieve the necessary performance to compete effectively with existing modes. In order to compete over these distances, it will be necessary to achieve long stretches of sustained very high speed (200 mph or more) on dedicated track. Neither British Rail's IC 225 nor the Italian or Swedish tilt train systems will meet this standard; the competitors are the Shinkansen, TGV, and ICE. Among these it seems clear that, at present, the clear winner is the TGV. At the time of writing (May 1992) it has both the world speed record for ground transportation and the record for regular speed in revenue service, with the certainty of further improvements in the near future and the high probability of even higher speeds (200 mph+) within the decade. Further, it has demonstrated these capabilities over many millions of miles of service. It is true that both the Shinkansen and ICE are projected to make further speed improvements during the current decade, and may closely challenge the TGV, although considering present evidence they seem unlikely to surpass it.

We conclude that:

(1) The system to be adopted in California should be steel-wheel-on-steel-rail, at the standard American rail gauge of 4'8-3/8".

(2) The actual choice of operating system could well be made later, and would be subject to competitive tendering.

(3) However, the design of the system needs to be determined from the outset. To ensure maximum long-term effectiveness and competitive capacity, the technology of the California high-speed train should be based on the most advanced probable version of VHST technology; that is, the "next-generation" TGV technology embodied in the Australian VFT, with a maximum speed of 217 mph; wherever possible, it will be desirable to provide for even higher operating speeds should these become feasible.[9]

(4) It should be understood that adoption of these standards will embody some critical parameters, such as ruling gradients and curves. In particular, TGV technology may allow the adoption of considerably steeper grades than found in conventional rail technology (up to 5.0 percent), leading to considerable cost savings on certain stretches through hilly terrain; in Californian conditions, this will be a material consideration. In order to compete in a tendering process, other steel-wheel technologies would have to meet these standards.[10] The practicability of a sustained 5 percent ruling grade seems fairly well confirmed at this time. This will receive further discussion in the sections on mountain crossings in Chapter 4.

(5) It is possible that one of the other technologies, particularly the tilt train, might fill a specialized market niche on certain parts of the system: for instance, between the Bay Area and Sacramento, where the sharply curved alignment may well limit conventional TGV-type technology to speeds well below the tilt train's 155 mph maximum. This question also will receive further examination in Chapter 5.

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[9] It should be recognized that in urbanized areas, even with maximum use of noise attenuation measures, maximum speeds may have to be restricted to well below these levels, as low as 100 mph.

[10] It should be noticed that the ICE-M trains, now being designed for the Frankfurt-Cologne services due to start in the late 1990s, employ a design parameter of 4 percent ruling grades.

3.. ASSUMED TECHNOLOGY AND NETWORK OPTIONS

As mentioned at the end of Chapter 2, the choice of technology will influence the route of the system. It is worthwhile to present in more detail the key features of very high-speed steel-wheel-on-rail technology that have affected the proposed California network. Sections of the route can be separated into three categories: high-speed sections, where trains will operate as close as possible to maximum speed at all times; mountain crossings (also at high speed); and sections through urban areas. Following is a definition of the assumed technology for this report, a description of its performance characteristics, and a discussion of the implications of the technology on each category of rail alignment. The network described in the second section of this chapter reflects the characteristics of the assumed technology.

Performance Characteristics

Table 3.1 gives some performance characteristics of a VHST technology which henceforth will be referred to as the CalSpeed Train ("CST"). For comparison, figures are shown from the Texas TGV franchise application and an Australian proposal for very fast trains[11] (Australian VFT). Parameters included are acceleration and braking capabilities, geometric constraints, and maximum vertical grades.

Early on in the research, approximations of the acceleration and braking curves were extrapolated from an FRA report[12] (Table 3.2). The table was used as a reference in simulating the performance of the CST trainset over the route and to estimate travel times by calculating stopping and acceleration distances. A later comparison with curves published in the Texas TGV report (Figure 3.1) showed that the extrapolations were reasonable approximations of actual curves.[13] Additionally, computer simulations[14] of selected segments generally agreed with the previously done spreadsheet calculations.

Following the Australian example, the CST requires 6,000 m (19,680 ft) as the minimum curve for high-speed sections, assuming that a 217 mph maximum operational speed will soon be standard. However, because this report is geared towards the earliest possible implementation, a

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[11] This is the Australian VFT report, a summary of which is included as Appendix C.

[12] FRA, 1991.

[13] Differences may result, in part, from the Texas report assuming a more advanced version of the TGV technology. Namely, the stopping distance from 200 mph is 6.38 miles according to the Texas report and 7.4 miles according to the FRA report.

[14] Huber, 1992.

Table 3.1
The CalSpeed Train

	CalSpeed Train (CST)	Texas TGV	Australian VFT
Trainset Performance*			
Acceleration			
from 0 to 50 mph	.4 mile	.36 mile	---
from 0 to 100 mph	1.9 mile	1.85 mile	---
from 0 to 200 mph	14.8 mile	14.76 mile	---
Maximum Emergency Braking			
from 200 to 0 mph	2.72 miles	2.72 miles	---
Operational Deceleration (.75 mph/sec)	7.4 mile	6.38 miles	---
Maximum Operational Speed	200 mph	200 mph	217 mph
Track Specifications**			
Horizontal Curve Minimum	19,680 ft.	15,600 ft.	19,680 ft.
Gradients	5%	3.5%	3.5% (preferred) 5% (exceptional

* Trainset performance characteristics were based on the FRA report, "Safety Relevant Observations on the TGV High Speed Train", 1991. These characteristics were later compared to the Texas TGV specifications.

** Track specifications were based on the Australian VFT report which assumed a maximum operating speed of 217 mph.

Table 3.2
CST Performance Characteristics
Deceleration (.75mph/sec)

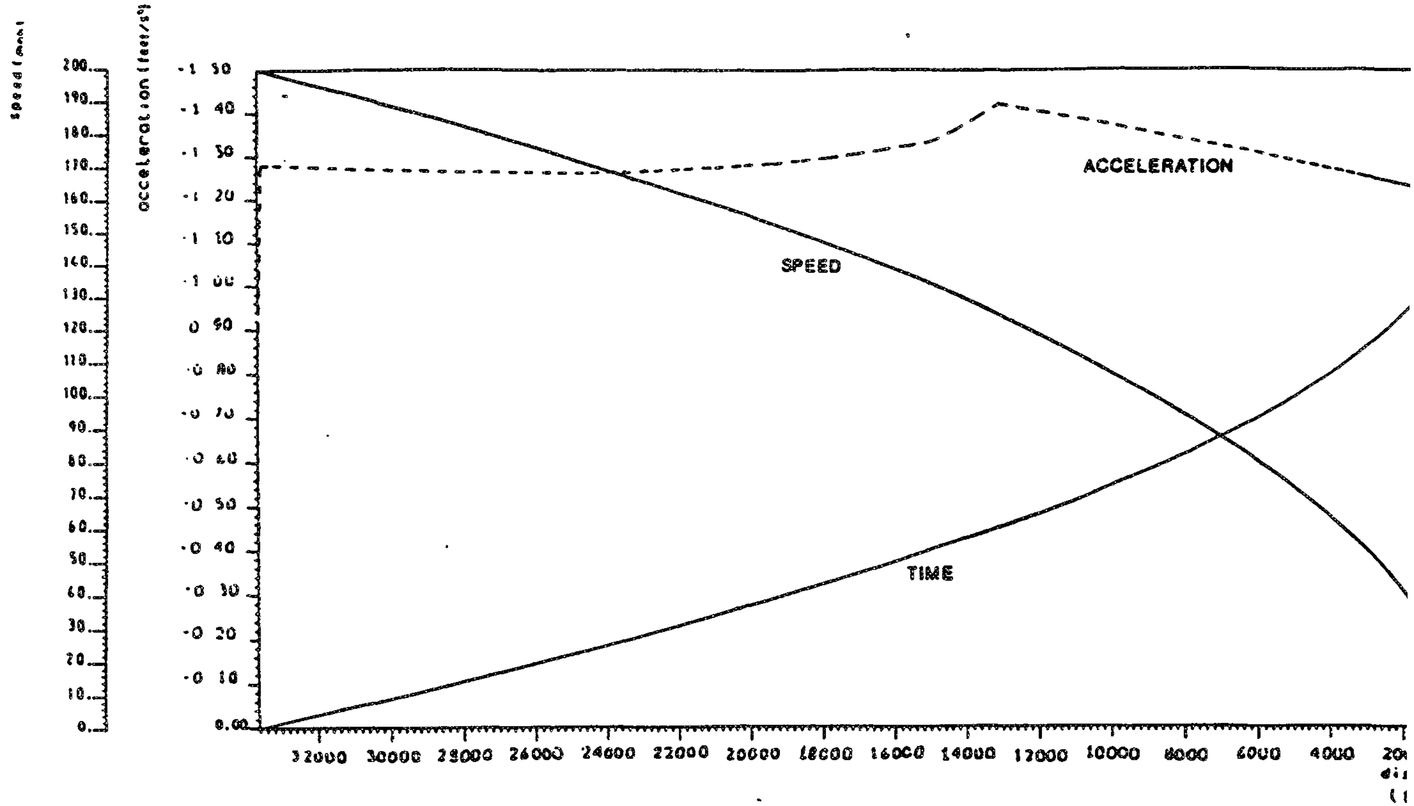
(mph) From/To	Distance (miles) 200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	10	0
200	0.0	0.7	1.4	2.1	2.7	3.2	3.8	4.3	4.7	5.2	5.6	5.9	6.2	6.5	6.7	6.9	7.1	7.2	7.3	7.4	7.4
190		0.0	0.7	1.3	1.9	2.5	3.1	3.6	4.0	4.4	4.8	5.2	5.5	5.8	6.0	6.2	6.4	6.5	6.6	6.7	6.7
180			0.0	0.6	1.3	1.8	2.4	2.9	3.3	3.8	4.1	4.5	4.8	5.1	5.3	5.5	5.7	5.8	5.9	6.0	6.0
170				0.0	0.6	1.2	1.7	2.2	2.7	3.1	3.5	3.9	4.2	4.4	4.7	4.9	5.1	5.2	5.3	5.3	5.4
160					0.0	0.6	1.1	1.6	2.1	2.5	2.9	3.2	3.6	3.8	4.1	4.3	4.4	4.6	4.7	4.7	4.7
150						0.0	0.5	1.0	1.5	1.9	2.3	2.7	3.0	3.3	3.5	3.7	3.9	4.0	4.1	4.1	4.2
140							0.0	0.5	1.0	1.4	1.8	2.1	2.4	2.7	3.0	3.2	3.3	3.5	3.6	3.6	3.6
130								0.0	0.5	0.9	1.3	1.6	1.9	2.2	2.5	2.7	2.8	3.0	3.1	3.1	3.1
120									0.0	0.4	0.8	1.2	1.5	1.8	2.0	2.2	2.4	2.5	2.6	2.6	2.7
110									From	0.0	0.4	0.7	1.1	1.3	1.6	1.8	1.9	2.1	2.2	2.2	2.2
100											0.0	0.4	0.7	0.9	1.2	1.4	1.6	1.7	1.8	1.8	1.9
90												0.0	0.3	0.6	0.8	1.0	1.2	1.3	1.4	1.5	1.5
80													0.0	0.3	0.5	0.7	0.9	1.0	1.1	1.2	1.2
70														0.0	0.2	0.4	0.6	0.7	0.8	0.9	0.9
60															0.0	0.2	0.4	0.5	0.6	0.6	0.7
50																0.0	0.2	0.3	0.4	0.4	0.5
40																	0.0	0.1	0.2	0.3	0.3
30																		0.0	0.1	0.1	0.2
20																			0.0	0.1	0.1
10																				0.0	0.02

Acceleration

(mph) From\To	Distance (miles) 0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
0	0.0	0.1	0.1	0.2	0.3	0.4	0.7	1.0	1.3	1.6	1.9	3.2	4.5	5.8	7.1	8.4	9.7	11.0	12.2	13.6	14.8
10			0.1	0.1	0.2	0.3	0.6	0.9	1.2	1.5	1.8	3.1	4.4	5.7	7.0	8.3	9.6	10.9	12.2	13.5	14.7
20				0.1	0.1	0.2	0.5	0.8	1.1	1.4	1.7	3.1	4.4	5.6	6.9	8.2	9.5	10.8	12.1	13.4	14.7
30					0.1	0.1	0.4	0.7	1.0	1.3	1.6	3.0	4.3	5.6	6.9	8.2	9.4	10.7	12.0	13.3	14.6
40						0.1	0.4	0.7	1.0	1.3	1.6	2.9	4.2	5.5	6.8	8.1	9.4	10.7	12.0	13.2	14.5
50							0.3	0.6	0.9	1.2	1.5	2.9	4.1	5.4	6.7	8.0	9.3	10.6	11.9	13.2	14.5
60								0.3	0.6	0.9	1.2	2.8	3.8	5.1	6.4	7.7	9.0	10.3	11.6	12.9	14.2
70									0.3	0.6	0.9	2.2	3.5	4.8	6.1	7.4	8.7	10.0	11.3	12.6	13.9
80										0.3	0.6	1.9	3.2	4.5	5.8	7.1	8.4	9.7	11.0	12.3	13.6
90											0.3	1.7	2.9	4.2	5.5	6.8	8.1	9.4	10.7	12.0	13.3
100												1.4	2.6	3.9	5.2	6.5	7.8	9.1	10.4	11.7	13.0
110										From			1.3	2.6	3.9	5.2	6.5	7.7	9.0	10.3	11.6
120														1.3	2.6	3.9	5.2	6.5	7.7	9.0	10.3
130															1.3	2.6	3.9	5.2	6.5	7.7	9.0
140																1.3	2.6	3.9	5.2	6.5	7.7
150																	1.3	2.6	3.9	5.2	6.5
160																		1.3	2.6	3.9	5.2
170																			1.3	2.6	3.9
180																				1.3	2.6
190																					1.3

Derived from "Table 2 - Trainset Parameters" in
"Safety Relevant Observations on the TGV High Speed Train", FRA 1991.

Service Braking Curve



Acceleration Curve

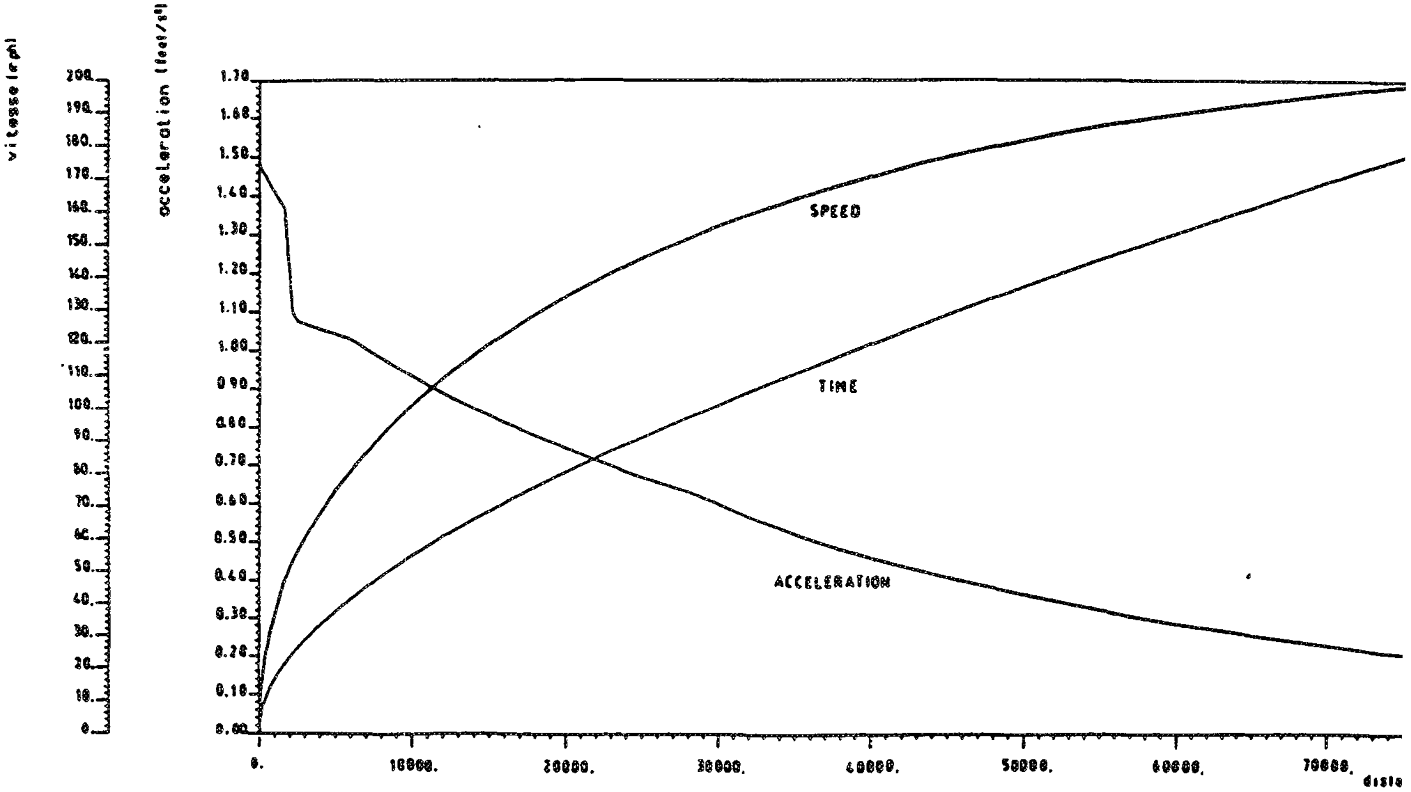


FIGURE 3.1

Texas TGV Performance Curves
Source: Texas TGV, 1990

maximum operational speed of 200 mph was used to calculate travel times; that is, we have incorporated today's trainset performance characteristics with tomorrow's track specifications. As a rule, high-speed rail alignments should exceed maximum curve radii wherever possible to allow for future increases in speed.

High-Speed Segments

"...One of the most important principles of high-speed railway operation is to accelerate the trains to maximum speed and keep them there until it is necessary to slow them down for station stops."[15] This follows from the relationship between kinetic energy, mass, and velocity: $K = \frac{1}{2}mv^2$. At a minimum operating speed, kinetic energy is also at a maximum. This kinetic energy allows the train to "coast," greatly improving energy efficiency. Braking destroys kinetic energy, which must be dissipated, and increases wear and tear on mechanical and electrical components.

The performance curves show that the rate of acceleration and braking levels off at higher speeds. Trains reach 100 mph in about two miles but 200 mph requires 14 miles. Stopping from 100 mph takes less than two miles but stopping from 200 mph requires seven miles.

As a result, maximum speed is not efficient except over long distances or sustained running. At an absolute minimum, stops should be at least 40 miles apart for trains to reach maximum speed. Even without stops, high *average* speeds require sustained periods of maximum-speed running. High average speeds are the goal as they, not maximum speeds, are the determinants of travel times. If trains must repeatedly slow for curves or to pass through towns,[16] the travel time benefits of high-speed technology are lost and energy efficiency is decreased.

Another important consequence follows from safety concerns. Because the emergency stopping distance is approximately 2.7 miles from 200 mph, at-grade crossings simply cannot be permitted. Even at lower speeds, the safety concerns are serious and high-speed right-of-way must be completely grade-separated and fenced.[17]

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[15] VFT, 1990.

[16] Reduced speeds of 125 mph through smaller cities and towns and 100 mph through extended urban areas, even with a completely grade-separated right-of-way, are consistent with foreign experience. These constraints result primarily from the noise produced by trains at higher speeds.

[17] In fact, *all* rail right-of-way within the California high-speed system will require grade separation and fencing; not just the high-speed segments. This requirement is standard practice in the French TGV system and proposed Texas TGV system.

Finally, high-speed operations are not compatible with slower freight or passenger trains. High-speed operations require advanced signalling capability, including automatic train control, in order to achieve the very low headways and high frequencies that will be so important in the California high-speed corridor. Freight and conventional passenger trains in this country do not have the signalling capability or speed to be run jointly with very high-speed trains on the VHST mainline.

In addition, the present high-speed technology does not meet U.S. industry standard buff load requirements. The U.S. standards grew out of a need for passenger trains to survive collisions with heavier freight trains. In contrast, freight trains in Europe are much lighter than in the U.S., and emphasis is placed on accident avoidance rather than accident survival. Major structural modifications to the high-speed technology in order to increase strength would impinge on its design integrity and performance, at least to some degree. The FRA is currently drawing up regulations governing TGV-type operations in the U.S., and it is safe to say that separation of traffic will play a larger part than modification of technology. Therefore, this report assumes, as did the Texas TGV project, that high-speed trainsets will not share tracks with freight trains on high-speed segments. Where separate freight and passenger tracks share a right-of-way, the two will be separated by a barrier.

The net effect of the technology on high-speed segments is to make existing rail rights-of-way most unattractive for high-speed operation. Use of existing rail rights-of-way, which were designed with much tighter curves and often pass through the center of towns, would have a very detrimental effect on system performance. Grade separation is much more expensive to accomplish on existing rail rights-of-way, which tends to run through towns with numerous at-grade crossings, than on a new rural right-of-way, which will usually cross many fewer roads or minor roads which may be closed. The additional cost imposed by the need to separate freight traffic is yet another argument for acquiring new, rural rights-of-way, well away from freight, for high-speed operations. Not only would existing rail corridors cost more to convert to high-speed operation; inherent characteristics of existing rail rights-of-way would hamper the delivery of a truly high-speed service.

Mountain Passes

The outstanding feature of CST technology in crossing mountain passes is its grade-climbing capability. By using sustained grades as steep as 5 percent, civil engineering costs, particularly tunneling, can be greatly reduced. This ability is especially important in California where geological conditions make tunneling extraordinarily expensive. Because of the expected high cost of tunneling and other civil engineering works in the California mountain ranges, routes should be designed using the steepest possible ruling grade (5 percent).

The technology also controls the speed at which these steeply graded mountain passes may be approached. Again recalling the relationship $K = \frac{1}{2}mv^2$, trains should approach the mountain passes at top speed. The less kinetic energy the train has, the more work the motors must do to reach the top of the pass. Safety rules require that trains be capable of starting from a stop on grades. Nonetheless, slow approaches to the mountain passes should be avoided in order to preserve energy efficiency and avoid undue wear on the trainsets. The implication here for route alignment is that mountain passes should satisfy the track geometry requirements for full-speed running.

Urban Areas

One of the key advantages of the rail mode is its ability to penetrate urban areas and more directly serve final origins and destinations. The opportunities for doing so, however, are fairly restricted to existing rail rights-of-way, highway median strips, or other existing transportation corridors. Most often, existing rail corridors are the only feasible means of approach to city centers. In addition, existing rail corridors provide an opportunity for intercity trains to travel along commuter rail lines (such as the regional commuter network being developed in Southern California) as a collector or distributor service for the high-speed portion of the journey. Such a collector service would greatly increase the accessibility of the CST system as well as further reinforcing the advantages of the overall rail network.

However, at least a limited amount of freight traffic remains on most existing urban rail corridors, in addition to ever-increasing levels of commuter service. Therefore, the question of compatibility between CST, commuter, and freight services is a vital issue in serving urban areas.

Where existing rail rights-of-way are used as the main approach to urban centers, all the separation measures specified for high-speed sections must be employed. This will involve provision of a separate track for freight and any commuter rail services making frequent stops. In addition, all at-grade crossings must be eliminated. In some locations, at-grade crossings may be so numerous and closely spaced that a viaduct will be the preferred solution. In other cases, short tunnels may be necessary to bypass congested tracks or areas.[18]

Apart from the main approaches to urban centers, it might be desirable for CST trains to share tracks with other types of traffic. If CST trainsets are to share tracks safely with commuter trains, other passenger trains, or a limited number of freight trains, *even at speeds of 80 mph or less*, certain conditions will have to be satisfied. Severe consequences can result from low-speed

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[18] An example of such a tunnel would be found in the approach to the new downtown San Francisco Caltrain terminal proposed in Chapter 4.

collisions of vehicles designed for different impact loads. In this case, commuter trains pose as great a hazard as freight trains.

The collision avoidance approach to rail safety would require the equipment of all services with automatic train protection (ATP). It seems highly unlikely that freight companies could be made to adopt ATP or change the size and weight of their equipment. Therefore, sharing track with freight on commuter routes is a doubtful proposition unless freight traffic is strictly separated from the CST trains by time of day.[19] However, with careful planning, commuter train fleets can be modernized to be compatible with CST trainsets through a combination of compatible-strength equipment and/or adoption of ATP.

The FRA has not yet promulgated any formal rules for this type of situation. Discussion with FRA representatives indicated that some combination of compatible-strength requirements and automatic train protection would be necessary. There also remains the possibility that VHST trainset manufacturers will be able to modify their designs for U.S. operations. Use of lightweight, high-strength materials has the potential to increase strength without significantly damaging performance, and VHST technology is being continually refined. However, the extent to which the technology may be strengthened remains unresolved.

A final important question, given the extensive and widely spread character of California's cities, is the speed at which trains may travel through urban areas. Speeds through urban areas will be restricted by the geometry of existing rail rights-of-way and noise impact concerns. Following European and Japanese practice, trains may pass through towns at up to 125 mph, using proper noise attenuation measures (sound walls, etc.) at sensitive locations. We have used a more conservative 100 mph for the major urban areas, on the grounds that residential and other sensitive development has tended to encroach upon rail corridors to a greater degree in major urban centers.

The CalSpeed Network Options

The first priority for an HSGT system for California must clearly be to provide the fastest feasible travel between the state's major travel markets. These are the Los Angeles Consolidated Metro Area, with a 1990 Census population of 14.5 million, and the San Francisco Bay Area, with

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[19] Tests of the Swedish X-2000 train will shortly be conducted on the Northeast Corridor which carries freight. According to the FRA, special provisions have been made to separate freight traffic and the test runs by time of day. Thus, it seems possible that *in urban areas* a limited number of freight trains might be allowed to operate over passenger tracks during off-hours, well away from any CST traffic. Effectively, this restriction limits CST traffic to lines from which freight has been completely removed or consists of a very limited number of local freight trains.

6.3 million: a combined population of over 20 million. Potentially these two metropolitan areas, some 380 miles distant by the most direct line, offer one of the strongest commercial potentials for HSGT in the United States, and even in the world.

A second priority must be to give the best possible service to the second rung of metropolitan areas, with a population of approximately 400,000 to 2.5 million each. These are the Central Valley Metropolitan Statistical Areas (MSAs) of Sacramento (1.5 million), Stockton (480,000), Modesto (370,000), Fresno (670,000), Tulare-Visalia (310,000), and Bakersfield (540,000); with a total of 3.9 million, which is projected to rise rapidly over the next 30 years; and the San Diego MSA with a population of 2.5 million. The total 1990 population of these areas is 26.9 million; this is over 90 percent of the entire population of California, and potentially a very profitable rail market.

A feature of the urban geography of California, highly favorable to HSGT, is the fact that these major urban areas are arrayed in linear or corridor fashion. One such corridor— including Sacramento, Stockton, Modesto, and Fresno— extends over approximately 170 miles within the Central Valley from Sacramento to Fresno. The San Francisco Bay Area is eccentric to this corridor but could readily be connected to it in the vicinity of Fresno. South of this point, one single line could connect all these areas to Los Angeles and on to San Diego.

In designing a system to serve these places, there are, however, three major problems.

(1) Although much of this corridor extends over the very easy terrain of the Central Valley, there are two major physical barriers. The Tehachapi and San Gabriel Mountains form a major barrier at the southern end of the Central Valley, separating it from the San Fernando Valley. The Coastal Ranges form a slightly lower barrier between the Valley and the San Francisco Bay, although they are crossed by three major passes, from south to north: the Panoche, Pacheco, and Altamont. To the north, the shores of the San Pablo Bay break the Coastal Ranges, but tend to offer a circuitous and slow route between the Bay Area and Sacramento. As already noted, these barriers affect performance, and pose difficult problems of trade-off between construction cost and speed.

(2) California's highly decentralized metropolitan areas offer very large tracts of medium-density suburbia that must be traversed. For instance, the total distance from Benicia, at the northern entry to the San Francisco Bay area's urbanized area, to Gilroy at its southern end, is just over 100 miles. The total distance from Newhall, at the northern entry to the Los Angeles Basin, to El Toro, at its southern exit, is about 80 miles. Of the total distance of about 380 miles between San Francisco/Oakland and central Los Angeles, about 90 miles (or just under one-fourth) is within urbanized areas. Existing rail rights-of-way, which by definition are noise corridors, exist through these

areas; however, because of the problems already noted, there are difficult problems of tradeoff. As suggested above, it may be necessary to restrict maximum speeds in urban areas to as low as 100 mph — only half the speed assumed for very high-speed operation outside these limits. This has important implications for overall timings and hence for the potential commercial viability of the system.

(3) Although California possesses a fairly extensive existing rail infrastructure, in particular two lines down the length of the Central Valley between Sacramento and Bakersfield, these are quite unsuited to high-speed operation. In practice, therefore, the choice lies between extensive (and expensive) upgrading, amounting in effect to complete reconstruction akin to the creation of a completely new railroad; and construction of a completely new dedicated line roughly along the same alignment. This suggests a basic approach: VHST on new dedicated track between the major centers, plus the highest-level HST on reconstructed track within the urban areas.

Bearing in mind these constraints, we have progressively developed the following concept of the CalSpeed rail network (Figure 3.2).

(1) Greater Los Angeles and the San Francisco Bay Area are connected by a dedicated VHST mainline in order to achieve the fastest feasible travel times. Such competitive travel times are achievable only with a route through the Central Valley, as the coastal rail corridor is not suitable for true high speeds. The growing population and economic activity in the South Bay dictate that this VHST mainline route should directly serve San Jose (population 1,450,000[20]). Once the two major metropolitan areas are connected, a VHST mainline branch may easily be added to provide service to Sacramento.

(2) Connected to this VHST mainline (henceforth referred to as the "CST mainline") would be supplementary HST branches connecting the Bay Area to Sacramento and Los Angeles to San Diego. Geographic constraints and market potential suggest that these corridors have only very long-term potential to justify VHST service and that they be upgraded to the best HST level possible and integrated with the CST mainline. These "supplementary" corridors are nevertheless important markets which might or might not be developed simultaneously with the CST mainline.

(3) The final level in the CalSpeed network would be provided by the Southern California commuter rail corridors. The widely dispersed area can be better served with a feeder service to the CST mainline. Initially, the commuter trains would provide this service, but existing rail corridors offer the long-term potential for direct CST service to outlying points.

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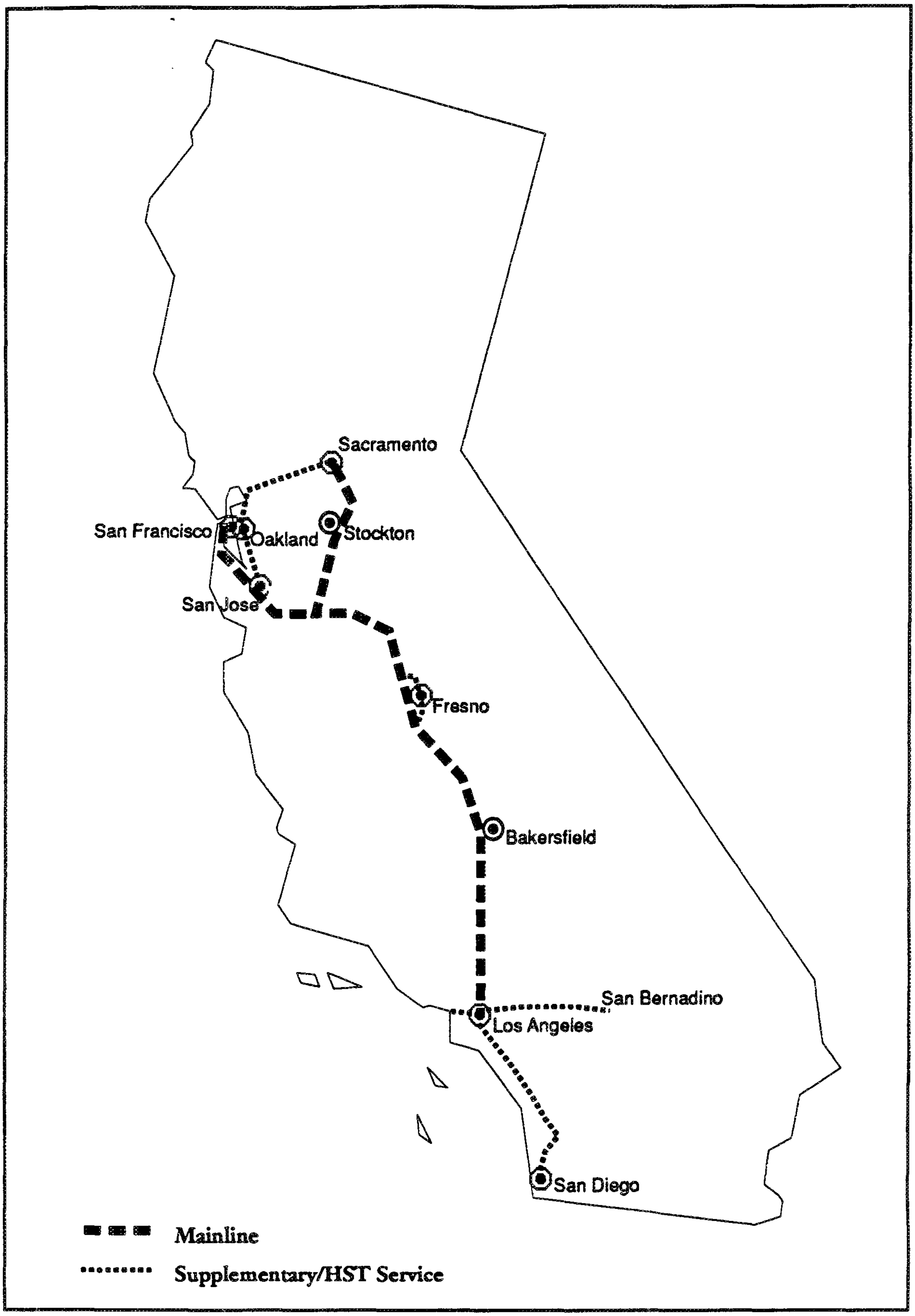
[20] This is the population of the San Jose subdivision of Santa Clara County according to the 1990 census.

FIGURE 3.2: THE CALSPEED NETWORK



With reference to the CST mainline:

From Los Angeles Union Station, construction of new dedicated passenger tracks along the SP alignment could be combined with the plan for upgraded commuter rail service in the area, for some 32 miles to Newhall at the northern edge of the San Fernando Valley. At least one station would be created in the San Fernando Valley at a location chosen for access both to freeways and to a future connection between the Metro Red Line and feeder buses.

Near Newhall a new line, constructed for VHST/Maglev operation, would cross the San Gabriel/Tehachapi mountains on a new alignment close to I-5 through the Grapevine, or an alternative route to the east of the Grapevine via Palmdale/Lancaster; a base tunnel is a third but considerably more expensive alternative. The choice of vertical alignment on the first alternative involves a tradeoff between cost and speed. A maximum gradient of 5 percent (rather than 3.5 percent) is almost certainly feasible and will save considerable construction costs with only a slight time penalty.

Thence the dedicated line would proceed directly northward through the Central Valley. There is a tradeoff here between speed, on the direct line haul between Los Angeles and the Bay Area, and provision of intermediate service for Bakersfield and Fresno; three alternatives are considered, one of which appears to involve the most satisfactory compromise.

At the approach to the Pacheco Pass, northwest of Fresno, the dedicated line would branch. One fork would divert NW across the Pacheco Pass, with another choice of ruling gradient to a point near Gilroy. From Gilroy the line would follow either a new alignment in the median of Highway 101, or a reconstructed Southern Pacific right-of-way to San Jose, where a station would be located next to the new Caltrain station.

Service would be provided over the Caltrain corridor up the Peninsula— with probable intermediate stops including Mountain View, Palo Alto, and San Francisco Airport— to a new downtown station in San Francisco. To be adequate for high-speed operation, this would involve comprehensive reconstruction similar to that in the Los Angeles area.

An optional mainline branch could run for 40 miles from San Jose to Oakland on reconstructed SP right-of-way, to a point close to Jack London Square. Here the tracks would be elevated on viaduct and/or depressed into cut-and-cover tunnel forming a dedicated section, serving a new West Oakland rail station near the West Oakland BART. San Francisco could therefore be served by two stations, one in the downtown, the other at West Oakland, with a convenient one-stop BART connection from the Embarcadero.

The other branch of the mainline would run from the junction northwest of Fresno, via Modesto and Stockton, to Sacramento. Here, a dedicated line is proposed in preference to reconstruction of the existing lines. This would serve new edge-of-city stations which could provide the basis for major new urban developments. Loops to the downtown areas of the major cities are a possible addition. At Sacramento the line could connect to the Capitol Corridor service, thus giving the possibility of a continuous northern California loop.

Regarding the supplementary and potential future HST corridors:

From West Oakland the line would operate via Southern Pacific tracks, upgraded for HST service, for 75 miles via Fairfield and Davis to Sacramento. A station in the North Bay (between Richmond and Martinez) could provide connection with BART and feeder buses, as well as park-and-ride facilities. Options exist between Pinole and Benicia for a dedicated high-speed line, possibly with a new crossing of the Carquinez Strait; these, however, involve considerable cost, and some have possible environmental impacts. An alternative would be to use tilt-train technology, which appears well-adapted to the sharp curves encountered between Pinole and Benicia, for Bay Area-Sacramento services.

Beginning at Los Angeles Union station, the LOSSAN corridor would be upgraded to support an HST link between these two markets. The station in downtown San Diego could provide a connection to the San Diego light rail.

Finally, with reference to the third level in the CalSpeed network:

Within the Greater Los Angeles urban area, the system could connect with the extensive commuter rail system now under development. Eventually, intercity service could originate from different centers such as Los Angeles International Airport (LAX); Anaheim Stadium (connecting with a future Las Vegas Maglev, with a possible extension to San Diego); and Riverside. These would use existing SP and ATSF tracks, comprehensively reconstructed[21] for HST and express transit service as part of the rail transit plan currently under development for this region, to converge at the Los Angeles Union Station. Union Station would need to be reconstructed or bypassed for through-running.

This routing is now described and evaluated in detail, with special consideration given to the evaluation of optional alignments, in Chapters 4 and 5.

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[21] The precise nature of this reconstruction is difficult to quantify at this point. The planned electrification of some of these routes will contribute to the effort, but additional work will be necessary. CST trainsets will need to be separated from existing freight operations along these corridors, although they may share tracks with commute trains.

4. THE VERY HIGH-SPEED MAINLINE: LOS ANGELES TO THE BAY AREA/SACRAMENTO

LOS ANGELES TO THE SAN FRANCISCO BAY AREA

A line from the Los Angeles Metropolitan area to the San Francisco Bay Area would be the primary link in a CST network for California. In determining routing alternatives between these principal population centers of California, it was necessary to limit the number of possible routes to those that warrant the most serious consideration. Therefore, this study focused its efforts on routes through the Central Valley which serve the city of San Jose in addition to San Francisco/ Oakland. Explanation for these assumptions was detailed in the previous chapter. In order to make the presentation of different routing alternatives easier, the corridor from Los Angeles to the Bay Area has been divided into the following segments: the Los Angeles Basin, the Southern California Mountain Crossing, the Central Valley, the Northern California Pass, the Santa Clara Valley, and the Bay Area. Figure 4.1 is a map depicting the regions encompassed by these different segments. For each of these regions, the different route alternatives are first determined, then described and summarized in terms of expected length, cost, and travel time. (The basis of the cost estimates is presented in Appendix B.) Additional information on each alternative (detailed route descriptions, cost estimate calculations, and travel time calculations) is presented in Volume II. It must be stressed that the LA-SF link has been broken up into segments for presentation purposes only; as a transportation corridor the route *must* be considered as a whole.

The Los Angeles Basin

Route Alignment Alternatives

Since the land between downtown Los Angeles and the beginning of the Southern California mountain crossing near Newhall has been extensively developed, the only feasible alternative for the CST route will be to make use of existing rights-of-way. Interstate 5 (I-5) and a Southern Pacific (SP) line provide the most direct corridors between these locations, and therefore are the most likely alternatives for this segment. I-5 has inadequate median widths (generally between 20 and 40 feet wide, and as little as 6 feet wide) for rail use. In addition, this section of I-5 has many tight curves. Desired urban rail speeds could not be obtained without major realignment of the freeway. As a result of these constraints, I-5 is an unacceptable alternative for the CST routing, leaving the SP right-of-way as the most attractive alternative. Figure 4.2 shows the SP right-of-way and the surrounding urban areas.

FIGURE 4.1: LOS ANGELES—BAY AREA SECTIONS

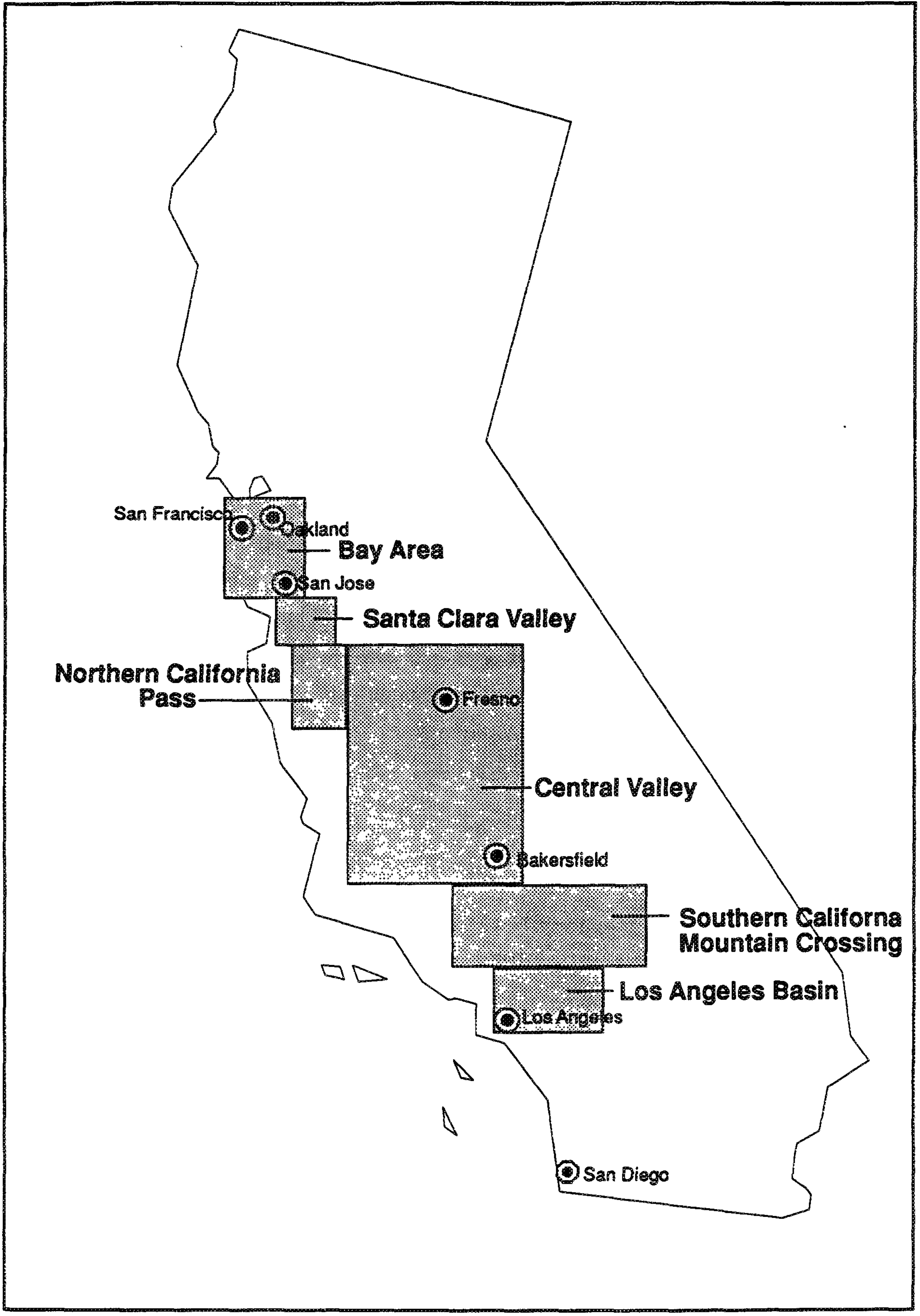
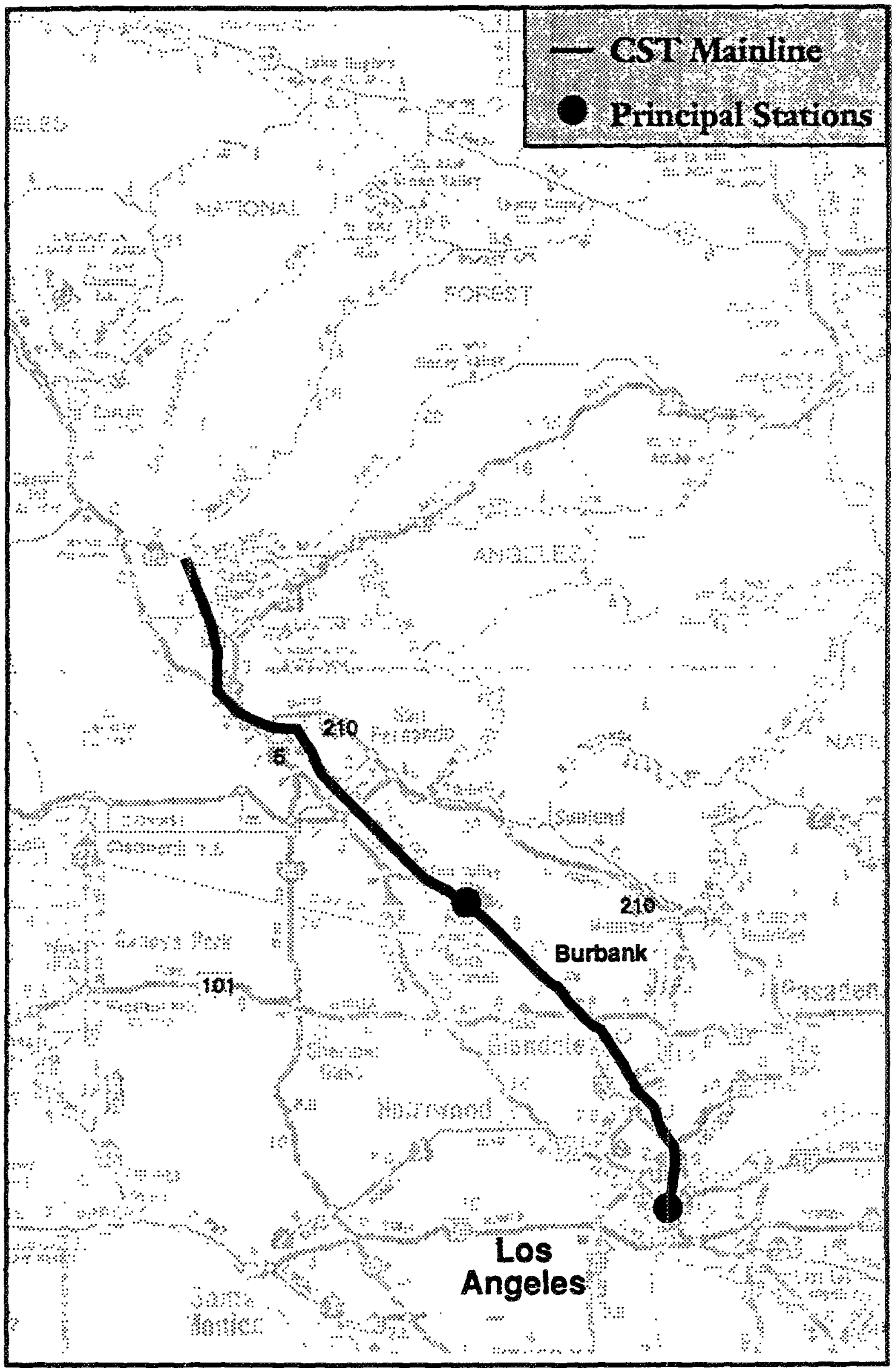


FIGURE 4.2: LOS ANGELES BASIN SP R/W



SP Right-of-Way Alternative

Fortunately, the SP right-of-way from downtown LA to Newhall provides an outstanding opportunity for the CST alignment. The SP right-of-way is approximately 100 feet wide throughout most of this segment, and is generally straight, having only a few restrictive curves. Through downtown Los Angeles, the routing is already nearly completely grade-separated. It is estimated that a maximum speed of 100 mph could easily be achieved through the LA urban area, increasing to a maximum of 125 mph north of Newhall.

Commuter rail service is expected to begin on this right-of-way in October 1992. Considering the high frequency and higher speeds of the CST over this alignment, it would be necessary to segregate the CST from all local passenger and freight services; there would, however, remain the possibility of integrating express commuter service on the CST tracks. As a result, four tracks would be desirable for this portion of the SP right-of-way; two tracks for the CST mainline and two tracks for the shared use of commuter rail and local freight.

Los Angeles' Union Station has been chosen as the logical starting point for the CST's primary link between southern and northern California. This report assumes that one other major stop should be considered in the L.A. basin. At this time, a station at Burbank would seem to be the most acceptable location. It would be logical to assume that there might be the demand for a suburban station in the Newhall/Saugus area as well. All trains would stop at L.A. Union Station, whereas most would travel through the smaller stations without stopping. The total distance of this segment is about 32 miles. The cost of building a new system at-grade on the existing right-of-way would be approximately $1.04 billion. This cost includes relocating existing tracks and constructing a barrier for segregating the CST service from the other tracks. Non-stop travel time over the segment beginning at L.A. Union station would be 21.6 minutes, averaging 90 mph.

Southern California Mountain Crossing

Route Alignment Alternatives

The crossing of the mountains separating the Los Angeles basin and the Central Valley is probably the most difficult engineering problem in creating a high-speed rail link between northern and southern California. Upon study of topographical maps of the region, it is clear that there are no simple solutions. Route choices are limited. Thus, after careful review, only two options utilizing passes through the mountains warranted consideration for this report. An additional "base tunnel" alternative was studied, which would go straight through the Southern

California mountains without any significant rise in elevation. Figure 4.3 shows the region studied and highlights the three mountain crossing alternatives.

When Caltrans planned the alignment of I-5, they faced this same challenging problem of a southern California mountain crossing. Certainly they determined the "best" pass given the restraints of freeway design and the goals of the project. The Grapevine route uses the most direct and lowest pass from the Central Valley to the Los Angeles Basin. This pass is characterized by steep grades at each end and a long, predominately level segment between. The freeway design utilizes 5-mile-long, 6 percent grades, to climb and descend the pass, and relatively tight 3,000-foot horizontal curves throughout.[22] Curves with as tight a radius as 1,500 feet were necessary at some locations at the beginning of the long grades. Although CST has much stricter horizontal alignment requirements, it is nevertheless logical to assume that an alignment closely approximating the I-5 pass might be the most appropriate for the Southern California mountain crossing. This is particularly true when considering a maximum ruling grade of 5 percent.

West of the Grapevine route, there are no truly viable options. The distance through the mountains is longer and the peaks of the mountains are higher than the Grapevine route. Moreover, this region is dominated by national forests and wilderness reserves (including the Spece Condor Sanctuary). To the east of the Grapevine there appear to be some potential alternatives to this route, although directly to the east is the Angeles National Forest.

It is evident that the shortest distance through the mountains would entail a crossing of the Techachapi Mountains just east of the Grapevine. Such an alignment could be accomplished by traversing the Antelope Valley. Any one of a number of canyons between the Angeles Forest and the San Gabriel Mountains could be utilized to bring the alignment from the San Fernando Valley to the Antelope Valley near Palmdale. This routing has the interesting advantage of being able to include a station that would serve the Lancaster/Palmdale area, which has a sizable (approximately 500,000) and increasing population. However, such a routing would be far more circuitous than the Grapevine.

Finally, it would be possible to tunnel straight through the mountains. The alignment for such a tunnel should minimize the travel distance and time between southern and northern California, and also the actual distance of the tunnel. A route just to the east of the Grapevine Pass best fulfills these requirements.

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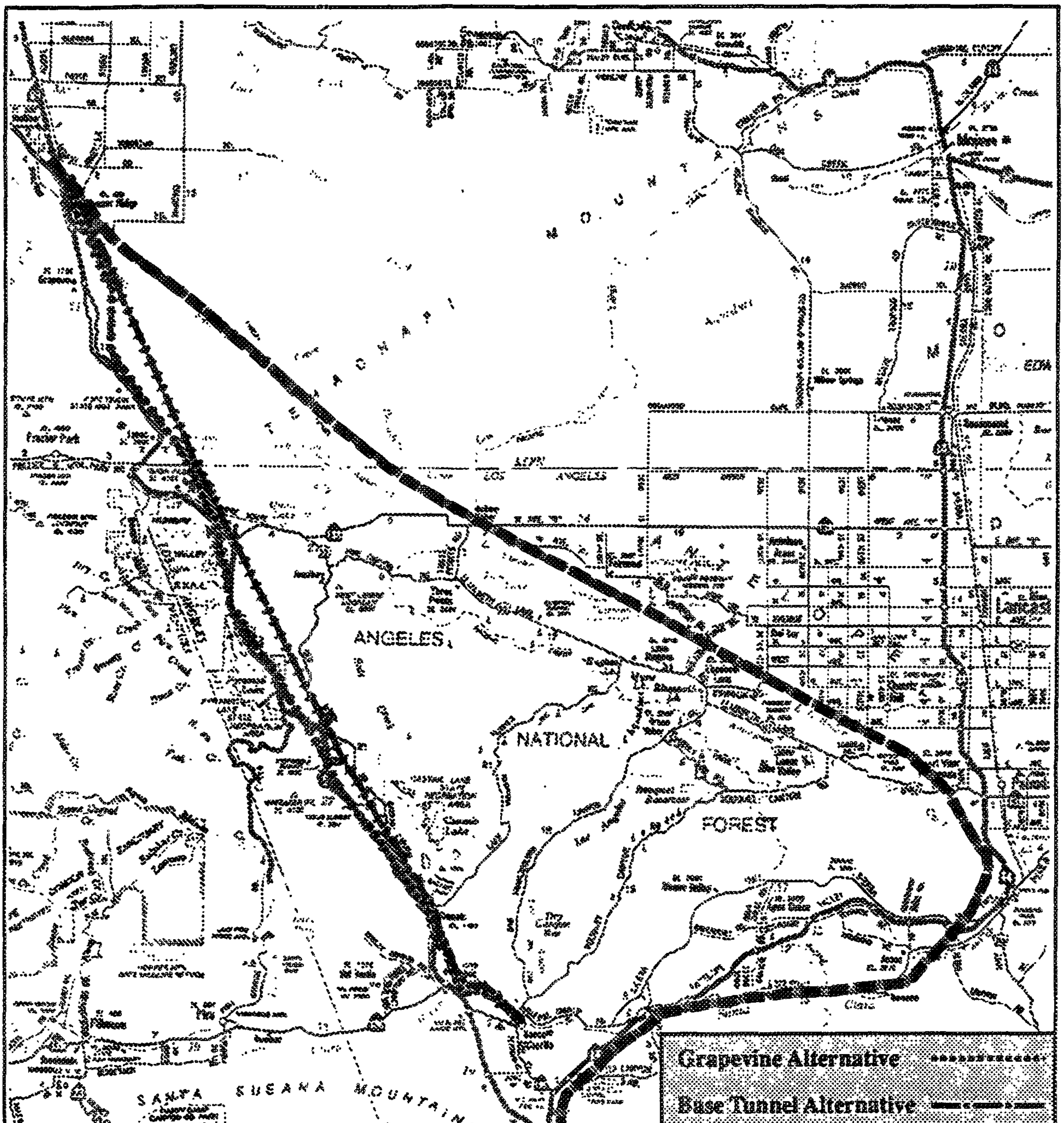
[22] According to the Caltrans Highway Design Manual, minimum horizonal curves are 5,000 feet for rural freeway design, 3,000 feet for urban freeway design.

FIGURE 4.3: SOUTHERN CALIFORNIA MOUNTAIN CROSSING



Grapevine Alternative

To achieve the Grapevine crossing, an alignment was chosen which closely approximates the existing I-5 alignment while using horizontal curvature standards necessary to maintain high speeds. With the exception of the Tejon Pass, the alignment generally strays no more than 1,000 feet distance from the freeway. When creating profiles of the route, two separate maximum grade options (3.5 percent and 5 percent) were calculated.

The total length of the Grapevine alternative is nearly 49 miles. The 3.5 percent maximum grade option would require 19 miles of bore tunneling (one 5.4-mile southern grade, and one 11.2-mile northern grade tunnel), and 7.25 miles of bridge/viaduct. This alternative would cost approximately $2.81 billion, and would take 15 minutes to traverse, averaging 189 mph. The 5.0 percent option would result in 10.98 miles of bore tunneling (58 percent of the 3.5 percent alternative total), but would require 0.86 more miles of viaduct and a two-minute greater travel time (167.5 mph average speed) because of the steeper grade. As a result of the reduced tunneling costs, the 5 percent option would be $2.02 billion, $790 million less than the 3.5 percent alternative.

Palmdale Alternative

The Palmdale Alternative, like the Grapevine alternative, follows the general alignment of existing corridors, yet on new right-of-way at high-speed standards. This alternative approximates the Antelope Valley Freeway until it reaches Soledad Canyon. The canyon brings the routing to the vicinity of Palmdale, where the routing veers west through the Antelope Valley, closely following the California Aqueduct. An outlying station would be built on the outskirts of Palmdale to serve this valley's population. The Tehachapi Mountains are crossed at the narrowest portion of the range with a 7.95-mile tunnel. The total length of the Palmdale Alternative is around 86 miles. Since the amount of tunneling cannot be reduced much with higher maximum grades, no significant cost savings could be achieved using a greater gradient. Therefore, only a 3.5 percent maximum grade was considered for this alternative. In total, 13.2 miles of tunneling and 4.6 miles of bridge/viaduct are required for this alternative. It would cost approximately $2.39 billion, and would take 27.3 minutes to traverse (without a stop in Palmdale), averaging 190 mph. However, to compare this alternative adequately with the Grapevine and Base Tunnel alternatives, adjustments must be made. As shown in Figure 4.3, the Palmdale Alternative begins south of the other alternatives. Therefore, time and costs must be reduced to account for this 7.5-mile savings in infrastructure (including a 1.32-mile tunnel). For comparative purposes, the total time for the Palmdale alternative is reduced to 22.5 minutes and the total cost to $2.14 billion.

Base Tunnel Alternative

The total length of the Base Tunnel Alternative is 47 miles. The dominant feature of this alternative would be the 33 miles of continuous-bore tunneling through the pass. It is estimated that the tunnel alone would cost $2.31 billion. In addition, this alternative requires 12.2 miles of at-grade alignment and 1.8 miles of bridge/viaduct, all to be built on new right-of-way. The total estimated cost for this alternative is $3.89 billion. It would take only 14.8 minutes to traverse, averaging 191 mph.

Preferred Route Alternative

The alternatives for the Southern California Mountain Crossing are summarized in Table 4.1. It is quite apparent that there are tradeoffs between travel time and cost when considering which maximum gradient should be used. However, in advance of the market studies (which constitute the next stage of the CalSpeed research project), it is difficult to quantify exactly what additional cost justifies a savings in overall travel time. At this point, choosing a preferred route must therefore rely on a degree of intuition as well as calculations.

Based on our summary, the Grapevine alternative at 5.0 percent maximum grade appears to be the best choice through the mountains. This is the most economical alternative, yet provides a through time which is very competitive with both the other Grapevine alternative and the Base Tunnel. A major question regarding this alternative was whether it is truly viable using current technology, particularly since the 5.0 percent climb at the northern end of the pass is 7.25 miles long. Recent evidence confirms that the new-generation TGV trainsets can accomplish the grade without sacrificing any margin of safety.[23]

It seems highly unlikely that a base tunnel would be desirable. A comparison between the 3.5 percent Grapevine alternative and the Base Tunnel Alternative show that less than a minute is lost in travel time, yet nearly $1.08 billion is saved in construction costs by using the 3.5 percent grade. Using the 5.0 percent Grapevine alternative, 2.8 minutes are lost, yet $1.87 billion is estimated to be saved in construction costs. Intuitively, the capital costs of a base tunnel tremendously outweigh its relatively minor time savings. Moreover, considering passenger comfort, the ten minutes through the tunnel would not be particularly pleasing to passengers. It must be noted that, visually, this portion of the entire CST routing could be the most scenic.

The estimates for the Palmdale alternative indicate that this alternative warrants further consideration. Only the Grapevine 5.0 percent option is less costly and has fewer total miles of tunneling. Since high speeds could begin 7.5 miles before the other alternatives, its much greater

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[23] Travel Time Simulations done by André Huber, Ph.D., GEC Alstom Design Manager based on modified Texas TGV trainset specifications. January 17th, 1992; Letter from André Huber 04/24/92.

CalSpeed

TABLE 4.1

SOUTHERN CALIFORNIA MOUNTAIN CROSSING

Comparison of Alternatives

ALTERNATIVE	DISTANCE (MILES)	EXPRESS TRAVEL TIMES (MINUTES)	AVERAGE SPEED (MPH)	COST ($)
GRAPEVINE 3.5%	49	15.6	189	2,810,000,000
GRAPEVINE 5.0%	49	17.6	167	2,020,000,000
PALMDALE *	79	22.5	190	2,140,000,000
BASE TUNNEL	47	14.8	191	3,890,000,000

* adjusted to relate to other alternatives

length is somewhat compensated for. Travel times are 4.9 minutes longer than the Grapevine 5.0 percent option and 6.9 minutes than the 3.5 percent option. As opposed to a Grapevine routing, this alternative serves the large population base of the Palmdale/Lancaster area.

To conclude, we believe the best alternative for the Southern California mountains would utilize as steep a gradient as possible through the Grapevine. Utilizing current technology, this would be at 5.0 percent. The base tunnel alternative is rejected, but the Palmdale route deserves further consideration to determine its market potential in comparison to a Grapevine alternative.

The Central Valley

Route Alignment Alternatives

The Central Valley is an ideal setting for the CST. Most of the Valley is flat and sparsely populated; land is plentiful and cheap. Relative to the rest of the state, there are few environmentally sensitive areas within the valley. Given these ideal conditions, and that this represents a substantial part of the distance between the principal markets of the Bay Area and the Los Angeles area (between 185 and 217 miles, depending upon the route chosen), the aim must be to achieve speeds as high as possible throughout this segment.

Service to valley population centers must also be a consideration. It should be recognized that there is a sizable population existing in this portion of the Valley (estimated 1.35 million), which includes the cities of Fresno and Bakersfield, and that this is one of the faster growing regions in the state. This region is not well served by air transportation, and often has winter weather conditions (severe fog) which make air or automobile travel dangerous. The region is politically supportive of rail improvements and, in particular, the concept of high-speed service. Any proposed service through the valley which bypassed the major urban areas would certainly meet strong political opposition from the valley.

There are three primary transportation corridors through the Central Valley: the I-5 corridor, the Santa Fe Corridor, and the Route 99/SP Corridor. I-5 is located along the western side of the valley, bypassing all urban areas. It represents the most direct route between southern and northern California. The other two corridors, on the eastern side of the valley, go through both Bakersfield and Fresno while serving nearly all the population between. Taking into account these existing transportation corridors, three alternatives through the Central Valley have been considered for the CST alignment: a new rail corridor to the west of Route 99, which would avoid existing urban areas yet offer direct service to Bakersfield and Fresno; the I-5 corridor; and an alignment which uses existing rail right-of-way. For the existing rail right-of-way alternative, the Santa Fe corridor was chosen in preference to the SP/Route 99 corridor since it is a less populated corridor and thus more logical for high-speed use. The SP right-of-way would be better suited for local service. Figure 4.4 shows the alignments of the three Central Valley alternatives.

New Central Valley Corridor

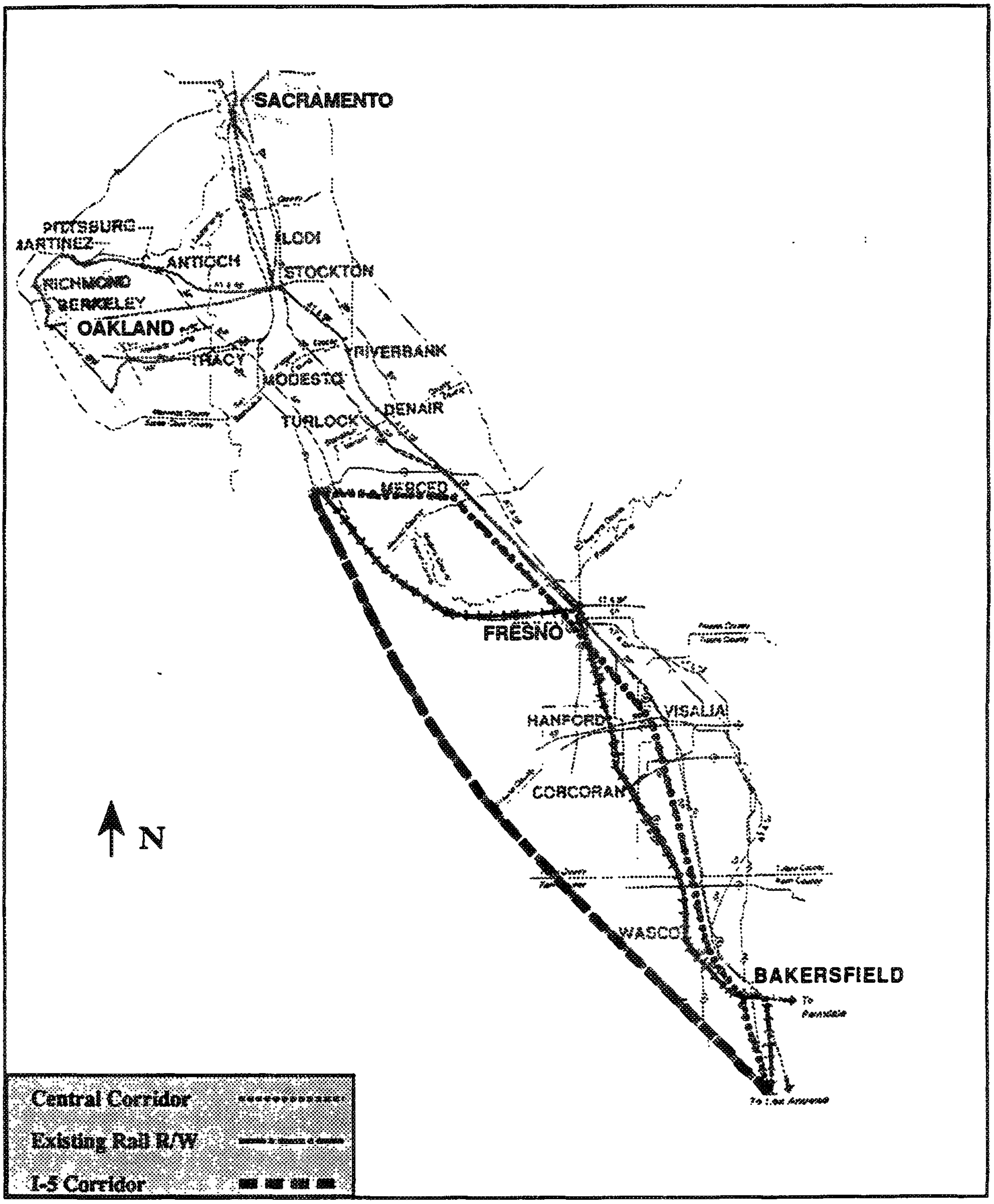
Since the Central Valley is largely undeveloped agricultural land, it should be relatively easy to build the CST alignment on completely new right-of-way. Although numerous different possibilities exist for the alignment, the routing should be built to allow the highest possible through speeds and therefore avoid all developed areas. The routing chosen for this report passes approximately one mile west of the limits of both Bakersfield and Fresno. Between these cities the routing would generally follow the alignment of Route 99, one to three miles to the west. Just north of Madera the routing veers west until it reaches the I-5 corridor.

The downtowns of Fresno and Bakersfield could either be directly served by short spurs utilizing existing rail right-of-way, or by outlying stations a few miles from the downtowns. In either case, through trains would not reduce speeds on the mainline through the valley. If there was adequate demand, outlying stations could be added at several locations in this segment (see Volume II regarding possible locations for outlying stations). The routing chosen is about 205 miles long. For the mainline it would require the purchase of 3,230 acres of new right-of-way at an estimated total cost of $34 million. The alignment would cross approximately 173 roads; however, most of these are lightly travelled small-farm roads, many of which could be closed. For the cost estimate, 100 rural grade separations were assumed. The total cost of this alternative, assuming outlying stations for Fresno and Bakersfield, would be $1.85 billion, with a through travel time of 61.5 minutes. If a loop through downtown Fresno were preferred over a outlying station, it would cost an additional $280 million. Likewise, a spur to Bakersfield would cost another $104 million.

Interstate 5 Corridor

From its interchange with Route 99 just north of the beginning of the Grapevine to the Henry Miller Road overcrossing adjacent to the San Luis Reservoir and the Pacheco Pass (to the west), I-5 traverses approximately 185 miles through the Central Valley. This segment is very flat, predominately straight, and avoids urban areas. Since it maintains a wide width (average 85'), is completely grade-separated (55 total crossings), is an existing transportation corridor, and probably could be used without land acquisition costs, the median strip of I-5 was first considered

FIGURE 4.4: THE CENTRAL VALLEY



for the CST alignment. After substantial research, it was determined that this was not a feasible alternative, primarily as a result of speed restrictions through curves and many construction difficulties (see Volume II for details). A separate CST right-of-way closely approximating the I-5 alignment would be a preferred alternative. Since I-5 avoids urban areas, land near the freeway is readily available for CST use at low cost. A high-speed segment could be built close to I-5, with no speed restrictions and little disturbance to the environment and existing developments.

In this portion of the Central Valley, only Bakersfield could easily be served by the I-5 alignment, via a short spur or an outlying station. To include a station in Fresno, it would be necessary to build a 54-mile spur from the mainline across the valley. It is most likely there would be no foreseeable future CST station locations between Fresno and Bakersfield with this alternative.

The mainline would be approximately 187 miles long, located just to the east of I-5. Nearly 2,947 acres of new right-of-way would be needed at an estimated price of $18.5 million. Its alignment would require 55 new grade separations and 55 bridges over rivers and canals. To build the mainline would cost about $1.56 billion; travel time (assuming 200-mph maximum speed with no restrictions) is estimated at 56.1 minutes. The Fresno loop would cost an additional $694 million. A spur to the Bakersfield downtown is estimated at $206 million, whereas a loop to an outlying station is about $3 million less.

Existing Rail Right-of-Way

From the downtown of Bakersfield to the downtown of Fresno, the 100' wide Santa Fe right-of-way could be used for CST service. South of Bakersfield, a new right-of-way would be necessary to connect Bakersfield with the Southern Mountain Crossing CST alignment. From Fresno, an existing SP line would bring the alignment from Fresno west across the valley to I-5. The total length of the segment is about 217 miles. The alignment would pass through the urban areas of Bakersfield and Fresno, and bisect the towns of Shafter, Wasco, Corcoran, Hanford, Kerman, Mendota, Firebaugh, South Dos Palos, and Los Banos.

Grade separation through these developed areas would require a significant cost in road undercrossings and/or overcrossings. The high-speed tracks would also need to be completely separated and protected from freight services. New right-of-way would need to be purchased to straighten out curves. It should not be surprising, therefore, that the expected cost of this segment would be high, estimated at $2.89 billion. For express trains making no stops, only an average speed of 142.1 mph could be expected assuming a 125-mph speed restriction through the towns and a 100-mph speed restriction through Bakersfield and Fresno. Therefore, the minimum travel time on existing right-of-way would be 91.7 minutes.

Preferred Route Alternative

The Central Corridor alternative appears to be the best for the Central Valley segment. This alternative clearly is the best balanced in terms of both travel time between the Los Angeles Basin and the Bay Area, and service to the major population centers in the Central Valley. Although 18 miles longer than the I-5 Corridor alternative, only a total travel time penalty of 5.4 minutes is incurred since the Central Corridor alignment allows for express service through the valley without speed restriction. Yet in comparison with an I-5 corridor, this alternative offers substantially superior service to the population in the Central Valley, particularly in the case of Fresno. Using the I-5 alternative, this city would be completely isolated, greatly decreasing the probability of its receiving frequent service. Because of the greater length, the main line portion would be about $290 million greater than an I-5 alignment. However, assuming that both Fresno and Bakersfield would need to be served in any event, the Central Corridor is the cheapest alternative.

Although we believe the Central Corridor is the most appropriate for this segment, the I-5 Corridor deserves continued consideration. This is based on the fact that an I-5 corridor would offer the best possible travel time between the two primary markets and that acquiring the right-of-way for this corridor would most likely induce the least amount of resistance and cost. If there was any significant opposition to a proposed new central transportation corridor in the Valley, use of the I-5 corridor would become particularly attractive. On the other hand, the use of existing rail right-of-way through this portion of the valley for the CST main line should be rejected. As previously discussed in this paper, the use of existing rail right-of-way is not compatible with true high speed. This alternative would be far more expensive than the new right-of-way alternatives and increase travel times to a point where the system would act more like a conventional rail line. This would greatly reduce the competitiveness of the CST network with other modes of transportation between major markets. In comparison with the Central Corridor, the existing rail alternative (including the downtown Fresno loop and a spur to Bakersfield) would cost about $656 million more and take 30 additional minutes to traverse.

In summary, the Central Corridor is thought to be preferred for the Central Valley segment of the CST routing. Yet study of the I-5 corridor should continue, whereas the Existing Rail Right-of-way alternative warrants no further consideration for the CST mainline. Furthermore, it seems desirable to directly serve Fresno's downtown with by an additional loop segment. However, an outlying station near the city limits of Bakersfield would be preferred as a result of the severe difficulties involved with direct downtown service of Bakersfield (see Central Corridor "Detailed Segment Description" in Volume II for further information).

The Northern California Pass

Route Alignment Alternatives

To serve the Bay Area from the Central Valley, it is necessary to cross the mountains separating the Central Valley from the Santa Clara Valley. Two mountain passes join these regions: the Pacheco Pass, which Route 152 utilizes, and the Panoche Pass, beginning some 46 miles south of the Pacheco Pass. Therefore, CST alignments through each of these passes were determined for comparison. Figure 4.5 shows the alignments of the two passes.

Pacheco Pass Alternative

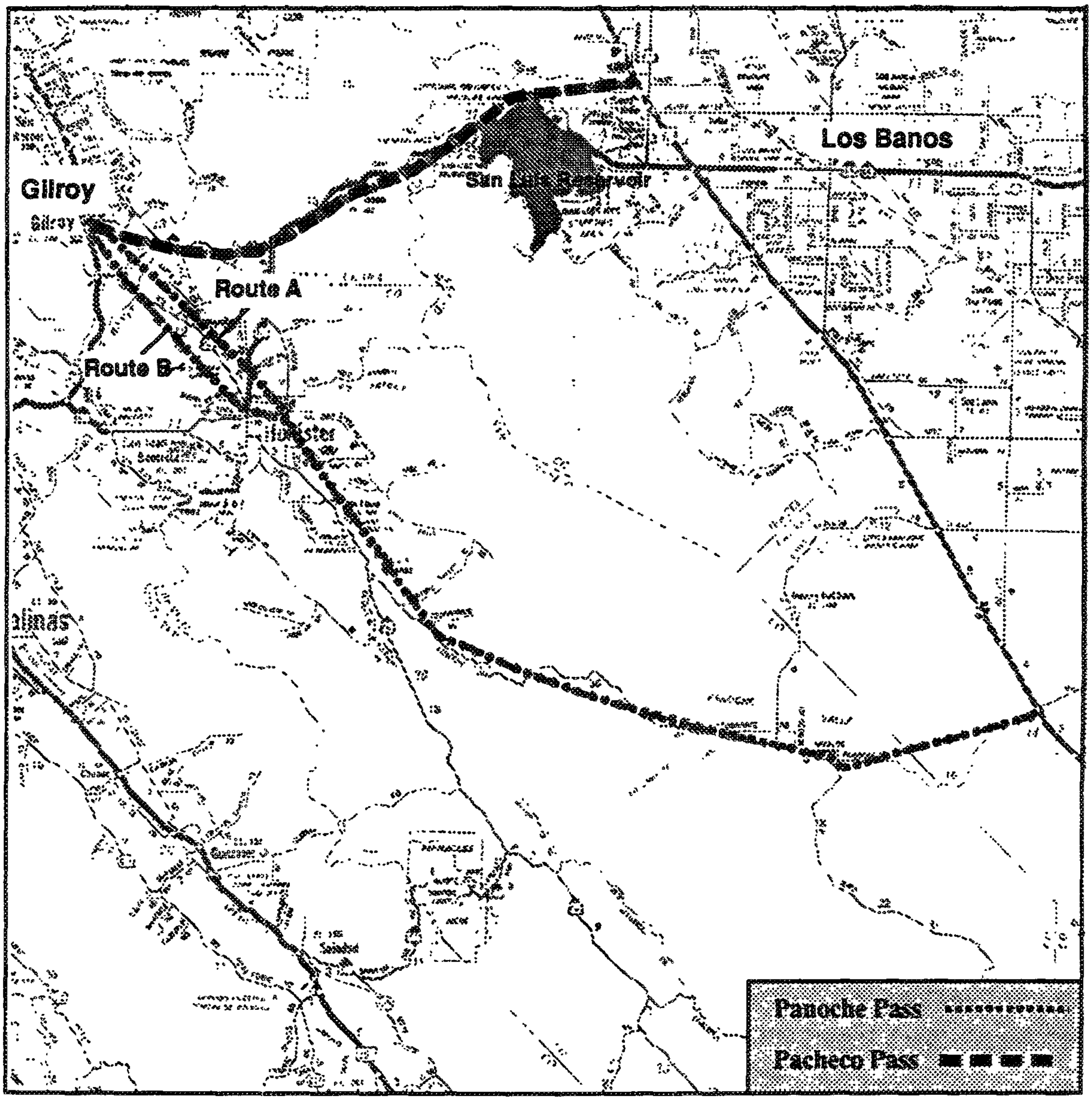
The Pacheco Pass alignment would closely approximate Route 152. It would begin near the Henry Miller Rd/I-5 interchange and end in Gilroy where US-101 and Route 152 meet. As with the mountain crossing in Southern California, the routing through the Pacheco Pass requires horizontal curvature standards necessary to maintain high speeds and two separate maximum grades options (3.5 percent and 5 percent) were calculated.

The total length of the Pacheco Pass alignment is nearly 34 miles. The 3.5 percent maximum grade option requires 6.4 miles of tunneling and 3.5 miles of bridge/viaduct. This alternative is estimated to cost nearly $1.31 billion, and take 10.7 minutes to traverse, averaging 188.5 mph. The 5.0 percent option would result in 5.6 miles of tunneling (89 percent of the 3.5 percent alternative), but require 0.2 more miles of viaduct and a slightly greater travel time because of the steeper grade. As a result of the reduced tunneling costs, the 5 percent option would cost about $1.24 billion, $70 million less than the 3.5 percent alternative. It would take 11.0 minutes to traverse, averaging 183.4 mph.

Panoche Pass Alternative

The Panoche Pass alignment begins at the Panoche Junction overcrossing of I-5. This location is about 40 miles west of Fresno and 13 miles south of where Fresno's downtown station would be located. Presently, only a narrow single-lane dirt road provides access through the pass. Consequently, a CST route would more closely follow powerline and pipeline alignments, since

FIGURE 4.5: THE NORTHERN CALIFORNIA PASS



the road winds through the pass with many very tight curves. Two different alternatives for the Panoche Pass were examined. Route "A" is 84 miles long and is completely built on new right-of-way. Route "B" uses 69 miles of new right-of-way before joining the SP right-of-way just north of Hollister. The SP right-of-way is then utilized for another 11.4 miles. Both alternatives end at US-101 where Route 152 joins the freeway in Gilroy. Since the two major tunnels through the pass could not be reduced much by a steeper gradient, only a 3.5 percent grade option was calculated for the two Panoche Pass alternatives.

Both Route A and B require 5 tunnels which total 8.8 miles in length. The longest tunnel is 3.3 miles long. The amount of bridge/viaduct varies only slightly, since both routes need about 1.2 miles. Route A would cost about $1.67 billion and take approximately 26 minutes to traverse, averaging 195 mph. Being shorter and without speed restriction, Route B has a travel time a little over a minute less than Route A. However, since track replacement and separation protection would be required as well as the purchase of rail right-of-way for the SP alignment portion of the route, Route B costs about $16 million more than Route A — approximately $1.68 billion. It would take about 25 minutes to traverse, averaging 194 mph.

Preferred Route Alternative

The Pacheco Pass is preferred over the Panoche Pass for several reasons. Although the Panoche Pass appears to be a more direct route from the valley, when using high-speed alignments, the total route distance via the Pacheco Pass is actually slightly less than using either of the Panoche Pass alternatives. The distance through the mountains is much less for the Pacheco Pass, less than half the distance through the Panoche Pass (16.2 vs. 37.9 miles). More importantly, the climbing distance for the Pacheco Pass is also less than that of the Panoche Pass (10.3 vs. 22.7 miles). It must be noted, however, that although the mountains through the Pacheco Pass are lower (peak elevation 1,240 feet vs. 2,600 feet), the actual pass is more abrupt. The Pacheco Pass is easily accessible as a result of the freeway (Route 152) passing through it, whereas the Panoche Pass is barren and crossed only by a small, steep, one-lane road. Thus, when considering access, construction and maintenance would be cheaper for the Pacheco Pass. Finally, since the Panoche pass leaves the Central Valley to cross the coastal range 46 miles south of the Pacheco Pass, its use would likely add at least $400 million to the cost of the continuation of the mainline up the Central Valley to Sacramento.

The Santa Clara Valley

Route Alignment Alternatives

Route possibilities are limited through the Santa Clara Valley from Gilroy to San Jose (Figure 4.6). Only existing transportation right-of-way should be considered since the narrow and increasingly urban valley offers no continuous open space and the surrounding ridges are extensive, difficult to tunnel, and environmentally sensitive areas. Two options, the SP right-of-way and US-101 median strip, have adequate right-of-way for the CST mainline and directly connect Gilroy to San Jose. Unfortunately, neither offers a simple solution in bringing the CST mainline from the Northern California Pass to San Jose.

SP Right-of-Way Alternative

The portion of the SP corridor that would be used for the CST line begins at the overcrossing of US-101, at the southern tip of Gilroy. From there, this alignment heads in a northerly direction for nearly 30 miles until reaching the Tamien (San Jose) station location. For most of this segment, until reaching San Jose, the right-of-way is only about 60 feet wide. The alignment is very straight and the eight curves are minor, easily allowing speeds of up to 125 mph with minimal realignment.

The right-of-way currently has freight traffic (typically four trains a day and two per night), and in the near future will become an extension of the Caltrain commuter rail service, with stations in south San Jose, Morgan Hill, San Martin, and a terminal in Gilroy. Other rail services pose a difficult problem here since there simply is not room to expand the number of tracks. The estimated 46 at-grade crossings (34 public, 12 private) represent an equally disruptive problem.[24] Since the Monterey Highway borders a majority (19 miles) of this segment of the SP road, over-crossings/underpasses of the crossing streets do not offer an option; there simply is not room.

It appears that the only acceptable option for using this right-of-way requires either a viaduct or a cut-and-cover tunnel (which would be difficult and expensive to construct while maintaining freight and Caltrain —Peninsula commuter rail— service) until the wider right-of-way and grade separations in San Jose are reached. The most cost-effective solution appears to be 25 miles of viaduct beginning in Gilroy just after the US-101 overcrossing. The expected cost of this segment is therefore high at $779 million. Sustaining a speed of 125 mph until approaching the Tamien station, the segment would take 14.6 minutes travel time.

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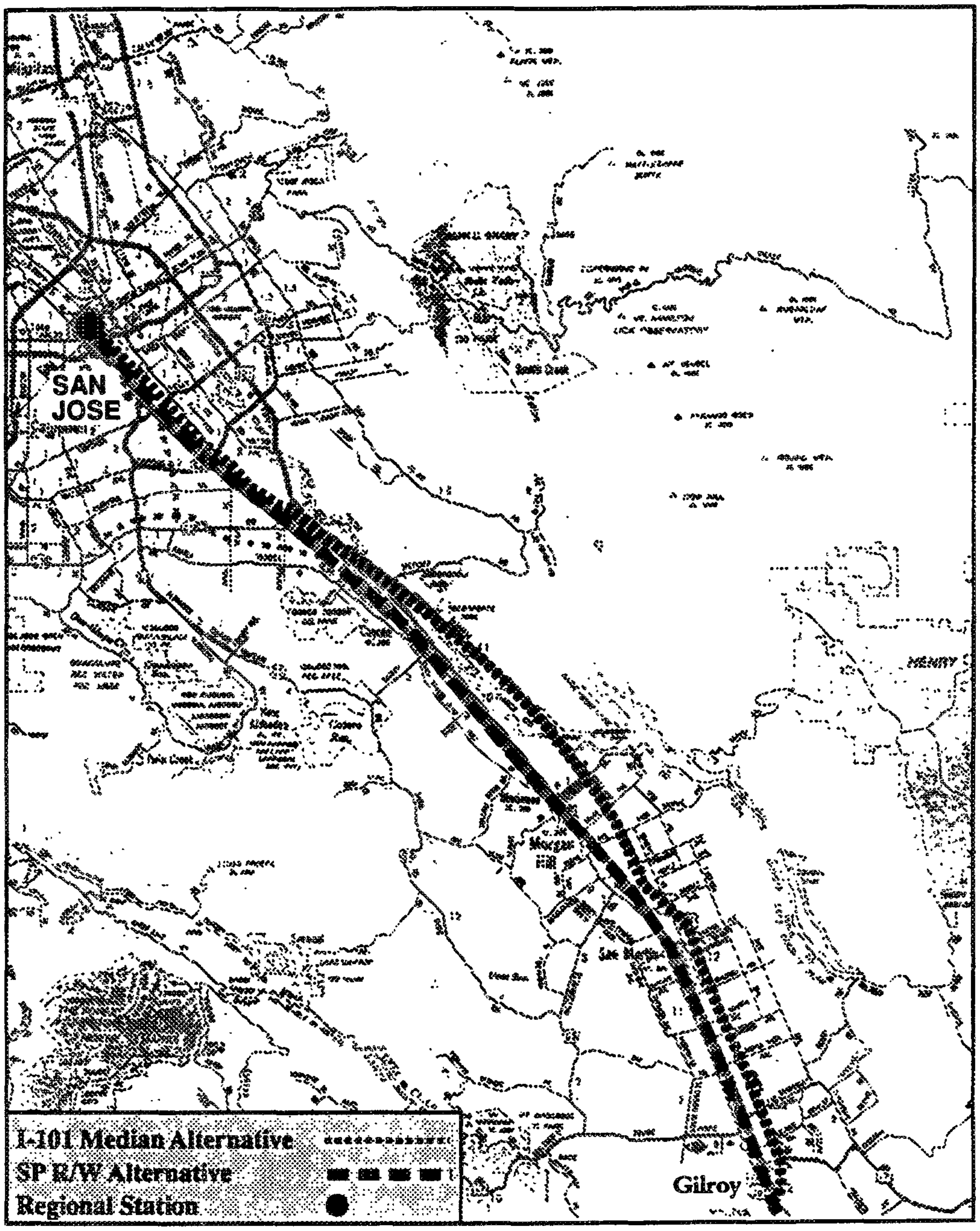
[24] FRA Crossing Inventory 02/92.

FIGURE 4.6: THE SANTA CLARA VALLEY



U.S. Highway 101 Median Alternative

A CST route in the US-101 median would begin in Gilroy at the Route 152 overcrossing and end just 1/2 mile prior to the Bernal overcrossing in San Jose. At this point, the CST routing would leave the highway to join the SP right-of-way. The length of this section of US-101 is 20.5 miles. The SP portion would be 8.5 miles, of which the first 4 miles would be on viaduct. The total segment, therefore, would be about 29 miles long. Presently, an adequate median width exists for CST use throughout the section of US-101. In the near future, however, this is likely to change.

Caltrans has received funding to expand portions of US-101; thus, by 1998, this entire segment of US-101 will be a six-lane highway with an average median width of 70 feet. In addition, Caltrans is in the advanced planning stages for the ultimate expansion of this portion of US-101 (construction to begin by 2005). By the year 2010, from Gilroy to San Jose, Caltrans expects US-101 to be an eight-lane freeway with an average median width of 46 feet.

With a 70-foot-wide median strip, US-101 could be a relatively simple and cost-efficient alternative for this segment of the CST routing. Although some excavation is needed at overcrossings to meet vertical clearance requirements, this would be a relatively minor cost. The highway was designed using 5,000 foot minimum horizontal curves; therefore, maximum speeds of 125 mph can be sustained throughout the median segment. Moreover, the first seven miles of the freeway are completely straight; thus even higher speeds could be achieved. This is true not only in the median segment, but also throughout the final few miles of the Northern California Pass segment. In addition, the US-101 median is completely grade-separated and, as a result of recent legislation, could likely be used at no cost. By utilizing this existing transportation corridor and running at-grade at reduced speeds, environmental concerns would be minimized. It is estimated that the complete link from Gilroy to San Jose would cost $514 million and would take 13.7 minutes to traverse, averaging 127 mph.

On the contrary, if the ultimate expansion of US-101 envisioned by Caltrans were to occur, the reduced median width would make it very difficult to fit in the CST alignment. The 46-foot median width would be barely wide enough for rail use, leaving the freeway with the narrowest allowable median shoulders. The central piers of the 11 overcrossings of the freeway could not remain. They would need to be replaced with piers on the outer edges of the median strip, substantially adding to the cost of this segment. If this alternative were to be permitted, the estimated cost rises to $649 million.

Preferred Route Alternative

Use of the median strip of U.S. Highway 101 is certainly preferred. It would be up to $265 million cheaper than an SP alignment, take nearly a minute less travel time, and be far more attractive from an environmental/political standpoint; the 25-mile-long viaduct proposed for the SP right-of-way would be likely to evoke environmental objection. The problem with using the median strip is that if US-101 is expanded (as Caltrans plans) to eight lanes, it is doubtful that the CST alignment would be permitted in the narrow median that would remain. With a 70-foot-wide median, US-101 provides a very attractive corridor for this segment. If the median width is reduced to 46 feet, it appears that the SP right-of-way must be utilized.

The San Francisco Bay Area

Historically, San Francisco has been the locus of cultural activity, economic activity, and population in the Bay Area. Serving San Francisco must be the primary objective in choosing the CST layout. However, geography and the now widely dispersed population and economic activities of the Bay Area suggest that the mainline could split into two branches from San Jose: one connecting San Jose to Oakland and continuing north to Sacramento, the other comprising the final Los Angeles-San Francisco link (Figure 4.7). Priority would be given to constructing the link to San Francisco since this route seems to have the greatest potential for attracting private investment in the CST network. In the interim, the East Bay may be served by an improved Capitol Corridor service connecting to the CST in San Jose.

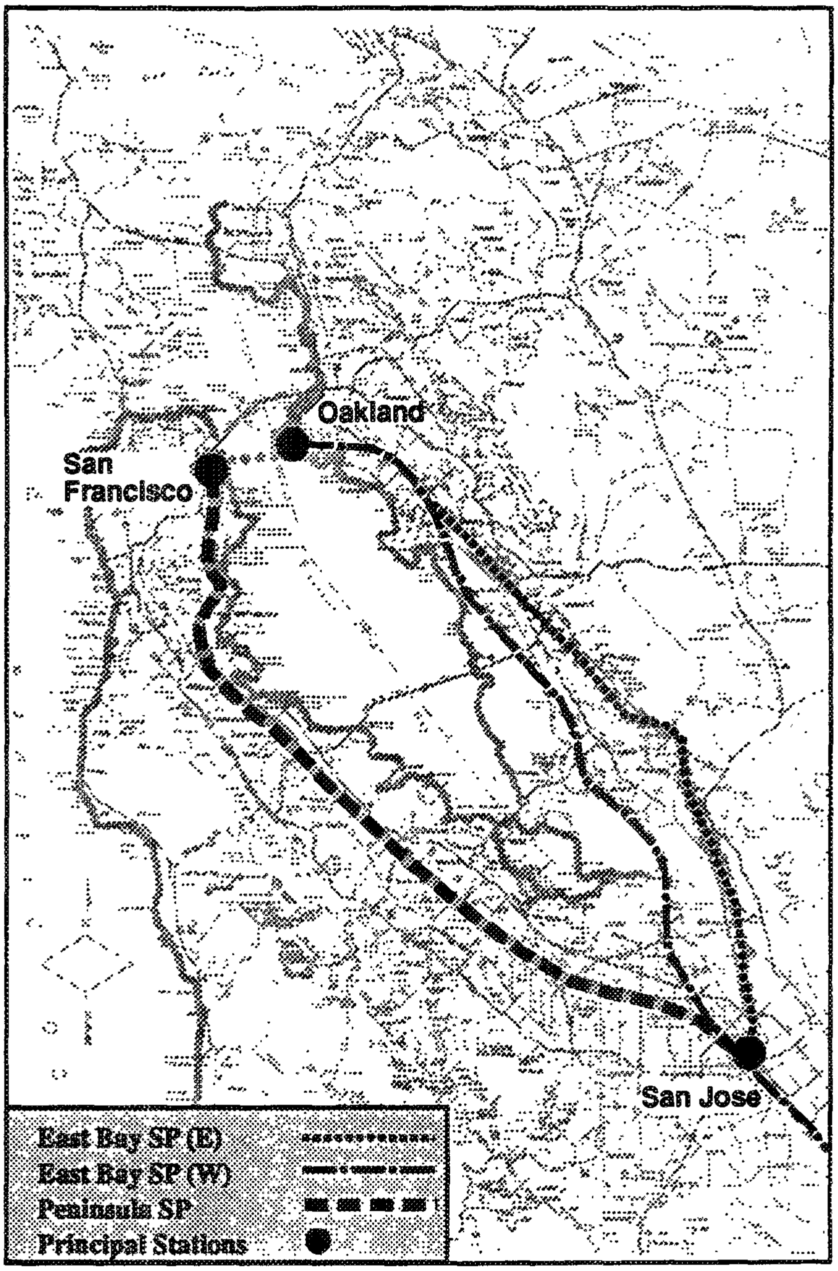
The SP rights-of-way on both sides of the Bay form the only practical options for extending CST service into the highly urbanized Bay Area. On the Peninsula, this right-of-way was recently acquired by a Joint Powers Board (JPB) which plans to expand and upgrade the existing Caltrain commuter rail service between San Francisco and Gilroy.

The Peninsula

The Peninsula link would provide service via the 49-mile Peninsula SP between the Tamien station in San Jose and a new terminal located in downtown San Francisco. The main obstacles to true high speeds in this corridor are noise considerations, at-grade crossings (which may be grade-separated), and the need to share a limited right-of-way with commute services.

The Tamien site, located at Lick and Alma Avenues, is currently favored by light rail service, good highway access, and a Caltrain commuter station. Long-range planning documents show

FIGURE 4.7: THE BAY AREA



that BART and the Santa Clara County light rail may ultimately be extended to the existing downtown station on Cahill. If these extensions are to occur, then the Tamien site should be planned as an interim station and the Cahill site designed to accommodate BART, commuter trains, and CST service. However, as the time frame for the BART extensions is indefinite, a Tamien station is assumed at this point.

Between Lawrence and Redwood City, and in places north of Redwood City, the line passes almost exclusively through high-quality residential areas. Despite the fact that this is an existing rail noise corridor, and that CST and electrified commuter trains are likely much quieter than the diesel locomotives currently in use, it is assumed necessary for environmental reasons to restrict speeds to a maximum of 100 mph on the Peninsula.

Frequent grade crossings represent a problem, particularly where they occur in or near city centers with busy traffic, notably at Mountain View, San Mateo, and Broadway. Of the 66 identified at-grade crossings, 11 are programmed for separation by San Mateo County. Costs for the remaining 55 are included in the estimate for the Peninsula link.

From San Jose to San Francisco, CST would share the SP right-of-way with Caltrain commuter services. With 15-minute frequency planned for the Caltrain service, additional track capacity will be necessary. The right-of-way is adequate along much of the corridor for construction of four tracks. Two tracks would accommodate CST intercity trains and express commuter trains (both services would have maximum speeds in the same range). The remaining tracks would carry local commuter trains making frequent stops and the few freight trains which use the corridor daily.

Expansion of track capacity will prove difficult in some locations, such as underneath the overhead structure of the I-280 freeway. In other locations, additional right-of-way may need to be acquired or a three-track configuration used, involving alternate working of the CST trains. The exact feasibility and cost of the operation could be determined only after detailed engineering examination.

The above implies that accommodating both express and local passenger train services on the Peninsula corridor will be complex. A possible solution to this difficulty might lie in letting future BART extensions down the Peninsula provide the local, all-stops commute service to a certain point. North of this point, the SP could be given over to express or limited-stop passenger operations.[25]

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[25] Two tracks would carry the passenger traffic and one track the limited amount of freight. In this scenario, three tracks would suffice without the need for alternate working of trains.

At the San Francisco end, the existing terminal station at 4th and Townsend is poorly located to serve the San Francisco central business district. The Peninsula Joint Powers Board proposes to extend their services in tunnel to a new terminal, either to a two-level terminal adjacent to the BART/MUNI Montgomery Street Station at Market Street, or to the existing Trans-Bay Terminal. Logically, CST services would share this extension. It would be important to secure a convenient interchange at either terminal with BART and Muni-Metro services.

The Peninsula link would cost approximately $1.3 billion,[26] assuming that the CalSpeed system bears the full cost of electrification and capacity expansion on the Peninsula and contributes $400 million to the downtown San Francisco terminal project. The fastest commuter train currently takes 63 minutes to travel from San Jose to San Francisco, with five intermediate stops. With upgrading and expansion of the SP right-of-way, this trip could be made in 45 minutes, including a stop at San Francisco International airport.

The East Bay Link

The East Bay CST link would run on SP right-of-way between the Tamien site in San Jose and a new station development in West Oakland. Either of two branches of the SP between San Jose and Oakland could be used. Once in Oakland, the route would use either tunnel or viaduct to avoid running within Oakland city streets.

In the East Bay, the SP branches into two parallel lines for some 30 miles (BART uses an entirely separate alignment, the Western Pacific). The westernmost or Santa Clara branch would be the preferable route for express CST service, since it is straighter and runs through fewer residential areas than the Niles branch. However, Southern Pacific prefers to reserve this line for freight, as it more directly serves industry along this corridor. The recently reintroduced Capitol Corridor service presently uses the western line but is scheduled to move to the eastern line as soon as track improvements are complete.

If freight remains on the western branch, separate passenger and freight tracks will have to be provided. However, currently the line is single-tracked on embankment through wetlands in the South Bay, and expansions might raise environmental objections. There is also a severe speed restriction at the junction with the Niles line branch near 98th Street in Oakland, which might be difficult to reconstruct for faster running. Though the western SP branch remains the preferred option, the more eastern Niles branch offers an alternative if reconstruction of the Santa Clara

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[26] This estimate includes costs for the Tamien station ($30 million) which should not be duplicated when adding the costs of the two Bay Area CST branches.

branch proves too difficult. In this case, CST services would share tracks with an upgraded Capitol Corridor service with passing loops for 100 mph operation. The two SP lines join in southern Oakland. After the I-880 freeway overpass, the SP tracks run within city street rights-of-way and trains are slowed to 5-10 mph. In order to avoid this restriction, two options were considered. One option would require a cut-and-cover tunnel under the street, probably extremely expensive given the probable utility relocations required and construction near the waterfront. Such a tunnel might also follow the freeway alignment. The other option would be to elevate the tracks on a structure serving the new West Oakland station. To avoid cutting off the Jack London waterfront development, the structure would have to be integrated with the existing I-880 and new Cypress replacement freeway structures. All of these options would require further engineering examination.

Amtrak proposes to relocate its main Oakland station from 16th and Wood Streets, where the historic structure suffered severe damage in the 1989 Loma Prieta earthquake and is now closed to the public, to a new station at Jack London Square. This appears logical for Amtrak operations, but high-speed operations would need to by-pass this section. The main CST station in Oakland, which would have a connection both to Amtrak and BART, would be at Kirkham Street close to the West Oakland BART station, where a large area of redundant Southern Pacific land is available. A connecting structure (probably including retail and other services) could be built on derelict industrial land, in such a way so as not to impinge on the West Oakland residential community, with direct access to the BART West Oakland station at its eastern end. This new station development would present significant opportunities for joint public-private development.

The cost of an East Bay CST branch would be about $1.3-1.4 billion,[27] depending upon the alternative selected for Oakland. Nonstop CST service between San Jose and West Oakland would take about 32 minutes with a dedicated structure in Oakland. Otherwise, assuming that street congestion does not delay trains, the trip would take about 43 minutes.

Preferred Alternative

Since a San Francisco CST link is likely to generate more financing interest from the private sector than an East Bay link, the Peninsula branch would be constructed first. As previously mentioned, the East Bay would be served by an upgraded Capitol Corridor service in the interim, until sufficient funds and/or market interest were generated to justify the East Bay CST link.

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[27] This estimate includes costs for the Tamien station ($30 million) which should not be duplicated when adding the costs of the two Bay Area CST branches.

The East Bay link might also be seen as the San Jose-West Oakland segment of an upgraded Capitol Corridor which could carry HST service between San Jose and Sacramento as well as CST trains terminating in West Oakland. Ultimately, the traveler should have the choice of comparably fast express service on both sides of the Bay.

If some uncertainty remains about the exact means of effecting CST service in the Bay Area (that is, the choice of right-of-way in the East Bay), this analysis has shown assuredly that coordinated long-range planning efforts are necessary in two areas. First, expansions and improvements to the Caltrain commuter service should be undertaken with regard to future integration with a high-speed intercity service. Second, if BART is to be extended down both sides of the Bay to San Jose, the relationship between BART, the Caltrain service, and future intercity services deserves careful thought.

Summary

Figure 4.8 shows the proposed complete routing between the Los Angeles Metropolitan area to the Bay Area. To review, the alignment is as follows:

1. *The L.A. Basin* —the SP right-of-way from L.A. Union Station to Saugus.
2. *Grapevine* —from Saugus, a new high-speed alignment through the Grapevine pass. Closely approximating I-5 to the Central Valley, the alignment utilizes a sustained 5.0 percent maximum grade at each end of the pass.
3. *Central Corridor* —a new high-speed alignment through the Central Valley. Generally one to three miles west of Route 99 until just north of Madera, where the alignment veers west across the valley. The alignment avoids all urban areas yet provides service to major population centers via outlying stations and a downtown Fresno loop.
4. *Pacheco Pass* —a new high-speed alignment across the coastal mountain range through the Pacheco Pass and ending at Gilroy. It utilizes a sustained 5.0 percent maximum grade on the western side of the pass.
5. *Santa Clara Valley* —uses the US-101 median strip until San Jose, where the SP right-of-Way is utilized through the downtown area.
6. *Bay Area* —SP right-of-way is used from San Jose to San Francisco.

This route is summarized by Table 4.2 under the heading "Route #1: Central Corridor, New Right-of-Way." Appendix D provides travel times for various city pairs considering both express and semi-express levels of service.

For purposes of comparison, a second route which uses the I-5 corridor through the Central Valley has also been tabulated and is shown as "Route #2" on Figure 4.9 and summarized by Table 4.2.

FIGURE 4.8: LOS ANGELES-BAY AREA: Route #1, Central Corridor

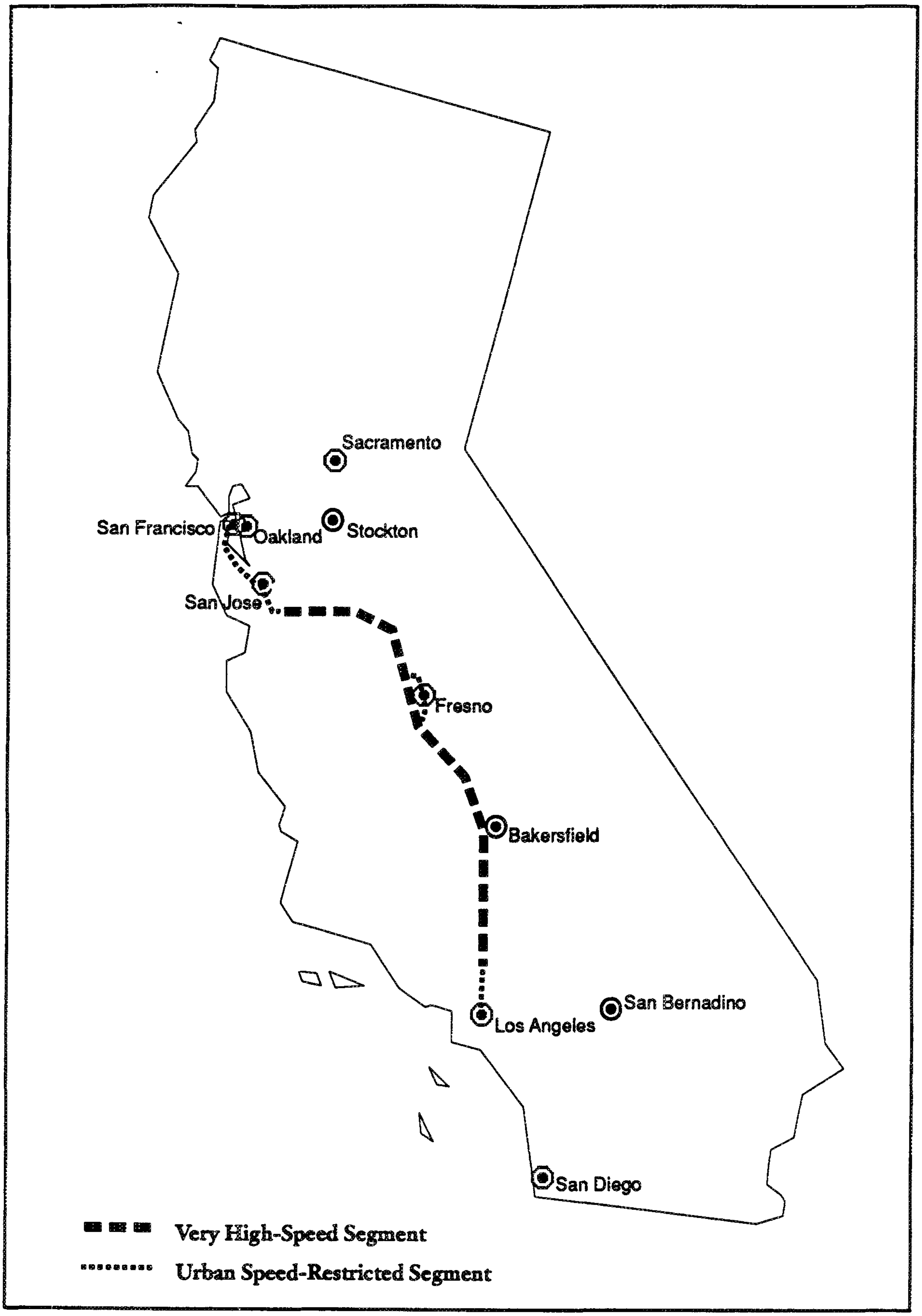


TABLE 4.2

LOS ANGELES TO BAY AREA: ROUTE ALTERNATIVES SUMMARY

5.0% Grade Option, 200 mph maximum speed

Route #1: Central Corridor, New R/W

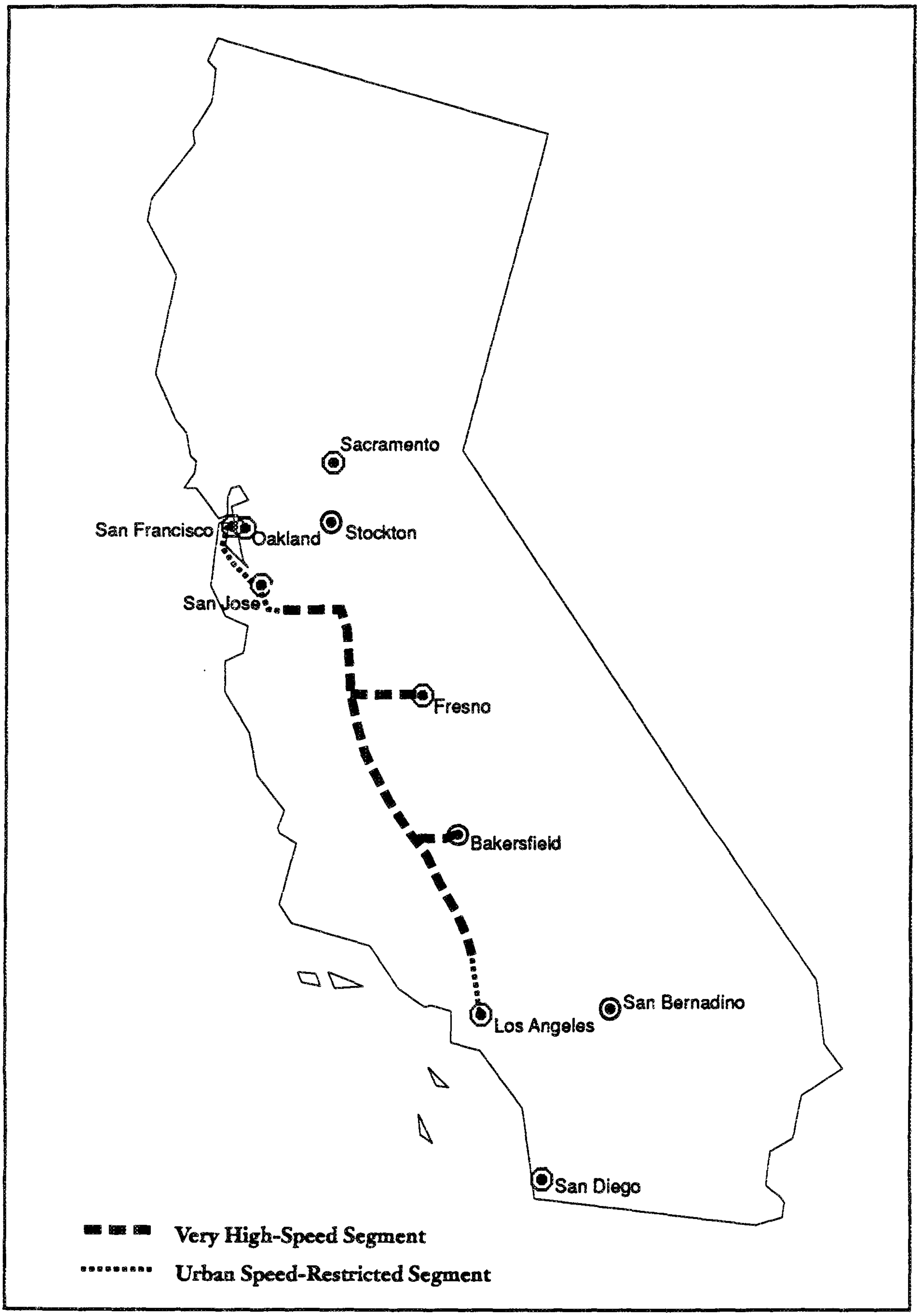
SEGMENT	TOTAL MILES	MAXIMUM SPEED	AVERAGE SPEED	TIME HOURS	MINUTES	COST
LA URBAN AREA	32	125	89.8	0.36	21.6	1,043,100,000
GRAPEVINE 5.0%	49	200	167.5	0.29	17.5	2,017,000,000
CENTRAL CORRIDOR *	205	200	200.0	1.03	61.5	2,236,600,000
PACHECO PASS 5.0%	34	200	183.4	0.18	11.0	1,237,300,000
SCV: US-101	29	150	126.6	0.23	13.7	514,200,000
SAN JOSE-SAN FRAN.	49	100	77.4	0.63	38.0	1,922,800,000
	398		146.1	2.72	163.3	$8,971,000,000

Route #2: I-5 Corridor, New R/W

SEGMENT	TOTAL MILES	MAXIMUM SPEED	AVERAGE SPEED	TIME HOURS	MINUTES	COST
LA URBAN AREA	32	125	89.8	0.36	21.6	1,043,100,000
GRAPEVINE 5.0%	49	200	167.5	0.29	17.5	2,017,000,000
I-5 CORRIDOR *	187	200	200.0	0.94	56.1	2,454,200,000
PACHECO PASS 5.0%	34	200	183.4	0.18	11.0	1,237,300,000
SCV: US-101	29	150	126.6	0.23	13.7	514,200,000
SAN JOSE-SAN FRAN.	49	100	77.4	0.63	38.0	1,922,800,000
	380		144.3	2.63	157.9	$9,188,600,000

* Includes Fresno Downtown Loop and Bakersfield Spur Costs

FIGURE 4.9: LOS ANGELES-BAY AREA: Route #2, I-5 Corridor



LOS ANGELES TO SACRAMENTO

An alignment through the Central Valley to Sacramento is very suitable for CST service. Unlike either the Los Angeles Basin or the Bay Area, Sacramento's city limits can be approached from the south without any speed restriction. As a result, even though distances are similar, travel times between Los Angeles and Sacramento could be considerably less than between Los Angeles and San Francisco. Moreover, a rural valley route to Sacramento would be flat and could avoid any major natural obstacles. Therefore, the cost per mile of this segment should be relatively low.

Route Alignment Alternatives

From the south, the routing to Sacramento would begin at a turnout from the Los Angeles to Bay Area (LA-BA) main line. Making an assumption that the Central Corridor alternative was used for the LA-BA main line, the turnout could be appropriately located either at the point where the LA-BA alignment heads west across the valley, or just before this routing crosses I-5 to begin the Pacheco Pass (if the I-5 Corridor Central Valley alignment were used for the LA-BA main line, only alternatives beginning from I-5 could be considered).

Since the line to Sacramento has no bearing on the travel time between Los Angeles and the Bay Area, it was thought necessary to examine several different types of service through the Northern Central Valley to Sacramento. Therefore, six alternatives (three for each of the studied turnout locations) using new rights-of-way, existing rail rights-of-way, and a combination of each were studied. Each alternative utilized the existing SP right-of-way through the Sacramento urban area and terminated at the Sacramento Downtown Station.

Using new right-of-way, outlying stations would serve the major cities between Fresno and Sacramento. These alternatives would be the cheapest and provide the fastest through times to Sacramento. Utilization of existing rail right-of-way provides direct downtown service to the cities between Fresno and Sacramento yet increases both capital costs and travel times. The alternatives are as follows:

1. Madera to Sacramento, Existing SP Right-of-Way
2. Pacheco Pass to Sacramento, Existing SP Right-of-Way
3. Madera to Sacramento, New Right-of-Way
4. Pacheco Pass to Sacramento, New Right-of-Way
5. Madera to Sacramento, New Right-of-Way & SP Right-of-Way
6. Pacheco Pass to Sacramento, New Right-of-Way & SP Right-of-Way

Figure 4.10 shows these different alternatives and each is described in detail in Volume II. Distances, costs, average speeds, and travel times were calculated for the alternatives and summarized by Table 4.3. Travel times for both Los Angeles to Sacramento and San Jose to Sacramento express services are also included in Table 4.3.

Preferred Route Alternative

The new right-of-way alignment beginning from the Pacheco Pass (Alternative #4) would be the most appropriate for the CST system. Since it offers the shortest distance from the LA-BA main line and avoids all urban areas south of Sacramento, this alternative is by far the cheapest; moreover, it provides the best combination of travel times between the major markets. The travel time non-stop from Union Station in Los Angeles to downtown Sacramento would be only about 2 hours and 18 minutes. From downtown San Jose to downtown Sacramento would be around 66 minutes. These services would thus be extremely competitive with existing modes of transportation.

In comparison with the other new right-of-way alternative (Alternative #3), the preferred alternative would be $425 million cheaper than the more easterly routing. It would provide a service to San Jose which is 22 minutes faster, while having a time to Los Angeles only about 5 minutes slower. Since no additional large population centers are served by the eastern route, the new alignment beginning at the Pacheco Pass is clearly superior.

The major benefit of the existing rail right-of-way alternatives (particularly Alternative #1) is that they directly serve the downtown population centers of the Northern Central Valley. However, although no other downtowns besides Sacramento would be served by the preferred alternative, the outlying station near Stockton is only a few miles from the downtown. Additional outlying stations would be near both Manteca and Modesto. Therefore these cities would recur service without sacrificing express travel time between the major markets. Since the markets are comparatively small, the benefits of serving additional downtowns through this segment could not offset the tremendous additional capital costs and the increases in travel time to Sacramento.

Furthermore, there are many serious proposals to create new towns throughout the transportation corridor of the northern Central Valley. These new towns would best be served by outlying stations, the precise location of which could be planned in conjunction with the new development.

FIGURE 4.10: SACRAMENTO LINK ALTERNATIVES

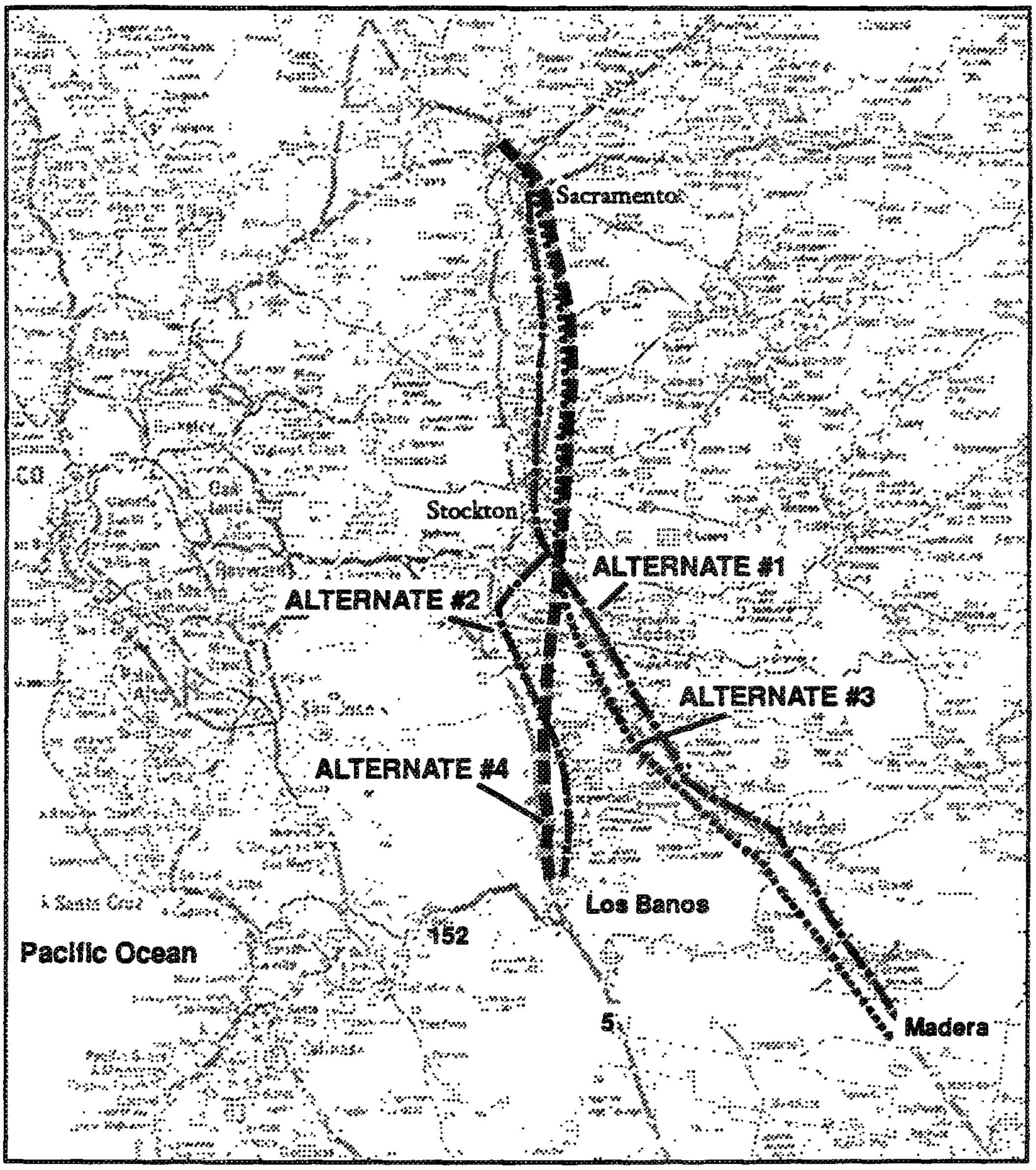


TABLE 4.3

SERVICE TO SACRAMENTO: SUMMARY OF ALTERNATIVES

ALTERNATIVES	DISTANCE	MAXIMUM SPEED	AVERAGE SPEED	TIME MINUTES	LA – SAC DISTANCE	LA – SAC HOURS*	SJ – SAC MINUTES*	SEGMENT COST
1. MAD–SAC SP R/W	148	175	125.9	70.6	382.6	2.59	111.0	$2,438,400,000
2. PP–SAC SP R/W	119	175	125.8	56.8	405.3	2.62	82.8	$1,933,200,000
3. MD–SAC NEW R/W	145	200	176.5	49.3	379.3	2.24	87.8	$1,683,000,000
4. PP–SAC NEW R/W	111	200	170.2	39.0	396.8	2.33	65.5	$1,258,200,000
5. MD–SAC NEW&SP	147	200	142.9	61.6	381.0	2.44	100.1	$2,156,500,000
6. PP–SAC NEW&SP	112	200	146.8	45.6	397.9	2.44	71.7	$1,587,600,000

* 5.0% Grade Option

5. FEEDERS AND SUPPLEMENTARY HIGH-SPEED SERVICES

SAN FRANCISCO BAY AREA TO SACRAMENTO

In order to complete a rail loop connecting the Bay Area, Sacramento, and the Central Valley cities of Stockton and Modesto, a link between West Oakland and Sacramento must be integrated into the CST network. A very modest level of rail service currently exists on this route, but the existing rail alignment presents severe challenges to higher speeds. At the same time, possibilities for new alignments tend to be quite restricted, extremely expensive, and possibly infeasible. For various reasons, which are discussed below, building a very high-speed line (200 mph operations) between the Bay Area and Sacramento would involve very high cost for only a limited return in terms of travel time.

The Bay Area-Sacramento corridor is an important travel market, however. The success of the recently reintroduced "Capitol Corridor" rail service between San Jose and Sacramento suggests a significant untapped market.[28] Improved travel times and frequency of service would undoubtedly lead to greater ridership.

Investment decisions for this corridor need to be made in light of the role that it will play in the California network. The Bay Area-Sacramento branch in the California network would serve a different purpose than the VHST mainline between Los Angeles and Northern California. Given the proposed network layout, people travelling between Los Angeles and Sacramento would take the very high-speed link through the Central Valley rather than traversing the Bay Area. Even travellers between Sacramento and San Jose would find the very high-speed Central Valley route more convenient, as the trip on this link would take only 66 minutes versus a projected 93 minutes via the East Bay. This Bay-Sac corridor will primarily serve, then, shorter-distance commute and business traffic between the Bay Area and Sacramento; thus a kind of local business and commute loop can be envisioned within the Bay Area, the Central Valley, and the Sacramento area.

The Capitol Corridor would also function as a feeder from locations between Oakland and Sacramento to the very high-speed portions of the network. A traveller from Richmond or Martinez, for instance, could take a Capitol Corridor train to join with long-distance service in Oakland or San Jose, depending upon whether the CST service is extended to Oakland. Alternately, a few

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[28] According to Caltrans, 17,683 people rode the trains in January 1992 and, as a preliminary estimate, 23,600 in February 1992. Considering the short period of time the trains have been in service, and that recreational ridership is low during winter, ridership is higher than anyone expected. Also note that there is not yet a significant business ridership with only three trains a day.

long-distance trains to and from Los Angeles could traverse the corridor to pick up and drop off passengers.

The existing service attains a maximum speed of 70 mph north of Benicia, with a maximum of 35 mph between San Jose and Benicia. This level of service is inadequate to serve the functions envisioned for the Bay Area-Sacramento link in the CST network. Therefore, a much-improved level of service is sought, either by reconstructing the Southern Pacific (SP) right-of-way currently in use or building track on new alignment.

The Southern Pacific Alignment Between Oakland and Sacramento

Current speed restrictions on the SP (Figure 5.1) vary from 10 mph to 70 mph. Apart from those restrictions which stem from antiquated track or signalling, which will be replaced, the route presents several inherent constraints on speed.

First, a significant portion of the SP passes through a densely urbanized area which precludes truly high speeds. Next, the SP follows a tortuously curved route along the southern shore of the Carquinez Strait between Richmond and Martinez. This problem is the most difficult to surmount since alternate routes are largely blocked by a combination of development, hilly terrain, and environmental constraints.

North of the strait, the SP alignment runs relatively straight, but the spacing of towns between Fairfield and Sacramento[29] presents a problem. Assumed speed restrictions of 125 mph when passing through these towns reduce the average speed achieved on the section to 127 mph. Thus, the full capabilities of a very high-speed trainset would not be used on the existing SP alignment.

Alternatives to the SP Alignment

Given the inherent constraints on speed of the alignment currently in use, alternate alignments were sought. This proved to be a difficult task as the Bay Area, both to the south and north of Carquinez Strait, is heavily built up. Thus, avoiding the most troublesome part of the SP— the curved section along the strait —proved most onerous.

A more detailed discussion on this process can be found in Volume II. The most promising opportunity for new alignment was found between Fairfield and Sacramento. Other options, such

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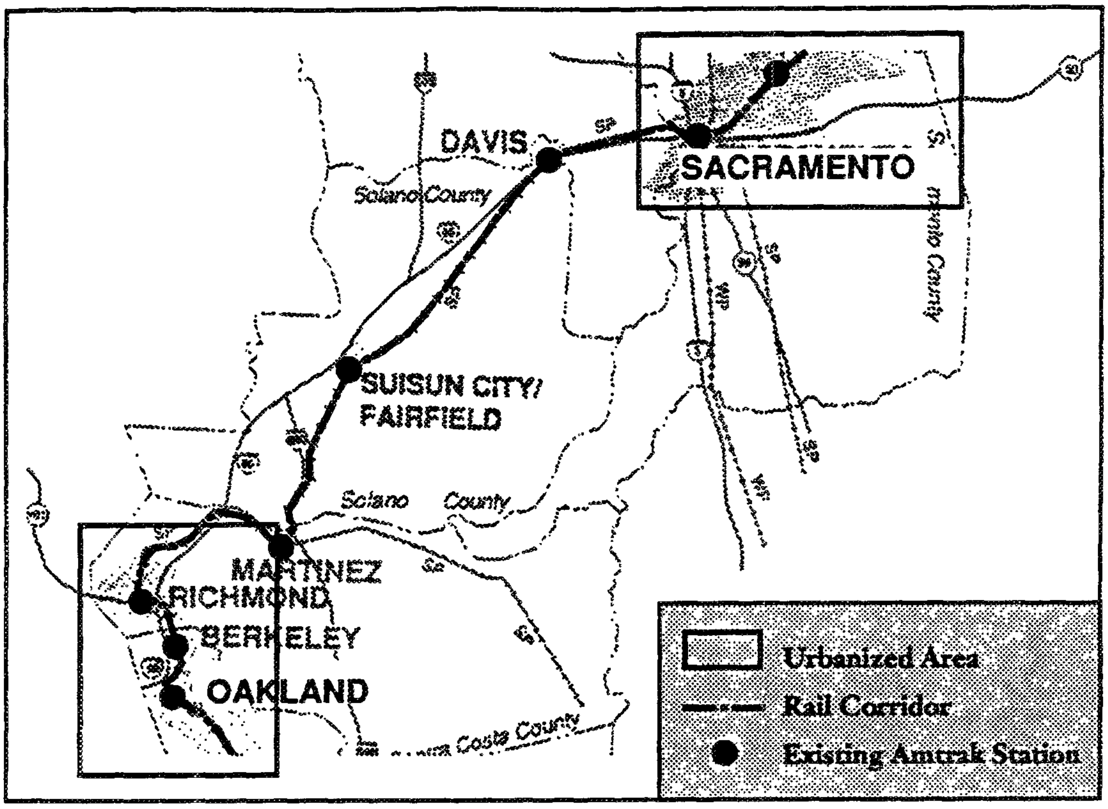
[29] The towns are Fairfield, 14 miles north of the Carquinez Bridge; Elmira, 7 miles from the Fairfield urban limit; Dixon, 6 miles from Elmira; Davis, 6 miles from the Dixon urban limit; and Sacramento, 9 miles from the Davis urban limit.

FIGURE 5.1: OAKLAND TO SACRAMENTO: SP R/W



as an alternative crossing of the Carquinez Strait, seemed excessively costly and environmentally difficult for the time savings achieved.

Conclusion

Table 5.1 summarizes five alternates for integrating the Bay Area-Sacramento corridor into the CST network. Detailed time and cost estimates corresponding to each segment denoted in the left-hand column can be found in Volume II. The alternates range from the more radical, costing $2.1 billion and involving extensive new construction on new right-of-way, to rebuilding the tracks along the existing SP right-of-way at a cost of $1.6 billion. Note that the "radical" options involve a great deal more uncertainty as to feasibility and cost than would an upgrading of the SP.

The comparison of alternatives is treated in detail in Volume II. In sum, the costs involved in using extensive new right-of-way do not seem to be balanced by the benefits gained. The most cost-effective improvements in service in this corridor can be gained by reconstruction on the SP right-of-way except, perhaps, between Fairfield and Sacramento. Here, if separation of high-speed passenger traffic from freight proves a major problem, or as an eventual expansion of capacity, a new right-of-way might be constructed.

The best option for the Capitol Corridor would involve reconstruction of the SP for HST service, with perhaps the use of tilt train technology to improve speeds along the Carquinez Strait. In addition, a new right-of-way between Fairfield and Sacramento should be given serious consideration. Option 1a, the new right-of-way, would cost about $1.5 billion and would make possible a travel time of under one hour between Oakland and Sacramento.

LOS ANGELES TO SAN DIEGO

The San Diego-Los Angeles corridor (LOSSAN) is one of the most favorable markets for rail service in California. The coastal Santa Fe rail corridor links over 12 million people within a 128-mile distance. Moreover, approximately six million of these residents live within five miles of this existing corridor.[30] Since 1971, the Santa Fe has been used by Amtrak for intercity service. Improvements in ridership over the years have made this route one of Amtrak's most successful. Within the Amtrak passenger system, this corridor is second in ridership only to the Northeast Corridor. In 1989/90, using eight daily San Diegan trains in each direction between the downtown San Diego station and Los Angeles Union Station, Amtrak served approximately 1.75 million passengers. Furthermore, Amtrak claims that revenues from the San Diego route exceeds operating

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[30] Wilbur Smith Associates, June 1987.

Table 5.1

OAKLAND - SACRAMENTO: OPTIONS

Segment	Cost (000's) I	Time (min.)	Cost (000's) Ia)	Time (min.)	Cost (000's) Ib)	Time (min.)	Cost (000's) II	Time (min.)	Cost (000's) III	Time (min.)
W. Oakland-Richmond	464,800	9.37	464,800	9.37	464,800	9.37	464,800	9.37	464,800	9.37
Richmond-Benicia Br.	279,400	20.05	279,400	20.05	---	---	---	---	---	---
Richmond-Hercules	---	---	---	---	121,300	6.85	121,300	6.85	121,300	6.85
Hercules-Fairfield (via Vallejo SP)	---	---	---	---	---	---	---	---	983,100	12.22
Hercules-Fairfield (via Sky Valley)	---	---	---	---	---	---	622,500	10.82	---	---
Hercules-Benicia Br.	---	---	---	---	216,100	7.98	---	---	---	---
Benicia Br.-Fairfield	161,300	8.64	161,300	8.64	161,300	8.64	---	---	---	---
Fairfield-Sacramento (SP ROW)	718,700	19.85	---	---	---	---	--- ---	--- ---	--- ---	--- ---
Fairfield-Sacramento (new ROW)	---	---	565,200	16.78	565,200	16.78	565,200	16.78	565,200	16.78
Total: Oakland to Sacramento	$1,624,200	58	$1,470,700	55	$1,528,700	50	$1,773,800	44	$2,134,400	45

←---less new r/w | more new r/w---→

Option I: Use of Southern Pacific ROW (Capitol Corridor route).

Option Ia): Option I plus new alignment between Fairfield and Sacramento.

Option Ib): Option Ia) plus new alignment between Richmond and the Benicia-Martinez RR Bridge.

Option II: New alignment from Richmond to Sacramento, new crossing of Carquinez Strait at Dillon Point.

Option III: New alignment between Richmond and Sacramento, new crossing of Carquinez Strait to Vallejo.

costs.[31] Typical rail travel time between L.A. and San Diego is 2 hours and 40 minutes. Seven additional stops exist on this routing (see Figure 5.2).

A study by the Federal Railroad Administration and Amtrak in 1981 designated the San Diego-Los Angeles transportation corridor as having the best potential for rail passenger development in the nation.[32] Shortly thereafter, a private consortium (the American High-Speed Rail Corporation) made an attempt to construct, operate, and maintain a $3.1 billion (1984 dollars) high-speed passenger rail service in this corridor scheduled to begin operation in 1989. In 1984, work on the project was stopped. A lack of short-term financing was cited as the reason behind the stoppage of the project. However, other important issues, including political diplomacy, environmental impact, and the reliability of ridership figures were also at work against the project.[33]

Even with the failure of the bullet train proposal, it is likely that many Southern Californians remain supportive of the idea of a high-speed service between San Diego and Los Angeles. However, while the LOSSAN Corridor is an outstanding rail corridor, with excellent potential for increased ridership, it is not realistically a candidate for *true* high speeds. Many of the problems encountered in attempting to create a VHST alignment for the Bay Area-Sacramento Corridor are the same for the LOSSAN corridor. Nearly 80 percent of the corridor is through urban areas, and almost the entire routing is environmentally sensitive. Since a majority of the routing follows the coast, there are many speed-restricting curves throughout the alignment. These constraints simply do not present a good opportunity for high speeds. In addition, the existing services on the Santa Fe are problematic. To maintain freight service and local commuter services, at least three tracks, but preferably four tracks, would be needed. Insufficient right-of-way widths would create the need for a considerable portion of the route being on elevated structures (as the bullet train proposal had assumed). It is nearly certain that from Los Angeles to Fullerton high-speed passenger trains would have to be on a viaduct. Needless to say, the environmental outcry of the early 1980s would be repeated once long stretches of viaduct were proposed.

The LOSSAN corridor would make an outstanding HST corridor. Maximum speeds between 100 and 125 mph are much more realistically attained throughout the corridor. Moreover, at these speeds it is much easier to integrate other levels of service on the same tracks. This is important, as presently 81 percent of Amtrak's present San Diego-Los Angeles trips use intermediate stations,[34] illustrating the need for more localized services. In addition, growing commuter rail services exist from Oceanside to Los Angeles and will soon begin from Oceanside to San Diego.

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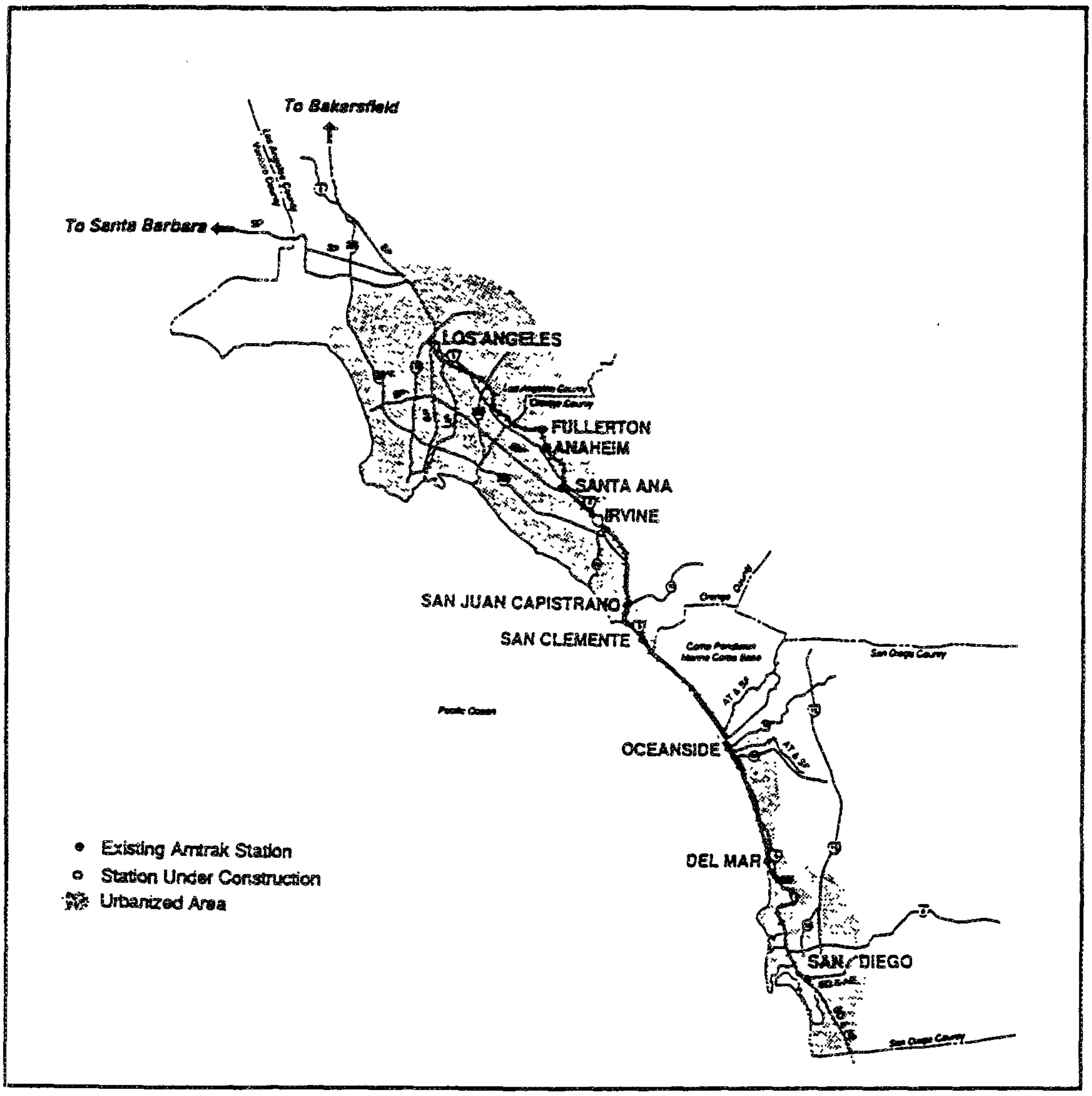
[31] In 1989/90 the San Diegans revenue/cost ratio was 103.6 percent. Caltrans, July 1991.

[32] Smith, G., 1987.

[33] Belden, T., "High Speed in Limbo," *Passenger Train Journal*, Feb. 1985.

[34] Wilbur Smith Associate, June 1987.

FIGURE 5.2: THE LOSSAN CORRIDOR



With lower maximum speeds, the service might be unable to attract private financing. Therefore, it seems that the corridor would be a good candidate for incremental upgrading, making it difficult to estimate a cost for an HST service through the LOSSAN corridor. For comparative purposes, an "ultimate" HST alignment was determined and costs estimated as if it were to be constructed as a whole. This service would cost as much as $3.24 billion; it would be completely grade-separated and require at least 28 miles of viaduct and 3 miles of tunnel. It would allow an express service between downtown San Diego and Los Angeles Union Station of about 1 hour and 10 minutes.

Another possibility exists for high-speed rail between San Diego and Los Angeles: a more inland corridor from San Diego to Los Angeles might be suitable as a VHST corridor. Such a route could follow the general alignment of I-15 and thereby serve the rapidly growing Moreno Valley area. Although detailed study of this option was beyond the scope of this report, the idea seems worthy of further study.

Conclusion

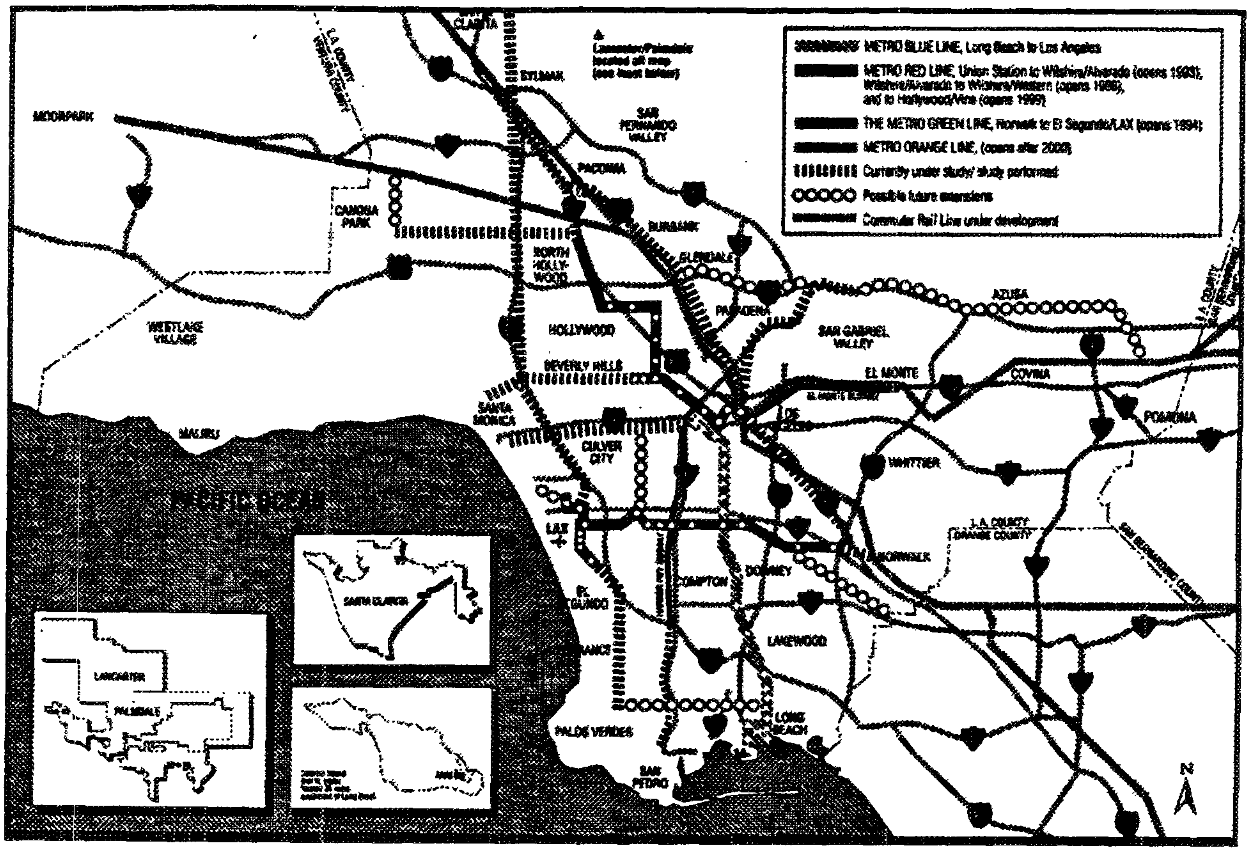
The LOSSAN corridor is best suited for HST service with maximum speeds between 100 and 125 mph. It is unlikely that private interest will be willing to take a large role in a partnership for such a service. The successful Amtrak service that exists can be gradually improved as money becomes available. Once the corridor is electrified and passenger tracks separated from freight, it would become an integrated part of the CST network. Until then, a transfer would be necessary at Los Angeles Union Station.

Although the idea of an new inland VHST corridor between San Diego and Los Angeles is interesting and should be studied further, as a part of the overall CST network such an alignment would presently be a low priority. Considering that an established passenger service already exists between the major markets, it seems prudent that funds be concentrated on the existing route first.

GREATER LOS ANGELES

The Los Angeles urban area has an interesting mix of commuter rail and rail transit networks in the planning stages or under construction. Five counties have formed the Southern California Regional Rail Authority (SCRRA) to implement a regional commuter network using existing rail right-of-way. Centered on Los Angeles Union Station, the planned Metrolink network will eventually extend to Moorpark and Santa Clarita to the northwest, Mentone and Hemet to the east, and Oceanside to the south (Figure 5.3). At the same time, the Los Angeles County Transportation Commission is developing its Metro system, a combination of different light rail technologies

FIGURE 5.3: SOUTHERN CALIFORNIA COMMUTER NETWORK



The Los Angeles County Transportation Commission and heavy rail. A transit route between Los Angeles International Airport (LAX) and Palmdale is being studied, as is a Maglev route between Anaheim and Las Vegas.

Connections to and integration with these networks will be a vital element in the success of the CST service. The aim is to provide access to the system from as many origins and to serve as many final destinations as possible. While actual demand to and from points in the Los Angeles Basin will require detailed market analyses, a look at a map of the area yields some idea of the more promising locations. First, a connection to LAX could provide a feeder service for long-distance domestic or international flights. Second, the market capture of the system would be greatly increased by serving communities to the east (San Bernardino and Riverside counties alone have a population of 2,588,793, according to the 1990 census). Third, extension of CST service south might eventually provide a transfer point to the proposed California/Nevada superspeed train near Anaheim stadium and would tie in with an upgrading of the LOSSAN corridor to HST service. This section will discuss the feasibility and practicability of such options.

Service to LAX

Alignment options for service between Union Station and LAX were studied in the "bullet train" proposal for high-speed service to San Diego. A consultant who worked on this project confirmed that the most practical option would run along the Union Pacific towards Long Beach before heading west on an existing rail spur. Most of this route would require elevated structure since these rail corridors are heavily congested. Thus, direct CST service to LAX will be costly. Note, however, that the Metro system will eventually connect LAX and Union Station (albeit with several transfers required). Also, the proposed route of the LAX-Palmdale transit corridor would provide an opportunity for a transfer in the San Fernando Valley.

Service to San Bernardino/Riverside

The preferred alignment for commuter service between San Bernardino and Los Angeles lies on the SP State Street and Baldwin Park lines to a point near Claremont and then continues on the Santa Fe Pasadena subdivision. The SCRRA owns the SP portions of the route, but use and purchase of the Pasadena subdivision is currently being negotiated with the Santa Fe. Shared use of this corridor by CST and commuter trains would depend on the extent to which freight traffic can be shifted to other lines. Following this, electrification and provision of suitable track and compatible equipment would also be required.

The proposed Riverside-to-Los Angeles service will operate over the San Jacinto and San Bernardino subdivisions of the Santa Fe. Part of this route operates over an important transcontinental Santa Fe freight line, and a detailed study of the feasibility of combining heavy freight traffic with commuter trains on the lines was made.[35] Since freight will most likely remain on these lines indefinitely, this route is not a good candidate for direct CST service.

The San Diego Subdivision

The San Diego subdivision of the Santa Fe is the route of the proposed Oceanside-Los Angeles commute service and currently used by the Amtrak San Diegan trains. South of Fullerton, the line will likely be acquired by public authorities within the next few years. North of Fullerton, the San Diego subdivision is a major freight route operating on very constricted right-of-way. This configuration impacts both the potential for high-speed service between Los Angeles and San Diego, as discussed in the previous section, and the potential for direct CST to points in Orange County.

Use of this route for CST service is closely related to the eventual electrification and upgrading of the LOSSAN corridor service. Operation of CST trains on the San Diego subdivision or even an L.A.-San Diego HST service would not be possible without a significant infrastructure investment involving elevated structure and other modifications. Once this investment was made, however, CST trains might someday connect to a California-Nevada Maglev route at a station adjacent to Anaheim stadium. This would also open the possibility of a through CST service to San Diego and electrified commuter lines.

A point that must be made here is that use of the San Diego subdivision will require a considerable investment, akin to the level proposed for the SP Saugus line which is the main CST approach to Los Angeles. The investment constitutes more than a "sharing" of electrified commuter tracks because separate express/skip-stop passenger tracks would need to be provided. The decision to undertake such an investment must, of course, be made with consideration of the travel market and the level of service that can already be provided on the corridor.

Costs and Conclusion

Recently, motivated by air quality concerns, the SCRRA studied electrification of the commuter system. The high estimated cost ($4.5 billion for nine commuter routes) for relatively low benefits (railroad operations are responsible for only 2.56 percent of NO_x emissions in the South

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[35] Morrison-Knudsen Engineers, Inc. (1990).

Coast Air Basin)[36] offers little justification for undertaking electrification on an air-quality basis. Cost might be better justified if the CST system, the Metrolink commuter system, and possibly an HST service on the LOSSAN corridor all shared the costs and benefits of electrification and right-of-way investments. Obviously, the integration of all these services will require a considerable cooperative planning effort on the part of the Southern California rail authorities and intercity service operators. Probably the most difficult issue would be the cost-sharing formula followed by coordination of equipment and schedules.

Given the significant costs of electrification and upgrading and the fact that the planned Metrolink and San Diegan trains will already be able to provide a feeder service to the CST mainline, operation of CST trainsets over the existing commuter rail corridors should be seen as a long-term goal. Construction of the CST mainline approach over the Saugus SP would make the Santa Clarita commuter service an obvious first choice for simultaneous electrification. Following this, resources would best be concentrated on the San Diego subdivision with the goal of providing the fastest possible HST service on the LOSSAN corridor. In the longer run, depending upon the degree of freight traffic consolidation which takes place, availability of funds, and the level of demand, shared use of other commuter lines remains a possibility.

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[36] SCRRA, Parsons deLeuw (1992).

6. SUMMARY AND CONCLUSIONS

An executive summary of the entire report forms the introductory section. The purpose of this chapter is different: it is to emphasize most important main points that, in our opinion, emerge for strategic policy choice.

1. Importance of Very High Speed

The first is the most important and basic of all. It is that a high-speed ground transportation system for California, if it is to justify the considerable investment that will need to be put into it, must be a *truly* high-speed system. In order to compete effectively with existing modes, particularly air, it must offer city-center-to-city-center times that are competitive. The precise competitive timings will be the subject of detailed market evaluation in the next stage of our study; but we can say with confidence now that times of ***three hours or less, from Los Angeles to the San Francisco Bay Area***, must be the objective. Our studies show that existing and well-tried technologies can deliver this performance, but only on the basis of sustained very high-speed running (200 miles per hour and more) between the major urban areas. This is especially important, because environmental considerations within the major urban areas at each end, representing some one-fourth of the entire route length, will probably reduce maximum speeds to only 100 miles per hour there.

In particular, it means that the high-speed line will pass at the edge of the existing urban areas in the central valley, with new peripheral stations—with the possible option of downtown loops, as discussed below.

2. The Choice of Technology

The choice of very high-speed technology is clearly crucial. It must lie between steel-wheel-on-steel-rail, and magnetic levitation technology. We want to stress again that on the basis of evidence presently available (May 1992), ***steel wheel is strongly to be preferred*** on the basis of proven revenue performance and compatibility with existing rail systems. That conclusion could well be modified in future, as Maglev demonstrates its capacities in revenue service; but that is most unlikely to occur until sometime after the 1990s. We believe in particular that some of the claimed advantages of magnetic levitation, in particular speed and grade-climbing capacity, may prove to be overstated in practice. Steel wheel on dedicated track can confidently be stated to be capable of regular operation at speeds over 200 miles per hour, and Maglev may well be limited to speeds not much greater than that because of noise impacts and energy consumption. The manufacturers of the TGV have now stated[37] that the latest version of their train can ascend 5 percent grades, which represents a major cost saving in the critical mountain crossing between Los Angeles and the Central Valley, at only a minor penalty in reduced speed toward the end of the climb. On this basis we are confident in recommending that the future line should be developed to the geometric standards of the best possible steel-wheel technology (220 miles per hour on flat ground; 5 percent ruling gradient where dictated by terrain), but in such a way that it could be adapted for magnetic levitation if subsequent re-evaluation made this desirable.

3. The Choice of Technical Standards for High-Speed Rail

Assuming that the choice is in favor of steel-wheel technology, a critical question concerns the technical standards to be adopted by the Federal Railroad Administration for high-speed train operation generally in the United States. This has to be a priority because it conditions all other decisions regarding the operation of CST trains over existing tracks with mixed traffic, which will be a necessity if they are to penetrate the existing built-up areas without unacceptable physical and environmental disruption. The basic choice is whether high-speed trains will be required to satisfy the existing design standards regarding impact survival and related requirements, which are much more stringent than those employed in Europe; and, if these standards are relaxed, what will then be the operating constraints to avoid collisions between high-speed and other trains. For instance, if it were determined that high-speed and stopping passenger trains could share a lower set of standards closer to those prevailing in Europe, could freight trains be allowed to occupy the tracks at times when passenger service had ceased, and if so under what conditions? These questions demand early resolution; and, because high-speed trains would occupy tracks carrying interstate freight and passenger traffic, there would need to be a resolution at the federal level.

4. Importance of Route Choices

A number of early decisions need to be made to safeguard critical route corridors. Otherwise, there is a risk that other commitments will be made which might compromise them. For instance, developments might occur that would physically impede certain routes. Or large-scale related development proposals might be made without regard to the mutual relationship to the high-speed route.

Some, though by no means all, of these occur within the major urban areas. Because the size and spread of these areas represent such major constraints to high-speed running, the choice of corri-

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[37] Letter from M. André Huber, GEC-Alsthom, April 24, 1992.

dors within them is crucial. Early choices will need to be made there. All of them, as explained above, will critically depend on the technical standards to be adopted by FRA for mixed-mode operation.

The most important of these routing decisions are:

> (1) The choice of corridor in the Central Valley. We have suggested that upgrading of any of the present rail rights-of-way is most unlikely to be cost-effective. The choice here lies between a direct route via the I-5 corridor, and a somewhat longer route which would serve Bakersfield and Fresno at the expense of an approximately 5-6 minute time penalty for non-stop services between Los Angeles and San Francisco. Either should be designed for the highest possible steel-wheel geometric standards so as to be capable of sustained 220 mph operation between the exit from the Grapevine and the entry into the Panoche/Pacheco Pass.
>
> (2) The option of a downtown loop for Fresno. There would appear to be no insuperable technical problems in providing this; the question is whether Fresno would be better served by a downtown station, or by a new peripheral station, or by some combination of the two. In any event, a decision should be reached at the same time as a resolution of the routing issue in (1) above, so that the right-of-way can be safeguarded.
>
> (3) The choice as between the Panoche and Pacheco Pass as a crossing of the Coastal Ranges. We have concluded that, though either is feasible, there is a definite advantage in favor of the Pacheco crossing. Its choice would shorten the branch from the mainline to Sacramento, and is better located from the point of view of serving the major new planned communities now projected for the Fresno-Stockton section of the Central Valley.
>
> (4) The choice of the corridor between Gilroy and San Jose, where the Highway 101 median would appear greatly superior to the Southern Pacific option. This would imply a decision by Caltrans to forego the future option of using the median to widen to eight lanes.
>
> (5) The precise configuration of the two rail corridors in the San Francisco Bay Area, north of San Jose. On the Peninsula corridor between San Jose and San Francisco, the need is to determine the precise mix of high-speed, stopping, and (occasional) freight trains within the constraint of the mixed 4-, 3-, and 2-track formation; and then to safeguard the line accordingly. In the East Bay, the need is to choose between the two Southern Pacific corridors between San Jose and West Oakland, which will depend on the optimal combination of high-speed, stopping, and freight services on these two corridors within the right-of-way constraints. In both cases the top priority is to safeguard the existing right-of-way against any further encroachments, and to determine whether repurchase of lost right-of-way might be desirable.

(6) Similarly, on the section from West Oakland to Sacramento, the first priority should be to secure the existing right-of-way. There will then be a need to study the options discussed in this report, involving new dedicated high-speed line between Pinole and Benicia, as well as the possibility of operating a mixture of high-speed, stopping, and freight services between Benicia and Sacramento.

(7) Within the Greater Los Angeles area, similar considerations arise to those in the San Francisco Bay Area. Here, use of the existing rail corridors to Anaheim (and on to San Diego), and to San Bernardino would entail shared occupation with the new Metrolink passenger commuter services and with freight, over right-of-way that is sometimes very constrained. In the light of a basic decision from FRA regarding technical safety standards, the question here is what further investment could be justified to accommodate through-running of CST trains over these sections, as against the option of using Metrolink to provide connecting feeder services via Los Angeles Union station.

5. Need for Integrated Transportation Planning

Several of the above choices, involving the optimal service within the major urban areas, underline another point. It will be virtually impossible, and in any case it will be most undesirable, to plan the new high-speed network in isolation from decisions on major urban transportation investments with which the network should be integrated. In the Bay Area, for example, careful consideration should be given to the relationship between the proposed BART extensions from Milpitas and the San Francisco Airport to San Jose, and the planned expansions and improvements to the Caltrain and Capitol Corridor services. Given that the BART extensions and the commuter trains would provide roughly the same service over the same corridors, there is a potential for BART to provide the local or all-stops service around the Bay while connected to the intercity rail network at interchange points. This would release critical rail capacity for non-stop high-speed CST trains and limited-stop-only Caltrain or Capitol Corridor trains.

Similarly, in a long-term configuration for Greater Los Angeles, the CST might eventually provide non-stop service for distances above approximately 30 miles (Los Angeles-Anaheim; Los Angeles-San Bernardino), while Metrolink provided intermediate all-stop services; this choice would then affect subsequent investment decisions regarding right-of-way acquisition and/or configuration, some of which will need to be taken in the relatively near future. The point is that these key decisions should be taken in concert, with full understanding of their implications. The passage of the 1991 Intermodal Surface Transportation Efficiency Act gives ground for belief that such integrated planning will become easier in the future; but it will need a clear understanding of the issues involved in each case. The major risk is that decisions which may be taken in the short term in other areas, particularly on urban commute services, could compromise the high-speed train.

6. The Need for a Staged Plan

Because the CST network represents such a huge investment, comparable only with the construction of the state's freeway system in the 1950s and 1960s, it is most important that priorities be set. It appears clear, even in advance of the detailed market study, that the Los Angeles-San Francisco mainline represents by far the biggest single market, and that it should therefore should be planned and built first, as the core of the entire future system. Because its primary purpose and justification is to link the two major urban areas, it is crucial that it be built and completed as a whole. Unlike a freeway system, where the benefits are incremental and cumulative, with this main link the benefits only come from simultaneous completion and opening. Further, staged opening would create a major potential hazard that the system were perceived as inferior, which could compromise its eventual prospects. Therefore, though there may well be a case for an early start to construction on some of the more difficult segments in engineering terms (for instance, Los Angeles to Bakersfield), this should be done only on the basis that construction times will be longer; ***the aim should be simultaneous opening of the entire trunk line between Los Angeles and San Francisco.***

The priority to be given to the remaining segments will depend on the detailed market survey to be completed in the next stage of the study. They are (not necessarily in order of priority):

(1) Branch from the mainline near Modesto to Sacramento.
(2) San Jose to West Oakland.
(3) West Oakland to Sacramento.
(4) Los Angeles feeders.
(5) Los Angeles to San Diego.

Only the first of these is assumed to be a completely new dedicated very high-speed line. The others represent upgradings of existing track (with possible new stretches in some cases), which need not necessarily be completed all at once; on some, early through service of high-speed trains might well be possible (at restricted speeds) for relatively modest initial expenditure. In all these cases, however, the feasibility and staging would need to be the subject of more detailed engineering studies; in addition, all depend to some degree on decisions to invest in linked urban rail systems, as discussed above. The important point will be to conceive them as all part of an eventual integrated system, and to introduce service on the different segments according to a staged priority plan.

7. Financing the System

These decisions are all related to a further question, not investigated in the CalSpeed study so far: the precise financial basis for investment in the proposed CST network. There seems to be some general agreement that—as in Texas—this should be basically a privately financed system. However, the involvement of Caltrans will almost certainly be crucial, especially in the early stages of planning the system. The critical questions which demand early resolution seem to be these:

> (1) *Legal and other processes*. Should Caltrans take responsibility for all planning stages, including EIR and land acquisition, so that a complete right-of-way could be offered on a tender basis to private contractors? Should it even go on to construct the system itself, offering it then to franchise? Or should it stop short of this, basically leaving it to the private sector to assume total responsibility?
>
> (2) *The possible case for subsidy*. This cannot be divorced from the question of subsidy. Some would undoubtedly argue that subsidy for a high-speed train would be justified on the basis of market failures and externalities arising from the present modal mix (for instance, air pollution and congestion). If this is accepted, the question arises as to where and how the subsidies would be best applied: to construction, or operation, or both. A related question would concern the form of subsidy, which might be through tax concessions or land concessions. The latter possibility, which was suggested for the Very Fast Train in Australia, is of particular interest; first because it was a traditional way of supporting railroad construction in the United States in the nineteenth century, and second because of the likelihood of large-scale urban development in the state during the next two decades, much of which is planned close to the likely route of the CST. Confirmation of the line of the route would clearly enhance the value of these developments, and would suggest some kind of cost-sharing agreement to support construction.
>
> (3) *Monopoly or competition*. Assuming private involvement, a critical question is whether to create an effective monopoly, or to open the system to competition. This of course would strongly condition the basic choice as to investment. If Caltrans planned and built the system, it could then franchise it to competing operators through the use of train path "slots" over a common right-of-way, on the analogy with airline services. The alternative would be to grant an effective monopoly to one operator for a defined period of years, which would almost certainly demand enforceable guarantees as to service levels and fares.

It is hoped that these questions can be examined in greater depth in the second year of the CalSpeed study, which—subject to funding—will begin in August 1992.

Appendix A

CalSpeed Working Papers and References

CalSpeed Working Papers

1. Taniguchi, M. 1992. *High Speed Rail in Japan: A Review and Evaluation of the Shinkansen Train.* Working Paper 557, Institute of Urban and Regional Development, University of California at Berkeley, March.

2. Streeter, W. 1992. *The French Train à Grande Vitess: Focusing on the TGV-Atlantique.* Working Paper 558, Institute of Urban and Regional Development, University of California at Berkeley, March.

3. Sands, B. 1992. *InterCity Express: A Technical and Commercial Assessment.* Working Paper 559, Institute of Urban and Regional Development, University of California at Berkeley, March.

4. ____. 1992. *The Transrapid Magnetic Levitation System: A Technical and Commercial Assessment.* Working Paper 560, Institute of Urban and Regional Development, University of California at Berkeley, March.

5. Taniguchi, M. 1992. *High Speed Rail in Japan: A Review and Evaluation of Magnetic Levitation Trains.* Working Paper 561, Institute of Urban and Regional Development, University of California at Berkeley, March.

6. Barnett, R. 1992. *Tilt Trains.* Working Paper 562, Institute of Urban and Regional Development, University of California at Berkeley, April.

7. ____. *British Rail's InterCity 125 and 225.* Working Paper, Institute of Urban and Regional Development, University of California at Berkeley, forthcoming.

References

Amezcua, R., S. Jaipersad, J. Ryan, and B. Wagstaff. 1991. *LAX to Palmdale Transits Link.* John E. Anderson Graduate School of Management, University of California, Los Angeles, March.

Arthur D. Little, Inc. 1990. *An Assessment of High-Speed Rail Safety Issues and Research Needs.* Federal Railroad Administration, U.S. Department of Transportation, Springfield, Virginia, May.

BHP, Kumagai, TNT, and Elders IXL, an unincoroporated joint venture. 1990. *VFT: Project Evaluation.* Australia, November.

Caltrans. 1991. California Rail Passenger Development Plan; 1991-96 Fiscal Years. Sacramento, July.

California-Nevada Super Speed Train Commission. 1989. *California/Nevada Super Speed Train Project Combined Feasibility Studies 1987-1989.*

Cheshire, P. C., and D. G. Hay. 1989. *Urban Problems in Western Europe: An Economic Analysis.* London: Unwin Hyman.

DeLeuw Cather & Company. 1992. *Southern California Accelerated Rail Electrification Program.* Los Angeles: Southern California Regional Rail Authority, February.

Federal Railroad Administration. 1991. *Safety Relevant Observations on the TGV High Speed Train.* U.S. Department of Transportation, July.

Glickman, N. J. 1978. *The Growth and Management of the Japanese Urban System.* New York: Academic Press.

Huber, A. (GEC Alsthom, Transport Systems). 1992. *California High Speed Rail Travel Times.*

Korve Engineering, Inc. 1991. *San Francisco Bay Crossing Study.* Metropolitan Transportation Commission, March.

Lichliter/Jameson & Associates, Inc. 1989. *Texas Triangle High Speed Rail Study.* Texas Turnpike Authority, February.

Morrison-Knudsen Engineers, Inc. 1990. RCTC/AT&SF Commuter Rail Study; Task 2 Report; Conventional Commuter Rail. Riverside County Transportation Commission, December.

Parsons Brinckerhoff, Quade & Douglas, Inc. 1990. *Final Consultants' Report.* Los Angeles-Fresno-Bay Area/Sacramento High-Speed Rail Corridor Study Group, June.

____. 1990. *Final Consultants' Report, Appendix.* Los Angeles-Fresno-Bay Area/Sacramento High-Speed Rail Corridor Study Group, June.

Peninsula Corridor Study Joint Powers Board. 1991. *Caltrain Peninsula Commute Service; Short Range Transit Plan FY 1991-92 to 1999-2000.*

Southern California Association of Governments. 1991. *Southern California High Speed Rail Feasibility Study.* Southern California Association of Governments, July.

Southern California Commuter Rail Coordinating Council. 1991. *Southern California Commuter Rail 1991 Regional System Plan.* Southern California Association of Governments, June.

State of California Department of Transportation. 1991. *California Rail Passenger Development Plan.*

Texas TGV. 1991. *Texas TGV Franchise Application to Construct, Operate, Maintain, and Finance a High-Speed Rail Facility.* Texas High-Speed Rail Authority, Austin, January.

Transportation Research Board. 1991. *In Pursuit of Speed: New Options for InterCity Passenger Transport.* Special Report 233, National Research Council, Washington, D.C.

Wilbur Smith Associates. 1989. *Los Angeles-Santa Barbara Rail Corridor Study, Executive Summary.* Southern California Regional InterCity State Rail Corridor Study Group, June.

____. 1990. *ACR 132 InterCity Rail Corridor Upgrade Study; Final Report.* Metropolitan Transportation Commission, November.

____. 1990. *InterCity Rail Right-Of-Way Inventory.* California Department of Transportation, May.

Appendix B

Cost-Estimating Methodology

COST-ESTIMATING METHODOLOGY

Lacking previous U.S. experience with constructing a high-speed rail system, an estimation of costs is difficult, particularly without detailed and design and engineering studies of specific corridors. For planning purposes, this report has attempted to make use of the best available information to formulate capital costs for the various CST route options.

The Texas TGV cost estimates provided in the franchise application reports were the primary source for the "Capital Cost Estimate" sheets created for this report. It was concluded that the Texas TGV project was the closest representation of the CST network costs available while recognizing that conditions in California would differ from those in Texas. Therefore, the unit costs used are a synthesis of many recent sources which estimate rail construction costs in the state of California and the Texas TGV costs. The Capital Cost Estimate Sheets, a key which explains the derivation of each cost item, and the research from which the values for each item was determined are provided in this appendix.

It must be stressed that CST costs represent the best estimates that are available on the basis of available data. A later CalSpeed study is planned to rigorously and critically test these estimates, particularly with reference to any available experience of cost escalation on comparable schemes elsewhere in the world. However, the pre-publication version of this report was reviewed by many experts in the field of rail transportation and the cost estimates of this report have been revised on the basis of considerable feedback.

CalSpeed

CAPITAL COST ESTIMATES:

LENGTH OF SEGMENT = ____________ miles
AVE. R/W WIDTH = ____________ feet

	QTY	UoM	UNIT COST	AMOUNT
EARTHWORKS				
GRADING		ACRE	$400	
EXCAVATION		CY	$3.5	
BORROW		CY	$4.5	
LANDSCAPING/MULCH		ACRE	$2,000	
FENCING		MI	$81,000	
SUBBALLAST		SY	$8.0	
SOUND WALLS		MI	$835,000	
CRASH WALLS		MI	$1,700,000	
SUBTOTAL				
CONTINGENCY (25%)				
TOTAL:				
STRUCTURES				
STD VIADUCT 20'-25'		MI	$14,000,000	
VIADUCT 25'-100'Pier		MI	$25,000,000	
VIADCT 100'-200' Pier		MI	$35,000,000	
VIADUCT > 200' Pier		MI	$50,000,000	
SHORT SPAN BRIDGE		EA	$1,000,000	
GRADE SEPARATION RUR		EA	$1,000,000	
GRADE SEPARATION URB		EA	$8,500,000	
ROAD CLOSURE		EA	$50,000	
DEPRESSED SECTION		MI	$16,000,000	
CUT AND COVER TUNNEL		MI	$35,000,000	
STD BORE		MI	$70,000,000	
BOX CULVERT		EA	$83,000	
CULVERT		EA	$3,500	
SUBTOTAL				
CONTINGENCY (25%)				
TOTAL:				
BUILDINGS				
REGIONAL STATION		EA	$50,000,000	
URBAN STATION		EA	$30,000,000	
SUBURBAN STATION		EA	$5,000,000	
INSP./SERVICE FAC.		EA	$6,000,000	
MOW BUILDINGS		EA	$300,000	
WAYSIDE PLATFORMS		EA	$200,000	
DEMOLITION		EA	$100,000	
SUBTOTAL				
CONTINGENCY (25%)				
TOTAL:				

Capital Cost Estimate

	QTY	UoM	UNIT COST	AMOUNT
RAIL				
TRACKWORK		TRK-MI	$760,000	
RAIL RELOCATION		TRK-MI	$760,000	
CONTINGENCY (25%)				
SUBTOTAL				
TOTAL:				
POWER/SIGNALS				
CATENARY/SUBSTATIONS		TRK-MI	$900,000	
SIGNAL/CONTROL		MI	$760,000	
SUBTOTAL				
CONTINGENCY (25%)				
TOTAL:				
RIGHT-OF-WAY				
RANGE LAND		ACRE	$1,500	
PASTURE/CULTIVATED		ACRE	$5,000	
SCATTERED DEVELOP.		ACRE	$25,000	
URBAN RAILROAD LAND		ACRE	$120,000	
LEGAL COSTS		ACRE	$3,500	
SUBTOTAL				
CONTINGENCY (25%)				
TOTAL:				
SUBTOTAL				
ADD-ONS (20%)				
TOTAL:				

CAPITAL COST ESTIMATES KEY

Earthworks

Earthwork unit costs were derived from the Texas TGV cost estimates provided in the franchise application reports and inflated by a factor of approximately 1.27 to account for higher construction costs in California.[1]

Grading: This includes clearing, grubbing, and leveling. The topsoil is taken off and kept for landscaping and mulch. The total amount for grading is determined by multiplying the length of segment by the right-of-way width. For this report, an average right-of-way width was assumed for each segment.

Excavation: This represents the lesser quantity of cut or fill for a segment. Since costs can be reduced by using cut segments for fill requirements, excavation is an equivalent amount of cut/fill for a segment. For Texas, which is very flat, the total amount of excavation averaged 86,560 CY/mile. For California, this number was used for new right-of-way flat segments. No excavation was assumed where existing rail right-of-way was used. For the mountain passes, quantities were estimated based on profiles derived from USGS topographical maps. These calculations assumed a level cross-section. The track section used was 50 feet with side slopes of 3 feet horizontal distance to every 2 feet of vertical height.

Borrow: This is the difference between the cut and fill quantities. An average 26,900 CY/mile of borrow was used for the Texas TGV estimates. This average was used for all flat segments of the California CST network. Through the mountain passes, there would be much greater amounts of cut than fill; therefore, a large quantity of borrow is shown for these segments.

Landscape and Mulching: These are calculated using the same quantities as grading.

Fencing: This is comprised of an 8-foot chain link fence. Assumed to be required throughout the entire length of at-grade segments (on each side of right-of-way).

Subballast: This is an 8-inch filter zone layer between fill and rock ballast. It is calculated for the entire segment length based on an average estimated width.

Sound Walls: These are used through areas sensitive to noise, particularly on aerial structures. This report limited their use to areas where HSR right-of-way was directly adjacent to hospitals, schools, or residential subdivisions.

Crash Walls: These are needed in shared right-of-way to separate freight from CST and to protect piers of viaducts from freight. For the Texas project, engineers are still working on an acceptable design for this problem. The most likely solution appears to be a concrete barrier similar to the Jersey Barrier now used on freeways.

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[1] Source: Means Heavy Construction Cost Data 1991. Calculated using the average cost indexes of selected cities in California and Texas.

Structures

The Texas TGV report provided only a few applicable unit costs for the different structure subheadings. Since Texas is very flat, there are no costs for structures and tunneling comparable to those which would be required to cross California's mountain ranges. Moreover, the Texas project does not run in urban areas to the extent that California CST lines would, which also greatly affects several unit costs. Therefore, cost information from various sources was synthesized to provide suitable unit cost for tunneling, bridges, and grade separations. Details of the cost-estimating research conducted, including costs and sources, are provided at the end of this Cost Estimation Appendix (see Cost Estimate Research sheets).

Standard Viaduct 20 foot-25 foot: This is a pre-stressed, reinforced concrete aerial structure which predominately maintains a standard clearance height in order to provide grade separation from highways, streets, marsh lands, etc. This type of structure would also be necessary in shared right-of-way corridors where the width was inadequate for all services at-grade. An aerial structure with a standard pier height/vertical clearance of at least 20 feet was assumed. For this type of structure, the Texas TGV report used a cost of $10.2 million per mile. This would translate to $13 million per mile when escalated to California's costs. In light of higher costs obtained from several sources, a more conservative unit cost of $14.0 million/mile was chosen.

Viaduct >25-foot Pier: The three different costs represent viaduct/bridge structures of various ranges of pier heights. These structures are primarily necessary in the mountain passes, and are assumed to be pre-stressed, reinforced concrete structures. Costs were derived from unit costs provided by Caltrans and a respected structural design firm.

Short-Span Bridge: This is a 200- to 300-foot-span bridge, able to cross most streams, canals, or streets. The cost calculation is based on an structural engineering firm's estimate for a 25-foot pre-stressed reinforced bridge designed for railroad loads.

Grade Separation: The average cost for urban and rural grade separations were based on California Public Utility Commission's "1990-1991 Nominations for Proposed Separations." The average cost for overhead separations and underpasses was $8.5 million. These nominations represented high-volume traffic areas with high accident potential, predominately in urban areas. Assuming that rural grade separations would be simpler and less expensive than urban separations, the minimum cost of $1 million was taken from the PUC report as the average cost per rural grade separation.

Road Closure: This is used primarily in rural areas. Some roads would be closed rather than construct a costly grade separation. The cost includes a standard Caltrans barricade and signing on each side of the rail right-of-way. Costs were anticipated to be minor, and an average of $50,000 each was assumed.

Depressed Section: This is used for the transition to tunnels, or narrow sections not deep enough to need tunneling. A unit cost of $16 million/mile was taken from the 8-foot high depressed section used for the Dublin/Pleasanton BART extension cost estimates.

Cut and Cover: This is a shallow tunnel which is created by first excavating from the surface, then building a structure within, finally followed by reinstatement of the ground to surface level. This type of tunneling would be used primarily in urban areas under transportation corridors where grade separation is otherwise not possible. Cut-and-cover tunnels would also be needed for some rural/suburban freeway undercrossings. Although this tunneling method can be effectively used for noise abatement, tremendous costs involved and decrease in passenger comfort make cut-and-cover tunneling undesirable. Although difficult to calculate an average cost for cut-and-cover tunnels, a figure of $35 million/mile was derived after consulting several sources (see Cost Estimate Information). This figure is just higher than the median amount used for the Dublin/Pleasanton BART cost estimates.

Standard Bore: These are structures constructed beneath ground level that only require surface occupation at the openings of the tunnel. In California, as a result of the high costs involved, bored tunnels were assumed to be used only in the mountain passes. Determining an average cost for boring tunnels in California was the most difficult task in the cost-estimating effort. The mountain ranges that need to be traversed are very difficult to bore tunnels in. Earthquake faults, methane gas, water, and a problematic geology are all factors which contribute to uncertainty in cost. What can be concluded is that bore tunneling through the Tehachapi Mountains and the Coastal Range will be very expensive. Estimates from professionals specializing in tunnel construction in California ranged from $50 million/mile to $100 million/mile. The most recent example of a coastal range tunnel was completed by the Bureau of Reclamation in 1979. A 9.5-foot-diameter, 7.1-mile-long tunnel was built in the Pacheco Pass for the San Luis Dam project. This project cost $14.4 million/ mile in 1991 dollars even though its cross-sectional area is nearly six times less than what would be needed for a *single* track bore. Although it is difficult to calculate what economies of scale could be expected for larger bores, the Pacheco Pass tunnel helps give some perspective of the high cost of tunneling in the California mountains. A bore tunneling cost of $70 million/mile was thought to represent a reasonable estimate for the planning purposes of this report.

Box Culverts: These are necessary for drainage and as undercrossings (cattle, tractors). The Texas TGV system will be primarily built on new right-of-way through rural areas, and therefore requires many box culverts. The Texas TGV report assumed an average box culvert (average 150-foot length) for every two miles of track. For this report, box culverts were only included in rural segments on new right-of-way. The $83,000 cost per box culvert was derived from the Texas report.

Culvert: Thirty-six-inch culverts are needed for drainage purposes. The Texas TGV project requires about 2.2 culverts per mile (assuming an average culvert length of 50 feet). A similar average was would be needed for the California network at a cost of $3,500 per culvert (derived from the Texas report).

Buildings

Regional/Urban Station: These are the primary stations in the CST network. Each of the major metropolitan areas served by the CST would have a CBD station. This report assumes two "regional" stations, one in Los Angeles and one in the Bay Area. These stations would require a greater cost as a result of the greater frequency of trains and the high demand expected at these intermodal sites. Costs have been derived from the Texas TGV report. Regional station costs were inflated from an average of the Dallas Union Station and San Antonio Station costs, whereas the other urban station estimate was based on an average of the Dallas/Fort Worth Airport and Houston CBD stations.

Suburban Station: These are small stations, predominately in urban areas where only some of the CST trains would stop. The CST network would have the flexibility of having many of these stations, depending on demand. These stations were assumed to be somewhat similar to existing new major rail stations. The upgrade study for the San Jose-to-Auburn corridor estimates a station "similar to the Santa Ana or Oxnard multi-modal terminal" at $3 million.[2] A $5 million cost, about 1.67 times as much as those reviewed by Wilbur Smith Associates, was used for suburban stations by this study.

Inspection/Service Facilities: It is assumed that these facilities will only be necessary at the express station locations and perhaps at Sacramento. Unit costs were derived from the Texas TGV cost estimates.

MOW Buildings: Maintenance-of-way buildings are needed to store equipment and materials use for regular track maintenance nightly. Based on the Texas estimates, these facilities would be required every 50 miles and cost approximately $300,000 each.

Wayside Platforms: These are simple concrete slab platforms used at some maintenance facilities, or in long stretches without a station (transfer platform for trains with problems). Costs were taken from the Texas TGV report. Although the Texas project averages one wayside platform per 65 miles, these would only be necessary through rural areas in California.

Demolition: Throughout the CST network, alignments have been chosen which avoid existing structures. This is particularly true in the urban areas where demolition would be very expensive. However, some locations require the need to remove buildings and other existing structures. For these locations, an average cost of only $100,000 was assumed since they occur predominately in sparsely populated regions.

Rail

Trackwork: This includes everything above the sub-ballast — rail and fastenings, ballast, and concrete ties. Trackwork is a lump sum figure based on the Texas estimates which includes the costs of turnouts, crossovers, and rail yards. In Texas, trackwork averages about $600,000 per mile of single track; for double track (according to an engineer who worked on the estimate) this cost is doubled. Escalating the cost for California, the cost per mile of single track would increase to $760,000 per mile.

Rail Relocation: Freight tracks occupy the center portion of most existing rail right-of-way, and would need to be moved for the CST tracks to share the right-of-way. In most cases the track/tracks would have to be replaced with new track/tracks. The cost of removing and replacing the freight track would virtually be the same as the cost per mile for trackwork, according to a Texas TGV engineer.

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[2] Wilbur Smith Associates, Oct. 1989.

Power/Signals

Catenary, Substations, Signal/Control: These costs were suggested by an engineer who has worked on recent electrification projects in California. The subheadings represent all costs necessary for the power and signalling requirements of the CST network.

Right-of-Way:

The different types of right-of-way used for the cost estimate were limited to those which would be needed for the proposed network. In urban areas, the CST will make use of existing transportation corridors. Therefore, no attempt was made to generalize urban land values beyond the pricing of existing rail corridors (according to recent federal legislation, the CST could use interstate highway medians without purchasing the right-of-way or paying fees). In rural areas the value of rail corridors was assumed to be the same as the value of the surrounding land.

The $120,000 per acre cost of urban rail corridors was derived from the recent purchases of SP right-of-way by SCRRA Metrolink[3] and the Peninsula Joint Powers Board.[4] Other land values were synthesized from estimates given by county officials.

CONTINGENCY COSTS AND ADD-ONS

The percentages for "Contingencies" and "Add-Ons" (engineering, construction management, utility relocation, insurance, etc.) were determined after examining the recent estimates used for several different California rail projects (see Cost Estimate Information), which included the RCTC/AT&SF Commuter Rail Study (1991) and the Dublin/Pleasanton Extension Project (1989). The 45 percent of the project subtotal (25 percent for Contingencies and 20 percent for Add-Ons) is at the high end of the range given in TRB's "In Pursuit of Speed" for these additional costs.

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[3] Metrolink paid $245 million for 174.5 miles of SP right-of-way. This amounted to 2115 acres purchased or $120,000 per acre. LACTC, 1992.

[4] For $211.6 million, the Joint Powers Board purchased 51.4 miles of SP mainline. This amounted to 607 total acres or $120,000 per acre. Peninsula Corridor Study Joint Powers Board, November, 1991.

CalSpeed

COST ESTIMATION RESEARCH

1	**Caltrans Estimates**	*(from conversation, estimating division)*			
	BRIDGES: STD width double tk =	43	feet		
	Prestressed Reinforced Concrete – Highway				
	25' height =	$65	/sq ft	$14.8	million/mile
	25–100' hieght =	$80	/sq ft	$18.2	million/mile
	> 100' height =	$100	/sq ft	$22.7	million/mile
	Steel (go up faster, longer spans):				
	average =	$150	/sq ft	$34.1	million/mile
	worst case =	$170	/sq ft	$38.6	million/mile
	(Advanced Planning Studies Manual, 1991)				
	CIP Box Girder R.R. =	$100.0	to	$250.0	/sq ft
		$22.7		$56.8	million/mile
	TUNNELS:				
	45' bore, mostly rock =	$15,000	/ln–ft	$79.2	million/mile
	(Caldecott Tunnel PV)				
	CUT AND COVER TUNNELS:				
	45'–5–' opening, 6' fill =	$7,000	to	$8,000	/ln–ft
	(Broadway)	$37.0	to	$42.2	million/mile
	65' opening (6 lanes) =	$160	/sq ft	$54.9	million/mile
	45' opening =			$38.0	million/mile

2	**Texas TGV Franchise Application**				
	Segmental Bridge =	$1,938	/ln–ft	$10.2	million/mile
	(Viaduct, 20')				
	23' Wide Tunnel =	100	/sq ft	$12.1	million/mile
	43' Wide Tunnel =	72	/sq ft	$16.3	million/mile
	(conversation with engineer)				
	TRACK				
	Main Line =	$86.0	/track ft	$454.1	thousand/mile
	Yard =	$77.0	/track ft	$406.6	thousand/mile
	Rail Reloc =	$86.0	/track ft	$454.1	thousand/mile
	TURNOUTS				
	STD	$515.0	thousand each		
	#46	$148.0	thousand each		
	#21	$450.0	thousand each		
	Yard =	$50.0	thousand each		
	Contingencies	3–10	%	Subheading Subtotal	
	Engineering/Design	7	%	Project Subtotal	
	Contruction Management	3	%	Project Subtotal	
	Utility Relocation	1	%	Project Subtotal	
	Customer Communications	1	%	Project Subtotal	
	Sales Tax	3	%	Project Subtotal	
	Trainsets	$26	million each		

PAGE2, COST ESTIMATION RESEARCH

3	SCAG: High Speed Rail Feasibility Study, 1991.			
	Bridges	$19.7	million/mile	(double track)
	Tunnels	$31.7	million/mile	(single track)
		$30.9	million/mile	(TGV A)
	Contingency	25%		

4	Civil Engineering for Underground Transport (J.T. Edwards, 1990) Civil Engineering Costs (do not include land aquisition)				
	TUNNELS: Range of Costs =	$16.4	to	$123.1	million/mile
	Twin tunnels with a single track in each				
	Lower figure: small-diameter tunnels, good cohesive ground, expanded concrete linings				
	Higher Cost: larger-diameter, poor ground, special techniques				
	CUT AND COVER TUNNELS:	$13.7	to	$32.8	million/mile
	Single structure containing two tracks				
	Lower Figure: good ground, above water table				
	Higher Figure: water-bearing ground, substantial temporary works, services diversions				
	SURFACE RAILWAY:	$5.5	to	$10.9	million/mile
	ELEVATED RAILWAY:	$13.7	to	$27.4	million/mile
	Viaduct Cost =	$8.2	to	$16.4	million/mile
	COST OF EQUIPPING TUNNELS:	$5.5	to	$10.9	million/mile
	(track, signalling and electrical supplies)				
	STATIONS: Range of Costs =	$2.7	to	$41.0	million/mile
	Lower Figure: simple surface station				
	Higher Figure: deep level station with escalators				
	ROLLING STOCK DEPOT:	$54.7	to	$109.4	million/mile
	(for 30 6 -car trains, surface construction)				

5	Train Riders Associate of California (per conversation)		
*	Base Tunnels (through Teh.) 30 miles =	$100.0	million/mile
	* contractor's estimate		

6	Structural engineering firm, specializing in bridge design				
	(conversation with engineer)				
	Assume STD width double trk =		43	feet	
	25' Pier, Highway	$80.0	sqft	$18.2	million/mile
	add 8% for railway	$6.4	sqft	$1.5	million/mile
	add 20% for mountains	$16.0	sqft	$3.6	million/mile
	Total =	$102.4	sqft	$23.2	million/mile
	Up to 600' span =	$170.0	to	$190.0	sqft
		$38.6	to	$43.1	million/mile
	Up to 900' span =	$220.0	to	$270.0	sqft
		$49.9	to	$61.3	million/mile

7	KORVE Engineering Inc.: San Francisco Bay Crossing Study, 1991.				
	BART (double track)				
	At-Grade	$30.0	to	$40.0	million/mile
	Aerial	$40.0	to	$60.0	million/mile
	Suburban Subway	$70.0	to	$100.0	million/mile
	Urban Subway	$170.0	to	$210.0	million/mile
	Transbay Tube	$160.0	to	$170.0	million/mile
	Main Bridge Span	$35.0	to	$40.0	million/mile
	Trestle Bridge	$20.0	to	$32.0	million/mile

8	PUC: 1990-91 Nomination for Proposed Separations *		
	Average Cost Overhead Separation =	$8.6	million
	Average Cost Underpass =	$8.1	million
	High Cost: Overhead =	$21.1	million
	Underpass =	$18.9	million
	Low Cost: Overhead =	$2.7	million
	Underpass =	$1.0	million

* high-volume traffic areas with high accident potential, predominately urban areas represented

9	Bureau of Reclamation		
	Pacheco Pass Tunnel, 1979 =	$62.0	million
	(9.5' diameter, 7.1 mile length)		
	1991 ($) =	$102.5	million

10 Bechtel Civil, Inc.: Dublin/Pleasanton Extension Project
(BART: Capital Cost Methodology, May 1989)

	Double Track				
	Subballast =	$22.0	/CY	$22.0	/LF
	Grading =	$1.0	/SY	$6.0	/LF
	Ballast =	$27.0	/CY	$54.0	/LF
	Ties =	$125.0	EA	$100.0	/LF
	(Concrete @ 30" OC)				
	Rail & Fstngs	$1,900.0	/TON	$152.0	/LF
	TRACK =			$306.0	/LF
	(minus grading & subballast)			$1.6	million/mile
*	Aerial Structure (25' h)			$11.7	million/mile
*	Aerial Structure (35' h)			$13.3	million/mile
*	Aerial Structure (45' h)			$15.3	million/mile
*	Aerial Structure (55' h)			$17.5	million/mile
	(height from ground to top of rail)				
*	Retained Fill Section (8' h)			$5.3	million/mile
*	Retained Fill Section (12' h)			$7.2	million/mile
*	Depressed Section (8' h)			$16.1	million/mile
*	Depressed Section (12' h)			$22.4	million/mile

10 Bechtel Civil, Inc. (continued)
(BART: Capital Cost Methodology, May 1989)

*	Cut and Cover Tunnel (20' h)	$25.1	million/mile
*	Cut and Cover Tunnel (30' h)	$34.2	million/mile
*	Cut and Cover Tunnel (40' h)	$43.9	million/mile
	(height from track to surface)		
	* Fixed Double Track Costs subtracted		

At-Grade Minimum Median 58' (freeway median strip)

Excavation =	$22.0	/LF	$0.1	million/mile
Backfill =	$50.0	/LF	$0.3	million/mile
Concrete Wall Footings =	$48.0	/LF	$0.3	million/mile
Concrete Wall Stems =	$180.0	/LF	$1.0	million/mile
Reinforcing =	$39.0	/LF	$0.2	million/mile
8" Underdrain =	$25.0	/LF	$0.1	million/mile
Chain Link Fence =	$20.0	/LF	$0.1	million/mile
Ballasted Double Track =	$335.0	/LF	$1.8	million/mile
Total =	$719.0	/LF	$3.8	million/mile

Contingencies	25%
Eng./Const. Management	25%
per BART (extension project manager)	

11 Construction Company, Heavy Construction Division

Twin Bores through Tehachapis =	$50.0	million/mile
BART 3 mile Tunnel (1966-9) =	$12.0	million/mile
1991 Dollars =	$42.6	million/mile

12 CIGGT Report TGV System for California
(1984 constr. $ X 1.16; land aqui. $ X 1.44)

Tunnels = 31.3 million/mile

Land Aquisition		
Range Land =	$922	acre
Pasture/Cultivated =	$4,025	acre
Orchards =	$18,000	acre
Vineyards =	$10,217	acre
Built Up, Scattered =	$18,720	acre
Built Up, Dense =	$142,307	acre
Railroad/Hghwy land =	$144,000	acre
Industrial land =	$252,000	acre
Legal Costs =	$4,392	acre
Superstructure		
Track =	$602,161	trk-mi
Turnouts =	$440,800	each
Crossovers =	$1,392,000	each
Signalling =	$368,254	trk-mi
Catenary =	$319,514	trk-mi

PAGE5, COST ESTIMATION RESEARCH

12 CIGGT Report TGV System for California (continued)

Power Supply =	$101,270	trk-mi
Telecommunications =	$16,240	rte-mi
Buildings =	$64,960	rte-mi
Terminals =	$83,238,120	lump sum
Maintenance fac. =	$80,550,400	lump sum
Trainset prep. cnter =	$1,765,520	lump sum

13 TRB, 1991. "In Pursuit of Speed"

Right of Way and Land Aquisition (per 80 ft r/w)		
Urban Core Area	$2,120,000	per acre
Urban	$212,000	
Suburban	$159,000	
Rural	$26,500	
Design, Engineering, and Contingency Costs		
Prelimin. Engineering	3-5	%
Final Design	5-10	%
Contingencies	10-20	%
Construct. Management	8	%
Totals:	26-43	%
TGV trainsets (400-mile corr.)	$24	million each

14 MK Engineers, Inc: RCTC/AT&SF Commuter Rail Study, 1991.

Contingency	30%
Engineering	15%

15 Parsons De Leuw Inc.: So. Cal. Accelerated Rail Elect. Program

Contingency (approx.)	62%
Project Reserve	20%

16 Lichliter/Jameson & Asso.: Eval. of Ground Trans. Options, 1991.
For Imperial County Regional Airport

Railroad Bridges	$20.6	million/mile
Railroad Tunnel	$52.8	million/mile
Downtown Station	$40	million
Airport Station	$25	million
Eng & Constr. Man.	10%	
Contingencies	15%	
Add ons	3%	

CalSpeed: Capital Cost Estimates

AVE. COST, ONE MILE: NEW R/W (RURAL)

LENGTH OF SEGMENT = 1.00 miles

AVE. R/W WIDTH = 130 feet

	QTY	UoM	UNIT COST	AMOUNT
EARTHWORKS				
GRADING	15.76	ACRE	$400	6,303
EXCAVATION	86,560	CY	$3.5	302,960
BORROW	26,900	CY	$4.5	121,050
LANDSCAPE/MULCH	15.76	ACRE	$2,000	31,515
FENCING	2.00	MI	$81,000	162,000
SUBBALLAST	18,000	SY	$8.0	144,000
SOUND WALLS	0.00	MI	$835,000	0
CRASH WALLS	0.00	MI	$1,700,000	0
SUBTOTAL				767,828
CONTINGENCY (25%)				191,957
TOTAL:				$960,000
STRUCTURES				
STD VIADUCT 20'-25'	0.00	MI	$14,000,000	0
VIADUCT 25'-100'Pier	0.00	MI	$25,000,000	0
VIADCT 100'-200' Pier	0.00	MI	$35,000,000	0
VIADUCT > 200' Pier	0.00	MI	$50,000,000	0
SHORT SPAN BRIDGE	0	EA	$1,000,000	0
GRADE SEPARATION RUR	0	EA	$1,000,000	0
GRADE SEPARATION URB	0	EA	$8,500,000	0
ROAD CLOSURE	0	EA	$50,000	0
DEPRESSED SECTION	0.00	MI	$16,000,000	0
CUT AND COVER TUNNEL	0.00	MI	$35,000,000	0
STD BORE	0.00	MI	$70,000,000	0
BOX CULVERT	0	EA	$83,000	0
CULVERT	2	EA	$3,500	7,000
SUBTOTAL				7,000
CONTINGENCY (25%)				1,750
TOTAL:				$9,000
BUILDINGS				
REGIONAL STATION	0	EA	$50,000,000	0
URBAN STATION	0	EA	$30,000,000	0
SUBURBAN STATION	0	EA	$5,000,000	0
INSP./SERVICE FAC.	0	EA	$6,000,000	0
MOW BUILDINGS	0	EA	$300,000	0
WAYSIDE PLATFORMS	0	EA	$200,000	0
DEMOLITION	0	EA	$100,000	0
SUBTOTAL				0
CONTINGENCY (25%)				0
TOTAL:				$0

PAGE 2

Ave. Cost, One Mile: New R/W (Rural)

	QTY	UoM	UNIT COST	AMOUNT
RAIL				
TRACKWORK	2.00	TRK-MI	$760,000	1,520,000
RAIL RELOCATION	0.00	TRK-MI	$760,000	0
SUBTOTAL				1,520,000
CONTINGENCY (25%)				380,000
TOTAL:				$1,900,000
POWER/SIGNALS				
CATENARY/SUBSTATIONS	2.00	TRK-MI	$900,000	1,800,000
SIGNAL/CONTROL	1.00	MI	$760,000	760,000
SUBTOTAL				2,560,000
CONTINGENCY (25%)				640,000
TOTAL:				$3,200,000
RIGHT-OF-WAY				
RANGE LAND	0.00	ACRE	$1,500	0
PASTURE/CULTIVATED	15.76	ACRE	$5,000	78,788
SCATTERED DEVELOP.	0.00	ACRE	$25,000	0
URBAN RAILROAD LAND	0.00	ACRE	$120,000	0
LEGAL COSTS	15.76	ACRE	$3,500	55,152
SUBTOTAL				133,939
CONTINGENCY (25%)				33,485
TOTAL:				$167,000
SUBTOTAL				$6,236,000
ADD-ONS (20%)				$1,247,200
TOTAL:				$7,500,000

CalSpeed: Capital Cost Estimates

AVE. COST, ONE MILE: EX. RAIL R/W (RURAL)

LENGTH OF SEGMENT = 1.00 miles
AVE. R/W WIDTH = 100 feet

	QTY	UoM	UNIT COST	AMOUNT
EARTHWORKS				
GRADING	12.12	ACRE	$400	4,848
EXCAVATION	0	CY	$3.5	0
BORROW	26,900	CY	$4.5	121,050
LANDSCAPE/MULCH	12.12	ACRE	$2,000	24,242
FENCING	2.00	MI	$81,000	162,000
SUBBALLAST	18,000	SY	$8.0	144,000
SOUND WALLS	0.00	MI	$835,000	0
CRASH WALLS	1.00	MI	$1,700,000	1,700,000
SUBTOTAL				2,156,141
CONTINGENCY (25%)				539,035
TOTAL:				$2,695,000
STRUCTURES				
STD VIADUCT 20'-25'	0.00	MI	$14,000,000	0
VIADUCT 25'-100'Pier	0.00	MI	$25,000,000	0
VIADCT 100'-200' Pier	0.00	MI	$35,000,000	0
VIADUCT > 200' Pier	0.00	MI	$50,000,000	0
SHORT SPAN BRIDGE	0	EA	$1,000,000	0
GRADE SEPARATION RUR	0	EA	$1,000,000	0
GRADE SEPARATION URB	0	EA	$8,500,000	0
ROAD CLOSURE	0	EA	$50,000	0
DEPRESSED SECTION	0.00	MI	$16,000,000	0
CUT AND COVER TUNNEL	0.00	MI	$35,000,000	0
STD BORE	0.00	MI	$70,000,000	0
BOX CULVERT	0	EA	$83,000	0
CULVERT	2	EA	$3,500	7,700
SUBTOTAL				7,700
CONTINGENCY (25%)				1,925
TOTAL:				$10,000
BUILDINGS				
REGIONAL STATION	0	EA	$50,000,000	0
URBAN STATION	0	EA	$30,000,000	0
SUBURBAN STATION	0	EA	$5,000,000	0
INSP./SERVICE FAC.	0	EA	$6,000,000	0
MOW BUILDINGS	0	EA	$300,000	0
WAYSIDE PLATFORMS	0	EA	$200,000	0
DEMOLITION	0	EA	$100,000	0
SUBTOTAL				0
CONTINGENCY (25%)				0
TOTAL:				$0

Ave. Cost, One Mile: Ex. Rail R/W (Rural)

	QTY	UoM	UNIT COST	AMOUNT
RAIL				
TRACKWORK	2.00	TRK-MI	$760,000	1,520,000
RAIL RELOCATION	1.00	TRK-MI	$760,000	760,000
SUBTOTAL				2,280,000
CONTINGENCY (25%)				570,000
TOTAL:				$2,850,000
POWER/SIGNALS				
CATENARY/SUBSTATIONS	2.00	TRK-MI	$900,000	1,800,000
SIGNAL/CONTROL	1.00	MI	$760,000	760,000
SUBTOTAL				2,560,000
CONTINGENCY (25%)				640,000
TOTAL:				$3,200,000
RIGHT-OF-WAY				
RANGE LAND	0.00	ACRE	$1,500	0
PASTURE/CULTIVATED	12.12	ACRE	$5,000	60,606
SCATTERED DEVELOP.	0.00	ACRE	$25,000	0
URBAN RAILROAD LAND	0.00	ACRE	$120,000	0
INDUSTRIAL LAND	0.00	ACRE	$250,000	0
LEGAL COSTS	12.12	ACRE	$3,500	42,424
SUBTOTAL				103,030
CONTINGENCY (25%)				25,758
TOTAL:				$129,000
SUBTOTAL				$8,884,000
ADD-ONS (20%)				$1,776,800
TOTAL:				$10,700,000

Appendix C

The Australian Very Fast Train

VFT Project Evaluation Report Summary

"The VFT project is a proposal to develop and operate a high-speed, wheel-on-rail passenger transport system linking Melbourne, Canberra, and Sydney, and serving the communities along the corridor" (VFT, 1990). This Australian high-speed rail project was initiated in 1984. The Project Evaluation Report Summary was completed in November, 1990. As originally planned, the project was to begin full operation by 1997; however, difficulties in securing financing has left the project on hold indefinitely.

The Project

The VFT routing was determined with the primary objective of serving Sydney and Melbourne (Australia's two principal markets), yet also going through Canberra, Australia's capital. The Evaluation Report states that the success of the VFT project depended upon trains achieving a three-hour journey from Sydney to Melbourne. The VFT study group concluded that this was the trip time necessary for rail to be able to compete with air travel. To achieve the desired trip time, a cruising speed of 350 km/hr (217 mph) was deemed necessary (maximum operating speed 360 km/hr). The total capital cost of the project was estimated at $6.5 billion. The project was to be "funded, built, and operated by private enterprise."

Routing

To achieve the high cruising speeds, it was determined that an almost completely new rail corridor would be necessary. The VFT alignment only makes use of existing transportation corridors through Sydney, Melbourne, and their suburbs. The entire routing will be double-tracked, grade-separated, and will be completely segregated from existing rail services even through urban areas. Less than 1 percent of the total 854 km (530.68 mile) route is through urban areas. There are 12 stops between Sydney and Melbourne; 9 of these serve cities/towns outside the metropolitan areas of Australia's two largest cities. In order to maintain high speeds, the nine stations serving regional centers would generally lie a few kilometers "outside of town." High-speed route sections would generally avoid being within 200 meters (656 ft) of any residential areas to avoid costly noise abatement measures.

Upgrading existing rail lines was deemed unsatisfactory since even after expenditure on upgrading, the travel times expected could not compete with air services (in addition, the existing line does not serve Canaberra). Nearly 40 percent of the existing line is curved, and more than half of the curved track has a radius of less than 1000m (3,281 ft).

Passenger Services

To meet anticipated demands, 30 fast trains in each direction between Melbourne and Sydney were deemed necessary for a typical workday. Each train would have about 400 seats. From the timetable provided in the report, a spreadsheet was created which shows trip distances and time information for the different VFT services (see VFT Timetable Information). There are several interesting features of the routing which become apparent from the spreadsheet:

- Very low average running speeds through urban areas are assumed; less than 80 mph through the Sydney metropolitan region and less than 60 mph through the Melbourne metropolitan region. The report cites alignment constraints as the reason for reduced speeds in suburban areas.
- Between Albrury-Wondonga and Wangaratta (31.69 miles), a relatively high average speed of 158 mph is achieved. Between Canberra and Yass (25.48 miles), the average is 127 mph, and between Wangaratta and Benalla (27.34 miles), 137 mph.
- Although having a cruising speed of 217 mph, the express averages 177 mph. Subtracting the metropolitan regions of Sydney and Melbourne, the average is slightly over 200 mph.

The report acknowledges that the possibility of commuter services exists and that their feasibility would be based on price acceptability and system capacity. According to the report, the VFT would "explore ways of meeting commuter demand, subject to there being no dilution of the financial viability of the project."

Freight

The carriage of high-priority freight (in a passenger train or dedicated freight train) would be supplementary to the VFT's principal role.

Technology

The VFT will be a wheel-on-rail system, electrically powered. According to the report, French National Railways is planning 350 km/hr for the next generation TGVs, and future TGV alignments will be designed for an ultimate operating speed of 400 km/hr.

Tilting trains were discounted since "the increase in speed that can be obtained from tilting trains is often overstated. . ." (may be as low as a 15 percent increase in curves), technical difficulties are associated with tilting trains, and the financial viability of high-speed tilting services has yet to be demonstrated.

Maglev is rejected primarily on the basis of its perceived higher capital costs as well as because it is an unproven technology. "The expected cost of this technology would be up to four times the cost of the technology proposed for the VFT." Moreover, "a commercial venture requires that the technology used be proven and reliable in regular service conditions. The high-speed magnetic levitation technology is as yet unproven in commercial application even over short distances."

Track

The track construction for the high-speed portions of the routing is "little different from conventional railway practice." The primary difference in the track specifications is the adoption of a normal minimum horizontal curve radius of 7,000 meters (4.35 miles), an absolute minimum horizontal radius of 6,000 meters (3.73 miles), and a preferred horizontal curve radius is 8.5 km (5.28 miles). The maximum grade will generally be 3.5 percent; however, up to 5 percent will be allowed.

Right-of-Way

The report calls for a minimum right-of-way of 40 meters (131.2 ft) and anticipates a maximum of 150 meters (482.7 ft). The actual VFT track formation is only 15 meters (49 ft). Allowances are made for other services, such as optic fiber cables, gas pipelines, and trackside equipment.

Demand

The estimated population in the corridor is 7.1 million. It was estimated in 1987 that 31 million passenger trips were made to or from each corridor zone. The mode choice was as follows: Car = 80 percent, Air = 13 percent, Bus = 6 percent, Train = <2 percent.

Passenger forecasts were undertaken on behalf of the VFT by three different consulting firms. Input data was provided by surveys conducted by the Macquarie Transport Group. Forecasts indicated an average growth of passenger transport in the corridor of 3.3 percent.

It was estimated that the VFT would have a market share of 6.99 million SYD-MELs/year. This represents 48 percent of the total for all modes. Of the VFT passengers, 24 percent are diverted from the auto, 24 percent from air, 10 percent from bus, and 2 percent from train. The largest single source of passengers is induced travel (40 percent). The VFT captured 27 percent of the previously expected auto market, 45 percent of the air market, 49 percent of the bus market, and 55 percent of the train market.

Two major surveys were conducted to gather data necessary for forecasting purposes. An "intercept survey" sought information on the trips of 30,000 travellers (between November and December 1987) by existing modes. The survey involved interviews to estimate the number of origin-destination trips by each mode and purpose.

A "face-to-face" survey of 2,000 travellers and non-travellers inquired about travel in the previous year and included questions about travel preferences for the VFT on the basis of various time and cost characteristics of journeys on alternative modes.

Kinetic Energy

> Braking destroys kinetic energy which has to be dissipated. It increases wear and tear on mechanical and electrical components and increases maintenance coats. Therefore one of the most important principles of high-speed railway operation is to accelerate the trains to maximum speed and keep them there until it is necessary to slow them down for station stops.

VFT TIMETABLE INFORMATION

Semi-Express Service (Example)

STATION	Distance (km)	Distance (miles)	Total Distance (miles)	Travel Time+ Stop (minutes)	Average Speed (mph)	Travel Time * (minutes)	Average Moving Speed (mph)
Sydney	0	0	0	0	0	0	0
Campbelltown	48	29.83	29.83	25	72	23	78
Canberra	207	128.63	158.46	45	172	42	184
Albury-Wodonga	310	192.63	351.09	65	178	63	183
Melbourne	289	179.58	530.68	63	171	63	171
Total =	854	530.68		198	161	191	167

Express Service

STATION	Distance (km)	Distance (miles)	Total Distance (miles)	Travel Time+ Stop (minutes)	Average Speed (mph)	Travel Time * (minutes)	Average Moving Speed (mph)
Sydney	0	0	0	0	0	0	0
Melbourne	854	530.68	530.68	180	177	180	177

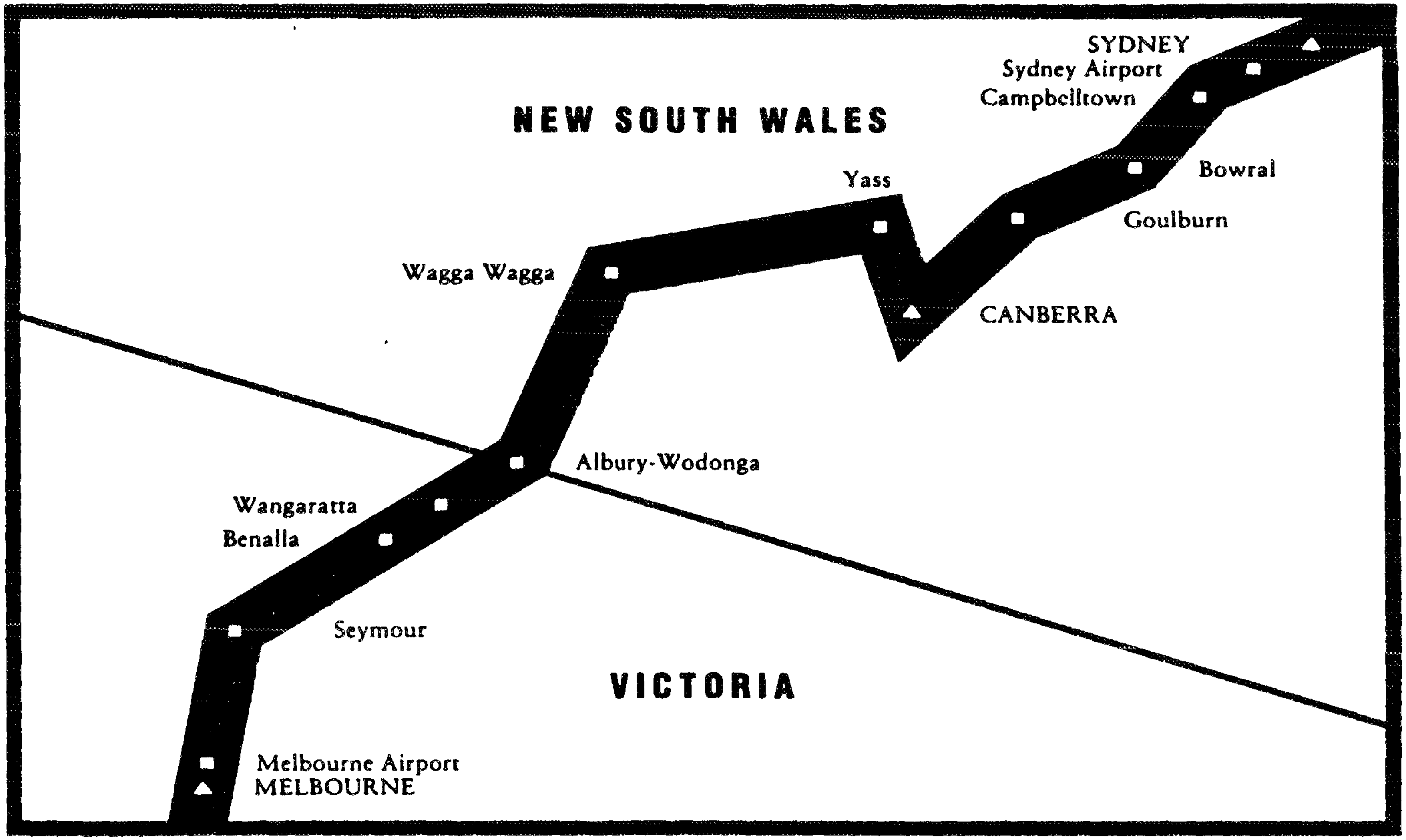
* assumed stopping time = 2 minutes
(Stop time at Canberra is 3 minutes)

VFT TIMETABLE INFORMATION

Local Services

STATION	Distance (km)	Distance (miles)	Total Distance (miles)	Travel Time+ Stop (minutes)	Average Speed (mph)	Travel Time * (minutes)	Average Moving Speed (mph)
Sydney	0	0	0	0	0	0	0
Sydney Airport	6	3.73	3.73	7	32	5	45
Campbelltown	42	26.10	29.83	22	71	20	78
Bowral	56	34.80	64.63	16	130	14	149
Goulburn	77	47.85	112.47	20	144	18	159
Canberra	74	45.98	158.46	18	153	18	153
	Subtotal=	158.46		83	115	75	127
Canberra	0	0	0	0	0	0	0
Yass	41	25.48	25.48	14	109	12	127
Wagga Wagga	147	91.35	116.82	34	161	32	171
Albury--Wodonga	122	75.81	192.63	31	147	31	147
	Subtotal=	192.63		79	146	75	154
Albury--Wodonga	0	0	0	0	0	0	0
Wangaratta	51	31.69	31.69	14	136	12	158
Benalla	44	27.34	59.03	14	117	12	137
Seymour	87	54.06	113.09	32	101	30	108
Melbourne Airport	88	54.68	167.78	24	137	22	149
Melbourne	19	11.81	179.58	12	59	12	59
	Subtotal=	147.89		82	108	76	117
Total =	854		530.68				

FIGURE C.1: THE PROPOSED ROUTE

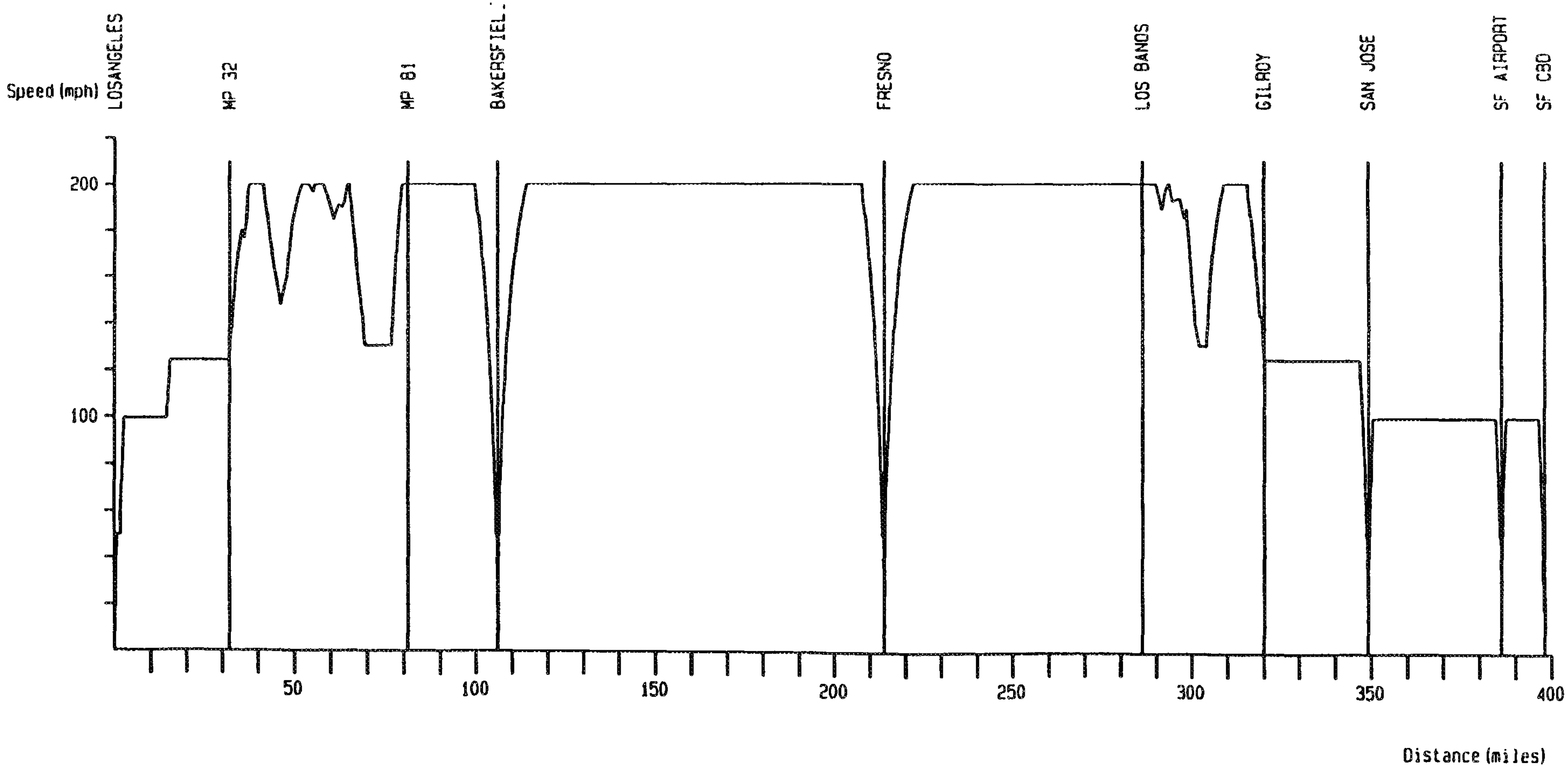


Source: VFT: Project Evaluation

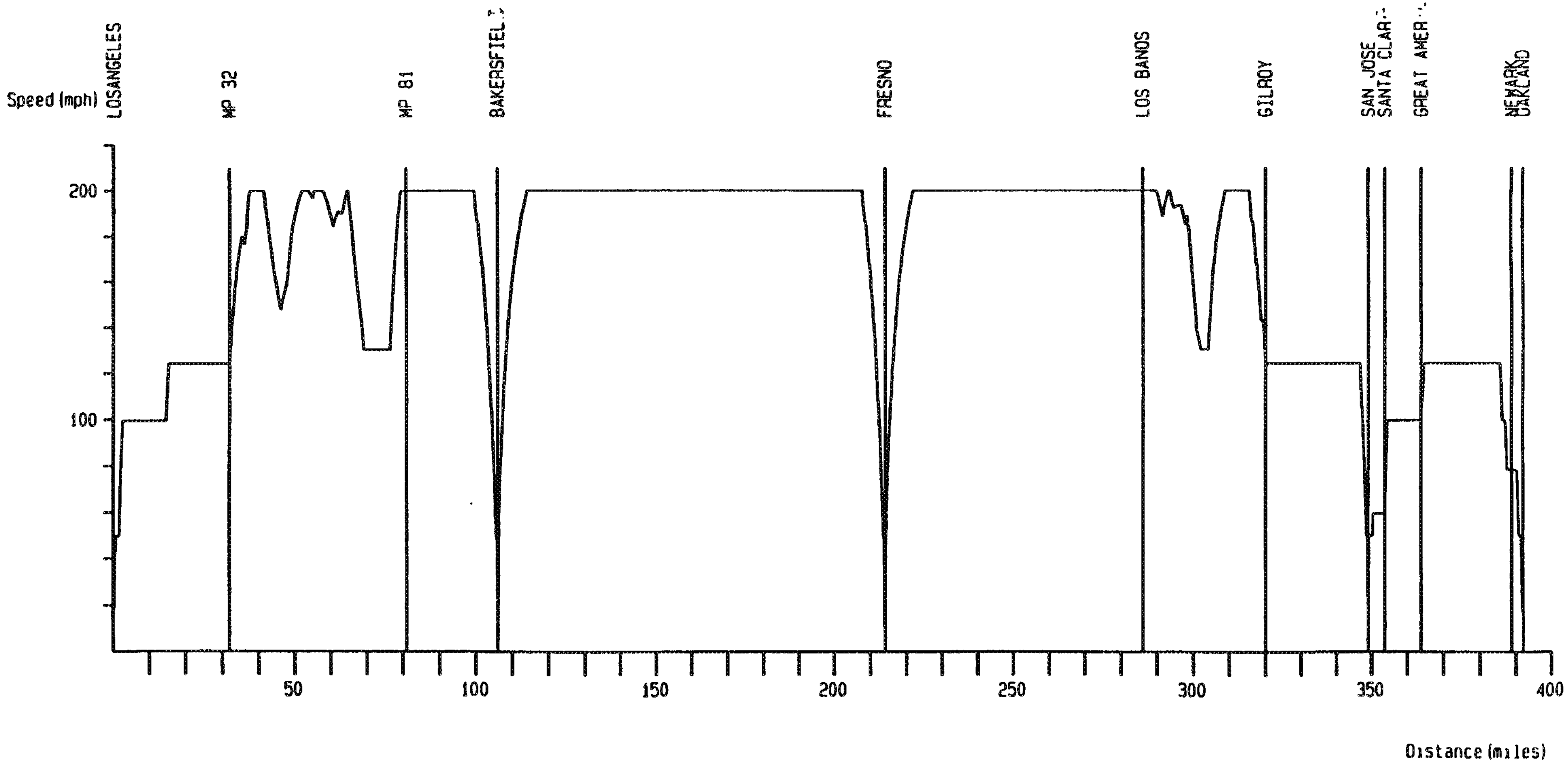
Appendix D

Travel Time Simulations

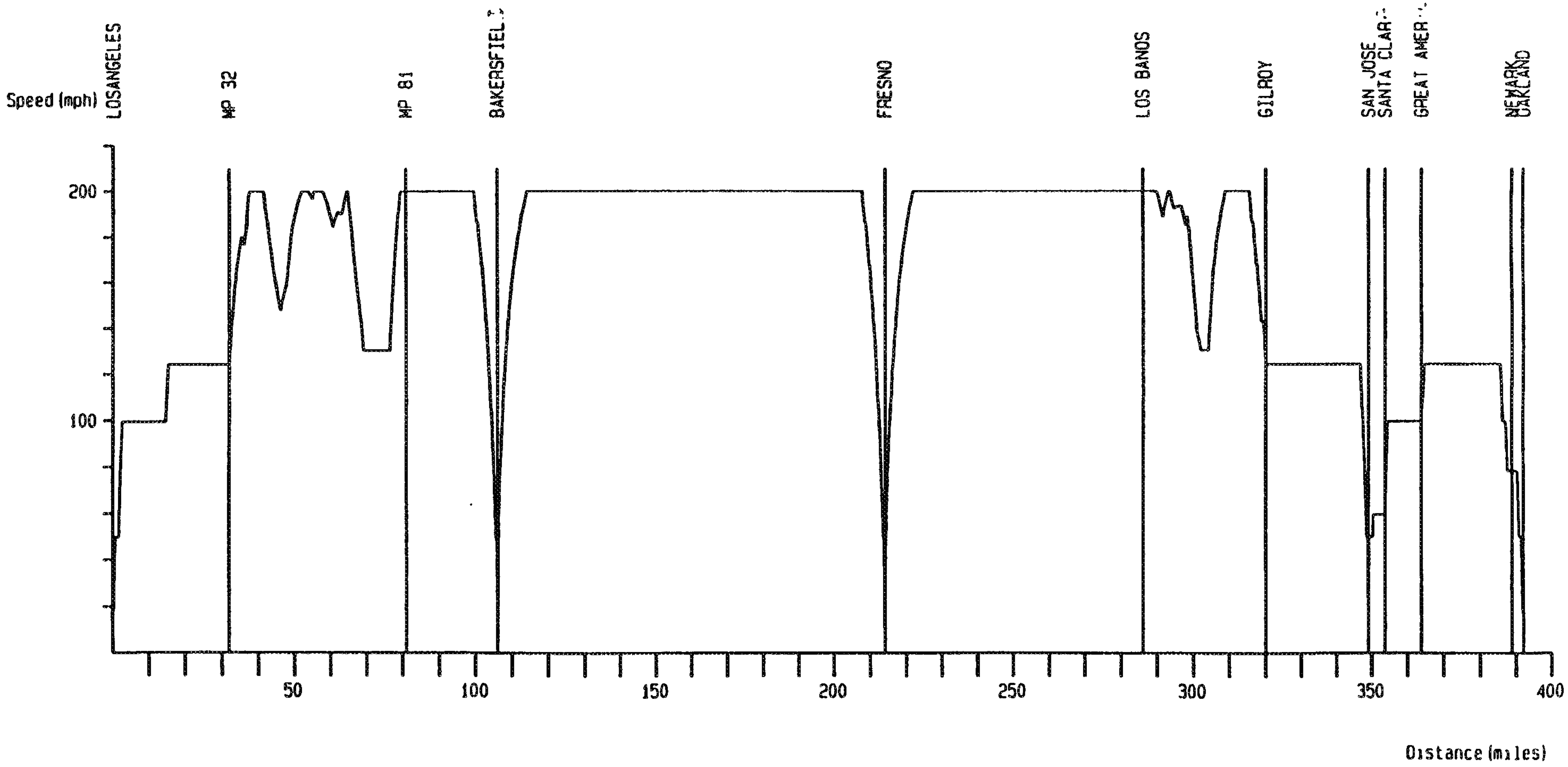
TGV Running Simulation
Los Angeles to San Fransisco
with stops in Bakersfield, Fresno and San Jose



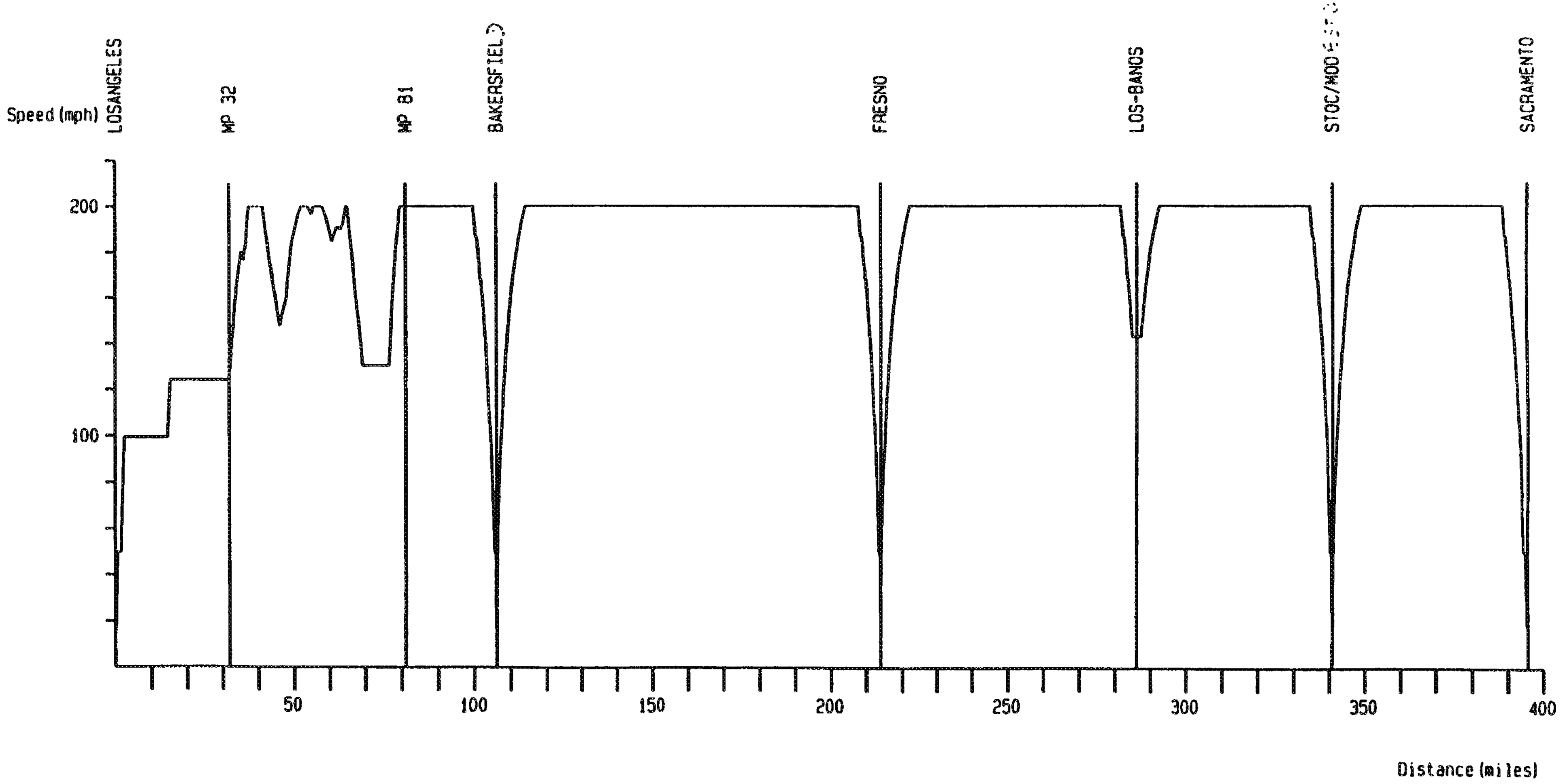
TGV Running Simulation
Los Angeles to Oakland
with stops in Bakersfield, Fresno and San Jose



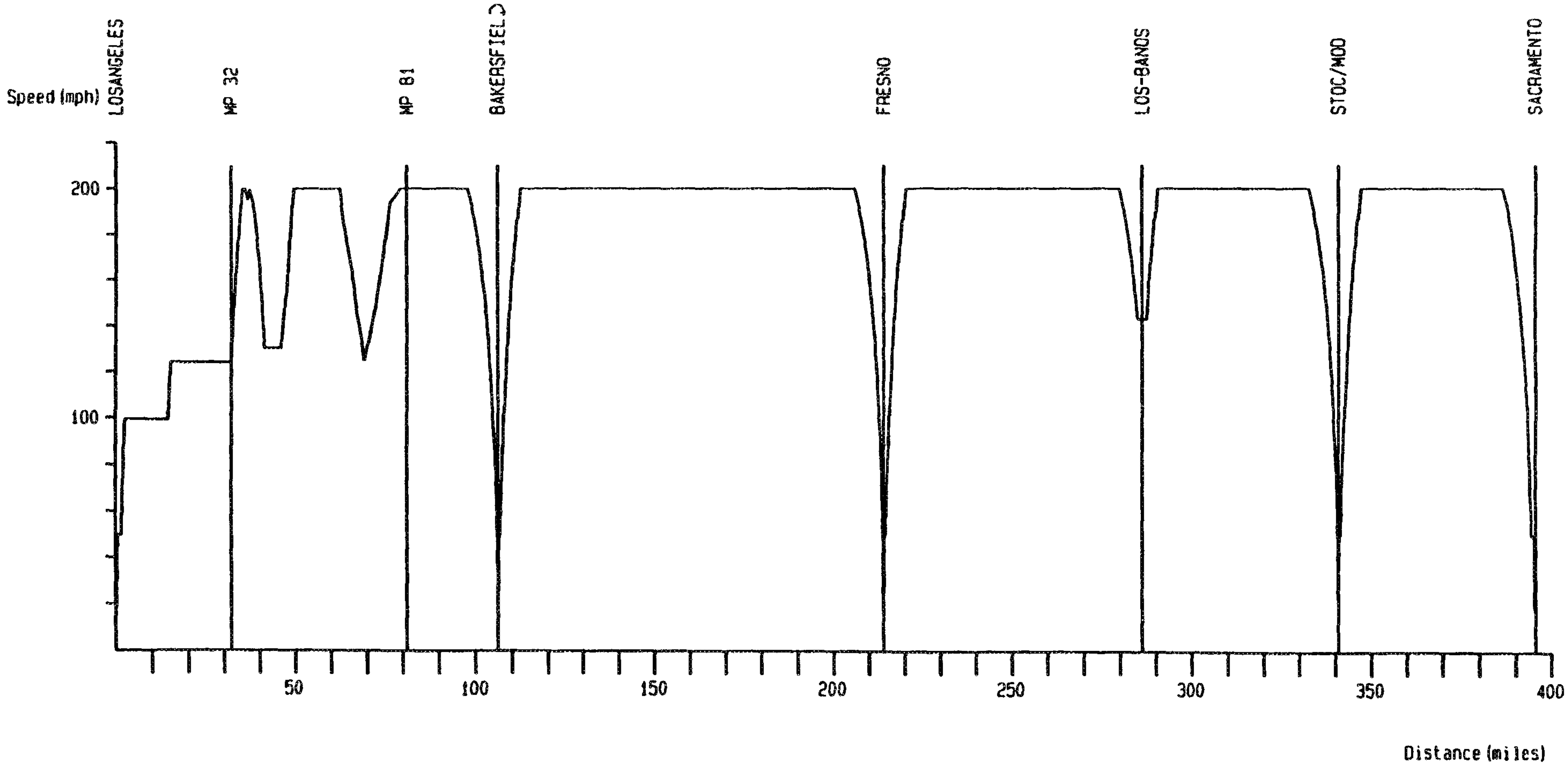
TGV Running Simulation
Los Angeles to Oakland
with stops in Bakersfield, Fresno and San Jose



TGV Running Simulation
Los Angeles to Sacramento
with stops in Bakersfield, Fresno and Stockton/Modesto



TGV Running Simulation
Sacramento to Los Angeles
with stops in Stockton/Modesto, Fresno and Bakersfield



DTR.P.T A.HUBER

LASFHORA.WK3, 24–Avr–92

CALIFORNIA HIGH SPEED RAIL TRAVEL TIMES

CITY	TO SAN FRANSISCO			TO WEST OAKLAND		TO SACRAMENTO		
	MILES	EXPRESS	NON–STOP	MILES	EXPRESS	MILES	EXPRESS	NON–STOP
LOS ANGELES	0	0:00	0:00	0	0:00	0	0:00	0:00
BAKERSFIELD	106	0:50–0:53		106	0:50–0:53	106	0:50–0:53	
FRESNO	214	1:32–1:35		214	1:32–1:35	214	1:32–1:35	
SAN JOSE	349	2:30–2:33		349	2:30–2:33			
SF AIRPORT	386	3:00–3:05	2:40–2:45					
SF CBD	398	3:15	2:55[1]					
WEST OAKLAND				392	3:05			
STOC/MOD						341	2:22–2:25	
SACRAMENTO						396	2:50	2:25

[1] Note that the Los Angeles-San Francisco travel time here includes a 5 minute stop at the San Francisco Airport along with the associated acceleration/decceleration whereas the CalSpeed-calculated time does not.

DTR P T A Huber GRAPEMOD.WK3, 16–Avr–92

Grapevine Selon fax IURD du 27 mars 1992

*from baseline

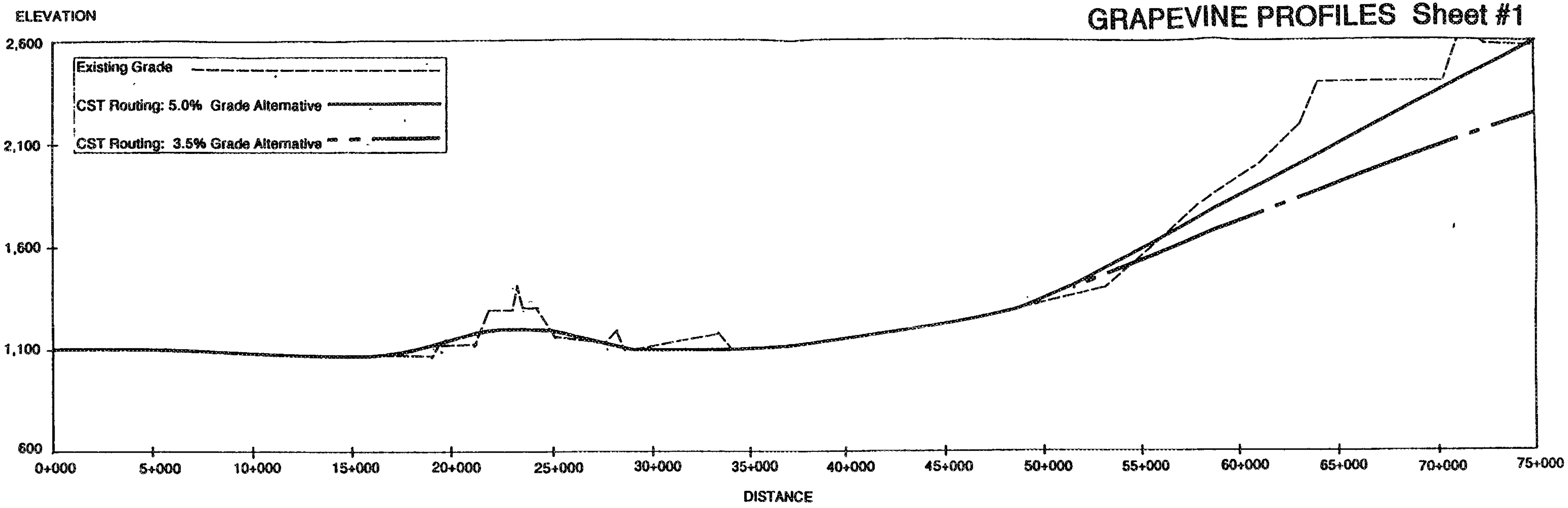
5% grade

Run	Distance	Rise	Elevation*	D(m)	Pente(o/oo)	Milepost
	0		0			31.26
5300	5300	0	0	1615	0.0	32.26
4000	9300	−30	−30	1219	−7.5	33.02
8400	17700	0	−30	2560	0.0	34.61
3600	21300	130	100	1097	36.1	35.29
3800	25100	−10	90	1158	−2.6	36.01
2800	27900	−110	−20	853	−39.3	36.54
3700	31600	−10	−30	1128	−2.7	37.24
3700	35300	20	−10	1128	5.4	37.95
11300	46600	170	160	3444	15.0	40.09
3000	49600	50	210	914	16.7	40.65
25000	74600	1270	1480	7620	50.8	45.39
9100	83700	170	1650	2774	18.7	47.11
4700	88400	−30	1620	1433	−6.4	48.00
3800	92200	−30	1590	1158	−7.9	48.72
11700	103900	40	1630	3566	3.4	50.94
11300	115200	80	1710	3444	7.1	53.08
6700	121900	160	1870	2042	23.9	54.35
8300	130200		1870	2530	0.0	55.92
6300	136500	−90	1780	1920	−14.3	57.11
5800	142300	160	1940	1768	27.6	58.21
9100	151400	320	2260	2774	35.2	59.93
7400	158800	70	2330	2256	9.5	61.34
5300	164100	120	2450	1615	22.6	62.34
3000	167100	30	2480	914	10.0	62.91
18500	185600	−90	2390	5639	−4.9	66.41
10800	196400	−220	2170	3292	−20.4	68.46
38300	234700	−1940	230	11674	−50.7	75.71
15400	250100	−350	−120	4694	−22.7	78.63
8500	258600	0	−120	2591	0.0	80.24
				0	ERR	31.26
	78821.28			78820		

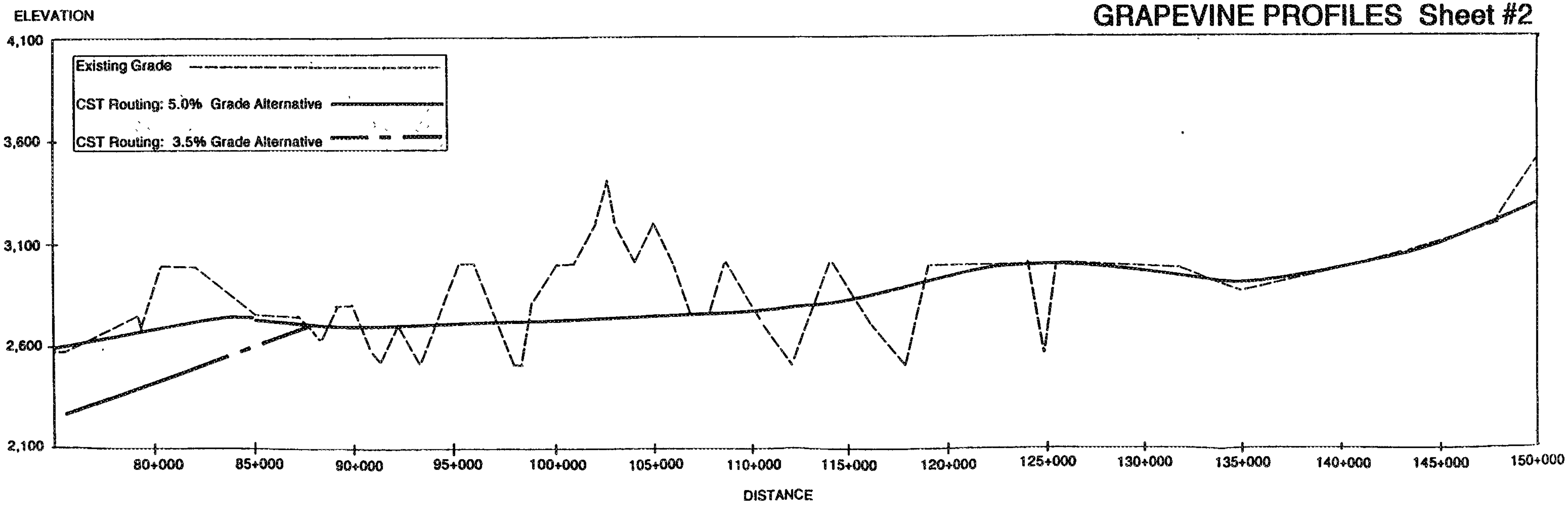
Appendix E

Mountain Profile

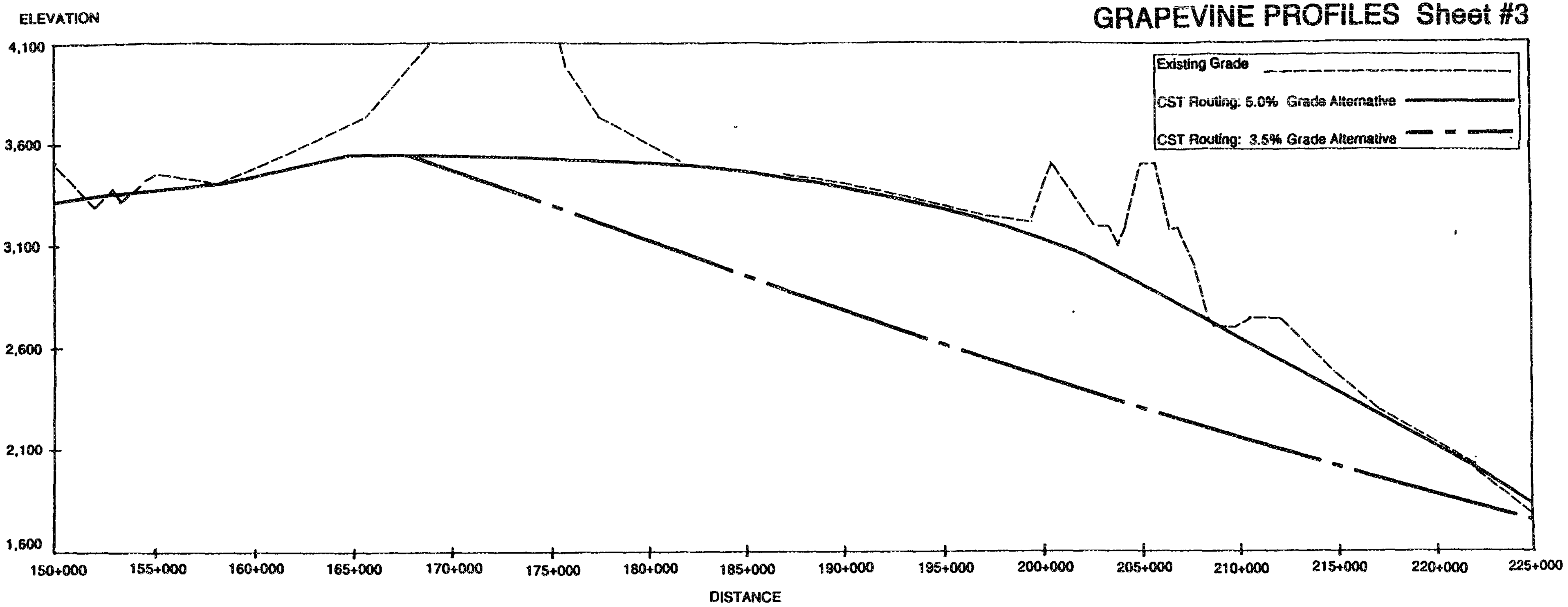
GRAPEVINE PROFILES Sheet #1



GRAPEVINE PROFILES Sheet #2



GRAPEVINE PROFILES Sheet #3



GRAPEVINE PROFILES Sheet #4