Capacity Challenges on the California High-Speed Rail Shared Corridors: How Local Decisions Have Statewide Impacts

by

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Abstract

In 2012, as a cost-control measure and in response to local opposition in the San Francisco Bay Area, the California High-Speed Rail Authority (CHSRA) adopted a "blended system" at the north and south bookends of the planned first phase of its high-speed rail line. In this blended operation, the high-speed rail line will share track and other infrastructure with commuter rail, intercity rail, and freight on the 50-mile Peninsula Corridor in Northern California and on 50 miles of right-of-way between Burbank, Los Angeles, and Anaheim in Southern California. This thesis provides a critical review of the blended system and discusses the level of cooperation and coordination necessary between host railroads and the high-speed rail tenant operator.

In Northern California, the Peninsula Corridor Joint Powers Board's *Caltrain* commuter rail service between San Francisco and San Jose is experiencing record levels of ridership. This thesis explores the impact of both the electrification of the line and its extension into San Francisco's central business district on future ridership demand. With the California High-Speed Rail Authority competing spatially and temporally with Caltrain for access to high-revenue and high-cost infrastructure, we review different strategies for coordination and integration between the two agencies.

In Southern California, the final form of the blended system is more nebulous than its northern counterpart. For the first few years of high-speed rail service, the *Metrolink* service operated by the Southern California Regional Rail Authority is expected to complement the high-speed rail system. However, since Metrolink operates on congested rail infrastructure, some of it owned by capacity-conscious freight railroads, there will exist the challenge of providing quality service and transfer opportunities for time-sensitive high-speed rail customers.

The change to a blended system was a dramatic change of direction for the CHSRA; as a result, a new paradigm is needed for implementation of the system over the next 15 years. This thesis reviews the upcoming local design choices to be made on the local rail corridors and evaluates them from the perspective of the future statewide rail network. We find that the decisions made on the local blended corridor level will affect both the financial viability of the overall project and the quality of service experienced by customers across the entire California rail system.

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Title: JR East Professor of Civil and Environmental Engineering and Engineering Systems

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Sam Levy
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Contents

List of Abbreviations

ACE—Altamont Commuter Express

BART—Bay Area Rapid Transit

BNSF—Burlington Northern and Santa Fe Railway

CHSRA—California High-Speed Rail Authority

CS—Cambridge Systematics

HSR—High-speed Rail

IOS—Initial Operating Segment (for high-speed rail)

LACMTA/Metro—Los Angeles County Metropolitan Transportation Agency

LAUS—Los Angeles Union Station

LOSSAN—Los Angeles-San Luis Obispo-San Diego

LTK—Louis T. Klauder Engineering Services

NCTD—North County Transit District

PB—Parsons Brinckerhoff

PCJPB—Peninsula Corridor Joint Powers Board

RailPAC—Rail Passengers Association of California and Nevada

SCAG—Southern California Association of Governments

SCRIP—Southern California Regional Interconnector Project

SCRRA—Southern California Regional Rail Authority

SFMTA—San Francisco Municipal Transportation Agency

SJRRC—San Joaquin Regional Rail Authority

TJPA—Transbay Joint Powers Authority

UP—Union Pacific Railroad

VCRR—Ventura County Railroad

VTA—(Santa Clara) Valley Transportation Agency

1 Introduction and Motivation

1.1 Problem Statement

In 2012, as a cost-control measure and a response to local opposition in the San Francisco Bay Area, the California High-Speed Rail Authority (CHSRA) adopted a "blended system" at the bookends of the state's planned high-speed rail line (CHSRA 2012). In this blended operation, the high-speed rail line will share track and other infrastructure with commuter rail, intercity rail, and freight on the 50-mile Peninsula Corridor in Northern California and on 50 miles of track between Burbank, Los Angeles, and Anaheim in Southern California (ibid). This change to "blended" from "dedicated" reflects the truth that the costs and challenges associated with constructing new, dedicated rail infrastructure are enormous, especially in urban areas. Shared rail corridors represent the possibility of more efficient use, that is, higher utilization, of precious rail infrastructure. Multiple railroads can share the burden of track maintenance and traffic control, both of which require high fixed costs. Sharing track, when done properly, is an attractive option for both passenger rail agencies and freight railroads and increasingly common in the United States. However, sharing track comes with challenges for all participating railroad operators as well.

1.2 The Importance of Capacity Management on Shared Rail Corridors

Of course, sharing track requires coordination and more often than not, it is between non-homogenous rail traffic. Rail capacity is not a fixed quantity; it depends on how the infrastructure is used. In this thesis, we discuss freight traffic (typically few stops, slow speeds), commuter rail traffic (many stops, medium speeds), and high-speed traffic (few stops, high speeds). A rail line can accommodate much more homogenous traffic (same speed and stopping patterns) than a rail line with heterogeneous traffic. In the next section, we will discuss the growth in demand for *all* types of railway traffic in the United States.

1.2.1 Increasing Demand for Passenger and Freight Service

In the United States, managing rail capacity is increasingly important as demand for rail infrastructure grows. This growth arises from increases in both passenger and freight traffic over the last several decades. On the supply-side, capacity improvements have not kept pace. The combination of these two developments means that railroads—both freight and passenger—are increasingly competing for rail capacity on corridors across the United States. California, which is the focus of this thesis, will be at the forefront of addressing this challenge.

Freight Rail

In 2012, freight rail carried 40% (measured by ton-miles) and 16% (measured by tons) of America's intercity cargo (Grunwald 2012). The $65 billion US freight rail industry has posted strong growth in revenue and efficiency since the US Congress passed the Staggers Act in 1980 which eliminated regulation on shipping rates and contracts (Palley 2011). The industry has consolidated to seven Class I railroads (systems with an annual operating revenue of $433.2 million or more) from 14 in 1990; these railroads account for more than 90% of industry revenue—California freight rail is dominated by two Class I railroads, the Union Pacific Railroad (UP) and the Burlington Northern Santa Fe Railway (BNSF), both of which had operating revenues of approximately $22 billion in 2013 (Grenzenback et al. 2007, Knight 2013, BNSF 2013). While rates have climbed with rising fuel prices in the last half-decade, freight rates adjusted for inflation were the same in 1981 as they were in 2011 (Lawrence 2015). Most importantly for this thesis, Class I railroads have realized an 88% growth in train-mile traffic in that period while shrinking their networks on a track-mile basis by 42% (Grenzenback et al 2007). While some of this efficiency can be attributed to longer train lengths, railroads are seeing their networks carry higher and higher amounts of traffic (Connell 2010). According to FRA data (as seen in Figure 1-1), ton-miles of freight doubled between 1980 and 2006 while traffic density (measured in ton-miles per mile of track) has tripled (Grenzenback et al 2007). Forecast rail traffic growth between 2006 and 2035 is projected to grow another 88% (ibid).

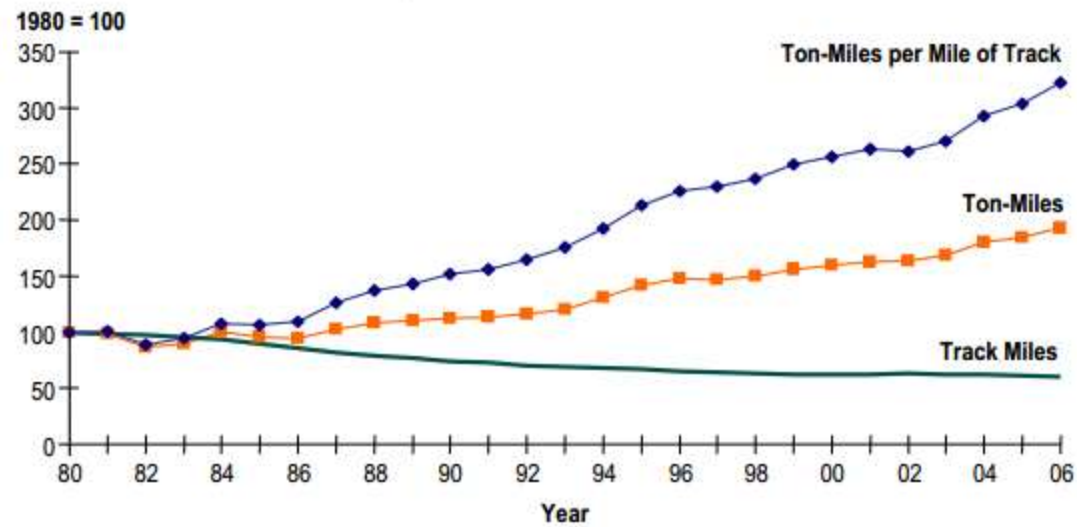

Figure 1-1: Changes in rail freight traffic since the 1980 Staggers Act
Source: Cambridge Systematics

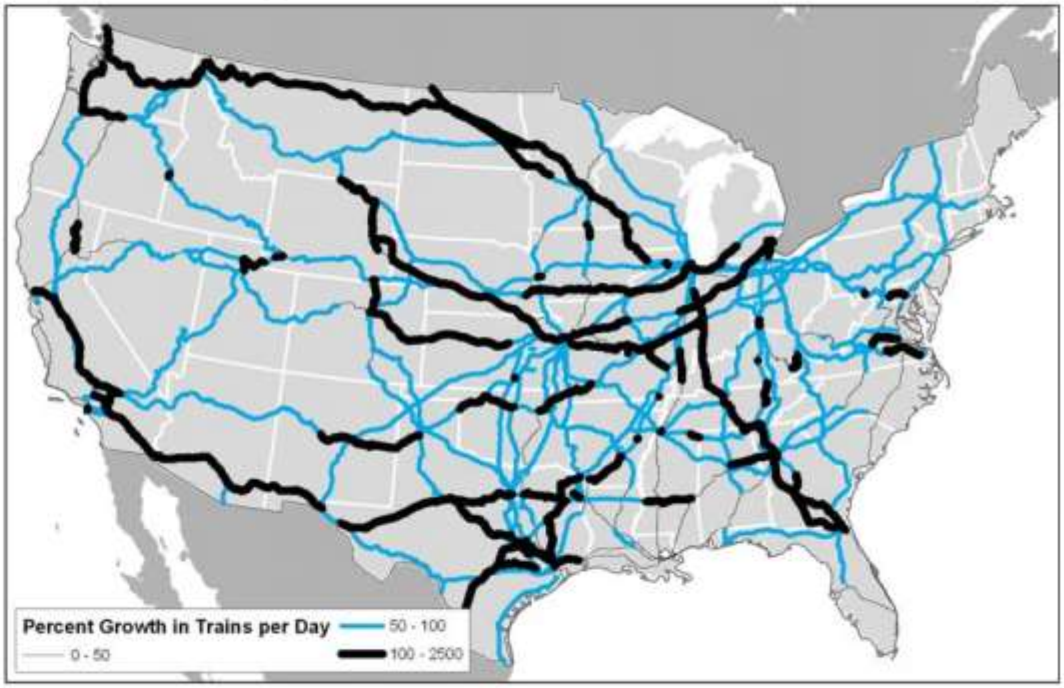

Figure 1-2: Percentage growth in trains per day from 2005 to 2035 by Primary Rail Corridor
Source: Cambridge Systematics

Freight rail traffic will continue to grow because of the relative affordability of rail transportation, especially for longer trips. It takes less time to ship from Asia to ports in California and ship cross country than to ship from Asia to the East Coast of the US; for this reason, much of this growth with be concentrated around California's Los Angeles-Long Beach port complex (and to a lesser extent, the Port of Oakland). Some of California's busiest freight subdivisions see traffic volumes as high as 64 trains per day[1].

Passenger Rail

We are seeing increased demand on the passenger side as well. Between 2000 and 2010, both unlinked commuter rail passenger trips and commuter rail passenger miles have increased 66% while total vehicle miles has nearly doubled (Neff and Dickens 2012). The reason behind this growth has been attributed, in part, to rising fuel prices which has pushed commuters from automobiles to more affordable public transportation alternatives[2] (Haire and Machemehl 2007). Aside from commuter rail, intercity passenger rail, operated by Amtrak and state agencies, has increased from roughly 21 million passenger miles in 2000 to 31.2 million in 2012 (Neff and Dickens 2013). In short, this means that track occupancy time and capacity usage by commuter rail has increased substantially.

[1] Recent expansions in the Panama Canal have been matched by expansions at California's main ports in Los Angeles and Long Beach and should counter potential Panama Canal-based market share loss.
[2] Higher traffic congestion, the opportunity to be productive in-vehicle, and increased quality-of-life as well as many other factors have contributed to transit ridership growth

A Brief Introduction to California Geography

Before we proceed further, we feel it is necessary to introduce the reader to the general geography of California. At nearly 40 million residents, California is the most populous state in the United States and on its own, the world's eighth largest economy. However, population is concentrated in several urban areas with lots of open terrain in between. The state is often divided both politically and culturally into two regions: Northern California and Southern California. San Francisco (837,000 people) and the surrounding San Francisco Bay Area serves as the cultural capital of the north and Los Angeles (3,840,000 people), the largest city in the state and second largest in the nation, as the hub of the south (Census Bureau 2015)[3]. San Diego, the state's second largest city (1,356,000 people with 3 million in its metropolitan area) sits adjacent to the Mexican border at the southwestern corner of the state (ibid). The capital city of Sacramento (475,000 people) serves as the anchor of the San Joaquin and Sacramento River Valleys, collectively referred to as the Central Valley and a vital farming region that accounts of 8% of the United States' agricultural output (ibid). While the state population currently sits at approximately 40 million persons, the state is expected to add 10 million more by 2050 with growth concentrated in the Central Valley (CA Department of Finance 2014).

Figure 1-3: Topographic Map of California. Source: worldatlas.com

[3] The San Francisco-Oakland-San Jose region combined statistical area has a population of approximately 7.5 million (about 20% of California's total population); the Los Angeles metropolitan area has a population of approximately 13 million (about 35%)

Following the same trend as the rest of the nation, both intercity and passenger rail have increased their ridership in California in the past 20 years without any significant increases to their network size. The intercity routes operated by Amtrak California, in particular, have increased service to the tune of nearly 50% more annual train miles on a route network where Amtrak is always a tenant railroad on another host railroad's (freight or government agency-owned) network[4]. The *Capitol Corridor*, an intercity rail service between northern Sacramento, Oakland, and San Jose has nearly doubled its services. Fortunately, the Capital Corridor's route is almost entirely on a single railroad's network (Union Pacific) thereby simplifying capacity negotiations. The *Pacific Surfliner (*or *Surfliner)*, one of Southern California's many responses to regional automobile traffic congestion, has increased its annual train mileage 26% between 2000 and 2012. Unlike the *Capitol Corridor* which operates predominantly on Union Pacific tracks, however, the *Pacific Surfliner* uses tracks owned by multiple railroads—both public and private—so train scheduling and use of capacity is a much more complex challenge.

Figure 1-4: California Passenger Rail Network. Note the "rail gap" between Bakersfield and Greater Los Angeles
Source: Rail Passenger Association of California (RailPAC)

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[4] A "tenant" railroad is a guest on a "host" railroad's infrastructure. The host owns the track and the tenant accesses through "trackage rights," though the tenant may be responsible for track maintenance, signals, etc.

Table 1-1: Amtrak California's Passenger Rail Growth, 2000 to 2012

Route Name	***Pacific Surfliner***	***San Joaquin***	***Capitol Corridor***	**All Lines**
Network Owners	*SCRRA, UP, NTCD, VCRR*	*UP,BNSF*	*UP, PCPJB*	
Passenger (Pax) Miles				
2000	1,661,704	733,152	1,030,837	3,425,693
2012	2,664,935	1,133,654	1,770,616	5,569,205
Percent Change	*60%*	*55%*	*72%*	63%
Pax Miles/Train Mile				
2000	106.2	103.7	106.0	105.6
2012	135.4	124.0	93.7	116.7
Percent Change	*27%*	*20%*	*-12%*	11%
Train Miles				
2000	15,647	7,070	9,725	32,442
2012	19,682	9,142	18,897	47,721
Percent Change	*26%*	*29%*	*94%*	*47%*

Source: 2013 California State Rail Plan

Commuter rail systems have also grown in in the past decade. Ridership on the Caltrain (San Francisco-San Jose) and Metrolink (Los Angeles metropolitan area) networks have increased nearly 50% while California's other two commuter services, ACE (Bay Area-Central Valley) and the COASTER (San Diego County) have seen significant growth as well. Train-miles are increasing across these systems as well. Having seen double digit annual ridership growth for the last several years, Caltrain has reached a practical capacity on its network and is now planning to add to its train length instead of adding frequency to meet passenger demand (Keller 2015). In Los Angeles, service expansions on the COASTER and Metrolink systems creates new capacity management challenges with the Class I freight railroads.

Like it does with Amtrak California intercity rail, network ownership plays an important, though different, role in the commuter rail capacity management narrative. Unlike the intercity services, however, Californian commuter rail agencies own a significant portion of the track that they use.

Table 1-2: California Commuter Rail Passenger Rail Growth, 2001-2012

Commuter Rail System	Caltrain[5]	Altamont Commuter Express (ACE)	COASTER	Metrolink	Totals (All Commuter)
Operating Agency	PCJPB	SJJPA	NCTD	SCRRA	
Geographic Location	San Francisco Peninsula	East Bay Area Counties	South Coast (Oceanside-San Diego)	L.A. Metro Area	
2001 Ridership	9,942,082	738,969	1,281,124	8,510,558	20,472,733
2012 Ridership	14,134,117	786,947	1,624,211	11,977,540	28,522,815
% Chg. Ridership	42%	6%	27%	41%	39%
2001 Revenue Train-Miles	1,249,980*	86,000*	206,000*	1,792,000	3,333,980
2012 Revenue Train-Miles	1,337,548	160,677	277,179	2,677,136	4,452,540
% Chg. Train-Miles	7%	87%	35%	49%	34%
2012 Network Size	77.5 miles	86 miles	62 miles	512 miles	737.5 miles
Mileage Owned (% Owned)	51 (66%)	0 (0%)	62 miles (100%)	216 (42%)	329 (45%)

*estimated from timetable analysis, all other data from National Transit Database

Caltrain runs the lion's share of its services on its own track; only six of its nearly one hundred weekday runs use another railroad's (Union Pacific's) territory. The COASTER in San Diego runs entirely on its own trackage and Metrolink owns nearly half of its network. Commuter rail agencies, then, have a degree of control over access to their network, though much of this control is dictated by long-term trackage-rights agreements.

[5] The PCJPB (Peninsula Corridor Joint Powers Board) operates Caltrain, the NCTD (North County Transit District) operates COASTER, and the SCRRA (Southern California Regional Rail Authority) operates Metrolink. To reduce confusion for the reader, we will try to use the service name (e.g. Caltrain) instead of the owner when possible.

Figure 1-5: Growth in Interregional Personal Travel (all modes)
Source: California High-Speed Rail Ridership and Revenue Model, 2012

What is driving this growth in passenger rail demand and services? The simplest answer would be population growth, and as we noted earlier, California is expected to grow nearly 25% by 2050 (CA Department of Finance 2014).

We have also seen trends that suggest that rail will see an increasing share of trips. Car ownership, once a rite-of-passage into American adulthood, is no longer a priority among many millennials (Ball 2014)[6]. In 2013, the portion of Americans age 16-24 with driver's licenses fell to its lowest level in almost 50 years (ibid). While fuel price increases have a positive cross-elasticity with transit use and helped pushed vehicle-miles travelled down to the same level as 2004, there is evidence to show that once users change to public transportation due to a fuel price spike, it is less likely they will return to their automobiles after prices fall; that is, ridership responds asymmetrically to a rise in fuel prices versus a fall (Chen et al 2011). Fuel price volatility, then, will continue to drive rail trips upward. It is factors like these that suggest that California's passenger rail growth seen over the last 10 years will continue into the middle of the 21st century.

One solution to capacity constraints on a railroad is to simply run longer trains. As noted earlier, the freight rail industry has managed demand growth to some extent in this manner. However, for passenger rail service, it is not as easy. Consumers value frequent service; all else being equal, it is more likely that passenger rail agencies would prefer to increase service frequency than simply make trains longer. The U.S. air industry has realized the importance of frequency and serve some of their busiest markets with smaller planes in order to maximize traveler convenience and capture market share (Belobaba 2009). European railroads also aim to provide frequent service between major city pairs at hourly intervals or less (Nash 2003). The challenge of using frequency to provide capacity is that, due to signaling constraints, six, one-car trains require even more than six times the track occupancy time than does one, six-car train. As passenger rail agencies look to increase frequency to provide more attractive options for customers, the importance of capacity management increases as well.

1.2.2 Proliferation of Shared Track Corridors

Amtrak operates over about 22,000 miles of track, most miles of which are owned by Class I freight railroads. According to Liu et al., all of the 18 existing and 38 proposed commuter railroads operate on shared tracks with freight railroads or other transit agencies; that is, even though some passenger railroads may own all of their right-of-way, they still open their track to freight traffic (Liu, Yang, and Chen, 2011). Since freight railroads own key sections of right-of-way, regions are finding it more cost-effective to build stations on existing freight rights-of-way rather than build new lines. Oftentimes, commuter rail agencies will acquire track from freight railroads; however, freight railroads often require continued access to the track through easements or trackage rights.

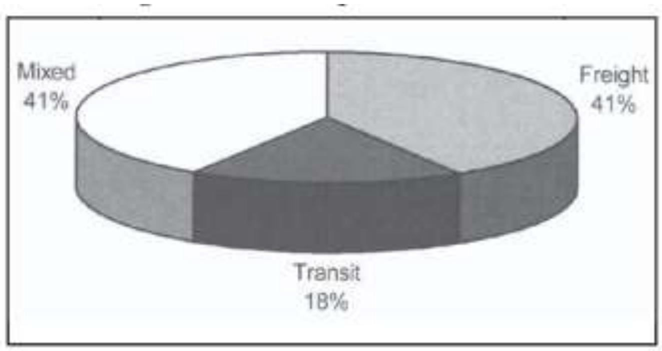


Figure 1-6: Ownership structure of commuter rail tracks in the U.S. For example, 41% of commuter railroads operate on lines owned by both freight railroads and transit agencies.

The California State Rail Plan lists no less fewer than 13 planned intercity and commuter rail projects, all of which would share track with freight rail lines or operate in territory owned by freight companies. While it is safe to assume that not all of these projects will push the track's capacity to its

[6] Millennials are people born between 1980 and the early 2000s, according to the Census Bureau

limit, there will be unique challenges in managing the operation and administration of each of these new shared-use corridors.

1.2.3 Delay Costs

Poor capacity management can make both passenger and freight rail operators experience delays. Delays are a cost to both passenger and freight operators, but their profit incentive makes freight railroads especially sensitive to delays. As a result, there has been much research on costs of railroad delay in the freight sector. Cost of rail delays to freight railroads range anywhere from $200 to $1400 dollars per hour depending on the type of train—intermodal trains tend to have higher delay costs than trains shipping bulk commodities (Lovett 2014). Components of these delay costs include wasted fuel, crew compensation, deprecation and rental expenses of locomotives and cars, as well as the costs of lost revenue or unsatisfied customers. Passenger rail operators experience much of these same costs, however, as subsidized entities and the fact that containers cannot themselves complain, the impact of delays on lost cargo (passenger) goodwill is of more importance than financial costs to passenger rail operators.

Shared rail capacity is subject to peaking much like highways, airports, or other transportation systems. While some sections of track are almost always have excess capacity, certain critical rail junctions or specific urban areas at almost always congested (McClellan 2006). Historical population centers that drive passenger rail traffic are, for many of the same reasons, historical centers of freight traffic. Chicago, Illinois, for example, is a hub for both national intercity, local commuter passengers and freight traffic and experiences extreme rail congestion—it can take two-thirds as long to move a freight train across Chicago as it does to move a freight train from outer Chicago to Los Angeles (Moser 2012).

11 48A	1021		Salinas, CA Monterey, Carmel —see back			6 28P
1 38P	1119		Paso Robles, CA			4 37P
3 20P	1157		San Luis Obispo, CA (Morro Bay)	QT		3 35P
6 02P	1274		Santa Barbara, CA	QT		12 40P
D7 05P	1310		Oxnard, CA	QT		11 44A
D7 48P	1341	Ar	Simi Valley, CA	QT		R11 11A
D8 22P	1358	Ar	Van Nuys, CA–Amtrak Station	QT		R10 40A
D8 31P	1363	Ar	Burbank-Bob Hope Airport, CA			R10 29A
9 00P	1377	Ar	Los Angeles, CA (PT)	QT	Dp	10 10A

Figure 1-7: Example of schedule padding on Amtrak's Coast Starlight. The travel time from Los Angeles to Burbank is 10 minutes shorter than the travel time from Burbank to Los Angeles
Source: Amtrak

How do commuter and intercity passenger railroads address these bottlenecks? Because on-time-performance is an oft-sought-after goal, agencies have simply added time to their schedules—a practice known as "schedule padding." As shown in Figure 1-7, between the second-to-last station (Burbank-Bob Hope Airport) and the terminal station in Los Angeles, the Coast Starlight's inbound trip is scheduled to take 10 minutes longer than the outbound trip on the same 14-mile segment; the Coast Starlight's most frequency cause of delays was freight train interference in March 2015. While this improves the on-time performance by accounting for potential delays, this costs the agency in that it makes their services appear less competitive with alternative modes. The industry standard for schedule padding is 6% of the running time (LTK 2012)

Improved management of capacity can lead to a more efficient rail line that allows for better, more accurate schedule planning which in turn would allow public agencies to offer more competitive options to customers. Furthermore, effective capacity management will provide opportunities for growth of not only shared-use commuter rail services but also expansion of energy- and logisticallyefficient freight rail. Perhaps most importantly, it provides a buffer before the last-resort capacity increase solution: construction.

1.2.4 High Capital Costs and Led Times for Additional Capacity

While the capacity gains are likely more significant, an engineering solution is an expensive solution to increasing capacity and requires longer lead times to realize the capacity gains than capacity management solutions (Hunt 2014). While costs vary depending on existing conditions, a new controlled rail siding costs multiple millions of dollars per mile and can be even higher if significant grading or property acquisition is needed to create space for the track (McClellan 2006). In addition to the capital costs, any new length of track requires a larger maintenance budget so operating costs increase as well (ibid).

The long lead times to implement engineering capacity solutions also presents a challenge. Timescales are on the level of multiple years meaning that significant confidence about the state of future demand is required. Or if capacity expansion is reactive, the long lead times result in several years of rail congestion before the solution is operational.

We are in the middle of moving from an “infrastructure era” and into a “systems era,” shifting away from a physical “build what we want” perspective to a “manage what we have” paradigm. In a time of limited resources, in terms of capital and operational funding as well as physical rights-of-way, capacity management becomes all the more important—a “just build it” attitude is both costly and difficult to implement in the current fiscal situation.

That is not to say California agencies are no longer pushing for large capital infrastructure investments. California is ambitiously planning a bevy of rail projects. For example, the San Diego Association of Governments is planning on making its portion of the Los Angeles-San Diego rail corridor 97% double-tracked (up from 50% today) by 2034 at a cost of $800 million (Eschenbach 2014). This effort is composed of 19 separate rail projects, 15 of which are already funded (ibid). In Los Angeles, Metrolink is rehabilitating freight rail track for passenger service as part of its $250 million Perris Valley Line extension (Riverside County Transportation Commission 2015). Finally, in Northern California, the Altamont Corridor Express service is planning to increase to service from 4 daily round trips to 10 by 2022 by adding track in certain locations (San Joaquin Joint Powers Authority 2015). The biggest rail capital expenditure by far, however, is the $68 billion California High-Speed Train Project, which we will now introduce in further detail.

1.3 High-Speed Rail as a Transportation Capacity Solution

California, along with many other states, sees high-speed rail as a one of the most effective alternatives to meet rising transportation demand. The State argues that the cost of equivalent airport and highway capacity would be $158 billion with operation and maintenance costs of $132.8 billion over 50 years; this is opposed to $68 billion for a high-speed rail line that will theoretically operate without subsidy (CHSRA 2014b). Furthermore, in a state very concerned about climate change, high-speed rail is seen as a more environmentally-friendly solution than either automobile or air travel.

In his doctoral dissertation, “The Competitive Advantage of High-Speed Rail,” Reinhard Clever identified five advantages high-speed rail holds over air transportation. First, on distances up to 250 miles, high-speed rail is just as fast as aircraft service when comparing gate-to-gate and platform-to-platform time. Second, HSR trains can act as “subways” in metropolitan areas and take customers directly into downtown areas. Third, trains can split up so one train can serve multiple destinations. Fourth, is the "quick-stop" advantage—in rural areas, high-speed trains can serve smaller communities without the incurring the cost that an individual, separate flight would require. And finally, trains are much easier to automate than planes and hold to on-time performance standards. It is no surprise that a large portion of California's projected high speed rail travelers are air travelers in the Southern California-Northern California market and road travelers that cannot afford the expensive airfares out of the relatively rural Central Valley.

1.4 High-Speed Rail and Shared Corridors in California

1.4.1 California High Speed Rail: A Brief History

The California High Speed Rail Authority (CHSRA) was established in 1996 under the governorship of Pete Wilson with the mission of directing development and implementation of an "intercity high speed rail service fully integrated with the state's existing intercity rail and bus network," for the purpose of meeting future transportation demand without putting excessive demand on California's intercity air and road network (Kopp 2006). It was not until 2008, however, that Governor Arnold Schwarzenegger placed Proposition 1A on the ballot, a $9.95 billion bond issue that, if passed, promising construction of a line capable of transporting passengers between Los Angeles and San Francisco in no more than 160 minutes with trains capable of running at least 200 miles per hour (Davis and Parra 2008). $9 billion of the bond issue would be available for direct construction of the line itself, the remaining $950 million specified for improvements connectivity to the existing California rail network (ibid).

In November 2008, Proposition 1A passed with a 52.2% majority, with 10 of the 16 counties containing the proposed alignment voting for the bond issue, including 7 of the 8 counties through which the San Francisco-Los Angeles alignment was to traverse (L.A.

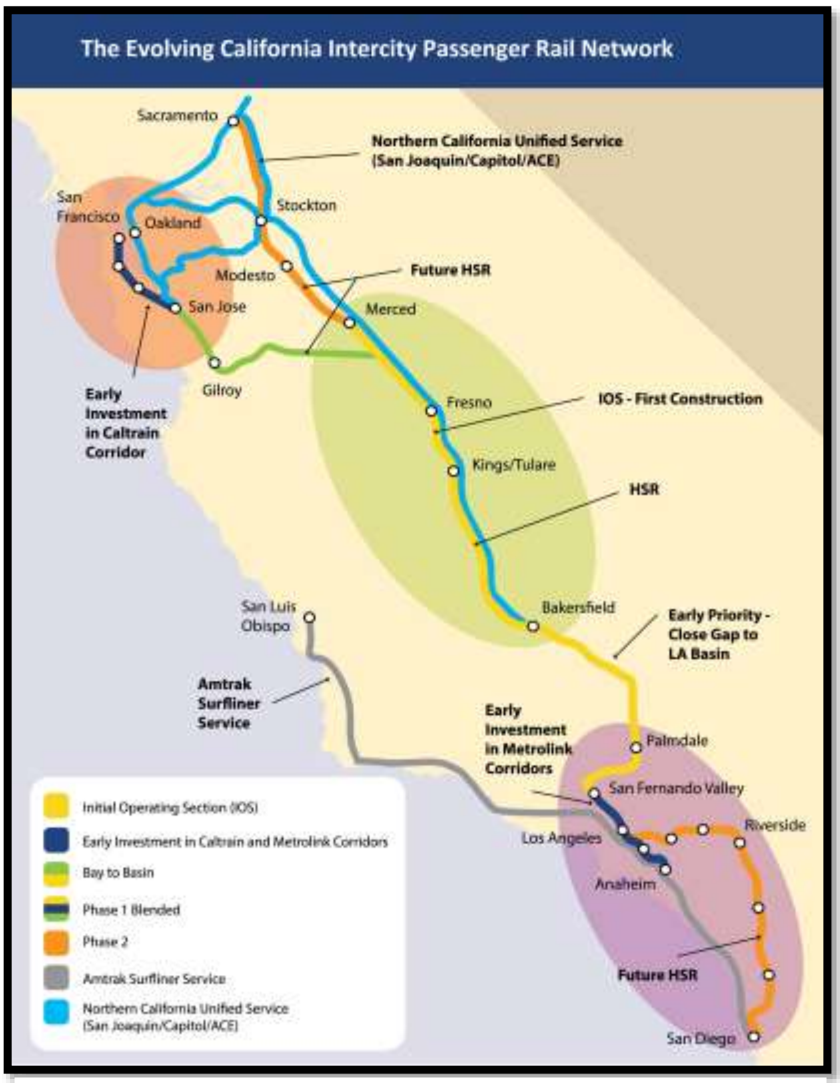


Figure 1-8: California High-Speed Train Project according to its 2014 business plan
Source: CHSRA

Times 2008). In 2010, various California rail projects were awarded an additional $2.334 billion in federal funding from the American Recovery and Reinvestment Act, including $2.25 billion for California High-Speed Rail (White House 2009). Additional funds from the FRA's High Speed Intercity Passenger Rail (HSIPR) program—including high-speed rail funding "returned" from the governors of Wisconsin and Florida—have brought the total federal commitment to $3.5 billion (Fleming 2012). The deadline to spend this federal stimulus money is September 2017; and though the CHSRA awarded two billion-dollar design-build contracts for the first 94 miles of the alignment in California's Central Valley, amid eminent domain lawsuits and other issues to be described later in this thesis, at the time of writing, construction (aside from utility relocation and demolition) has yet to begin (Rosenberg 2015).

According to the latest business plan, the project will be phased in sections. The summary of the phasing for the project is shown below in Table 1-3:

Table 1-3: California High-Speed Rail Authority Phased Implementation Plan (2014)
Source: CHSRA

SECTION	LENGTH (APPROX)	ENDPOINTS	SERVICE DESCRIPTION	PLANNING SCHEDULE	CUMULATIVE COST (YOE$, BILLIONS)
Initial Operating Section (IOS)	300 miles	Merced to San Fernando Valley	→ One-seat ride from Merced to San Fernando Valley. → Closes north-south intercity rail gap, connecting Bakersfield and Palmdale and then into Los Angeles Basin. → Begins with construction of up to 130 miles of high-speed rail track and structures in Central Valley. → Private sector operator. → Ridership and revenues sufficient to attract private capital for expansion. → Connects with enhanced regional/local rail for blended operations with common ticketing.	2022	$31
Bay to Basin	410 miles	San Jose and Merced to San Fernando Valley	→ One-seat ride between San Francisco and San Fernando Valley. → Shared use of electrified/upgraded Caltrain corridor between San Jose and San Francisco Transbay Transit Center. → First high-speed rail service to connect the San Francisco Bay Area with the Los Angeles Basin.	2026	$51
Phase 1	520 miles	San Francisco to Los Angeles/ Anaheim	→ One-seat ride between San Francisco and Los Angeles/ Anaheim. → Dedicated high-speed rail infrastructure between San Jose and Los Angeles Union Station. → Shared use of electrified/upgraded Caltrain corridor between San Jose and San Francisco Transbay Transit Center. → Upgraded Metrolink corridor from LA to Anaheim.	2028	$68

In this thesis we will discuss the implications of this phased implantation; that is, how the phasing affects the decisions of other entities that touch the network, be it freight, commuter, or intercity rail. We will also discuss the "blended system" in detail and the implications it brings for both Metrolink in Southern California and Caltrain in the north.

1.5 Motivation: How Might We Improve Capacity Management in California?

The overarching goal of this thesis is to offer recommendations on how California's rail capacity might be managed better and to develop a methodology to approach design decisions that affect capacity. As travel patterns and freight demands move across rail corridors with different owners, capacity planning becomes increasingly important. The following ideas will guide this thesis's recommendations in helping California realize not only its passenger rail service goals, but also provide the goods movement capabilities that allow it to maintain its leadership within the United States and the global economy.

1.5.1 Integration and the Impact of Local Decisions on "System Optimal"

The demand for freight and passenger rail services in the 2nd (Los Angeles-Long Beach) and 11th (San Francisco-Oakland) largest metropolitan areas in the United States has surpassed the supply of existing and undeveloped right-of-ways; freight and passenger sharing of corridors and track in California is a financial imperative. Demand patterns for both freight and passenger traffic have compelled railroads to operate in the "territory" of other host railroads. This context demands that agencies and freight railroads work together to ensure service quality for both cargo and passengers. Agencies need to adopt a systems perspective and understand how their decisions regarding capacity improvements and service changes affect the service possibilities for other agencies: a decision made in San Francisco regarding capacity improvements can affect the quality of service experienced by travelers in Los Angeles and vice versa. This will be especially true as high-speed rail arrives in California directly linking the two regions and putting capacity demands on both rail networks. This thesis strives to explore the upcoming local rail decisions and discuss their effect on the California rail network.

Regarding public and private coordination, freight railroads and passenger railroads need to plan capacity improvements concurrently. This is easier said than done. Since track ownership—especially in Southern California—is fragmented between freight and local agencies, corridor planning often involves multiple owners. Freight carriers have final approval on any new operations on their track, but capacity decisions made outside of freight rail territory could very well affect their ability to allow new passenger rail service (Fox et al 2014). In this thesis we hope to present the key benefits of integration and warn of the risks of agencies taking an individualistic perspective.

1.5.2 Should California follow the European Union's lead in capacity allocation codification?

Over the last 20 years, the European Commission, through a series of directives known as the railway packages, has pushed member states to have vertical separation of infrastructure ownership and operations and allow for open access to railway networks (Levy et al 2015). Actual separation between railroad operators and infrastructure managers varies from country-to-country, but nevertheless, every railroad operator is in theory competing for track access against all other operators. The railway packages have mandated that the infrastructure managers must establish a set of rules governing access to the network. This comes in the form of an annually-published "Network Statement," a document with standardized sections that describes how operators access the network. In particular, in its network statements, the infrastructure manager must specify how to allocate capacity when more train-paths are requested than the network can accommodate.

While it might be unrealistic to expect freight railroads or even public owners in the United States to voluntarily surrender ownership of track to a third-party, we might consider the possibility of multi-lateral agreements on rules governing track access. This is especially possible in regions like Southern California where freight and passenger rail trade off roles between host and tenant railroad.

On the San Francisco Peninsula, railway capacity will need to be allocated between high-speed service and local commuter service. The California High-Speed Rail Authority intends to sell the right to operate the high-speed line as a concession. Since this requires the operating portion of the railroad to be profitable, we could expect any high-speed operator will expect a certain amount of power in gaining track access (or at least have a guarantee of a profit-enabling amount of track access). This will involve a compromise with the commuter rail authority who has a public service obligation to provide service on the same corridor. A set of rules for allocating track capacity might not only reduce the risk for the consortium bidding on the concession contract, but also help the commuter rail agency better plan capacity improvements. We will explore this idea later in this thesis.

1.5.3 Present a path forward for the California Rail Network

Finally, another key goal of this thesis is presenting the CHSRA and other passenger rail agencies in the state a way forward for the development of not just high-speed rail, but for the California transportation network. To this end, we want to present the options and recommend certain actions for specific agencies.

1.6 An Outline of the Rest of This Thesis

In Chapter Two, we perform a literature review and discuss the practical challenges railroads face when sharing corridors. In Chapter Three we will "zoom in" on the San Francisco-San Jose Peninsula Corridor and discuss the capacity challenges the railroads are facing today and into the future. In this chapter, we will present the incredible need for coordination between high-speed rail, commuter rail, and freight on the corridor. We also review in detail the concept of a "blended system." In Chapter Four, we will discuss how this coordination is currently progressing and apply a train-operator financial model to understand the relationship between the agencies on the Peninsula Corridor. Next, in the Chapter Five, we introduce the Southern California rail network and upcoming challenges with the introduction of high-speed rail in the region. Finally, in Chapter Six we present a California rail network "wish-list;" that is, a list of statewide rail goals. We then evaluate four localized decisions and discuss how the impact of those decisions affect the fruition of the aforementioned "wishes."

We thank the reader for joining us and hope this thesis will provide not only a valuable overview of the challenges and opportunities faced by rail agencies and freight operators in California, but also a new paradigm to evaluate the choices being made today by the California High-Speed Rail Authority and other entities in the state.

2 California High-Speed Rail and Sharing Capacity—Literature and Practice

In this chapter, we will introduce capacity allocation mechanisms, discuss the specific challenges of shared corridors from a theoretical and practical standpoint, review the contemporary research on the California High-Speed Rail project, and explain the debate between vertical separation and vertical integration in the rail industry. Finally, we will look at capacity sharing in Europe where vertical separation is written into law.

2.1 Forms of Capacity Allocation and Rail-Specific Challenges

In this next section we will discuss different methods of allocating rail capacity and the specific challenges of distributing rail capacity versus other public utilities.

2.1.1 Stephen Gibson's Mechanisms for Allocating Capacity

Stephen Gibson defines three overarching mechanisms for allocating rail capacity: 1) administrative mechanisms, 2) cost-based mechanisms, and 3) market-based mechanisms (2003). Gibson's writing is focused on rail capacity allocation in the United Kingdom where, unlike in the United States, track ownership and train operators are completely separate entities. However, Gibson's definitions can be modified to generally characterize mechanisms available to railroad operations in the United States.

Administrative (or rule-based) mechanisms are the most prevalent in the United States and Europe and are typically the result of historic precedents and agreements between rail operators. Decisions are not made based on prices or values of the specific rail capacity, but rather a set of rules such as "commuter rail gets priority over freight" or "freight will have track access between 12 A.M. and 5 A.M." These rules might take the form of track-use agreements and could be changed with the consent of both the track owner and the railway operator.

Cost-based mechanisms attempt to "signal to capacity users and providers the costs of consuming or providing" additional services; that is, if a freight operator wanted to use the track during a peak passenger service period, it would need to pay the infrastructure owner a higher price. The difference between this and the administered mechanism is that here the railroad operator has unlimited access to track assuming it can afford the access charges offered by the infrastructure owner.

Finally, market-based mechanisms would attempt to reveal the true value of a particular train to an operator through some form of auction for capacity or track access-trading scheme. Due to the complexity of capacity, which will be described later, market-based mechanisms are particularly difficult to implement in the rail industry.

2.1.2 Rail-Specific Challenges

Capacity is shared between operators in other industries such as utilities, radio bands, and airports. However, several key aspects of rail operations make sharing rail capacity a unique challenge.

Patricia Perennes highlights some of the key challenges that are rail-specific (2013). First, unlike in the telecom industry where phone calls use the same line simultaneously, trains cannot pass one another—in fact, there is a finite and substantial required separation between trains on the same track. Airports gates are similar in this regard—there is a finite and substantial required separation between planes at the same gate (i.e. two planes cannot be at the same gate at the same time). However, rail capacity is a bit more rigid—a stopped train (whether from a mechanical breakdown or stopping at a station) cannot simply be taken apart and moved somewhere else while an airplane could be moved to a different gate or an outlying area on the tarmac. As Perennes puts it, "airport capacity is a one-dimensional process (time) where rail capacity allocation is two-dimensional (time and location) (2). While not the case across all gates at an airport, planes can be switched to different gates; because the number of tracks on a rail line (or even at stations[7]) is orders of magnitude smaller than the number of gates at an airport, rail capacity is much more dependent on how the entire network used.

Another key-element of rail capacity is that railways are not nearly as homogenous as other forms of infrastructure. A kilowatt-hour of power is the same kilowatt-hour whether or it came from a coal-fired power plant or a wind turbine and all phone calls take up more or less the same amount of cable. In aviation, we see bigger heterogeneity, but ultimately, these only amount to a few extra minutes of separation upon takeoff and landing (to avoid wake turbulence effects for safety reasons) or a few extra minutes at a gate to unload and load a larger number of passengers. The heterogeneity of rolling stock in railroad operations, however, with trains operating with different speeds, power-sources, dynamic envelopes, and weight all using the same infrastructure (railway track) create a many shared-use challenges. We group these shared-use challenges into three categories: physical, operation, and institutional. However, these buckets are not in silos—decisions made to address to the challenges in one category affect how operators face challenges in others. We will discuss these shared-use challenges in more detail later in this chapter. First, however, we will introduce some of the research that explores more efficient (in terms of higher infrastructure utilization) strategies to manage capacity.

2.1.3 Novel Approaches to Managing Capacity

Academic research has put forward other possible methods of allocating capacity. In his paper, "Towards a welfare enhancing process to manage railway infrastructure access," Jan-Eric Nilsson develops an allocating mechanism in which operators submit "bid functions" for their preferred train path as well as an indication of their lessened willingness to pay for an alternative path (2002). Nilsson draws some inspiration from the Federal Communications Commission's auctioning of radio frequency which he claims proves that "it is indeed feasible to give particular services a preferential treatment as well as

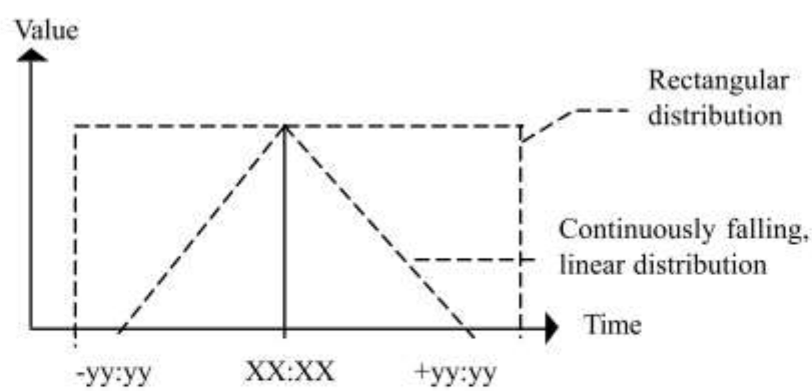


Figure 2-1: Nilsson's operator bid function distribution
Source: Jan Eric Nilsson

[7] The US's busiest rail station, Penn Station, has 21 tracks, while the busiest airport, Hartsfield-Jackson Atlanta International Airport, has 207 gates.

to handle the risk that some operator comes to dominate a market" (434). However, Nilsson leaves the task of prioritizing bids to the government as he admits it is a political problem, not an optimization one.

Nash and Johnson suggest an alternative where congestion charges are based on the opportunity cost of an incumbent operator not being able to run a train at a desired time (2008). The opportunity cost is based on 1) lost revenue from not running a certain train, 2) the consumer's surplus resulting from the "additional quality" and capacity provided by the new train, 3) the savings of external costs to road users, and 4) less the operating expenses of the incumbent running the train. This could conceivably work for a private operator operating on publically-owned rights-of-way as would be the case in California; and while the incumbent data would be available since these are public services, agreeing on a cost methodology will be challenging.

One of the biggest challenges in allocating capacity in a railroad is the network effects of passenger services. One train may be of great value if it can connect to another train at a railroad hub, but be of almost no value otherwise. Borndorfer attempts to rectify this by proposing a combinatorial auction in which railroad operators bid on bundles of slots with "positive synergies between the slots" (2006). Borndorfer suggests an iterative programming approach to solve the auction. While he proves that this is implementable in the Hannover-Fulda-Kassel area in Germany and "can induce a more efficient use of capacity", it might be more complicated a procedure than California agencies and freight railroads are willing to accept.

In her doctoral thesis, Maite Pena-Alcaraz evaluates price-based and auction-based capacity allocation mechanisms on the Central Corridor in Tanzania and the Northeast Corridor in the United States (2015). In the price-based mechanism, the infrastructure manager sets a price and operators choose which trains to operate based on priority rules. In the auction-based mechanism, the operators indicate the price they are willing to pay for each train as well as their flexibility if the schedule is adjusted (similar to Nilsson's flexibility bid function. The infrastructure manager then chooses the profit maximizing solution (solved via an adaptive relaxed linear program). Pena-Alcaraz finds that the auction performs better from an infrastructure manager cost-recovery standpoint, but operator profits and service levels are decreased.

Ahmendreza Talebian presents a sequential bargaining game for allocating capacity in vertically integrated systems, using the proposed Chicago-St. Louis high-speed line as a case study (2015). We will discuss the distinction between vertical integration and vertical separation in the railway industry later in this chapter. Talebian's approach is as follows: the tenant operator will present their ideal timetable along with a schedule-delay penalty (its compensation for an alternative train slot). The infrastructure owner/host railroad will offer the tenant railroad an access charge. The tenant railroad can accept and the "game" is over. Or the railroad can reject in which case the host railroad offers a new timetable and access charge scheme. The tenant railroad can now offer a new schedule-delay penalty and the host railroad can accept or reject. The equilibrium result is a utility-maximizing schedule for both railroads.

2.2 Integration and Institutions

Reinhard Clever, in his paper, promotes integration in transit agencies. He outlines his Six States of Integration and argues that increasing levels of integration are directly correlated to ridership in transit systems (2013). The lowest level of integration (no integration) means passengers are forced on poorly-timed, long walking-distance rail-to-rail transfers. The highest level of integration, or what Clever describes as “Convergence” is a non-transfer, one seat ride from suburb to urban center. This no doubt comes with institutional and regulatory challenges such as allowing inter-urban lines to run on urban transit infarstrcuture (consider the Acela running on New York Subway tracks, for example), but Clever argues the rewards could be enormous. Clever presents a potential solution for convergence with the Northern California end of the high-speed rail line, an idea we will discuss later in the thesis.

Figure 2-2: High-speed rail (left) sharing platform with interurban train (right) in Karlsruhe, Germany, an example of integration
Source: Mundus Gregorius via Flickr

In a similar sense, Meyer et al. discuss collaboration in transportation, calling it “the key to success” (2005). The authors look at various settings to look for collaboration in the form of “efforts in transportation systems management and operations, responding to disruptions caused by unexpected or unusual events, managing transportation assets across modal boundaries, integrating traveler information systems, and integrating transportation and land use strategies.” Collaboration versus competition is a very important theme in this thesis and Meyer et al explain the distinction between the two in Table 2-1.

Table 2-1: Meyer et al distinguish between collaboration and competition between agencies in the transportation sector

Collaboration		Competition
Process-oriented		
Top leaders support collaboration	versus	Top leaders foster competition
Open communications	versus	Withholding of information
Staff assigned to foster collaborative activities	versus	Staff assigned to encourage and attain competitive advantage
Focus on joint problem solving	versus	Individual action to "beat" other competitors
Institutional mechanisms for joint action	versus	Separate structures for individual action
Reward staff who are successful in collaborative activities	versus	Reward staff who are able to "beat" the competition
Possible evolutionary growth into full partnership on many issues	versus	Little chance for cooperative partnership
Individuals' perspectives		
Common language and terminology designed to foster communications	versus	Different language and terminology designed to guard competitive advantage
Concern for mutual benefit and gain	versus	Focus on own interests
Emphasis on trust among participants	versus	Distrust of others
Respect for the interests of those collaborating	versus	Suspicion of the motives of others
Easy access to other partners	versus	Little interaction with others
Readiness to be helpful	versus	Use of threats and coercion

How does collaboration and competition unfold when one entity is a for-profit entity (such as freight operators or high-speed rail) and one is a subsidized public entity? A for-profit entity will ostensibly have a higher-willingness to pay for what is necessary to be profitable. Baritaud and Stefanescu identify three issues with subsidizing public operators against private operators (2000). First, there is the "loose budget" effect where extra subsidies can drive up costs for everyone since the subsidized operator has an increased willingness to pay to access infrastructure. Second, there are distributive issues in that *all* tax payers have to subsidize users of the public transport system. Finally, there is a lack of information about users' willingness to pay for the fixed costs of a transportation system. Baritaud and Stefanescu concede that "any attempt to clarify subsidies to the rail industry…will remain biased" and that access pricing needs to "consider the existence of externalities" (20). Collaboration between a for-profit operator and a subsidized commuter operator will require careful regulation to ensure that the private operator is not a beneficiary of subsidies (or lack thereof).

2.3 Research on the California High-Speed Train Project

There is much literature already written on the California High-Speed Train project. Most of the research has focused on predicting ridership and feasibility of the system, particularly the dedicated system that was planned until the 2012 transition to "blended system."

2.3.1 Reviews of Revenue, Ridership, and Feasibility

There have been numerous studies done (both independently and for the California High-Speed Rail Authority) examining ridership and revenue potential of the system. In 2000, Charles River Associates (CRA) examined revenue and ridership for various alignments and technologies such as steel wheel/steel rail or magnetic levitation. CRA also forecasted diverted demand from air and road as well as stimulated demand from the new system. In preparation for the 2008 bond measure, Cambridge Systematics (CS) provided a ridership and revenue forecast for the Authority, including performing a comprehensive stated-preference (SP) survey at California airports. David Brownstone, Mark Hansen, and Samer Madanat of UC Berkeley's Institute for Transportation Studies completed a peer review of CS's forecast in 2010 and identified thirty areas of concern that included questioning the firm's methodology. Dr. Lance Neumann and Dr. Kimon Proussaloglou of CS, however, stood behind their procedure claiming that it followed generally accepted best practices and provided "objective and unbiased results" (2010). After hearing support for CS's forecast from several members of the public as well as public agencies, the CHSRA sided with CS claiming this is a "classic disagreement between the academician and the industry practitioner" (Van Ark 2010). Since 2011, perhaps in response to the UC Berkeley's criticism, the Authority itself has convened a peer review group of academics and industry practitioners to evaluate revenue and ridership projections furnished by CS and others.

California Assembly Bill 3034, the bill that became Proposition 1A, established an independent peer review group to evaluate "funding plans and prepare its independent judgment as to the feasibility and the reasonableness of the Authority's plans, appropriateness of assumptions, analyses and estimates, and any observations or evaluates the Group deems necessary" (Davis and Parra 2008). In their latest review of the 2014 CHSRA Business Plan, the Peer Review Group identified several issues, some of which we will review in this thesis. These include a funding shortfall of $20.934 billion, the requirement to spend $2.5 billion worth of American Recovery and Reinvestment by September 2017, and a critical look at the blended system (including platform heights, electrification compatibility with freight, and positive train control interoperability), and the costs of revenue risks that would need to be passed to the private operator of the system (Thompson 2014).

2.3.2 High-Speed Rail's Relationship with Air Transportation

In her PhD dissertation, Regina Clewlow compares the environmental consequences of high-speed rail versus air transportation (2012). While this author is not concerned with the environmental implications, Clewlow does discuss the degree to which high-speed rail can capture market share from air travel. She asserts that high-speed rail's market share is more related to journey time rather than distance and that short-haul air-travel demand in Europe "has clearly been affected by the introduction of improved rail travel times" (24) This loss of market share to rail may not necessarily be a loss to the airlines, writes Clewlow. Airlines can then focus on longer haul traffic, more profitable long-haul traffic and use HSR as a complement to their network.

Daniel Albalate, Germa Bel, and Xavier Fageda take a detailed look at competition and cooperation between HSR and airlines and find that while the two modes are often in direct competition, there is "some evidence that HSR can provide feeding services to long haul air services in hub airports, particularly in hub airports with HSR stations" (2013). This could be of particular importance in California where SFO serves as both a hub airport for United Airlines and an HSR station. In Los Angeles, LAX serves as a hub for United Airlines, Delta Airlines, American Airlines as well as a focus city for Southwest Airlines; while LAX is not directly connected to the HSR system, the airport and the HSR station will be a mere 25-minute shuttle ride transfer apart.

2.3.3 California Rail Network Service Planning

In the spirit of the blended system (in which high-speed rail coexists with conventional services), Ulrich Leister applies what he describes as a "Swiss Approach" to high-speed rail in California by emphasizing a lean approach that features a high-speed "trunk" in the middle of the state connecting to major transfer stations that serve the metropolitan areas of San Francisco and Los Angeles (2011). Leister proposes an approach which moderately increases travel time between California's major metropolitan areas, but also (according to Leister's own estimations), greatly reduces the project's overall cost. Ross Maxwell, in his 1999 TRB paper, also emphasizes the Swiss strategy of timed transfers and provides a conceptual schedule map for northern California operations with a San Jose hub. Writes Maxwell, "Like the Swiss, North Americans need build only what is needed, but they should build what is truly needed to develop a fully integrated system. To build only to meet the market on a corridor-by-corridor basis runs the risk of underinvesting and thus failing to maximize the public good." Maxwell and Leister both espouse the importance of cooperation and integration in their service planning for California HSR.

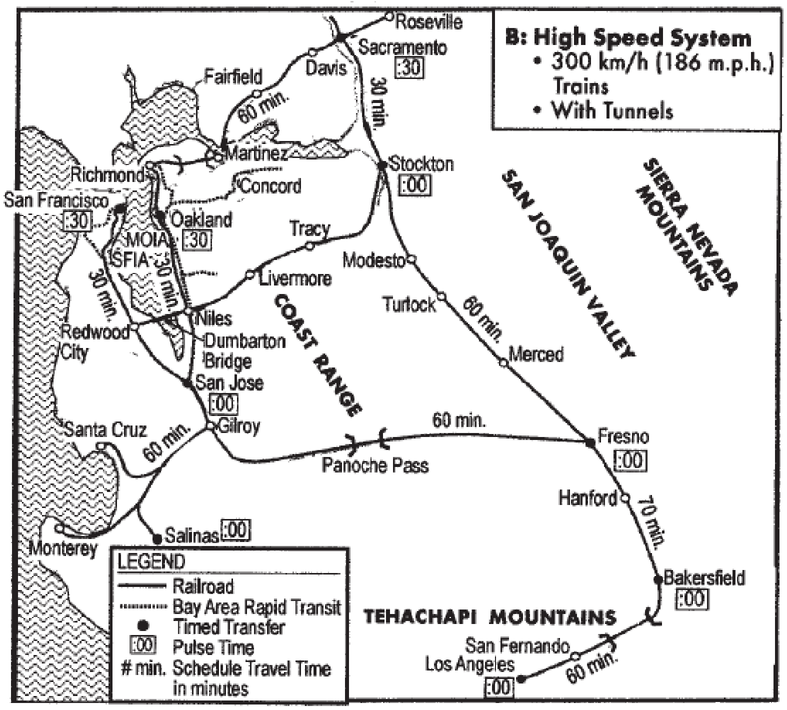


Figure 2-3: Ross Maxwell's proposed "pulsed hub" system for the California Rail Network which uses a San Jose timed transfer to move passengers between Los Angeles and San Francisco

Source: Ross Maxwell, 1999

Shuichi Kasuya, in his 2005 master's thesis, also discusses the opportunity for California HSR to act as a commuter service at those major metropolitan areas. He suggests that the low cost of rolling stock relative to the total cost of the infrastructure means that sharing rolling stock for intercity and commuter service is "essential for efficient rail transportation." Sakura performs a case study of Metrolink's Antelope Commuter Rail Line in the Los Angeles basin and concludes that for little additional cost, the HSR operator can increase profits by acting as a commuter service and commuters can benefit up to a 50% travel time savings.

As far as research regarding the current plan for the blended system, we have not been able to find any further academic work. LTK Consulting produced a short feasibility study of the blended system in 2012 and concluded that the system is in fact feasible; however, the author contends that the report did not fully explore the implications of the blended system and will discuss this later in the thesis.

2.4 Physical Challenges

2.4.1 Rail Infrastructure and Equipment Design

While all railroad tracks connected to the United States' national railroad system are standard gauge (4' 8.5" between rails), rolling stock is not nearly as compatible. In this paper, we split the physical challenges in sharing capacity into two broad categories: rail geometry and above-rail geometry.

2.4.2 Rail Geometry

In spite of the American standard gauge, track designed for conventional passenger rail differs from freight rail which in turn differs from high-speed rail. Take, for example, superelevation, which is the practice of "banking" curves to allow for higher speeds. High-speed rail might demand superelevations of up to seven inches; that is, the upper rail in a curve would be seven inches higher than the lower rail (CHSRA 2009). If a heavy, lower-speed freight train were to run consistently through that sever-inch superelevated curve, the lower rail would deteriorate due to "crushing" and rail ties and track surface would be quickly degraded (Zarembski, Blaze, and Patel 2011). This would lead to additional maintenance expense and cause tracks to be out of service while rail and fasteners get replaced. Conversely, if we designed all track for the freight trains and removed superelevation, high-speed trains would be limited to slower speeds through curves causing network delays. Operating high-speed passenger trains too fast through non-superelevated curves can lead to derailments, centripetal lateral forces stresses on the outside rails, as well as decreased passenger comfort (ibid).

If we say that superelevation causes compatibility issues laterally; grade requirements cause compatibility issues longitudinally. Freight trains cannot climb as quickly as passenger trains requiring any shared tracks be brought down to the lowest-common denominator (i.e. freight) in terms of elevation changes. While lower grades do not pose a maintenance or safety risk for passenger train, they do increase capital costs by adding constraints in construction such as building more significant approaches to overpasses and underpasses.

2.4.3 Above-Rail Geometry

The operating envelope of rolling stock creates challenges in shared corridors above the rails. The method with which trains receive their power create compatibility issues in shared corridors. The three basic types of traction power in use today are 1) internally powered (i.e. diesel-electric), 2) third-rail, and 3) overhead catenary systems.

Diesel-electric trains do not require wayside power generation equipment however they do emit carbon monoxide exhaust. This presents a ventilation challenge in tunnels and subways.

Third-rails are physical rails that power trains via an electrical pickup shoes. Third rail power for commuter railroads is rare in the US outside of the New York City area. Because its proximity to the track, the third-rail makes it difficult for freight trains to share tracks. Freight trains in New York that use third-rail tracks need to be modified to avoid scrapping the third-rail and some freight railcars are not permitted whatsoever (Rail New York 2014). Regardless of whether or not freight rail can use the tracks, third-rail operation requires a wider right-of-way than diesel-electric operation.

Overhead catenary poses a similar challenge to third-rail except the clearance issue is vertical as opposed to lateral. Overhead catenary systems could require tunnels to be rebuilt to accommodate the additional height required from the overhead wire (McCallon 2014). Like third-rail power, in catenary power systems catenary poles and wayside equipment such as traction power substations take up increased right-of-way.

Train operating envelope requirements differ between passenger rail and freight rail. To account for brakemen riding on the edges of freight cars or for moving potentially hazardous materials, freight rail requires lateral clearances between the side of the train and platforms. This presents compatibility issues in US shared systems where passenger rail services have high-level platforms. High-level platforms provide for faster boarding and alighting because passengers do not need to step up or down into passenger carriages. However, Americans with Disability Act requirements mandate a maximum gap between rail 1car and platform, directly conflicting with freight lateral clearance requirements (Harkin 1988). Solutions to this require operationally cumbersome or expensive gauntlet or bypass tracks, retractable platforms or mini-high platforms with car-borne, conductor-operated, wheelchair ramps.

2.5 Operational Challenges

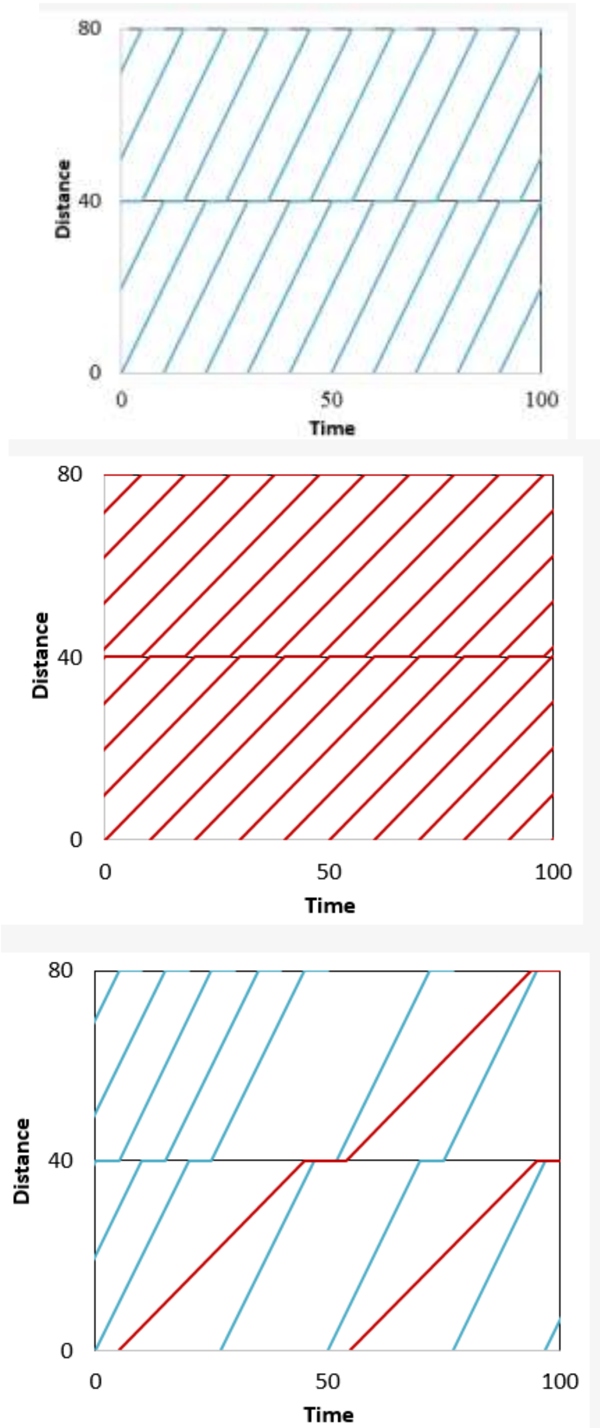
Assuming railroads can rectify the physical design challenges associated with running shared track operation, there are still many challenges associated with the actual operation of the shared-use line.

2.5.1 Variables Train Speeds and Lengths

One of the most unique challenges to sharing rail infrastructure versus other infrastructure is the non-homogeneity of capacity: some trains run faster than each other; and unlike cars and trucks on a freeway, passing opportunities are rare. Imagine a single-track rail line with no passing sidings. Passenger trains following slower freight trains would be forced to run slower as well. An alternative would be for passenger trains to allow the slow moving freight trains a “head-start” so the passenger train could run at normal speed as it closes the gap between it and the freight train ahead. This arrangement though means that a large amount of capacity between the freight train and passenger train goes unused.

On systems using block signaling, trains may not enter a section of track (block) until the train ahead of it has left the block. Train spacing is then dictated by the size of the block. Long freight trains with significant braking distances running under block signaling control require larger blocks which limit the capacity of a line. An all-passenger line might be able to accommodate more trains per hour since block lengths can be shorter with shorter trains. Freight railroads claim that one Amtrak long distance train uses between two and five freight train slots given the different speed and length characteristics of Amtrak trains versus freight trains (Wilner 2013).

In California, high-speed rail and commuter rail will be sharing a predominantly two track, bi-directional corridor. In Northern California, even though they will be operating with virtually identical performance characteristics on the corridor (top speed, braking ability, etc.), because the high-speed train will be making fewer stops, it is essentially operating at a higher speed. In her doctoral thesis, Maite Pena-Alcaraz elegantly depicts the loss of capacity induced by mixed traffic operations.



The diagrams on the left are time-space diagram. Each line represents a train travelling across an 80-unit corridor during a 100-unit time period. At unit 40, there are passing tracks that allow trains to pass one another. There is a 10 time-unit space restriction between each successive train. The top diagram represents a system with only fast trains; the capacity of the system based on these constraints is 10 trains per 100 units of time. The middle diagram represents a system with only slow trains; the capacity of the system is also 10 trains per 100 units of time. The bottom diagram represents a shared corridor with mixed traffic. Because of the spacing and passing constraints, the capacity of the mixed traffic system is only 7 trains per 100 units of time.

There is a technique called “timetable compression” in which the timetable is modified and optimizes a train schedule to maximize the throughput of trains per hour. However, timetable compression represents a tradeoff between maximizing utilization of the corridor and presenting an appealing timetable for customers. In summary, mixed operations limits the overall capacity of a rail line.

Figure 2-4: Space-time diagrams showing how the capacity of an all fast-train system (top) is equivalent to the capacity of an all slow-train system (middle). The mixed traffic system (bottom) capacity is lower than the homogenous systems Source: Maite Pena-Alcaraz (2015)

2.5.2 Safety

Safety is a major concern on shared rail corridors—since different operators use different rolling stock and carry different types of cargo or passengers add to the complexity of safety rules, regulations, and operating procedures. The FRA is in the process of reforming its crashworthiness standards from one based on "prescriptive regulations to a more performance-based regulatory environment. This should allow for shared track operations of light-weight, higher-efficiency railcars (Nunez 2013). Liability and insurance becomes increasing complex as well. The cost of liability for passenger injury or death can be exorbitant for new operators and keep potential host freight railroads from allowing passenger rail access rights (TRB Intercity Passenger Rail Committee 2011).

2.5.3 Positive Train Control

Positive train control, a GPS-based technology that is capable of preventing train-to-train collisions, over-speed derailments, and work-zone incursions was federally mandated after a September 2008 train-to-train collision in Chatsworth, California (Metrolink 2014). The largely unfunded federal mandate, which applies nationwide on all shared-track corridors, did not specify a specific supplier of the technology yet required interoperability so that one railroad could operate on any track of another (Baker 2012). In response, the four Class I railroads—BNSF, UP, CSX, and NS—formed the Interoperable Train Control Committee and agreed to use Westinghouse Air Brake Technology's (Wabtec)'s Interoperable Electronic Train Management System (I-ETMS) as the supplier of their PTC system (ibid). While the Wabtec system is being adopted by many other freight and passenger railroads such as Metra, Sound Transit, Metrolink, it is not universal and integration challenges lie ahead.

2.5.4 Grade Crossings

Every day in the US, trains travel across more than 212,000 highway-rail grade crossings; collisions at grade crossings cause about 270 deaths a year, or about 35% of all rail-related deaths in the United States (Federal Railroad Administration 2015a). Highway-rail grade crossing regulations differ for services at different speeds, so naturally high-speed rail and commuter rail or freight rail will face different regulatory conditions. The Federal Railroad Administration (FRA) sets a maximum highway-rail grade crossing speed of 110 mph, but grants waivers with increased protection at speeds up to 125mph (FRA 2015b). In order to share tracks with commuter rail, high-speed rail typically needs to reduce speeds to commuter rail speeds. This increases travel time for high-speed rail services and makes it less competitive with other intercity modes.

2.5.5 Train Derailments

Freight train derailments pose an additional concern in shared rail corridors. Even if freight trains and passenger trains do not share track, freight derailments can "spill" onto parallel passenger tracks and cause further damage. The FRA has safety standards the require passenger trains to be able to withstand collisions with heavy freight trains. In California for example, Caltrain will use partially-compliant FRA vehicles that will share track with conventional compliant commuter rail rolling stock as well as limited freight traffic (Saat and Barkan 2013). In order to acquire this waiver, Caltrain had to show that there would be temporal separation between its trains and freight equipment; however, this temporal separation leads to track downtime issues as we describe in the next section.

2.5.6 Maintenance Windows

One challenge that railroads operating on shared use track and corridors face is finding time windows to perform routine maintenance. Because closing sections of track requires significant set-up and clean-up times, closing track sections for very short windows is unproductive. This challenge is exacerbated by requirements on many railroads requiring temporal separation of freight and passenger rail; that is, freight is only allowed on the track after passenger rail has completed the day's services. This means that maintenance periods have a higher likelihood of affecting the operations of one of the operators.

2.6 Institutional Challenges

All of the aforementioned shared-use challenges are shaped by the institutions—railroad operators, infrastructure owners, local, regional, and federal government entities—however, the challenges in this section reflect a more fundamental question about how a corridor is to be administered and run. Train priority, for example, undoubtedly has to do with the operations of the rail line, but the decision about which trains (if any) get priority comes from an institutional level. Institutional questions range from who will pay for capacity expansions and investments to who will clean up a fallen tree on the railroad tracks There may be no perfect shared use solution or agreement, but the more open communication there is between operators the more likely the institutional relationships will be successful and long-lasting.

2.6.1 Track Ownership, Dispatch, and Priority

The details regarding the ownership of the tracks and right-of-way on a shared-use corridor, the dispatcher of trains on that corridor, and the priority of certain operating companies versus other operators have a profound effect on the ultimate operation of the corridor.

Owners, that is, the entity that has the property rights associated with the track and/or right-of-way dictate (within regulations and previously agreed-upon contracts) which operators can access the track. With ownership comes the duty to perform or contract out track maintenance.

Dispatching means being in control of train movements along the corridor. For example, dispatchers can choose whether Train A should wait for Train B at a siding or if Train A should proceed potentially delaying Train B. Dispatching does not necessarily come with ownership: for example, Shore Line East and Amtrak in Connecticut runs on Northeast Corridor track owned by the Connecticut Department of Transportation yet trains are dispatched by Metro-North Railroad from Grand Central Station in New York City.

While dispatchers can give priority to certain trains in certain situations, priority often is codified as well. This can be very important in timetable and service planning. Having a lower priority will lead to delays when there are capacity demands that exceed that which the rail line can supply. In many railway systems, priority determines which railroads are able to schedule services at which times. Later in this chapter, we will explore the differing rules European countries maintain for allocating capacity on congested, high-demand rail infrastructure.

2.6.2 Competition versus Collaboration

When there are multiple passenger railroads operating on the same corridor, there is the challenge of determining how customers perceive and use the two services—are these train services complementary or substitutes for one another? In the case of complements, there is a potential for collaboration which adds challenges such as interline ticketing and schedule coordination. However, if the rail products are similar enough and there is no collaboration between the operations, the rail operators could also find themselves competing for the same customers.

In California, Amtrak often finds itself in a unique situation with respect to the railroads whose track it uses to provide its intercity services. Frequently, there is much overlap between Amtrak routes and commuter rail services. Amtrak's product, aside from a slightly fewer station stops, on-board food service, and the opportunity for in advance (yet unreserved seat) reservations, is practically the same as the services offered on its commuter rail hosts. This relationship plays out differently in different parts of the state. In Southern California, Amtrak accepts passengers on certain trains to supplement the commuter rail services in a program called Rail2Rail. On the Peninsula in Northern California, the San Joaquin Regional Rail Commission (operator of Altamont Corridor Express) are not allowed to even sell tickets let alone provide intra-corridor origin-destination trips on its shared track with Caltrain (PCJPB 2013a).

2.6.3 Special Services

There will be times that rail operators will be interested in running additional services whether it is a special train bringing passengers sporting event or an extra freight run to satisfy a time-sensitive shipment demand. These special trains will be subject to previously-agreed upon priority rules. On corridors with scheduled services, special trains will not only need to fit within the operating schedule, but other operators will need confidence about the preservation of their own timetables. If the additional train causes delays, there needs to be a way of compensating other operators—a problem specific to shared-use rail infrastructure.

2.7 Vertical Separation and Vertical Integration

2.7.1 The EU Railway Packages

In 1991 the European Union's European Commission, citing that the "future development and efficient operation of the railway system may be made easier if a distinction is made between the provision of transport services and the operation of infrastructure," issued its First Railway Directive (Holvad 2009) This directive along with additional directives issued in 2001 that outlined requirements for infrastructure charging and capacity allocation systems collectively known as the First Railway Package. The Second Railway Package in 2004 created the European Railway Agency to oversee technical interoperability across EU states without technical, regulatory, or operating constraints. The Third Railway Package in 2007 and Fourth Railway Package proposals in 2013 continued to move towards a Single European Transport Area with full separation between infrastructure managers and railroad operators (Temple 2014). Outside of Europe, vertical separation is relatively rare with the exception of some countries with very low levels of rail traffic.

2.7.2 Comparing Institutional Structures

As evidenced by the Railway Packages, the European Commission strongly believes in vertical separation, also known as "unbundling," of infrastructure and operations. Since rail infrastructure is a natural monopoly, vertical separation supposedly encourages competition at the operator level. This competition leads, in theory, to operating efficiencies. The operating efficiencies, however, could be outweighed by the transactional costs of negotiation between now separate operation and infrastructure entities.

Most of the papers in the literature analyze access charges in railway systems from the perspective of the IM. Maria Herrero provides an economic model for railway capacity costs as a method for (1) railway congestion pricing of scarce railway capacity, (2) timetable optimization between train operators, and (3) quantifying the benefit of railway capacity investments (2014). Her paper draws a parallel between road congestion and rail congestion noting that rail (at least in the European Union) has special characteristics in that railway services are scheduled and that infrastructure is separate from operations. Herrero suggests that it may be possible to find an "optimal toll" for rail capacity, but her paper does not provide a formulation that accounts for the unique characteristics of rail. As Chris Nash and his colleagues explain, determining "optimal charges" that reflect the marginal social cost of railway capacity is not easy (2011).

Drew and Nash, however, warn against the EU moving ahead quickly with unbundling. They point to limited evidence that vertical separation improves rail performance. They note that typically "countries with vertically separated railways have issued fewer operating licenses than those with vertical integration" which runs contrary to the claim that unbundling reduces barriers to entry and allows for increased competition (Drew and Nash 2011). In a report, Steer Davies Gleave points towards high "transaction costs" (e.g. access charges and administrative costs) that result when operators and infrastructure managers are separate. Gomez-Ibanez, once a staunch critic of unbundling points to success in Germany "the costs of the subsidized regional services and commuter services have gone down around 20% since Deutsche Bahn [Germany's national train company] was split up" (Kille 2014). However, Gomez-Ibanez agrees that results have not been as positive in other vertically-separated systems.

In his policy paper for the World Bank, Louis S. Thompson points out some of the benefits of separating tracks from trains (1997).

First, Thompson points out, is the reduction in unit costs; as traffic increases on the network, the cost on a per train basis decreases. This, Thompson claims, is why railroads are keener on serving as "tenant railroads" on tracks owned by other railways than by construction and maintaining their own track to create a redundant network. Outside of the Northeast Corridor and parts of Michigan, Amtrak functions in this manner; rather than building new track, Amtrak is a "tenant" to freight railroads and local commuter rail agencies.

Second, with separation intra-rail competition is now possible, provided there is some level of neutrality between the competing railroads. For example, if one railroad owned the track and the other one was a tenant, then the host railroad could make it nearly impossible to gain access (e.g. the host could charge an exorbitant access charge). While this will be discussed later in the thesis, this neutrality is relevant to the San Francisco Peninsula corridor where the CHSRA operator will compete for track access with freight railroads and the owner of the corridor and operator of commuter rail services.

Next, Thompson says that separation allows for specialization—operators can focus on providing top-quality service and owners can focus on safety, state-of-good-repair maintenance, and corridor upgrades. Again, Amtrak was created under this idea; as Thompson writes, "The only hope for sustaining national passenger services [in the United States] seemed to be to create a separate company (Amtrak) focused entirely on passenger services"

Finally, Thompson claims that "infrastructure separation can also help improve the balance between the public and private sector…critical infrastructure can continue to be public planned and provided, but rail services can be divvied up between public and private agencies." In California, there is a blurring of lines between public and private which will continue with high-speed rail. Today, almost the entirety of the state's key passenger rail infrastructure was built by private railroads and the CHSRA hopes that a private operator will finance the public infrastructure based on returns from operating the high-speed rail line.

Academic studies analyzing the results of vertical separation and integration in railways have come to different conclusions, but one paper — published earlier this year by Japanese professors Fumitoshi Mizutani and Shuji Uranishi in the *Journal of Regulatory Economics* — adds nuance to the question by considering the influence of traffic density (2013). The authors conclude that when traffic density is low, separation reduces costs while the opposite is true with high traffic density. The reason this happens because it high traffic system, vertical separation requires high coordination costs (i.e. maintenance scheduling, safety during busy trains operation that outweigh the lowered production costs resulting from specialization of activities (i.e. operating trains and managing infrastructure) (16).

Vertical separation even among the passenger services without the presence of freight can lead to some of the aforementioned shared corridor challenges. For example, SNCF, France's main rail operator bought trains that were too wide for the existing platforms because of lack of communication with RFF, the infrastructure manager (Lewis 2015). In the United Kingdom, Virgin Trains announced plans for a new fleet of electric tilting trains, designed to operate at up to 140mph, but trains could not realize their full potential because necessary signal upgrades never materialized (Railway Technology 2010). While vertical separation does offer the chance for competitive efficiencies, it does not obviate the challenges of sharing infrastructure; in fact, it may magnify them.

2.8 Shared Corridors in Practice

Shared corridors exist across the world. However, in many countries rail services, the challenges are diminished for various reasons. Sometimes rail services are often government-controlled eliminating many institutional challenges. Or passenger rail services are operated by the same entity as freight services minimizing operational challenges. Sometimes one service type comprises such a small share of traffic that capacity allocation schemes are not necessary. For these reasons, we will take a look at Europe and the United States where shared corridors are not only prevalent with high levels of mixed traffic, but also where freight operators are typically distinct from passenger service providers.

2.8.1 Shared Corridors in the United States

In the United States, most of capacity is shared though trackage rights agreements in which the "host railroad" allows a "tenant railroad" access to the track for either a specified time period or for a specified number of trains. Tenant railroads pay host railroads on a negotiated per-train-mile or per-ton-mile basis that is agreed upon at the time of contract. Agreements are amended as needed, and, in the case of service expansions, require the host railroad to evaluate whether or not its services can sustain the additional trains without causing delays. Amtrak is required by law to receive dispatch priority in freight rail-owned territory and in utilizing freight-railroad owned track, Amtrak pays a user fee that is reduced in the event of excessive delays (Wilner 2013). Making significant changes to services requires detailed capacity studies which are often funded by the tenant railroad and the host railroad has no obligation to accept tenant railroad services increases even if the studies find that delay increases are negligible (though the host railroad in this case has an incentive to collect additional track-access charges).

2.8.2 Shared Corridors in Europe

The aforementioned railway packages managed that the infrastructure managers in EU member states must establish a set of rules governing access to the network. As mentioned in Chapter 1, this comes in the form of an annually-published “network statement,” a document with standardized sections that describes how train operators access the network. While each infrastructure manager’s regulatory framework for capacity allocation is different, we will examine a select group of states to showcase the variability of these allocation mechanisms and priority rules for congested rail infrastructure.

In Europe, a number of studies on capacity pricing have been conducted, following the Railway Reform in the early 2000s. The International Union of Railways (UIC) has performed a number of longitudinal studies in 2005, 2007 and 2012, looking at charges for passenger high-speed and intercity services (Teixeria and Prodan 2012). The studies provided an overview of the difference in pricing used in each European country, and also provided a longitudinal evaluation of charging systems, concluding that charging mechanisms are getting more heterogeneous. The 2012 UIC study also considered the importance of having charges that are consistent across borders in sending the right incentives to the train operators. It concluded that there was a lack of coordination for charges across borders between infrastructure managers. The International Transport Forum (formerly known as the European Conference of Ministers of Transport) conducted a number of studies in 2005 and 2007, with similar conclusions to the UIC studies, stating that cost recovery principles differ from country to country (EU 2005, Thompson 2008). Both of these sources concluded that there is no agreement between European countries on either how much to charge for capacity or how to structure the charges. Furthermore, a lack of coordination between different infrastructure managers on infrastructure charges had a potential negative effect on cross-border train services due to difficulties of capacity allocation and capacity pricing.

At the time of writing, there is little actual sharing of track in Europe as most of the formerly state-owned services still dominate the market. The degree of intra-rail competition within countries depends largely on their regulatory policies and the market power of incumbent railway operators (which are often former state-owned undertakings). In some states, long-established incumbent railway operators have absorbed smaller ones. In the United Kingdom, competition takes the form of competition “for the track” versus competition “on the track;” that is to say, rail operators bid against each other for the right to operate franchises that have no direct competition.

In Italy in 2012, NTV, a private high-speed operator (of which the French operator, SNCF, owns a 20% share), entered the Italian market. NTV's entry marked the first case of competition in the HSR market in Europe. In September 2014, NTV requested intervention from the Italian government in the high-speed rail market in response to Italian infrastructure manager, RFI's plan to increase track access charges (Day 2014). NTV alleges that RFI which is controlled by the same group that controls Trenitalia, the main incumbent provider of passenger rail service in Italy, is trying to force the competition out of the market (Faiola 2013). In 2011, NTV had accused RFI of making last-minute changes to its network statement that delayed NTV’s inauguration of service (Railway Gazette 2011).

Belgium (Source: 2013 Network Statement)

If there is a conflict between rail operator requested train-paths that Infrabel (the Belgian infrastructure manager) and the operators cannot solve through negotiation, the following guidelines, not in ranked in a particular order, apply:

- Operational utilization of the track; that is, the rate at which track is used by operating trains under different operator train-paths
- If both operators had services in the previous timetable, the effective utilization rate of train path reservations by the operator in the previous timetable
- The number of hours reserved and the number of train paths

Operators can appeal Infrabel's decisions if they choose. In order to encourage amicable train-path resolution, Infrabel charges the operators the administrative costs of settling the dispute.

There are some sections of the Belgian railway network that Infrabel has designated as "congested." In that case, Infrabel awards train-paths based on the train type priorities based on the line type; that is, high speed trains will have priority on congested high speed lines. In the event of two high speed trains (or any two similar trains) competing for access in a congested zone, Infrabel awards the train-path to the applicant that will pay Infrabel the higher amount of infrastructure access charges (based on the rail operator's planned services).

Germany (Source 2013 Network Statement)

DB Netz, a subdivision of DB, is the infrastructure manager in Germany. There is a multi-step capacity allocation process. Operators send their requests for trains ("proposals") to DB Netz which is responsible for identifying conflicts. DB Netz then negotiates with operators. Then the final scheduled is published and the operators have 5 days to accept it.

In the coordination period, DB Netz suggests resolutions to conflicts. If a new conflict arises it will be solved separately, but it is not possible to solve the new conflict without disrupting a previously solved conflict. The negotiation process is anonymous if the conflict is small or it implies a high cost for one party. Otherwise it is an open negotiation and alternate routes and services within 1 hour for passengers and 2 hours for freight are discussed. There is a maximum of two conversations to discuss each alternative. If no agreement is reached, then these priority rules will be applied:

1. Express services
2. Hourly or better services
3. Regularly-scheduled freight services
4. Special event services

If there is still a conflict after these priority rules have been applied, then each operator will submit a bid to the regulatory office. The highest bid will get the train scheduled.

Netherlands (Source: 2013 Network Statement)

ProRail is the Dutch infrastructure manager in charge of capacity allocation. For a large number of corridors, ProRail sets minimum frequencies for high speed service. In the event of the conflict, then, between a high speed operator and a conventional operator, the high speed service will win the slot if minimum frequencies on that line are not met. After these high speed frequency conditions are met, ProRail refers to a priority list of train services starting with metropolitan public transportation service as the highest priority going down to private passenger transportation service as the lowest priority. In the case of unresolved conflicts, ProRail then favors train paths with highest utilization (for revenue service operations) of its network.

Portugal (Source: 2012 Network Statement)

REFER, the Portuguese infrastructure manager, works with operators to solve conflicting train-path requests. If a resolution is not found during negotiations with operators, REFER will make a decision based on these qualitative considerations (ranked in order of importance):

1. Overall impact on timetable structure (higher impacts less likely to win train-path)
2. Optimization of capacity use, particularly in terms of quality
3. Priority rules in congested areas (see next paragraph)
4. Number of used identical paths (operators that run frequent service are favored)
5. Chronological order in which requests were received (earlier requests are favored)

In declared congested zones, REFER first allocates capacity to public service operators over private freight service. Next REFER uses a priority table based on service types and time bands. Service types range from high frequency suburban passenger services to international freight to dead-head trains. Typically international and intercity passenger services have highest priority, expect during peak hours, when high frequency (six trains per hour) commuter services have priority. Finally, if there still are conflicts, REFER will apply the following criteria (in descending order of priority):

1. Requests which cause less relative network impact (measurement of this is not defined)
2. Requests which use the highest number of identical paths
3. Requests which use the most train-kilometers on the network
4. The chronological order in which requests were received

Spain (Source: 2013 Network Statement)

ADIF (the infrastructure manager) has the ability to make schedule adjustments. The applicants will be consulted and modifications shall be agreed upon by each applicant, although the infrastructure manager may exercise its power to coordinate, study possible technical solutions, and eventually mediate between applicants. Applicants' requests are considered fulfilled if 1) they are rewarded the paths they requested; 2) the timetable of commercial stops for passenger trains is not altered; and 3) for freight trains, the path does not vary by more than 15 minutes at any point en route.

If operators request the same time slot, the following priority rules apply:

1. Priorities, if any, established by the Ministry of Public Works for the different types of service of each line.
2. Those services declared of public interest by the Ministry of Public Works
3. Train paths allocated and used effectively during the term of the preceding service timetable
4. Requests which are subject to the existence of an previous agreement
5. The highest frequency operators to request a path within the timetable

Switzerland (2013 Network Statement)

The infrastructure manager, Trasse Schwiez, puts together the timetable on an annual basis. Reflecting to Switzerland's highly coordinated, cadenced timetabling, regularly scheduled trains; that is, trains that have "clock-face" service on 30-, 60-, 120-minute intervals take priority. After this, the rail operator that announces the higher projected contribution from that train wins the path. However, in order to win the path, the rail operator pledges 8% of projected passenger revenues for regional trains and 13% of project passenger revenues for franchised long distance trains. This 8%/13% pledge helps prevent operators from overestimating revenues in order to win paths.

United Kingdom (2013 Network Statement, 2012 Network Code)

Network Rail, the infrastructure manager, awards franchises in a competitive proposal process for specific lines, called "track access agreements," on the following basis (in a specifically non-hierarchal order):

- developing innovative timetables which build on the core train service requirement published by the Department for Transport
- investment in innovative ways to transform the customer experience on trains and at stations
- identifying further opportunities for investment along the route, particularly at stations
- making the route and train operations more considerate of the environment
- involving communities along the route in local decision making
- demonstrating how their proposals will support economic growth along the route

While the rail operator has sole authority to operate trains on the line for a set number of years, many of these lines overlap with other franchises. In these cases, Network Rail does not have clear-cut capacity priority rules in the event of conflicting train paths, but has what it describes as a "flexing right" to adjust train slots within track access agreements with rail franchises. Network Rail uses this flexing right in accordance with its "Objective" to "share capacity on the Network for the safe carriage of passengers and goods in the most efficient and economical manner in the overall interest of current and prospective users and providers of railway services." In order to accomplish this Objective, Network Rail has a list of eleven (non-ordered) "Considerations" such as keeping journey times as short as possible or enabling operators of trains to utilize their assets efficiently.

In the case that Network Rail cannot include all train slots even after using its flexing right, it will prioritize the slots as follows:

1. Timetable participants that exercised rights to run trains for the entire timetable period.
2. Timetable participants that have exercised timetable rights in force at the Priority Date and expect to have similar timetable rights continue after their current rights expire.
3. Timetable participants that applied for rights before the Priority Date (40 days before the timetable period begins) that Network Rail expects to be in force during the timetable period.
4. First-come, first-serve for Timetable participants that applied for rights after the Priority Date but before 26 days before the timetable period.

Nash and Johnson use the British rail network as a case study for congestion charging. The authors lament that "once an operator gains a slot, they have no incentive to seek to make more efficient use of capacity, for instance by retiming, rerouting or accelerating their train" (Johnson and Nash 2008).

2.8.3 Is the European Experience Applicable to the United States?

Europe offers a multitude of examples of codified capacity allocation strategies that could theoretically be implemented on corridors in the United States. There are two significant challenges standing in the way of this implementation. First and foremost is the integration of infrastructure ownership and operations on U.S. freight railroads and many U.S. commuter railroads. There is no incentive for a freight railroad or commuter railroad to relinquish control of capacity on its tracks—the loss of control presents an increased risk of operators losing the ability to run trains at profit- or customer-critical windows. The second challenge is one of freight railroads running timetable-free operations in the United States. Planning specific slots (as opposed to windows of operation) means that freight railroads have to have a strong sense of their future demand over the timetable horizon.

Both of these challenges could be overcome, however, and both passenger railroads and freight railroads might agree to some version of capacity allocation where it is in their best interests. This is most likely to occur in corridors where there is mixed freight and passenger ownership. As we will discuss later in this thesis, even if a certain corridor has mixed ownership, freight rail and long-distance passenger rail planning on a corridor affects the nature of service in other parts of the network. Timetable planning and capacity allocation, therefore, needs to be network-wide; or at the very least, timetable the networks effects of a capacity allocation plan should be understood by all parties.

This network effects concept begs the question: what is the extent of the network? In California, do we consider the effect a capacity allocation scheme on the Peninsula has on train services in Southern California? How about freight or long-distance services that run to Chicago? And what about the connecting freight trains and passenger trains in Chicago that move goods and people to the Eastern Seaboard? For the purposes of this thesis, we consider California the extent of the network, but we keep in mind that operators (especially freight railroads) will likely have out-of-network constraints.

2.9 Conclusions

In this chapter, we discussed current literature on capacity allocation as well as the constraints that make capacity allocation in the rail sector unique. We broke down rail-specific challenges into three broad categories: physical, operational, and institutional challenges. We discussed the philosophies of vertically-integrated and vertically-separated railroad structures, the latter undergoing a full-scale trial in the European Union for the last two decades. Finally, we take a look at capacity allocation mechanisms in the United States and Europe, both of which would fall under Gibson's "administered" category, though European capacity rules are typically much more complex given the vertically-separated environment. In comparing capacity allocation on both sides of the Atlantic, we introduce one of the key concepts of this thesis: it is unwise to confine capacity allocation to a single corridor without realizing the effects of any capacity allocation scheme on the rest of a network.

3 Northern California Blended Service Capacity Challenges

3.1 Introduction

In this chapter, will "zoom in" on the challenges that the northern end of the California HSR line faces in operating their service in conjunction with the commuter service operated on the Peninsula rail corridor between San Francisco and San Jose. We will discuss institutional relationships, some of the planned improvements on the corridor and the importance of the corridor in the future for local commuters and intra-California travelers alike.

3.2 The Peninsula Corridor Commute: History and Institutions

The 51.5-mile Peninsula Corridor between San Francisco and San Jose is poised to become the West Coast's premier example of a shared-use corridor. Five operators already use the corridor—Caltrain, Union Pacific, Amtrak, Amtrak California's *Capitol Corridor*, and the Altamont Commuter Express (ACE)—though the latter three only use the southernmost five miles and two stations. In 2012, the PCJPB and the CHSRA announced that the corridor, with minimal new construction of track-miles, would host both high-speed rail and commuter rail services when high-speed rail comes on-line in 2028.

3.3 The Southern Pacific Railroad Era

Figure 3-1: 1915 Southern Pacific Map of Peninsula Corridor surrounding areas. The Peninsula Corridor runs from center to top left of the map. n 2014, Caltrain celebrated 150 years of passenger service on the corridor.
Source: E.O. Gibson

After absorbing the original San Francisco-San Jose Railroad Company in 1870, the Southern Pacific Railroad Company operated several long-distance and commuter passenger trains throughout the majority of the 20th century including *The Coast Daylight* to Los Angeles, *The Del Monte* to Monterey, and the *Peninsula Commute* to San Jose, the last of which being almost the exact same service that PCJPB's commuter rail service, branded as *Caltrain*, provides today. Southern Pacific discontinued long-distance passenger trains in 1971 as permitted by the 1970 Rail Passenger Service Act (PCJPB 2015a). Since the Peninsula Commute was a commuter and not long-distance train, Southern Pacific was required to continue operation. In 1979 Southern Pacific attempted to discontinue the service (even offering to buy the 9,000 daily riders 1,000 vans), but the California Public Utilities Commission ruled that SP could not (Miller 1987). The battle ended when San Francisco, San Mateo, and Santa Clara counties as well as the California Department of Transportation agreed to subsidize the Southern Pacific's operating losses (ibid).

3.4 The Peninsula Corridor Joint Powers Board

In 1987, the state released ownership and management of the stations to a newly-formed Peninsula Joint Corridors Powers Board (PCJPB). The PCJPB is made up of nine representatives from the San Mateo County Department of Transportation (SamTrans) and the Santa Clara Valley Transportation Authority (SCVTA), and three appointees from the City and County of San Francisco (PCJPB 1996). The joint powers board serves as the policy-making body for service on the corridor and it has the power to "enter into contracts, employ employees, acquire property, and incur debt in the provisioning of passenger service on the corridor." One of the early and arguably most important acts of the new PCJPB was the acquisition, for $220 million, of the right-of-way from Southern Pacific in 1991. As part of the sale, the Southern Pacific retained the right to operate freight service on the corridor (PCJPB 2015b). Union Pacific Railroad, which merged with Southern Pacific in 1996 to form the largest rail company in the United States, assumed these trackage rights and maintains service today (UP 2015). South of San Jose, the PCJPB operates three Caltrain round trips on Union Pacific trackage to Gilroy, California.

3.5 Union Pacific Railroad and Freight Service

Freight service still has a significant presence on the Peninsula Corridor. In addition to a short-line railroad providing service between the Port of San Francisco and the corridor since 2000, Union Pacific has invested in its own short branch lines that connect to the corridor, including a $2 million upgrade in Redwood City in 2009. In total, 26 shippers transport about two million tons of freight cargo (mostly aggregates, scrap metal, food, and recyclable waste) through the corridor annually (Greenway 2013). This amounts to 20,000-30,000 rail cars annually or about 70 cars per night on three weeknight trains (Tillier 2009). Additionally, the Union Pacific operates a small rail yard in South San Francisco.

Union Pacific freight rail service is a small, yet entrenched entity that will likely stay on the corridor for many more years and it is not just the railroad's prerogative. Together, the Ports of Redwood City and San Francisco are working with the local freight trade group, the Seaport Industrial Association to ensure continued freight rail service between San Francisco and San Jose (Port of Redwood City, 2009). The aforementioned 1991 agreement helps to secure this continued use: Union Pacific "reserves the perpetual right of access to and from and use" of the corridor (UP/PCJPB 1991). Furthermore, Union Pacific is guaranteed one 30-minute window between 10:00 A.M. and 3:00 P.M. each day to run freight trains on each of the northbound and southbound tracks. Between midnight and 5:00 A.M., one main track is reserved for freight use.

If and when high-speed rail arrives, this contract will likely need to be renegotiated and the trackage rights agreement does have some provisions for these negotiations. First, Section 8.3b of the agreement stipulates that if PCJPB would like to "commence construction of facilities on all or substantially all of the length" of the corridor that are "incompatible with the double mainline Freight Service," PCJPB must modify the remaining single track to be "reasonably suitable" for the volume and speed of Union Pacific's freight service. If the construction is incompatible with continuing freight service, according to Section 8.3c of the agreement, PCJPB must file permission to abandon freight service on the corridor and Union Pacific must "be allowed to participate in the abandonment proceedings." Regardless of whether high-speed rail and Caltrain find a way to co-exist with Union

Pacific or not, the freight service on the Peninsula will play an important role in the future of the corridor.

3.6 The California Public Utilities Commission

As the agency that oversees California rail safety, the California Public Utilities Commission (CPUC) is an important rule-making body on the Peninsula Corridor. A few of the existing CPUC rules have the potential to significantly affect the future of the corridor.

3.6.1 Freight Train Lateral Clearance

In 1948, CPUC General Order 26-D (revising 26-C) declared that platforms between 8" and 48" above the top of the rail require have a side clearance of 7' 6" from the track centerline. As noted in Chapter 2, this rule is in effect to account for brakemen riding on the edges of freight cars or for moving potentially hazardous materials. Current platforms on the corridor are 8" above the top of the rail so a lateral gap of 4'8" required clearance applies; this 4'8" is measured from the track centerline, meaning about 2 feet beyond the rail (CPUC 1948). Any attempts to raise the height of the platform would mean that additional clearance would be required. However, as noted earlier, since ADA requirements mandate a narrow gap (<3") between the train and platform, these regulations conflict with level-boarding goals of passenger rail on the corridor.

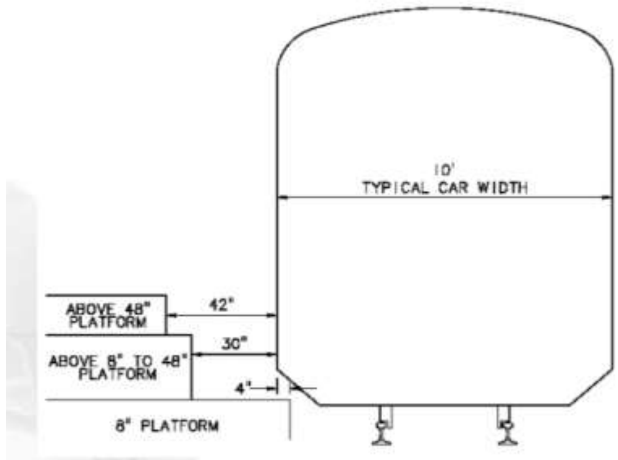


Figure 3-2: CPUC GO 26-D as applied to a Caltrain passenger car
Source: PCJPB

3.6.2 High Voltage Power Regulatory Framework

As the agency overseeing rail safety, the CPUC is developing the regulatory framework for high-voltage 25kV AC systems necessary for high-speed rail—the 750V DC system for light rail in Los Angeles and Sacramento and 600V DC system in San Francisco and San Diego does not provide enough power for the accelerations required by high-speed rail[8]. However, at the behest of both the Union Pacific Railroad and the California High-Speed Rail Authority, CPUC explicitly defines the scope of this current framework as limited to "high-speed rail passenger system capable of operating at speeds of 150 mph or higher, located in dedicated rights-of-way with no public highway-rail at-grade crossings and in which freight operations do not occur" (CPUC 2014) As the Peninsula has not only numerous highway-rail grade crossings, but also freight operations, this framework does not apply to the corridor's electrification plans including the plans of CHSRA itself. The author speculates that Union Pacific is seeking additional concessions from Caltrain in order to operate with freight and high-speed rail.

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[8] Low voltage DC power also requires more traction power substations, which increases costs and wayside land requirements

3.7 The Corridor Today

3.7.1 Baby Bullet Service

In 2004, Caltrain debuted their express "Baby Bullet Service" which radically changed service patterns on the corridor and is widely attributed to partially fueling Caltrain's ridership growth in the last decade. By constructing two-mile long, four track sections at roughly 1/5 and 4/5 of the way along the corridor, the agency opened up the possibility for express train overtakes, with the promise of connecting San Jose and San Francisco in under an hour. These Baby Bullets, named because their top speed of 79 mph was a "baby" speed relative to existing "bullet trains," run in two patterns of service that serve only a handful of stations along the route. With this new express service, overnight, rail commuters could now outrun an automobile driving on an adjacent freeway (see Table 3-1)

Table 3-1: Travel Time Savings with Baby Bullet Service

Station Pair	Mileage	2001 Timetable	2012 Timetable	Travel Time Saved*	2012 Average Train Speed+
San Francisco - San Jose	47.5	90 minutes	54 minutes	40% less time	53 mph
San Francisco - Palo Alto	30.1	61	35	43%	52
San Francisco - Millbrae	13.7	24	16	33%	51
San Jose - Millbrae	33.8	66	39	41%	52
San Jose - Palo Alto	17.4	28	20	29%	52
Millbrae - Palo Alto	16.4	38	19	50%	52

**Travel Times are typical times at peak period accounting for schedule padding at San Francisco/San Jose termini*
+Maximum Allowable Speed on corridor is 79 mph

Source: PCJPB, Calculations by Author

The make-all-stops, local rush-hour train disappeared with the new timetable: the only trains serving the corridor during the peak periods were the Baby Bullets and limited service trains that either ran as skip-stop or half-corridor local/half-corridor express (allowing for overtakes on the local portion). Of course, there were winners and losers in terms of stations with this new timetable format. Said former Caltrain engineer and service planner, Robert Doty: "We built a new schedule with new service patterns that optimizes crew and equipment utilization--without adding equipment or crews-and instituted what we call a 'pull model' that draws riders to where our trains need to be to execute the plan" (Johnston 2005). Caltrain also used parking availability as a metric for choosing the stations that the Baby Bullets would serve (ibid). In a region with poor last-mile connections to transit, cars are often a necessary tool to for many Peninsula residents to access train service; approximately 65% of Caltrain riders during the weekday peak had a car available for their trip according to a recent survey. (PCJPB 2013b). In the AM peak period, approximately half of passengers arrived at their station of origin via private automobile and 80% of those automobile drivers parked at their station. The implementation of the Baby Bullet service, by moving service away from local stations, has encouraged this "drive-and-ride" practice.

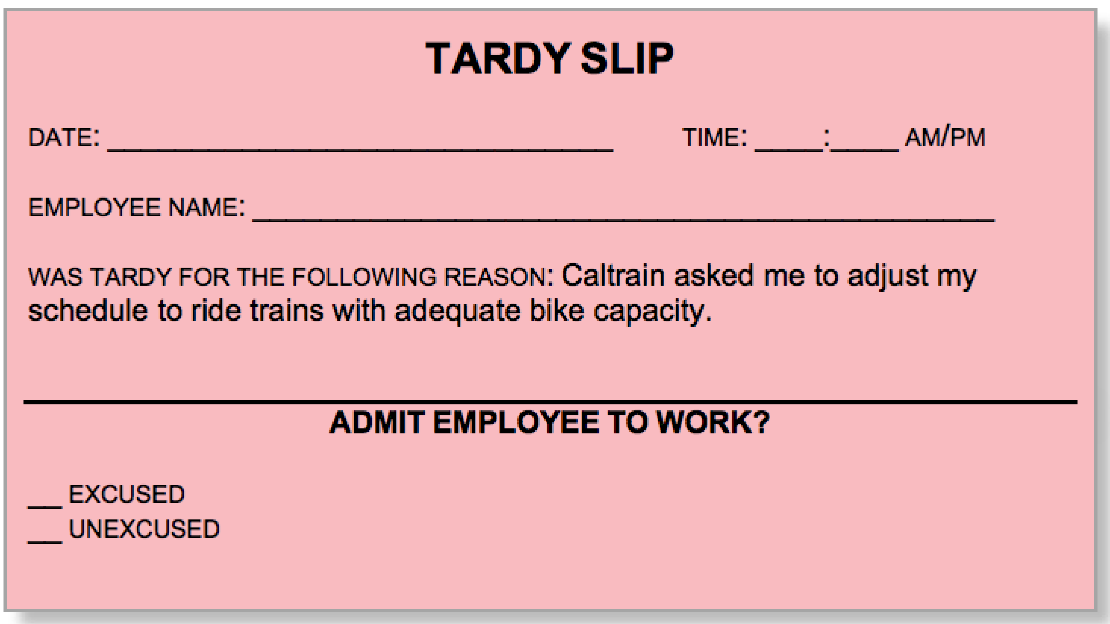
Figure 3-3: 2004 Caltrain map showing express "Baby Bullet" stations. Note that each "Baby Bullet" train only serves a portion of the express stops. Source: PCJPB

Because of the relative mobility of private automobiles on the Peninsula, Caltrain can afford to "pull" flows to Baby Bullet stations to improve travel times on the whole corridor. Drivers trade a slightly longer drive to a Baby Bullet station as a tradeoff for faster rides to their destination; the 10 Baby Bullet stations accounted for 83% of Caltrain ridership in 2014 despite representing approximately 1/3 of the stations served daily on the corridor (PCJPB 2014a). Again, it should be emphasized that Baby Bullet stations were chosen because of ample parking availability and because they were spaced adequate distances apart to allow for longer sustained high speeds; they are not necessarily places that enjoy high nearby populations or jobs.

3.8 Bicycle Usage

The other consequence of the skip-stop and Baby Bullet-style timetable is new behavior of bicyclists. Because the majority of Peninsula residents live on relatively flat terrain, bicycling is a viable last mile connection for many riders. Coupled with the fact that San Francisco's financial district is over a mile from the San Francisco terminal and that many tech campuses are several miles from the rail corridor, bikes are also a useful and often necessary form of transportation on both ends of many commutes (Wilson 2014). This has led to high bike ridership on Caltrain. The Baby Bullet timetable also creates increased bicycle demand because a bicycle affords cyclists the flexibility to take trains that do not necessarily stop nearest to their workplace or residence. Not surprisingly, the top 10 stations for cyclists, which account for 75 percent of cyclist-passenger volumes (San Francisco, 22nd Street, Millbrae, Hillsdale, San Mateo, Redwood City, Palo Alto, Mountain View, Sunnyvale and San Jose Diridon) are all Baby Bullet Stations (PCJPB 2014a). 14% of Caltrain commuters commute via bicycle and over 90% of those bicyclists take their bike on board with them suggesting that bikes are used at both ends of the train commute.

Bike usage on Caltrain is a mixed blessing. During Caltrain's annual passenger count in the rainier month of February, nearly 6,000 commuters took their bikes on-board on an average weekday; in the relatively dry summer and fall, when biking conditions are ideal, the author speculates that the figure is probably even higher (PCJPB 2014a). Bicycle usage is growing faster than Caltrain's ridership as a whole and has tripled in the last ten years as both San Francisco and Peninsula cities have made investments in bicycle transportation facilities; the number of passengers bringing bicycles on Caltrain has grown four times faster than overall ridership since 2008 (Wilson 2014, Boone 2015). Caltrain itself has improved its bicycle accommodations: Baby Bullet trains typically have capacity for 48 bicycles and other limited-stop and local trains have capacity for 80. However, demand is outpacing supply; in the aforementioned survey, Caltrain "bumped" 50 bicyclists per week due to lack of space. The San Francisco Bike Coalition, a bicycle advocacy group supplied riders with the following satirical "tardy slip" as a form of pushing for more bike capacity.



TARDY SLIP

DATE: ______________________________ TIME: _____:_____ AM/PM

EMPLOYEE NAME: ____

WAS TARDY FOR THE FOLLOWING REASON: Caltrain asked me to adjust my schedule to ride trains with adequate bike capacity.

ADMIT EMPLOYEE TO WORK?

__ EXCUSED
__ UNEXCUSED

Figure 3-4: San Francisco Bike Coalition "tardy slip" for bicycles.
Source: San Francisco Bicycle Coalition

Accommodating bikes however, comes at the expense of seats for riders. Caltrain claims that each bike displaces two seats (PCJPB 2014b). With an average of weekday peak trip length of 22.8 miles (or about 35 minutes), Caltrain must also cater to riders without bicycles who desire seats. Unlike subway or light rail systems, Caltrain cars lack dedicated standing areas, so standing room is limited and uncomfortable for standees (PCJPB 2014c). And as we see in the following section, a seat on a Caltrain commuter train is increasingly hard to come by.

3.8.1 Ridership Explosion and Balanced Commute

Since the Baby Bullet service plan debuted in 2004, Caltrain ridership has climbed dramatically. Average weekday ridership exceeded 60,000 passengers per day during the busier summer months in 2014 up from slightly under 24,000 passengers per day in 2004 (PCJPB 2014d). Increased ridership has resulted in higher levels of crowding on some AM and PM peak period trains. In 2014, 15 trains operated at above 95% of their seat capacity during Caltrain's annual survey period in February (again, a typically lighter travel month); this represents a 50% increase from 10 trains operating at over 95% of seated capacity in 2013.

One unique property of Caltrain service versus other commuter rail services in the nation is that commute patterns are relatively balanced; there is a 60/40 split between peak and reverse peak commuters (PCJPB 2014d). The reverse peak commuting behavior (living in San Francisco and commuting southbound) is partially attributable to tech campuses locating themselves in Silicon Valley where land is more abundant and more affordable than in dense San Francisco. Additionally, San Francisco appeals more to young millennials looking to live without owning an automobile; to accommodate the carless reverse peak commuters, dozens of employer-subsidized shuttles operate between Peninsula Caltrain stations and Silicon Valley employment centers.

3.9 Caltrain Modernization

Caltrain is currently undergoing two major capital projects with up to $800 million in funding support from the Proposition 1A's connectivity funding to improve the corridor and prepare for the entry of high speed rail in 2028 (PCJPB 2014e). These improvements should help Caltrain address some of the limited capacity issues it is starting to face as a system during peak hours.

3.9.1 Communication-Based Overlay Signal System (PTC)

In their compliance with the federal mandate of installing a positive train control system on corridors supporting operation of both passenger and freight rail, Caltrain is developing a unique system known as the Communication-Based Overlay Signal System or CBOSS. Caltrain claims this system will allow the railroad to reduce both separation between trains and "gate down" time at grade-crossings (PCJPB 2014e). With construction underway and the system scheduled to be operational by 2015, CBOSS will require specialized in-cab equipment which raises compatibility concerns with Union Pacific, Amtrak, and eventually the CHSRA operator.

3.9.1.1 Electrification

The electrification of the Caltrain corridor between San Francisco and San Jose (the Peninsula Corridor Electrification Project or PCEP) has the power to change the Caltrain timetable once again. At the time of writing, Caltrain plans to continue operating the Baby Bullet service using diesel locomotives, but add in more frequent service to all stations during the rush-hour commute. An electrified Caltrain will have a service frequency of six trains per hour per direction up from five, a change that it estimates will alone increase demand by 10% (2009 EIR). Because the electric multiple unit (EMU) trains that Caltrain plans on procuring are able to accelerate and decelerate faster than the diesel trainsets, the agency will be able to serve more stations on a single train run while preserving the travel time savings. Below are the anticipated station service levels according to the 2013 Final Environmental Impact Report for the PCEP.

Table 3-2: Anticipated change in service levels at Caltrain stations after electrification project

Station Name	Baby Bullet Service*	Daily Trains in 2014 Timetable	Daily Trains After Electrification Project	Percent Change in Daily Trains
SF-4th & King	Yes	92	114	+24%
SF-22nd Street	No	58	90	+55%
Bayshore	No	40	66	+65%
South SF	No	46	78	+70%
San Bruno	No	56	66	+18%
Millbrae	Yes	82	114	+39%
Broadway	No	0	54	N/A
Burlingame	No	58	66	+14%
San Mateo	Yes	70	96	+37%
Hayward Park	No	40	66	+65%
Hillsdale	Yes	74	102	+38%
Belmont	No	46	66	+43%
San Carlos	No	64	78	+22%
Redwood City	Yes	72	102	+42%
Atherton	No	0	54	N/A
Menlo Park	No	66	96	+45%
Palo Alto	Yes	86	108	+26%
California Ave	No	52	66	+27%
San Antonio	No	46	66	+43%
Mountain View	Yes	80	108	+35%
Sunnyvale	Yes	62	84	+35%
Lawrence	No	56	66	+18%
Santa Clara	No	58	66	+14%
College Park	No	4	4	0%
San Jose	Yes	92	114	+24%
Tamien	No	40	48	+20%
Change in Daily Train Summary				
Baby Bullet Stations		**710**	**942 (+232 vs 2014)**	**+33%**
Other Stations		**730**	**1096 (+366 vs 2014)**	**+50%**

**Regular Commute Direction (Northbound in AM, Southbound in PM)*
Source: Fehr and Peers, Author's Calculations

Increased service to non-Baby Bullet stations like Lawrence, California Avenue, Belmont, Hayward Park or South San Francisco will reduce Peninsula commuters need to use their bicycle or automobile because three-mile connections between a train station and a workplace or home now become one-mile or less connections instead. Many residents who need a bike on both ends of their commute might find themselves only needing their bicycle on one end of their commute.

This new timetable could enable residents to store a bike at a station and not carry it onboard a train. This should relieve some of Caltrain's bicycle crowding challenges, but could also drive overall ridership demand. There may be bike-averse riders who have been driving their cars between San Francisco and their Peninsula destinations; with increased traffic on the region's highways and rail service that brings riders "close enough" to their origins or destinations, it is quite probable that a certain degree of mode-shift to Caltrain will occur. Also, to a lesser extent, if Caltrain can remove bike capacity in exchange for more seats, riders who place a high value on having a seat for their commute might return as well.

3.10 The Transbay Transit Center and Downtown Extension

If an electrified corridor draws commuters to Caltrain because of its more comprehensive coverage for last-mile commuters, then the Downtown Extension (DTX) to the Transbay Transit Center (TTC) project should draw even more riders to the rail system; in the words of a 1987 Metropolitan Transportation Commission report (the Bay Area's metropolitan planning organization), the extension is "the single most important improvement that can be made to [Caltrain]". Though the project is delayed due to a current funding gap, the most recent scheduled date of completion (scheduled as of 2014) was in 2024, well ahead of high-speed rail's expected arrival in 2029. In the words of Gillian Gillett, San Francisco current transportation policy director, "We have been trying to extend Caltrain into downtown, where the ridership is, since 1900 (Bialick 2013)." While the current Caltrain San Francisco terminal is well-connected to transit, it is over a mile from the city's downtown financial district. Whether riders make their terminal-to-workplace connections via transit, bicycle, or on foot, the transfer requires a non-trivial amount of time (Transbay 2001). The following table shows that the estimated commute time reduction on for commuters travelling between the Peninsula and San Francisco is on the order of 15 minutes or anywhere from 20% to 40% shorter depending on the origin and destination pairs; given this savings coupled with the political unwillingness and financial infeasibility of expanding freeways in San Francisco or San Mateo counties, this project will very likely bring amount a significant mode shift to from automobile to Caltrain.

*Table 3-3: Estimated Travel Time Savings for Trips on Caltrain with the new Downtown Extension**

Origin	Destination	Travel Time (hour: min)			Projected Travel Time Savings (minutes)
		2001	2020 No-Project	2020 Extension to Transbay Terminal	
Downtown San Jose	Downtown San Francisco	2:05	1:39	1:24	15
Sunnyvale	Downtown San Francisco	1:51	1:40	1:26	14
Palo Alto	Downtown San Francisco	1:36	1:17	1:02	15
Millbrae	Downtown San Francisco	1:08	0:52	0:37	15
San Bruno	Downtown San Francisco	1:04	0:54	0:40	14
Downtown San Francisco	San Francisco Airport	1:11	0:56	0:47	10
Redwood City	Concord	2:26	2:13	1:59	14
Downtown Oakland	San Carlos	1:41	1:28	1:15	13

Notes: *The travel times are for average peak-direction conditions and include access, wait, transfer, and ride times at both ends of the trips between central origins and destinations in the cited cities.

Source: Parsons Transportation Group Ridership Model, September 2001.

3.10.1 The Transbay Transit Center: Location, location, location

How much better situated is the Transbay Transit Center to jobs in San Francisco? To examine this, we perform a GIS analysis to look at number of employees located near each Caltrain station. We use a mapping tool called "buffer" which draws an imaginary ring around each station and then use employment data from ArcGIS's business analyst tool to count 1) how many employees work inside each ring and 2) how many people lived inside each ring. We chose rings of ¼ and ½ of a mile to represent a reasonable walking distance from the train station.

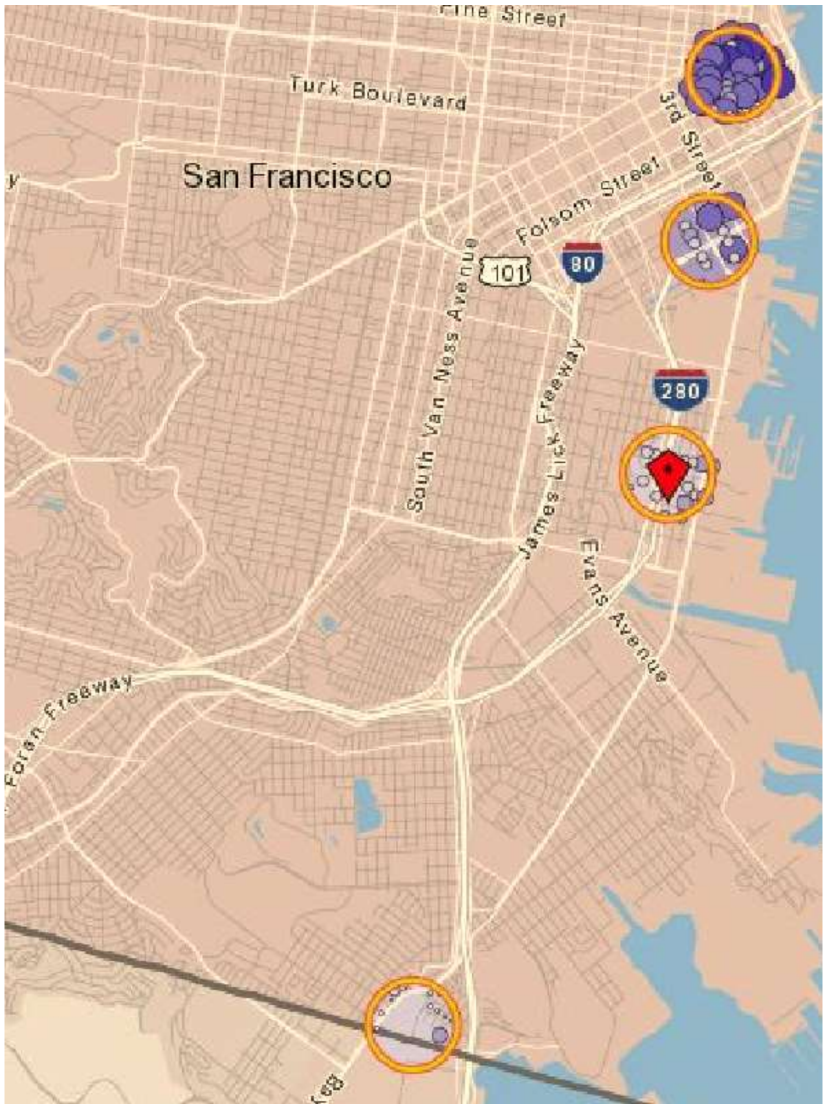
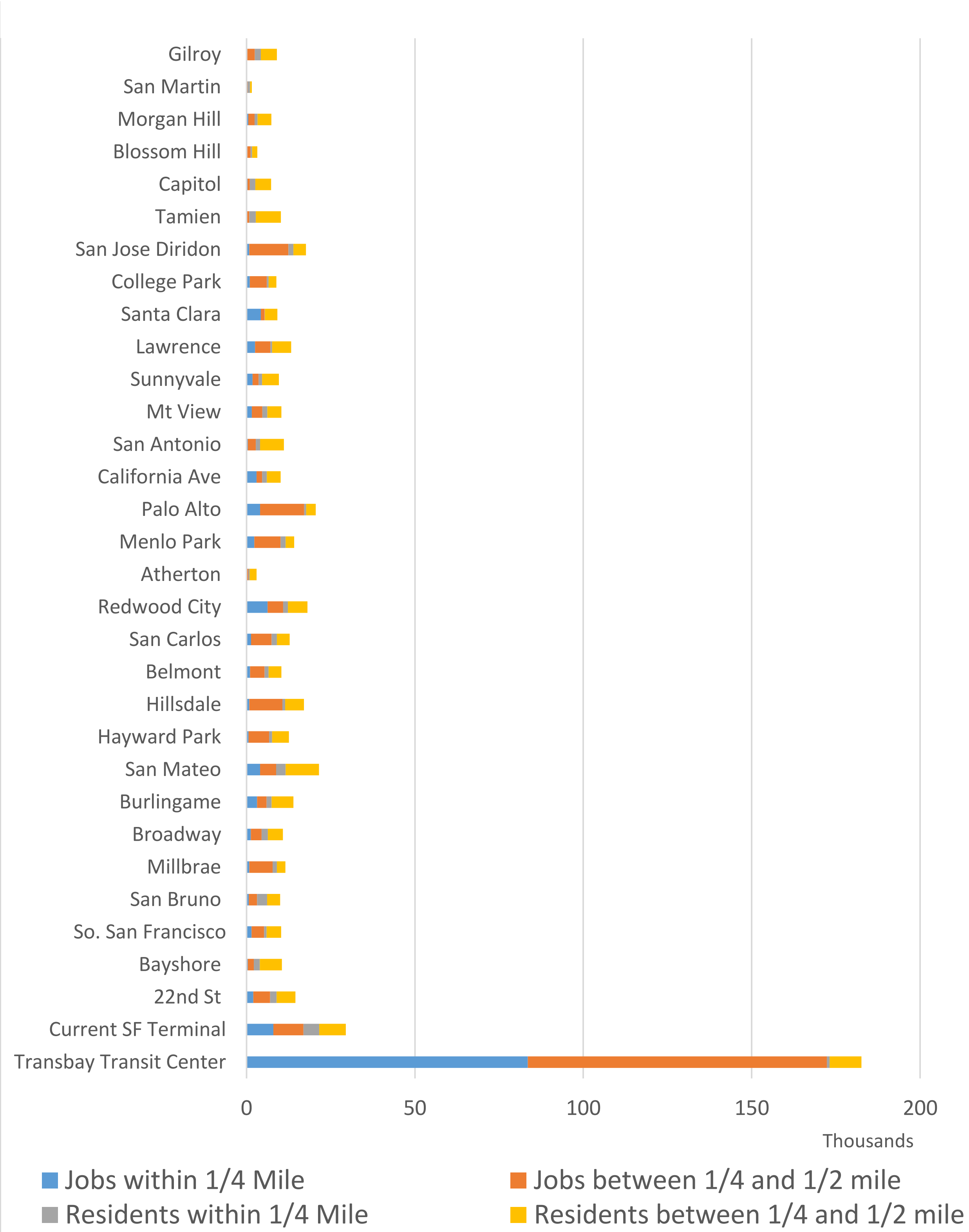


Figure 3-5: Example of the buffer tool used on (from top) Transbay Transit Center, current Caltrain terminus at 4th and King Street, Caltrain stop at 22nd Street, and Bayshore Caltrain station

As we see in Table 3-4, the Transbay Transit Center has an extremely high proportion of Caltrain-friendly jobs nearby. It is worth mentioning that this is based on historic data from 2012; the Transbay Transit Center development itself is anticipating 4,400 units of housing, over six million square feet of office space, and over 100,000 square feet of retail (Transbay 2011) when construction is completed. Using assumptions of 2.63 persons per household (Census Bureau 2015), 225 square feet per person in offices, and 450 square feet per person in retail locations (U.S. Green Building Council, 2008), that is an additional 12,000 residents and 27,000 employees. Of course, other stations (e.g. Hayward Park and San Carlos) are planning Caltrain-oriented development projects of their own, but that will only increase reliance on Caltrain as a mode of transportation. In summary, the Transbay Transit Center will be a huge source of potential Caltrain riders.

Table 3-4: Residents and Jobs within 1/4 mile and 1/2 mile of Caltrain stations



Source: ESRI Business Analyst, 2013 dataset

Depending on service assumptions, the ultimate effect of the extension on Caltrain ridership is unclear. In a recent presentation, the Transbay Joint Powers Authority (TJPA), the entity responsible for coordinating financing, design, construction, operation, and maintenance of the terminal, estimated a demand increase of 50% for Caltrain. The 2001 environmental impact report, which was written when Caltrain had a daily ridership of 35,000 (Caltrain now sees in excess of 60,000 riders on some days) estimated a 2040 ridership of 64,000 riders, an increase of over 80%. A 2013 study by the San Francisco County Transportation Authority estimated that with the extension, Caltrain's ridership in and out of San Francisco would increase 201% by 2040; that represents a ridership into San Francisco increasing from approximately 12,000 in 2013 to 36,000 in 2040. Finally, transportation engineering consultancy, Fehr and Peers, responsible for the environmental impact report for the Peninsula Corridor Electrification Project (PCEP), estimates San Francisco ridership to increase from its 2013 estimate of 11,000 to 14,000 with electrification in 2020 to 25,000 with the extension in 2040 of which 8,500 would go to the Transbay Transit Center. That the ridership split between the Transit Center (16,500) and the current terminal at 4^{th} and King Streets (8,500) is skewed in favor of the latter represents the impact of service planning with California High-speed Rail in which only two of every 6 Caltrain services per hour reach the downtown Transbay Transit Center.

Table 3-5: San Francisco Caltrain weekday ridership forecasts
Source: TJPA 2001, Fehr and Peers 2013, SFCTA 2013, and TJPA 2013

Planning Document	2020 PAX (no TTC)	2040 PAX***	Train Volume	Notes
2001 Transbay Transit Center Downtown Extension EIS/EIR	12,950 (-5% vs. 2001)^	32,135 (+136% vs 2001)	132 per day	Drafted before Baby Bullet ridership growth spurt (2004), but 2040 accounts for electrification/high speed rail
2013 Fehr and Peers Final Environmental Impact Report for PCEP	13,692 (+27% vs. 2013)***	23,056 (+114% vs. 2013)	114 per day	Blended HSR service with 1 of 3 trains into Transbay Transit Center, 2 of 3 terminating at 4^{th} and King
2013 SFCTA San Francisco Transportation Plan Update	Not available	36,309 (+170% vs. 2013)*	6 trains per hour at peak	Uses transportation SFCTA SF-CHAMP** activity model
2013 Downtown Extension Presentation at November Transbay JPA meeting	"increase Caltrain riders into SF by more than 50%" (Slide 9)"			Service assumptions and planning year unknown, but most likely operating under Blended Service HSR planning assumptions
*Assumes current split of passengers to other stations in San Francisco (i.e. 22^{nd} Street Station) **San Francisco County Transportation Agency, San Francisco **CH**ained **A**ctivity **M**odeling **P**rocess ***Ridership into SF in 2013 according to the Fehr and Peers study was 12,063 passengers/day ^Does not account for Baby Bullet ridership growth or electrification project being complete				

The above table summarizes forecasts for San Francisco ridership on Caltrain. In comparing the 2013 SFCTA study which had full Caltrain service (6 trains per hour) into the Transbay Transit Center with the Fehr and Peers study which had two Caltrain trains per hour into the Transbay Transit Center, we see the impact and importance of the Transbay Transit Center to Caltrain. The ridership difference between partial (two trains per hour) and full (six trains per hour) Caltrain service into the Transbay Transit Center is nearly 13,000 riders per day. Since we are counting riders into San Francisco and not just the Transbay Transit Center, this means that these 13,000 riders are using means other than Caltrain (i.e. BART, private shuttle, bicycle, or automobile) to access San Francisco increasing their own disutility and increasing traffic congestion on adjacent freeways.

3.10.2 Concluding Thoughts on Caltrain's Ridership Boom

Caltrain has seen significant ridership growth in the last decade with a system that, aside from the inauguration of Baby Bullet service, has not significantly changed since 1907. However, electrification and the Transbay Transit Center have the potential to stimulate unprecedented levels of demand.

In Figure 3-7, we have a simplified model of a Peninsula resident deciding how to commute into the central business district (CBD) of San Francisco in the peak direction. Because the Baby Bullet service makes it difficult to use minor stations during rush hour periods, the resident needs to have the ability to either drive, take transit, or walk to a "major" station; that is, one with Baby Bullet service. Electrification eliminates "Decision #1" since an electrified Caltrain can serve all stations during the peak period (the answer will be "Yes" to Decision #1 for many more Peninsula residents.) The extension to the CBD at the Transbay Transit Center eliminates "Decision #2" since, assuming most Peninsula residents have the ability to reach a minor station via walking, transit or automobile, the connection to the CBD is complete. With the constraints of a necessary bike or transfer penalty as well as the constraint of having to reach a major station eliminated, ridership should grow even faster. Of course, this is an oversimplification: not all residents can reach a minor Caltrain station nor do all commuters into San Francisco work in the downtown core. However, the fact that neither of these improvements (electrification and the extension into downtown) have been realized yet and that Caltrain ridership has more than doubled since 2004 suggests that Caltrain's current capacity challenges are minor compared

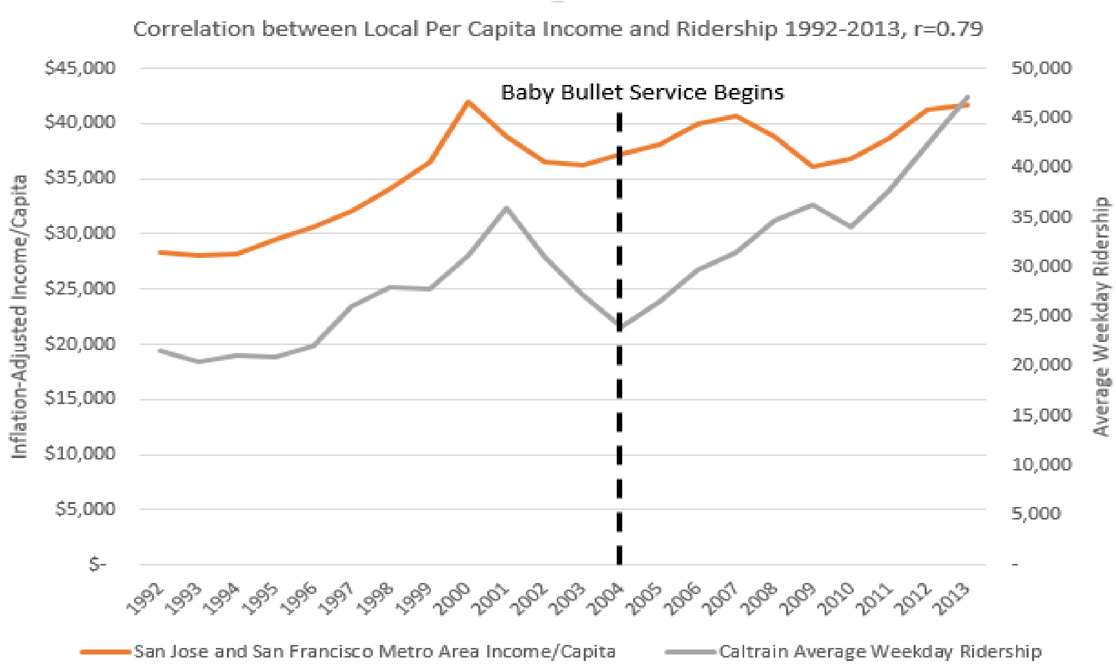


Figure 3-6: Caltrain's ridership growth before Baby Bullet service was highly correlated (r=0.91) before Baby Bullet service began. In the last decade, the author believes the travel time savings and millennial preferences for car-free lifestyles have fueled ridership (Source: Bureau of Economic Statistics/PCJPB)

to what the system will face in the coming decades. While Caltrain's current ridership boom has a high correlation to a booming Bay Area economy (with some growth possibly attributable to the travel time savings from the Baby Bullet service and changing attitudes towards car ownership), the future growth is instead a result of not-yet-existing physical infrastructure and new planned transit-oriented development.

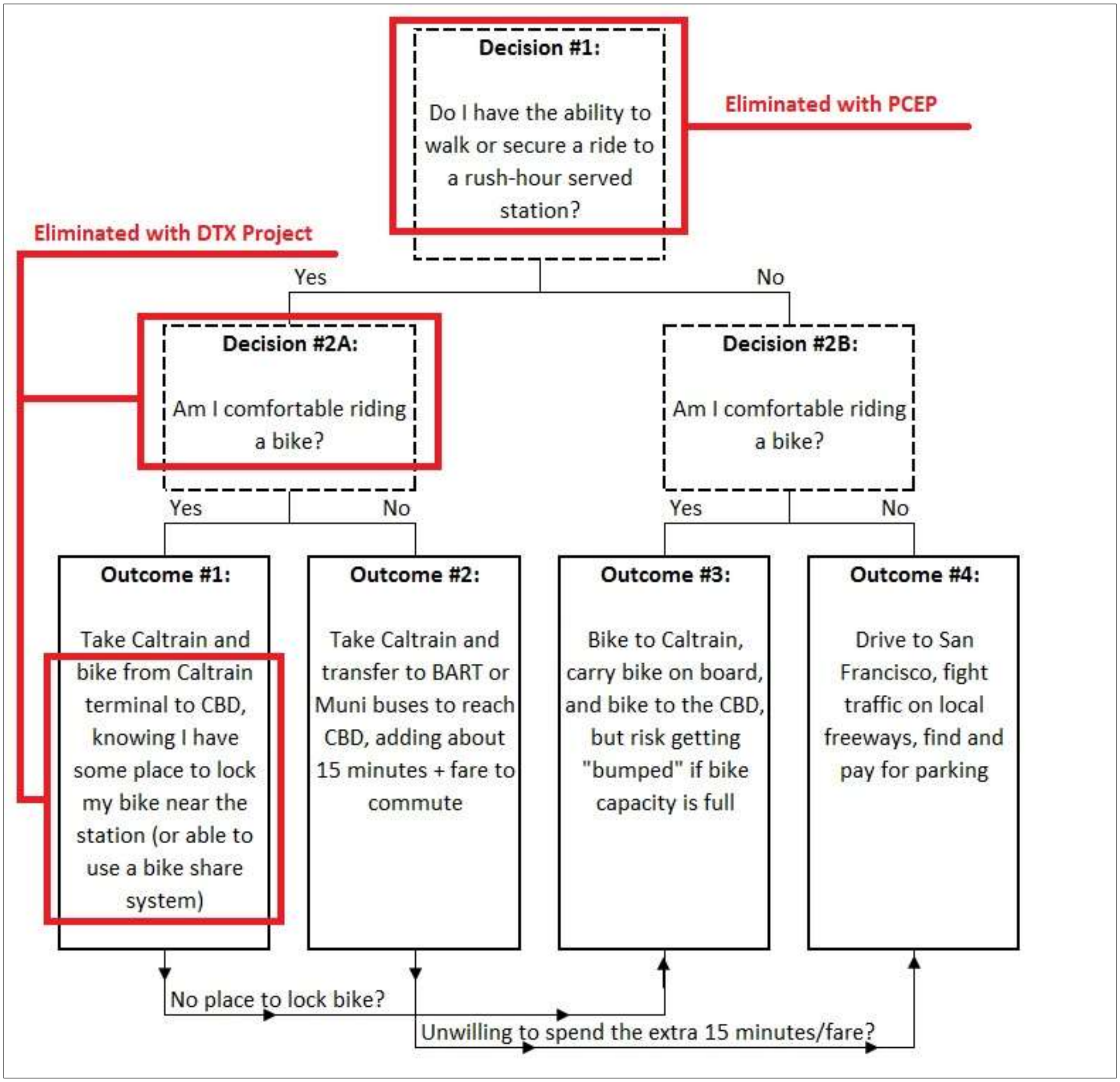


Figure 3-7: Typical Caltrain commuter and Peninsula resident decision tree
Source: Author

3.11 CHSRA and the Development of Blended Service on the Peninsula Corridor

We have now taken an in-depth look at Caltrain's upcoming capacity challenges. What we have ignored so far, for the most part, is Caltrain's financial and future operational partner on the Peninsula corridor: California High-Speed Rail.

When voters passed Proposition 1A authorizing bond money for the high-speed rail project in 2008, the plan called for a completely separate high-speed service between San Francisco and Los Angeles. On the Peninsula Corridor, high-speed rail was to run on tracks separate from Caltrain, but in the same right-of-way; that is, the corridor was to be changed from a mainly 2-track corridor to a 4-track one. The high-speed rail line, unlike the existing Peninsula corridor which has 40 grade crossings along its length, was to be fully grade-separated using a series of aerial structures, berms, trenches, and tunnels (LTK 2013a). It soon became clear that tunneling was the preferred option for Peninsula residents; for the CHSRA, tunneling was the most expensive option, and therefore, the least preferred. Cities along the Peninsula protested the Authority's plans; the city of Burlingame went so far as to erect two 59 foot poles with a net in the middle to "model the visual impact" of an aerial alignment and the *Palo Alto Voice* likened the project to a modern-day Berlin Wall cutting through the Peninsula.

Figure 3-8: Burlingame's HSR "mock up" aimed at building a consensus against CHSRA plans for a dedicated corridor
Source: San Mateo Daily Journal

In 2010, civic leaders representing residents of San Mateo and Santa Clara counties on the San Francisco Peninsula, the 4th and 5th strongest Proposition 1A supporters (60.8% and 60.3% respectively), sued the CHSRA over not exploring the negative impacts the project would have on local homeowners adjacent to the alignment (L.A. Times 2008, Durand 2013). Furthermore, cost estimates had ballooned from $45 billion to nearly $100 billion (Draft 2012 Business Plan). Lawmakers in Sacramento and Peninsula congressmen in Washington began pushing instead for what became known as a "blended system," in which high speed rail trains would "share use of an electrified/upgraded Caltrain (PCJPB-owned and operated) corridor between San Jose and the San Francisco Transbay Transit Center" (CHSRA 2012).

3.11.1 Strategic Shift in 2012

In May 2012, the CHSRA released an updated business plan calling for the "blended system," and revised their project cost estimate to $68.5 billion down from nearly $100 billion for the fully-separated system (CHSRA 2012). One month later, the California State Assembly, in an endorsement of the blended system and the revised business plan approved the sale of $4.7 billion in state bonds for construction of the first phase of the project (California Senate 2012). This included $706 million for the electrification of the Caltrain corridor and $42 million for upgrades to Caltrain's signaling system; the CHSRA describes these improvements as "bookends" to "strengthen and improve existing rail networks, while also connecting them with the future high-speed rail system" (PCJPB 2014). And finally, in early September 2013, Governor Jerry Brown signed into law a bill heavily restricting the possibility of a four-track alignment on the Peninsula (it would take a nine agency agreement to return to a four-track system), cementing the likelihood of a blended corridor (Durand 2013).

3.11.2 What is meant by "Blended Service"

The California High-Speed Rail Authority uses the term "blended service" and "blended system" when referring to the shared corridor with Caltrain. Essentially this means "maximizing the use of existing regional and commuter rail systems in urban areas" subject to the constraint of achievable travel time between Los Angeles and San Francisco of no more than 160 minutes and between San Francisco and San Jose of no more than 30 minutes. This "achievable travel time" has come to mean the ability of a high-speed train running in ideal conditions without stopping (CHSRA 2014, Thompson 2014). Additionally, the CHSRA defines "blended operations" as "at all phases of development, seek to use new and existing rail infrastructure more efficiently through coordinated delivery of services, including interlining of trains from one system to another, as well as integrated scheduling to create seamless connections" (CHSRA 2012). It remains to be seen what the Authority means by "interlining of trains," but it does leave room for the possibility of co-branded commuter/high-speed services (e.g. a Caltrain "high-speed" service). "Coordinated delivery of services" could mean as little as working with Caltrain to optimize a timetable or as much as using Caltrain to operate the last leg (San Jose-San Francisco) of a Los Angeles-San Francisco run. We will discuss possible coordination scenarios later in the thesis.

3.12 Capacity Needs of California HSR

What kind of capacity needs will the future California High-speed Rail line require? The text of the 2008 bond measure (Proposition 1A) that authorized nearly $10 billion for California High-speed Rail provides some insight into the capacity required. Section 2407.09(c) of the proposition requires an "achievable operating headway time" of five minutes or less. If we take the inverse of that statement, the system should be able to handle twelve trains per hour per direction.

Even if that is the case, it has become apparent that the CHSRA does not intend to operate 5-minute headways on the Peninsula as part of its blended service with Caltrain[9]. The latest service planning document issued by the Authority as part of its 2014 business plan shows headways of 15 minutes between San Francisco and San Jose (or four trains per hour per direction). The blended operations analysis done by a consultant for Caltrain in 2012 (which we will review later in this thesis), also calls for four trains per hour per direction.

[9] The legality of the CHSRA's planned ultimate operating scheme has already been challenged in court and will not be discussed at length in this thesis

3.12.1 Revenue-Neutral Requirement

One of the cornerstones of both the campaign for Proposition 1A was that the California HSR line would be revenue-neutral; that is, operating revenues would meet operating costs. In fact, in the last two business plans, the Authority has claimed that once the initial construction segment is operational, private investment will finance the remaining sections with the expectation that operational profits will also cover part of the capital construction costs. The text of the bond measure itself reads “the planned passenger service by the authority in the corridor or useable segment thereof will not require a local, state or federal operating subsidy.” While several of the CHSRA’s ridership studies have supported this claim, if private enterprise cannot be convinced of ultimately profiting from operation, additional funding will have to come from the federal government. At the time of writing, the chances of voters passing another bond measure or California raising enough capital through the state budget process or the federal government funding the shortfall (about $50 billion) are slim.

In the next sections, we explore the importance of the San Francisco-San Jose segment and the Transbay Transit Center to the ultimate profitability of a California HSR line. We aim to show that any private operator needs a guaranteed level of access to the Transbay Transit Center and San Francisco to ensure profitability for the entire network.

3.13 High-speed Rail as a Short-Haul California Airline

High-speed rail works best for travelers travelling distances of 100-500 miles. For distances less than 100 miles, commuter rail services (and private automobile) offer superior service because of smaller “first-mile” and “last-mile connections” between stations (parking spaces) and ultimate origins or destinations. On distances longer than 500 miles, airplanes have an advantage due to their superior speed. In the middle range of 100 to 500 miles, the added time required for using airlines makes high-speed rail more competitive. Most of the city pairs in California fall into this 100-500 mile “sweet spot.”

However, because there is no high-speed rail alternative in California today, competition between the San Francisco Bay Area and the Los Angeles Basin in the airline industry is intense. Between the Los Angeles and San Francisco regions alone, all four major airlines in addition to JetBlue and Virgin America offered a combined 174 daily flights in 2013 (Perkins 2013). Delta Airlines operates a special west coast “Delta Shuttle” service that features hourly departures between SFO and LAX; in the 1990s, United debuted “Shuttle by United” with departures every half-hour between the airports until delays in and out of San Francisco hampered operations and compelled United to cancel its “airline within an airline.” And as recently as 2013, a new airline startup, “Surf Air” began offering subscription air service to smaller airports in the Bay Area and Los Angeles region.

Diverting passengers from air travel and capturing air travel spillover is going to be an important part of California HSR’s ridership and revenue. A 1999 Charles River Associates (CRA) study for CHSRA anticipated a 56% diversion of local air traffic to high speed rail (CRA). A more recent 2010 Aviation Systems Consulting study that assumed HSR fares to be 83% of an equivalent airfare forecasted Bay Area airports to experience a diversion of 54.4%, 63.1%, and 53.4% to the San Joaquin Valley, North Los Angeles Basin, and South Los Angeles Basin respectively (Association of Bay Area Governments 2010). Given the size of the intra-California air market and those diversion rates, it is safe to say that air diversion is a critical piece of the California HSR revenue model.

3.13.1 Value of Frequency to Business Travelers and HSR's competitive advantage

The ability of California HSR to attract business travelers and commuters will depend, not only on its travel speed, but its frequency. Ryan Westrom, in his thesis, finds that "The combination of high-speed and appropriate frequency will result in a service that is most advantageous, and thus competitive, for a trip of the right distance" (Westrom 2014). For high-speed rail service, much like the airline sector, frequency helps reduce schedule displacement between trains. Schedule displacement is the perceived "wait time"; for example, a traveler that ideally would depart at noon, but instead departs on a 12:45pm plane or train has a schedule displacement of 45 minutes.

Herein lies high-speed rail's competitive advantage. Because the marginal cost of adding rail service is much less than the marginal cost of an additional flight (rail's fixed costs are higher than those of airlines), rail can support much higher frequencies than air even if their railcars are not as full (in general, rail can run profitably with a lower load factor, that is, percent of seats occupied). Furthermore, in short-haul markets like California, frequency is more important than in long-haul markets because the ratio of wait time to travel time is much higher.

As noted before, the best frequency offered in the market today by a single airline (and only between SFO and LAX) is the Delta Shuttle with a single trip per hour. Markets like San Francisco-Merced, Los Angeles-Bakersfield, or Fresno-Palmdale see at best one or two trips per day from a single airline. Given its competitive conditions, California high-speed rail will divert business travelers from air and be successful only if it can provide reliable frequency into and out of its San Francisco and Los Angeles termini.

3.13.2 Value of Peak Trips to an Operator (HSR Revenue Management)

Peak trips, that is, those trips taking place during "rush hour" where temporal demand is highest, are also very important to a private operator's business model. Since consumer willingness to pay for peak trips is higher than off-peak, the operator could charge a fare premium maximizing yield (revenue per seat-mile). The operator could then lower fares in off-peak periods to capture additional passengers, simultaneously driving up load factor and offering an affordable option for families or leisure travelers. This practice grew out of the air industry, but has been adopted by rail operators worldwide including Amtrak (since 1991), SCNF (1993), VIA RAIL (1993), Deutshe Bahn (2002) and Great Northeastern Railway in the U.K. (2004). Later in this chapter, we will examine where exactly this peak might exist for San Francisco and how that peak compares to the peak demand time for Caltrain's commuter rail service.

3.13.3 Importance of San Francisco

On the Peninsula Corridor, San Jose may have a larger population, but it is less dense; and thus, the value of a station in the city's central business district is less important. San Francisco, on the other hand, should be a very lucrative hub for a high-speed rail operator. The Transbay Transit Center will be located adjacent to a dense downtown core with excellent transit connections to Oakland and the East Bay via BART as well as Marin County via frequent express bus service across the Golden Gate Bridge. In his thesis, Westrom claims that "any city, regardless of its distance from a metropolitan area, can move into the commutable realm of a central city if the travel time resulting from a HSR improvement moves to below one hour." Because of the Transbay Transit Center's central location within San Francisco, cities like Gilroy and Merced become reasonable commutes for commuters living and working in San Francisco.

3.13.4 The Transbay Transit Center Advantage versus San Francisco International Airport

One of the biggest advantages the Transbay Transit Center holds over San Francisco International Airport (SFO) is its proximity to San Francisco's Central Business District. SFO may be closer than the Transbay Transit Center to Silicon Valley, but HSR stations in Millbrae and San Jose shared with Caltrain service would give HSR an advantage in that regard. As opposed to a 5 minute walk from the Transbay Transit Center, a taxi trip from SFO to the CBD requires about 25 minutes and costs $45 and a similar BART trip costs $9 and takes about 5 minutes longer, at 31 minutes each way. Furthermore, San Francisco International Airport, who loses one its two runways during heavy fog levels (due to FAA minimum separation requirements), is also one of the most weather-delayed airports in the United States giving time-conscious travelers reason to avoid the airport if a reasonable alternative such as high-speed rail exists (Barba 2014).

3.13.5 Peaking problem at Transbay

The Transbay Transit Center is going to be an important piece of infrastructure for both Caltrain and HSR commuters. It is also going to be important at the same time of day. As one of the largest cities in both terms of population and jobs, San Francisco will no doubt be a key traffic generator for the California high-speed rail operator. If we are to use air travel demand as a proxy for HSR demand, we can see the importance of the San Francisco hub at the same time of the day as Caltrain demand into the Transbay Transit Center.

First, we look at Caltrain ridership based on the current schedule. We have taken a moving average to smooth the data between individual trains. The time axis shown is the time the train arrives (northbound) or departs (southbound) San Francisco. For northbound passengers, we adjust the arrival time 15 minutes later to account for the idea that if Peninsula commuters could save 15 minutes with a train to the Transbay Transit Center; they would depart from their Peninsula station 15 minutes later than they do today.

In examining the data, we look at the peak (commuting northbound in the morning) and reverse peak (commuting southbound in the evening). Again, it is worth mentioning that Caltrain's peak-reverse peak commute balance is approximately 60-40.

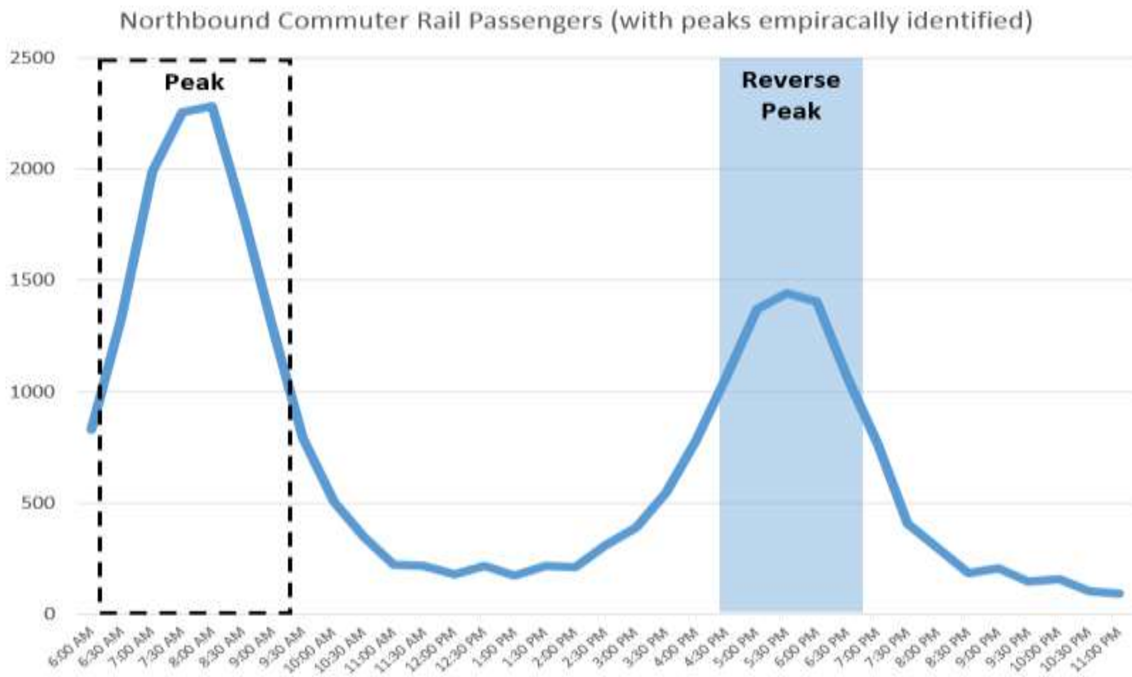


Figure 3-9: Northbound Caltrain ridership by time of day (adjusted 15 minutes earlier to account for transfer time. Peak travel periods selected empirically by author
Source: Caltrain Annual Passenger Counts

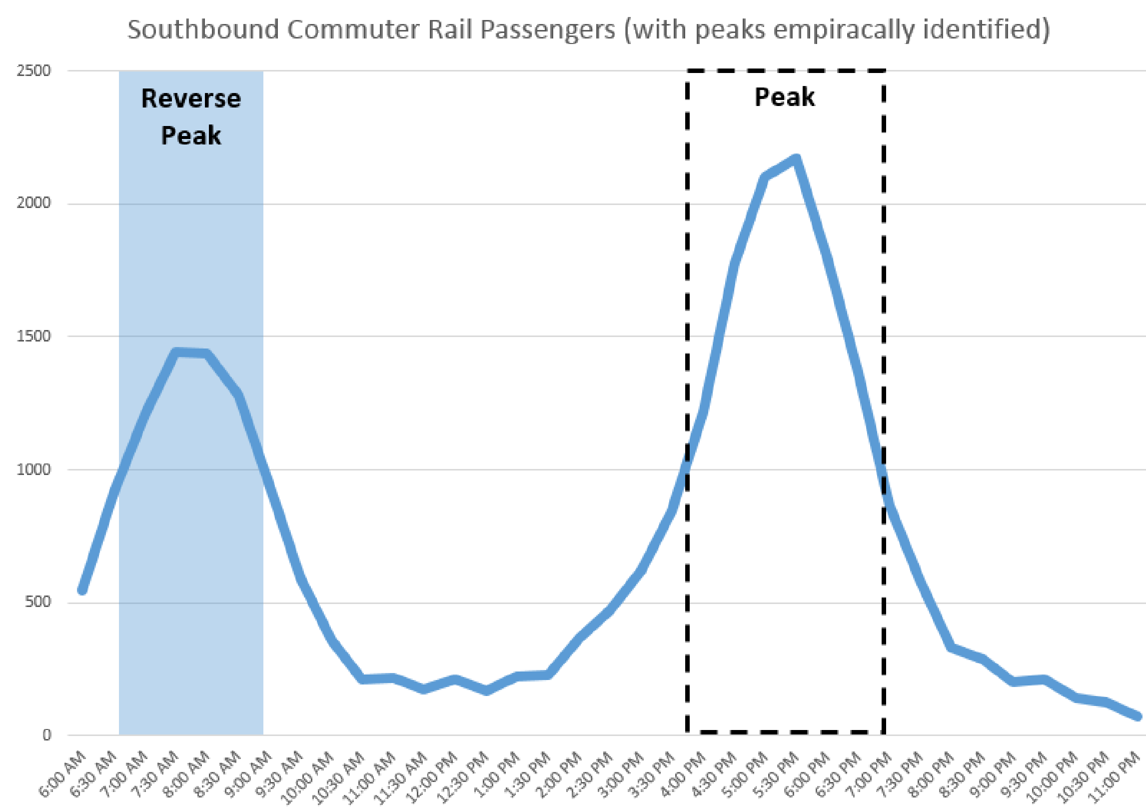


Figure 3-10: Southbound Caltrain ridership by time of day. Peak travel periods selected empirically by author
Source: Caltrain Annual Passenger Counts

Next, we look at 7000-plus seats available on airlines flying between San Francisco and airports along the high-speed rail route on an average January 2015 weekday. While SFO-LAX has the biggest share of the market (93.5% of seats), there was also service to Burbank (4%), Fresno (2%) and Bakersfield (0.5%). We round SFO departure times to the nearest 15 minute bin and take the 2nd moving average to smooth out peaks from individual flights (San Francisco International Airport 2015). Again, for northbound passengers, we adjust the arrival time to account for the fact that an air traveler would like to be in the central business district 45 minutes after his preferred arrival time (accounting for any deplaning process plus taxi or BART to San Francisco).

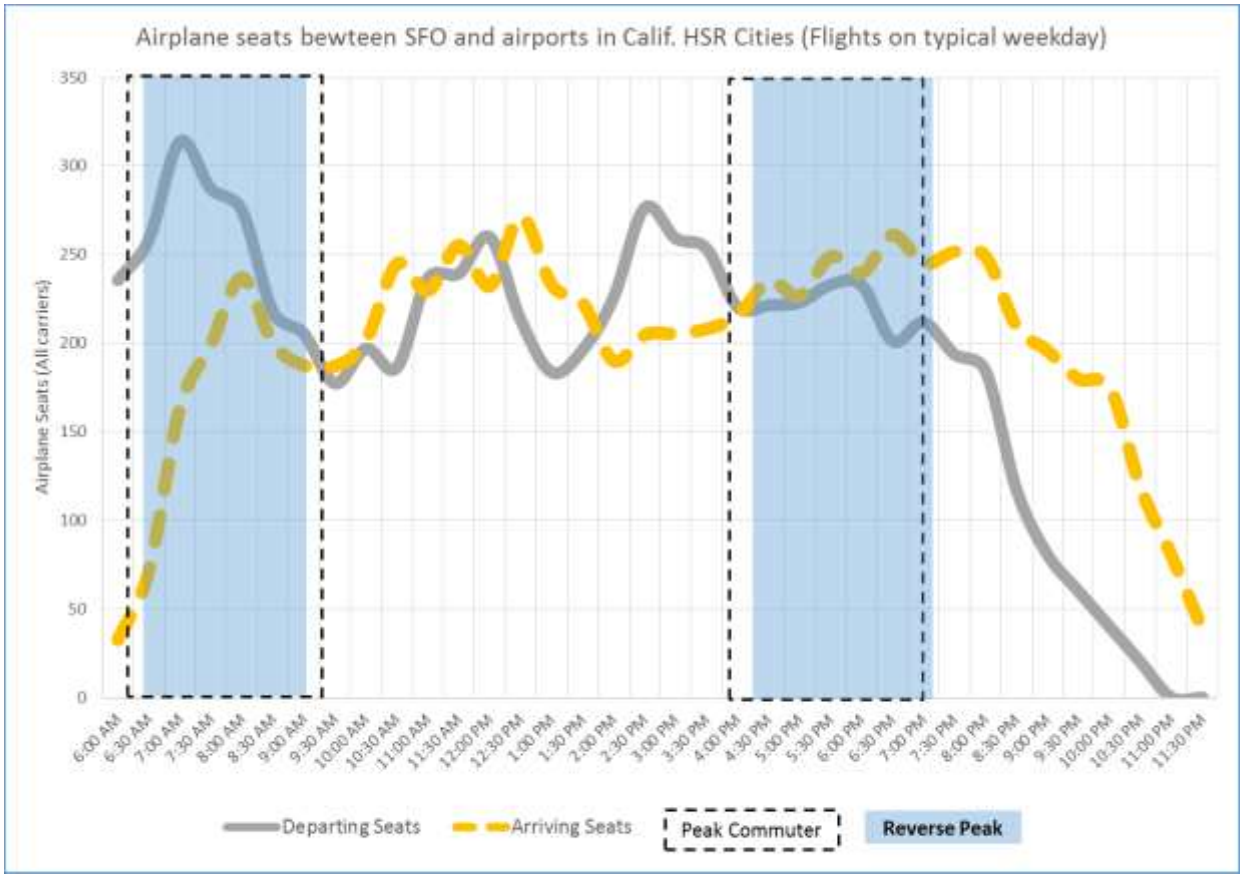


Figure 3-11: Comparison of air travel seat capacity and rail capacity. Note that peak seat departures overlap with peak Caltrain travel time.
Source: San Francisco International Airport

In looking at the above graph, we do see overlaps between Caltrain peak and reverse peak volumes and air traffic peak and reverse peak volumes suggesting that demand into the Transbay Transit Center will be temporally similar between Caltrain and California HSR.

A better metric than seats arriving and departing to compare air travel to potential rail travel would be "revenue per airliner" arriving and departing San Francisco. Unfortunately we cannot estimate average fare for these individual flights and airlines are not willing to share sensitive revenue data. However, Peter Belobaba, editor of *The Global Airline Industry* writes, "Peak departure times (early morning and late afternoon) are most attractive to a large proportion of travelers in many markets, as "time of day" distributions of desired departure times tend to be clustered around 8am to 9am in the morning and 5pm to 6pm in the afternoon." These times overlap precisely with Caltrain's regular and reverse peak (54).

Given the supply of seats at SFO and our knowledge of peak travel times of 8am to 9am and 5pm to 6pm, we can infer that the highest revenue intra-California flights into and out of San Francisco and by extension, the most valuable trains to a private high-speed rail operator in California, will be those arriving and departing San Francisco at similar times as Caltrain's peak.

3.14 Conclusions

In this chapter, we have described the upcoming challenges that Caltrain will face in terms of capacity. Without high-speed rail, the electrification project, or the downtown extension, Caltrain is already reaching its capacity limitations. Installation of the CBOSS positive train control system will allow Caltrain to run tighter headways of up to 6-trains per hour and a recent railcar investment will allow for 6-car trains instead of today's five car consists. However, the Peninsula Corridor Electrification Project will bring new demand as minor stations see peak hour service.

Fehr and Peers in their Final Environmental Impact Report for the project, claim that due to shorter passenger trips leading to higher turnover as well as riders taking trains at the edges of the peak, Caltrain will manage capacity better than it does today. Even so, Fehr and Peers' forecasts already appear out of date given Caltrain's astonishing ridership growth. Fehr and Peers predicted a no-project 2020 average weekday ridership of 57,047 passengers, up from a baseline of 47,066 in 2013. In 2014, just one year after Fehr and Peers report, ridership was recorded at 53,466, well past the halfway point between the 2013 baseline and the 2020 prediction (PCJPB 2014d). On multiple days in late 2014, average weekday ridership topped 60,000 riders (PCJPB 2015). Caltrain provides a valuable service on the Peninsula by keeping its patrons out of congestion and serving as a reliever for those to driving—out of choice or necessity—on Peninsula freeways. As its service patterns change and Peninsula land-use brings residents closer to stations, this ridership rise will only continue.

The Transbay Transit Center will bring even more demand into the Caltrain system. As we sketched out earlier, the project eliminates a missing link in the Peninsula-San Francisco commute by bringing commuters directly to the central business district. If any single project increases demand for peninsula rail services, this is the project. However, questions remain about Caltrain's service levels at the station, how the station will be operated, and the extent of crowding on the Caltrain system once tracks are built and service is extended there.

The Peninsula is a critical piece of high-speed rail too. CHSRA intends to sell the right to finance, build, operate, and maintain the California high-speed rail system to a private investor. As part of the Proposition 1A bond measure, the operating profits from high-speed rail should not only cover operating and maintenance costs, but also help recoup capital expenditures beyond the initial construction segment. In order for high-speed rail to be profitable in California, we claim that consistent, peak-hour service into San Francisco is vital. This is due to the business and leisure demand into the city as well as the Transbay Transit Center's ideal location in the resident-and job-rich urban core, one of the densest central business districts in the country.

In the next chapter, we look at the feasibility of operating two railroads that are "competing" not necessarily against each other (though the 2014 CHSRA business plan shows a bit of this behavior on the Peninsula), but rather competing for access to the same track at roughly the same time. We will review the degree present of institutional coordination as well as the analysis that has been completed supporting the feasibility of operations. We will discuss market-based alternatives to coordination as well as the implications of separating ownership of infrastructure from railroad operators as has been done in the Europe and could be done at the Transbay Transit Center. There are challenges in both approaches that might be solved with stronger, more service-based scenario planning and a higher degree of institutional coordination, not just on the Peninsula, but across the entire California passenger rail network.

4 The Blended System—Current Status and Implications

4.1 Introduction

In the last chapter, we completed an in-depth review of the future capacity challenges that we anticipate Caltrain and the California High-Speed Rail Authority will face. Caltrain is already, by some measures, at capacity. However, new transit-oriented development on the Peninsula, the electrification of the system and the extension to the Transbay Transit Center in the commercial heart of San Francisco will stimulate unprecedented levels of demand for the two-track rail system. When California HSR is added to the mix in the form of the "blended system", demand on the line will overlap spatially (in terms of San Francisco) and temporally (in terms of AM and PM peak travel). The blended system and its implications on the operation of the rest of the California rail network will be a theme throughout the rest of this chapter and this thesis.

In this chapter, we will start by discussing the level of analysis that been done regarding the blended system—we note that the extent of analysis is relatively minor given its importance to both Caltrain and high-speed rail. The two main sources of analysis are 1) memoranda of understanding between the California High-Speed Rail Authority and the Peninsula Corridor Joint Powers Board (PCJPB) and 2) a feasibility study conducted by LTK Engineering on behalf of the PCJPB. Next, we will review the Transbay Transit Center and Downtown Extension and its unique position as a third-party owned entity that will host both Caltrain and the California HSR operator. This will lead into a discussion of the financial ability of both operators to pay for entry into the Transbay Transit Center: would and should access charges lead to a market-based solution to the capacity crunch at the terminal? To that end, we introduce a model (developed previously in this author's Transportation Research Board paper) for understanding each operator's financial position and analyze the willingness to pay for access into the San Francisco terminal. Finally, we discuss the implications of our model's results and why coordination and integration of services might be a better solution for solving the challenge of limited line and terminal capacity on the Peninsula Corridor.

4.2 Current Extent of Coordination between Caltrain and the CHSRA

The history of coordination between the CHSRA and PCJPB (Caltrain) predates the 2008 HSR bond measure. The two agencies signed a memorandum of understanding (MOU) in 2004 to "set forth a framework for future cooperation" which included aims of sharing engineering and service plans for the sake of compatibility between the systems (PCJPB 2004). In 2009, after voters passed the bond measure, the agencies signed another MOU which established a "working group" to plan, design, and implement high-speed rail service on the Peninsula as a joint project between the agencies. The so-called Peninsula Rail Program, was staffed 50-50 by both agencies and existed until the politically-motivated shift from separated infrastructure to "blended service" in 2012.

In 2013, the agencies signed a third MOU that described the blended system in broad terms (PCJPB 2013). Before continuing, it is important to note that a memorandum of understanding is a non-binding document which describes the intent of both parties. While the following affirmations are important in understanding the institutional "mindsets," they are by no means guarantees of future conditions. In fact, a key recital in the 2013 MOU was to nullify the two previous MOUs described in the prior section. The 2013 MOU does provide some interesting insights into understanding the relationship between CHSRA and PCJPB: the corridor is very much still under local control—high-speed rail, at this point, is very much a “tenant railroad” and freight is not going to disappear easily. We will now review the 2013 MOU in more detail to distill some of the themes and institutional mindsets buried within the document.

4.2.1 Freight will remain on the corridor

The CHSRA and PCJPB agreed that freight will remain in operation on the corridor as per the existing trackage rights agreement with Union Pacific Railroad. This brings a host of challenges that were described in earlier chapters, including clearance issues, regulations regarding HSR equipment crashworthiness, and track design constraints. Furthermore, freight’s presence on the corridor will tighten work windows during the construction phase, potentially delaying the project.

4.2.2 Utilize primarily the existing track configuration

This recital was likely inserted to mollify the critics of the original high-speed rail construction plan. While it is a non-binding document, it does reaffirm the commitment to blended service.

4.2.3 Caltrain service remains operational during Blended System construction

While the theme of this goal is “minimize disruption,” the wording when combined with the non-binding nature of the MOU itself says very little. In addition to commuter rail service, this recital attempts to protect the operations of other passenger rail services (i.e. Altamont Corridor Express and Amtrak California) as well as freight rail services.

4.2.4 PCJPB retains ownership of improvements and right-of-way

This might be the most important recital in the MOU because it reaffirms the PCJPB’s control of operations on the corridor. The fact the CHSRA is paying for a lion’s share of the improvements in terms of positive train control and electrification does not give them any more control than if PCJPB had financed the improvements on their own. At a future date, the CHSRA will likely have to negotiate some form of minimum service guarantee for high-speed rail on the corridor. Otherwise, PCJPB, as corridor owners, would have the right to squeeze high-speed rail service to a point where it is no longer possible to operate profitably on the corridor or at all.

4.3 Caltrain EMU Vehicle Procurement

Caltrain will need to make a decision on platform height which will dictate the design of their new EMU vehicles. The latest plans call for high-speed rail to have a 50” boarding height and level boarding. In Caltrain’s most recent board meeting, Marian Lee, the executive officer for PCJPB’s Caltrain Modernization Program said that her staff would “focus on boarding height compatibility with high-speed rail vehicles” in the spring and summer of 2015. It appears unlikely that high-speed rail will select a platform height compatible with commuter rail agencies; however, it appears quite likely that the CHSRA will use level boarding on their platforms. Level boarding is very important to HSR reliability due to aforementioned dwell time variations with stairs and passengers with wheelchairs, bicycles, or excess baggage.

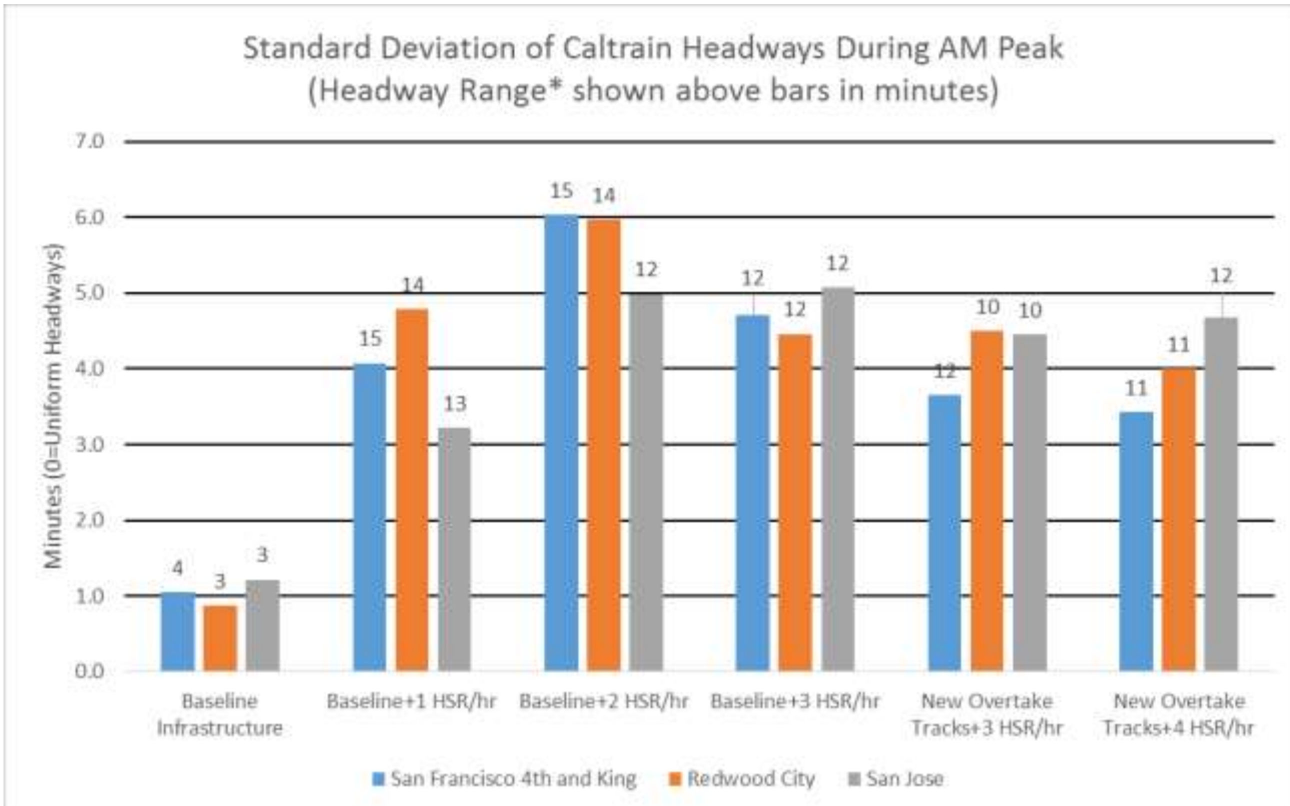
In their project update report in March 2015 to the California State Legislature, the CHSRA also stated that they are working with Caltrain to develop an RFP for Caltrain’s new vehicles that will “provide boarding capabilities at both high and low levels. This configuration will allow Caltrain to operate at existing platform levels once electrified service in the Peninsula is underway, yet provide flexibility for ultimate conversion to a common high-level boarding solution" (CHSRA 2015a)

4.4 Blended Operations Analysis

In transitioning strategies from separate right-of-way to the "blended system" Caltrain hired LTK Engineering Services to prepare a "proof of concept" for the future operations on the corridor. This report was published in March 2012 (LTK 2012). LTK used a proprietary rail simulation tool to model the corridor as well as several new sections of passing track that could be constructed. LTK concluded that the line, at its present state plus electrification and a new signal system, could at most support six Caltrain trains and two high-speed rail trains per hour per direction. Off-peak high-speed rail service was assumed to be two high-speed rail trains per hour per direction. According to LTK's analysis and simulations, improvements to the system such as mid-line passing tracks would allow for the six Caltrain trains and four high-speed rail trains. LTK's model strangely did not include the Transbay Transit Center, though this was updated in 2013 (LTK 2013).

Below is a summary of the results from the operations simulations. Using the output string-line (time-space diagrams) in the report, we calculate the standard deviation of headways experienced by the Caltrain commuter between 7 a.m. and 9 a.m. at three major stations on the corridor: San Jose, Redwood City, and San Francisco (current terminal, not the Transbay Transit Center). We also calculate the headway range to show the longest wait by a customer at that station during the AM peak versus the shortest wait experienced by a customer at that station. This is another measure of the schedule irregularity that LTK must introduce to accommodate high-speed rail on the corridor. In all these simulations, HSR runs at evenly-spaced, uniform headways.

Figure 4-1: Evaluation of Blended Service Plans



**Headway Range = Maximum Headway - Minimum Headway*
Source: Author's Calculations based on Blended Service Operations Analysis

The LTK analysis shows that Caltrain will not be able to run very uniform headways in a blended system. The standard deviation of headways in the "baseline" scenario is low (about one minute) meaning that Caltrain services are practically uniform without high-speed rail. The difference between the longest and shortest headway is also small (four minutes in San Francisco and three minutes at Redwood City and San Jose). As soon as a single HSR train is added to the blended system, though, the variation between headways versus the baseline triples at San Jose and nearly quintuples at Redwood City. At San Francisco 4th and King station, the shortest headway is four minutes and the longest headway is 19 minutes, resulting in a 15 minute maximum headway gap.

Caltrain does not use uniform headways now, but these gaps in service might be undesirable for several reasons. First, at six evenly-spaced trains per hour, Caltrain becomes a "walkup service" during the peak period at main stops meaning that riders do not need to consult timetables, a significant amenity, especially for casual users and commuters with unpredictable schedules (MBTA 2010). Second, uneven spaced train services will lead to crowding on trains immediately following a temporal gap in service (this is known in the transit industry as the "bunching" effect) (Daganzo 2009). Finally, even headways allow for users to commit timetables to memory (e.g. "the train leaves San Carlos at 5; 15; 25; 35; 45; and 55 minutes past the hour"). In Caltrain's pre-blended system plan when high-speed rail was on its own separate tracks, the PCJPB envisioned uniform skip-stop service as high as 10 trains per hour per direction with four trains per hour running into the Transbay Transit Center (American Public Transportation Association 2006).

4.4.1 Blended Analysis: Stakeholder Considerations Report

The original 2012 analysis neither included the Downtown Extension nor acknowledged the presence of freight. At the request of local stakeholders, LTK issued another report in 2013 that addressed some of these missing analyses.

In the new 2013 report, LTK included a new simulated service plan with the Downtown Extension incorporated. The report suggested that only two Caltrain trains per hour could use the Transbay Transit Center during the AM peak. Furthermore, this schedule functioned with a long mid-track overtake requiring significant new construction[10]. LTK did not simulate the as-built infrastructure nor did it simulate the possibility of running additional (more than two trains per hour per direction) Caltrain trains to the Transbay Transit Center. Concludes LTK, "the DTX and the TTC support the blended system. However, they result in higher levels of signal delay and more added Caltrain station stops to support the service extension to downtown San Francisco."

Regarding freight service, LTK admitted that the 30-minute window allotted to freight in the middle of the service day may need to be renegotiated to midnight-5 a.m. only. A 30-minute window guaranteed for freight limits passenger service (Caltrain or HSR) to only two trains per hour. However, LTK only made qualitative remarks regarding the service and did not say whether or not it would be temporally possible given Caltrain and high-speed rail service levels.

Upon reviewing the report, we conclude that there is a lot more service planning that needs to be done regarding the blended system. When stakeholders complained that the Transbay Transit Center was not included in the original blended service analysis, LTK's response was a short analysis where the firm conceded that the blended system was possible, but with only two Caltrain trains per hour. On top of that, the simulation was not shown in a string-line chart so we cannot speak to the uniformity or desirability of the already-limited Caltrain headways. As we discussed in Chapter 3, two commuter services per hour per direction is, in the author's opinion, probably not enough to satisfy the intense job and housing concentrations at the Transbay Transit Center.

4.5 Design of Transbay Transit Center and Platform Sharing

The current design of the Transbay Transit Center calls for two HSR platforms supporting four tracks and a single Caltrain platform supporting two tracks. These segregated platforms are due to differences in the planned rail vehicle types for HSR and Caltrain.

In Caltrain's August 2014 board meeting, the agency claimed that Caltrain's new electric multiple unit (EMU) train sets would be incompatible with those of California high-speed rail. Caltrain claimed that their floor threshold would be 25" above top of rail (ATOR) while CHSR's would be 51" (PCJPB 2014b). This would make it impossible to share platforms; Caltrain reemphasized this point in an October 2013 board meeting (PCJPB 2013). In a November 2014 presentation to the board, Caltrain made their first indication that they would consider shared platforms with CHSR (PCJPB 2014). As noted in Chapter Two, the CPUC requirements pertaining to freight service that are in conflict with ADA

[10] Ironically, the mid-line overtake would necessitate four-tracks through the communities that rallied against the original planned four-track system in favor of the mostly two-track blended system.

requirements regarding minimum gaps stand as a major obstacle to level boarding, and by extension, shared platforms.

In December 2014, however, in a presentation to the Transbay Transit Center Citizen Advisory Committee, the Transbay Joint Powers Authority Board of Directors made their most serious commitment yet to platform sharing. The Board cited improved train storage, delay recovery, commuter rail capacity, and flexibility as the main reasons to pursue shared platforms. In January and February 2015, the Caltrain will make a "tradeoff assessment and plans to arrive at a policy decision by May 2015" though at the time of our writing, this decision has not been made (PCJPB 2015).

Caltrain's equipment for Baby Bullet services are relatively young. As a result, Caltrain intends to keep using that equipment after electrification in what they describe as an "interim period" of mixed electric and diesel operations. Caltrain recently "doubled down" on this strategy by committing $15 million to purchase 16 surplus Bombardier rail cars (the same type as the Baby Bullet cars) from Metrolink. These cars will be used to extend trainsets on peak hour trains (PCJPB 2014f).

Level boarding presents a challenge for this interim period because of discrepancies in platform heights; if platform heights were raised to accommodate level boarding on the EMU trains, the diesel equipment could no longer function due to a lower door height that the level of the platform. Caltrain's latest proposal is to run the diesel trains at Baby Bullet stations and provide local service with EMUs (2014). Mini-high platforms could be used to serve EMU trains at the low-platform stop (MBTA 2015). In the next chapter, we will discuss the impact of platform heights and shared platforms on service plans not just on the Peninsula but throughout California.

4.6 Case Study: Metro-North Railroad and Acela on the Northeast Corridor

Metro North Railroad and Amtrak operate in a shared corridor on the New Haven line that is similar in some ways to how the blended system will function in California[11]. Metro North, the commuter line providing service upstate New York and Connecticut and New York City, owns the line (along with Connecticut Department of Transportation) between the New York City border and New Haven, Connecticut. This line is also part of the Northeast Corridor between New Rochelle, New York and New Haven; in addition, then to Metro-North's 125,000 weekday commuters, Amtrak operates its profitable *Northeast Regional* and *Acela* trains along the line was well.

Like Caltrain and future California HSR on the Peninsula, the Northeast Corridor portion of the line is congested. Amtrak has the right to operate trains that do not cause "undue interference" with Metro North trains and reimburses Metro North for costs relating to maintenance and electricity on a car-mile basis. Metro North does not profit from Amtrak services nor does it receive a premium for peak hour or express Amtrak services, even though Amtrak is able to capture additional revenue from those trains. While Metro North will accommodate additional Amtrak trains if the schedule permits (and will modify its schedule by a few minutes in either direction if necessary), Amtrak is not allowed to add trains that cause undue interference to Metro North operations. On the same token, even though they own the corridor, Metro North is not permitted to act unilaterally and add trains that disrupt Amtrak services. These train slots are held by the two railroads indefinitely, which makes significant timetable changes cumbersome. Mr. Mel Corbett of Metro North Railroad, said if he had a blank slate in California, he

[11] We would like to thank Mr. Mel Corbett of Metro North Railroad for providing the information described in this section.

would encourage a more "business-like arrangement" that included some sort of capacity charge that reflects express services that displace other train services or peak-period services that are more valuable to both commuter and intercity railroads (and by extension, commuter and intercity passengers).

4.7 Separating Infrastructure from Operators

Given the new concept of blended service and the challenge of Caltrain and HSR competing for the same track space, there is an opportunity to reorganize the institutional structure of the corridor to allow for separation of infrastructure from operations. An important consideration that has not been fully addressed to date is how the Transbay Transit Center fits into the HSR-Caltrain puzzle from an institutional perspective. The ultimate form of this arrangement will affect the operational structure of the Peninsula Corridor, and to some extent, the rest of the California HSR network.

4.7.1 Transbay Transit Center: Funding and Ownership

The $1.9 billion Transbay Transit Center (Phase 1) and $3 billion Downtown Rail Extension (Phase 2) are using a variety of funding sources, the largest of which is $2.7 billion in revenue from a special taxes, and impact fees from developers building in a designated Transbay Redevelopment District surrounding the terminal (Transbay 2011). Additionally, the Transbay Joint Powers Authority (TJPA) received $400 million in funding from the FRA's High Speed Intercity Passenger Rail Program for Phase 1 of the project (CHSRA 2015). Bay Area toll revenues, federal New Starts funds, and contributions from the City of San Francisco are expected to make up the rest of the funding for the two phases (Cauthen and Lydon 2015). Two notable entities absent from this list are the California High-Speed Rail Authority and the Peninsula Corridor Joint Powers Board (Caltrain)—the ultimate users of the Downtown Rail Extension. Undoubtedly, this will offer the TJPA some independence from the two operators; however, the Peninsula Corridor Joint Powers Board does have a seat on the TJPA Board of Directors[12]. The rail extension project is currently slated to be a design-bid-build, but the TJPA is also investigating the feasibility of a public-private partnership model (Transbay 2014).

At the time of writing, according to the author's conversations with the authority, the ownership of the Transbay Transit Center and Downtown Railroad Extension is going to remain with the Transbay Joint Powers Authority (or the private partner should the project proceed as a public-private partnership). Separation of infrastructure ownership from the operating railroads could lead to a more transparent allocation of infrastructure capacity; that is, each operator would understand why or why not it is awarded a train slot. This transparency could allow a high-speed operator to understand the risks associated with running trains on the Peninsula Corridor. Since the Transbay Joint Powers is going to own the tracks of the Downtown Extension as well as the Transbay Transit Center itself, it might facilitate separation of infrastructure ownership from operations along the entire corridor.

4.7.2 The Transbay-Penn Station Analogy

The Transbay Transit Center has been hailed as the "Grand Central Station of the West," though from a transit-operations perspective, a more apt name would be the "Penn Station of the West" (Transbay 2011). Metro-North Railroad, for the time-being, enjoys the luxury of being the sole operator of inter-city rail services at Grand Central. Penn Station, on the other hand, hosts not two, but three different

[12] The rest of the TJPA board of directors includes representatives from the San Francisco Board of Supervisors, the office of the Mayor of San Francisco, AC Transit (the main bus tenant in the terminal), and the San Francisco Municipal Transportation Agency

rail operators and is experiencing capacity constraints on its own. The author's research colleague, Rebecca Heywood, is taking an in-depth look at developments at Penn Station and—similar to this thesis—how capacity improvements have impacts at the urban, metropolitan, and mega-regional level. Ms. Heywood and the author have collaborated in the development of the following table to help compare the "Penn Station of the West" with its century-old neighbor:

Table 4-1: Comparison of Tranbay Transit Center and Penn Station

	Transbay Transit Center	Penn Station
Platforms/Tracks	3/6 (potentially shared-use)	11/21 (some shared-use, some exclusive)
Owner	Transbay Joint Powers Authority or Private Partner	Amtrak
Operating Railroads	California HSR, Caltrain	Amtrak, New Jersey Transit (NJT), Long Island Railroad (LIRR)
Operating Configuration	Caltrain and HSR will enter and exit on three tracks (with interlockings) from the south	NJT enters from Hudson River Tunnels (west), LIRR enters from the East River Tunnels (east), and Amtrak accesses from Empire Connection (west) as well as Hudson/East River Tunnels
Dispatching/Control	TBD—likely Caltrain since Caltrain already dispatches 51 miles of corridor south of terminal	Amtrak (for Amtrak and NJT) and LIRR (for LIRR trains)
Peak Hour Service Levels	6 HSR, 2 commuter (planned)	8 Amtrak, 39 NJT, 26 LIRR (current)
How do tenant railroads add additional train services?	TBD	Amtrak and LIRR control dispatching; permanent new service unclear, limited by tunnel capacity
Passenger Facility Charges	TDB—TJPA suggested a small surcharge on tickets for Caltrain and California High Speed Rail	Unknown
Planned Improvements	Tail tracks and train box extension to allow for storage of additional trains	• Gateway Tunnels to supplement Hudson River tunnels • Addition of Metro-North Railroad service (due to East Side Access in Grand Central Terminal and shift of some LIRR trains to Grand Central) • Two new concourses for passenger circulation
Key Capacity Concerns	Caltrain demand will exceed supply with only 2 trains per hour per direction; shared platforms	No additional capacity in Hudson River Tunnels, concerns about stability of tunnels due to Hurricane Sandy damage

Source: Author and Rebecca Heywood

One of the key differences between the Transbay Transit Center and Penn Station is the ownership structure. There is not a "Penn Station JPA" that might act as an unbiased arbiter of rail capacity in the terminal; Amtrak is the owner and exercises its ownership power at the expense of New Jersey Transit.

Since the Hudson River Tunnels are at capacity during the peak hours, Amtrak does not currently accept new services from New Jersey Transit, forcing many commuters to transfer to the select New Jersey Transit trains that run direct to Penn Station on the other side of the Hudson River at Secaucus Junction or Hoboken Terminal. Because the tunnels are at capacity (at 24 trains per hour), it becomes a zero-sum game: if Amtrak wanted to add a train across the Hudson during the peak (e.g. an extra Northeast Regional, Acela, or any of the 8 other Amtrak routes that use the Hudson River tunnels), New Jersey Transit would have to remove one of their peak trains from the system.

Transbay will likely face capacity challenges of its own; but fortunately as of yet, the two operators still have time to find a better method for sharing control of capacity allocation in the system. If Caltrain has too much control, it will be difficult for the high-speed rail authority to find a private concessionaire to finance the first phase of the high-speed project. If the CHSRA has too much control, commuters on the Peninsula and in San Francisco will lose access to the most valuable (in terms of convenience to residents and jobs) station in the Caltrain system.

In the next section, we imagine how operators will respond to an infrastructure owner such as the Transbay Joint Powers Authority and how that response affects the level of service experienced by intercity travelers and commuters alike.

4.8 Analyzing the Financial Relationship between Railway Industry Players in Shared Railway Systems

The following section is adapted from TRB-2015-15-1697, a paper written by this author, Maite Pena-Alcaraz, and Alex Prodan, which examines the train operator's perspective in shared railway systems. The original paper used the Northeast Corridor as a case study (Levy et al. 2015). This thesis adapts the model to examine operations on the Peninsula and at the Transbay Transit Center. Parallels can be drawn between the Northeast Corridor (NEC) between Boston and Washington, D.C., and the Peninsula Corridor. Both corridors host (or will host) a mix of freight, commuter, and intercity passenger rail and both have multiple owners (assuming PCJPB does not take ownership of the Downtown Extension).

The federal 2008 Passenger Rail Investment and Improvement Act (PRIIA) addressed Amtrak's role as the majority owner and sole intercity passenger operator on the corridor (PRIIA 2008). Section 208 requires Amtrak to develop a plan to bring the corridor to a state of good repair. Section 212 of the law requires the establishment of the Northeast Corridor Infrastructure and Operations Advisory Commission. The role of this commission is to develop a plan for the future of the corridor, including a plan to charge infrastructure track-access charges (fees). Amtrak must not cross-subsidize commuter, intercity and freight services, and each service must pay the costs incurred by operating that service on the network (can be interpreted as "operating/marginal/direct cost recovery"), as well as proportionate costs that can be distributed to more than one service (can be interpreted as "fixed cost recovery"). The NEC Commission released their proposed policy framework that allocates costs based on a variety of metrics such as train moves, train miles, and gross-ton miles, in January 2015. The law, however, does not change the status quo of having Amtrak be the sole intercity passenger operator on the NEC.

4.9 Modelling the Train Operator's perspective

This model analyzes a corridor capable of supporting high-speed and commuter rail services along a corridor. This is not unlike the NEC or the future Peninsula corridor. Rail capacity is fixed in our medium-term time horizon; that is, there is no opportunity to make infrastructure improvements that will increase the maximum train throughput of the corridor. Train operators may be able to adjust their capacity to better serve the users in this time frame. For the purposes of this thesis, freight traffic is ignored, but we acknowledge the importance of both passenger operators reaching an agreement with Union Pacific on the corridor.

4.9.1 System Players

Five main players are being considered in this analysis: society, the government, the regulator, the IM, and train operators. Behind each entity's actions are differing motivations.

Society represents the view of the best interests of the entire population. On the Peninsula corridor, this represents intra-city California travelers as well as commuters.

The ***Government*** is usually the investor in the infrastructure and does not necessarily represent the same views as society. The government is responsible for creating laws and regulations that govern different aspects related to operating the railway, from financial relationships between different players to safety of operations. On the Peninsula Corridor, this might be the California State Legislature or the three counties—San Francisco, San Mateo, and Santa Clara—through which the corridor traverses.

The ***Regulator*** is responsible for enforcing existing laws and regulations. In the EU, each state's regulator is responsible for ensuring that the state's national legislation is followed by all other entities. In the US, the Federal Railroad Administration regulates safety on US railroads.

The ***Infrastructure Manager (IM)*** is the entity that, at a minimum, is responsible for managing and maintaining the infrastructure. As of today, the plan is for the Transbay JPA or its public-private partner to be the infrastructure manager for the Downtown Extension and the Transbay Transit Center. For the purposes of this thesis, we will also imagine an infrastructure manager for the entire Peninsula Corridor, a fictitious "Peninsula Infrastructure Management Organization" (PIMO).

Train Operators (TOs) are the entities providing passenger or freight services. They may or may not receive subsidies, but it is assumed that any entity (perhaps, the counties of San Francisco, San Mateo, and Santa Clara) subsidizing rail operators is separate from the IM; that is, the IM will be under no obligation to favor one operator over another.

In the United States, commuter train services are sometimes planned and offered for bid by railway agencies while railway operators provide operations staff, perform maintenance, and collect fares. By our definition, the Peninsula Corridor Joint Powers Board is an example of a railway agency, while Veolia Transportation or TransitAmerica Services are examples of railway operators. For the purposes of this paper, all references to TOs would refer to both players; the operator of commuter rail services on the Peninsula will be referred to as "Caltrain."

4.9.2 Understanding the Relationship between TJPA/PIMO, Caltrain, and the California HSR Operator

One of the key goals of this section is to understand how different players respond to capacity access charges that a third party might impose on Caltrain or CHSR. Therefore, the focus in our overall work will be primarily on the relationship between Train Operators and Infrastructure Manager (CHSRA and Caltrain operating and TJPA or PIMO managing). We will develop a model for the relationship between train operator and infrastructure manager and then apply it to both a high-speed rail operator (CHSR) and a commuter operator (Caltrain).

4.10 Modelling the Train Operator-Infrastructure Manager Relationship

This paper analyzes a corridor capable of supporting high-speed or long-distance passenger service and freight rail service as well as commuter rail service around large urban areas along the corridor. This is an accurate representation of the Peninsula Corridor, with the exception that high-speed rail will go beyond the corridor's limits In this model, capacity is fixed in our medium-term time horizon; that is, there is no opportunity to make infrastructure improvements that will increase the maximum train throughput of the corridor. However, train operators may be able to adjust their capacity (e.g. adding to service levels) to better serve the users (traveling public) in this time frame.

In order to analyze TO profits and cash flows, a simplified model that captures main revenue and cost streams is proposed for the medium-term time-horizon (PPIAF 2011). TOs are assumed to be rational entities, and will only operate if their cash flows (after recovering capital costs at an adequate rate of return) are positive in the medium term; for a subsidized entity such as Caltrain, government subsidies are included in these cash flows. TOs are driven by profit maximization. TOs' main decisions are 1) the number of services that they are willing to operate, 2) their willingness to pay to access the infrastructure, and 3) the fares that they will charge the final users. We acknowledge that passenger rail operators may have public service requirements that dictate minimum frequency levels, service spans, or fare ceilings; but nevertheless, profit maximization are the operators' objective.

While there is intermodal competition (e.g. commuter rail versus automobile traffic or bus transit service), it is assumed that there is no intra-modal competition: there is no direct competition for traffic in the corridor between operators. The only time at which that operators compete directly is when competing for available track capacity where they can run scheduled services. We also assume that the services, offered by different TOs, are not substitutes. In the case of California, this is mostly true, though the CHSRA predicts that a small share of ridership (about 1500 riders per day) will be concentrated in Northern California, and consequently, competing almost directly with Caltrain (CHSRA 2014).

4.10.1 Train Operator Profits and Cash Flow

TO profits and cash flow can be determined by analyzing TO revenues and costs for a given number of trains, n. A TO faces cost of accessing the tracks, $ac(n)$ or track-access charges, some fixed costs, fc, such as the cost of buildings and the purchase of trains, and variable costs of operating trains, $vc \cdot n$, such as fuel, personnel, train maintenance, and train lease, if trains are being leased.

The two main sources of revenue come from the government, s (subsidies), and from transporting users (passengers). The revenues obtained from transporting users can be determined by multiplying the fare (f) by the demand served. The demand served is limited by either the capacity (reduced by a reasonable average load factor) of the trains ($c \cdot n$) by user demand (d). According to literature, user transportation demand depends fundamentally on the fare (f), the frequency of the service (proportional to $\frac{1}{n}$), and the travel time (tt) (Bebiano 2014). While intercity passengers are typically more sensitive to the fare and the travel time, commuter passengers are typically more sensitive to the fare and the frequency.

Summarizing, the costs and revenues of a TO can be determined using the following formulas:

$$Cost(\boldsymbol{n}, \boldsymbol{ac}) = fc + vc \cdot \boldsymbol{n} + \boldsymbol{ac}(\boldsymbol{n}) \qquad (4\text{-}1)$$

$$Revenues(\boldsymbol{n}, \boldsymbol{f}) = s + \boldsymbol{f} \cdot min(d(\boldsymbol{f}, \boldsymbol{n}, tt), \boldsymbol{n} \cdot c) \qquad (4\text{-}2)$$

Here, bold letters are used to denote the main TOs' decision variables. Please note that some of these variables may be pre-determined or conditioned by regulations. For instance, the fare of commuter services is typically set by the government (or the operating agency which is accountable to the government). Likewise, access charges under cost-allocation and priority-rule mechanisms are fixed inputs for TOs.

The TO level of service and the fares, given the access charges (*ac*), can be determined maximizing profits:

$$\max_{\boldsymbol{n},\boldsymbol{f}} revenues(\boldsymbol{n},\boldsymbol{f}) - costs(\boldsymbol{n}) \tag{4-3}$$

$$\max_{\boldsymbol{n},\boldsymbol{f}} s + \boldsymbol{f} \cdot \min(d(\boldsymbol{f},\boldsymbol{n},tt), c \cdot \boldsymbol{n}) - fc - vc \cdot \boldsymbol{n} - ac(\boldsymbol{n}) \tag{4-4}$$

Equation (4-4) is equivalent to: $\max_{\boldsymbol{n},\boldsymbol{f}} \boldsymbol{f} \cdot \min(d(\boldsymbol{f},\boldsymbol{n},tt), c \cdot \boldsymbol{n}) - vc \cdot \boldsymbol{n} - ac(\boldsymbol{n})$.

The TO willingness to pay to access the infrastructure, given the level of service and the fare (*n,f*), can be determined ensuring that the resulting cash flow is positive:

$$revenues - costs(\boldsymbol{ac}) \geq 0 \tag{4-5}$$

Note that capital expenditures and financing costs are also required to compute cash flows. However, we will assume that TOs have almost no CAPEX and negligible financing costs.

$$s + f \cdot \min(d(f,n,tt), c \cdot n) - fc - vc \cdot n - \boldsymbol{ac}(n) \geq 0 \tag{4-6}$$

$$\boldsymbol{ac}(n) \leq s + f \cdot \min(d(f,n,tt), c \cdot n) - fc - vc \cdot n \tag{4-7}$$

4.11 Results and Implications: A California HSR operator's perspective

The previous formulas can be further extended in different scenarios to understand the behavior of different types of TOs operating in a shared railway system. In this first scenario, we will use the these formulas to determine service level and fare when passengers' demand is a linear function of the fare, with some elasticity e

In this case, the elasticity is defined as $e = -\frac{\Delta d / d_0}{\Delta f / f_0} = -\frac{(d-d_0)\cdot f_0}{(f-f_0)\cdot d_0}$, and the demand as a function of the fare can be determined using $d(f) = -e \cdot \frac{d_0}{f_0} \cdot f + (1+e) \cdot d_0$.

4.11.1 Calculations:

The optimal level of service and fare (n^*, f^*) to maximize profits can be determined separating the problem in two subcases:

Case 1: If $d(\boldsymbol{f},\boldsymbol{n},tt) \geq c \cdot \boldsymbol{n}$, i.e., if the passenger demand is constrained by the capacity of the trains scheduled (as is likely the case with future Caltrain scenarios) then we can start computing the optimal fare for a given level of service $f^*(n)$. In this case, obtaining the fare that maximizes profits is equivalent to obtaining the fare that maximizes revenues. That means that maximizing fare with the objective of ensuring a demand ($d(f) = -e \cdot \frac{d_0}{f_0} \cdot f + (1+e) \cdot d_0$) still higher to or equal than the capacity ($c \cdot n$). Doing the computation we obtain:

$$f^*(n) = arg\max_f f \cdot c \cdot n : d(f) \geq c \cdot n \leftrightarrow f^*(n) = \frac{(1+e)}{e} \cdot f_0 - \frac{c \cdot f_0}{e \cdot d_0} \cdot n \quad (4\text{-}8)$$

Given this, the optimal level of service can be obtained maximizing profits:

$$n^* = arg\max_n s + f^*(n) \cdot c \cdot n - fc - vc \cdot n - ac(n) \quad (4\text{-}9)$$

Assuming that track-access charges are linear, as they essentially are in the Northeast Corridor ($ac(n) = ac_f + ac_v \cdot n$), the optimal level of service is either:

$$n^* = 0, f^* = 0 \quad (4\text{-}10)$$

$$n^* = \frac{(1+e) \cdot d_0}{2 \cdot c} - \frac{e \cdot d_0 \cdot (vc + ac_v)}{2 \cdot c^2 \cdot f_0}, f^* = \frac{(vc + ac_v)}{2 \cdot c} + \frac{(1+e) \cdot f_0}{2 \cdot e} \quad (4\text{-}11)$$

Note that these computations assume that any level of service is possible. Slight adjustments should be made to obtain the optimal solutions considering that possible service levels are discrete (integer number of trains).

Case 2: if, conversely, $d(\boldsymbol{f}, \boldsymbol{n}, tt) < c \cdot \boldsymbol{n}$**,** i.e., if the passenger demand is less than the train capacity, we can still compute the optimal fare for each level of service $f^*(n)$. Again, maximizing profits is equivalent to maximizing revenues. That means to maximize the revenue with the objective of ensuring a demand ($d(f) = -e \cdot \frac{d_0}{f_0} \cdot f + (1+e) \cdot d_0$) lower than the capacity ($c \cdot n$). Doing the computation we obtain:

$$f^*(n) = arg\max_f f \cdot d(f) : d(f) \leq c \cdot n \leftrightarrow f^*(n) = \frac{(1+e)}{2e} \cdot f_0 \quad (4\text{-}12)$$

Given this, the optimal level of service can be obtained maximizing profits:

$$n^* = arg\max_n s + f^*(n) \cdot d(f^*(n)) - fc - vc \cdot n - ac(n) \quad (4\text{-}13)$$

Assuming again that track-access charges are linear ($ac(n) = ac_f + ac_v \cdot n$), we obtain that the optimal level of service is:

$$n^* = \left\lceil \frac{(1+e) \cdot d_0}{2 \cdot c} \right\rceil, f^* = \frac{(1+e) \cdot f_0}{2 \cdot e} \quad (4\text{-}14)$$

Summarizing, the optimal level of service and fare (n^*, f^*) to maximize profits are either:

$$n^* = \left\lceil \frac{(1+e) \cdot d_0}{2 \cdot c} \right\rceil, f^* = \frac{(1+e) \cdot f_0}{2 \cdot e},$$

$$n^* = \frac{(1+e) \cdot d_0}{2 \cdot c} - \frac{e \cdot d_0 \cdot (vc + ac_v)}{2 \cdot c^2 \cdot f_0}, f^* = \frac{(vc + ac_v)}{2 \cdot c} + \frac{(1+e) \cdot f_0}{2 \cdot e}, \text{ or} \quad (4\text{-}15)$$

$$n^* = 0, f^* = 0$$

4.11.2 Implications:

Despite the complicated mathematical expressions, these formulas can be distilled to obtain some implications:

1. When variable costs are small with respect to the fares that users can afford, the optimal solution is to maximize revenues and offer the minimum number of trains that allow serving all the demand for the optimal fare.
2. When variable costs are comparable to the fares that users can afford, the optimal solution is a trade-off between maximizing revenues and covering variable costs. In this case, the capacity provided by the TO should be optimized in such a way that most passenger demand is served without providing excess train capacity.
3. Finally, in those cases in which the users cannot viably accept a fare level that allows TOs to cover at least the variable costs, the TO should not operate any train.

We can illustrate these points with an example using data derived from CHSRA's operational cost estimates.

According to the CHSRA's 2012 business plan, it faces fixed operational (direct) costs of $fc = \$400.2\ million$ per year ($fc = \$1.124\ million$ per day) and variable operational costs of $vc = \$41.6\ million$ per train and per year ($vc = \$10{,}400$ per train and per day). The elasticity of the demand is estimated to be equal to $e = 0.67$ (Lago et al, 1981). The CHSRA predicts an average fare to be $47.68 per rider (averaged across all riders, regardless of distance traveled) and the level of service to be $n = 219$ trains per day, with a realized demand of $d_0 = 76{,}400$passengers per year ($d_0 = 76{,}400$ passengers per day), and with an average train capacity of $c = 760$ passengers, with 80% load factor (Morrison 1990). We found the 80% load factor, a measure of train seat capacity utilization, to be a reasonable input given CHSRA's business plans and Amtrak's NEC 2015 financial plan and operating data (CHSRA 2014, Amtrak 2014). Again, for the purposes of our equations, since the CHSRA expects the train to be at worst revenue neutral, the operator does not receive operating subsidies, meaning $s = 0$.

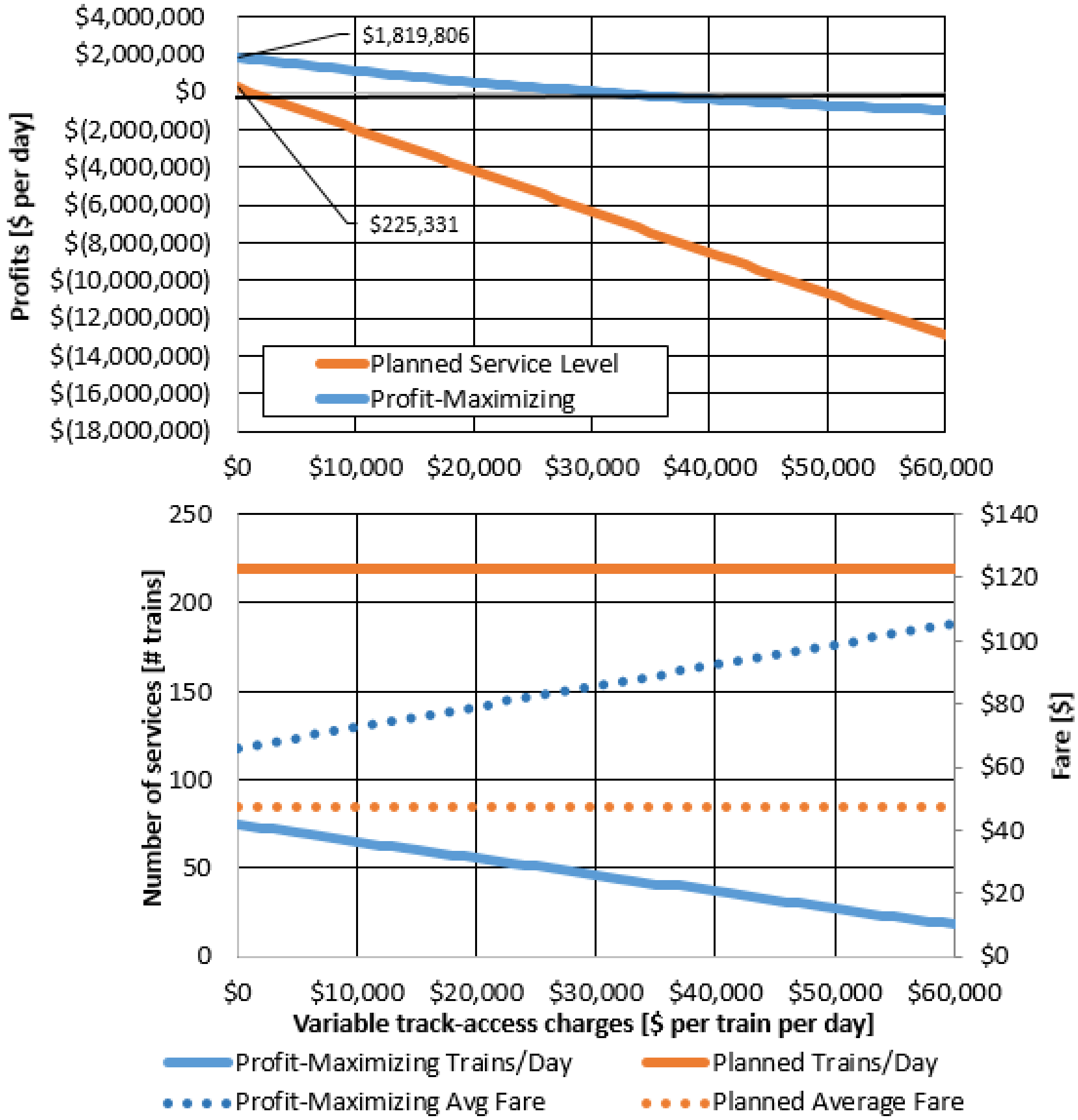


Figure 4-2: California High-Speed Rail Operator Response to Access Charges

Figure 4-2 represents the CHSR operator's expected profits when the strategies presented in Equation 4-15 are used to determine the level of service and the fare. We then compare the profits and service-decisions obtained with these strategies to those obtained using planned levels of service and expected average fares.

While these numbers are based off of forecasts and omit many details regarding actual operational procedures (e.g., number of services is not a good indicator of the mix of services or whether or not the trains arrive at ideal times), it does reasonably model the impact of an access charge for part of the infrastructure. As the access charge increases, the profit-maximizing operator will decrease services and increase fares; in essence, the operator passes PIMO's "Peninsula tax" on to its customers. This would open up space at the Transbay Transit Center for commuter rail services at the expense of intercity California travelers. The model shows that the access charge quickly becomes unbearable for the projected operator's business plan. Even so, if San Francisco represented enough revenue, the operator may still choose to concentrate its services there.

One shortcoming of this model is that is does not take into effect the elasticity of frequency. Frequency is important up to a point. Again, we draw a parallel to the air travel market and refer to Belobaba's *Global Airline Industry* text:

> There exists a "saturation frequency" in each market, defined as the point at which additional frequency does not increase demand, even for business travel). For example, in the short-haul Boston–New York shuttle market, two competitors currently each offer non-stop flights every hour (one at the top of the hour and the other at 30 minutes past each hour), such that flights in this market depart every half hour. It would measurable positive impact on the total volume of demand in this market (100).

We believe that a profit-maximizing operator will survive longer by cutting some of its Peninsula service. The operator will do this because, even with poor frequency, the value of the direct-to-downtown service is attractive to the business traveler. Once the access charge crosses a certain threshold—in our model about $35,000 per train per day ($1028/train/day for the planned service levels)—the high-speed operator is no longer profitable and the Peninsula would stop seeing high-speed rail service.

This model also shows what might happen if there were some kind of CHSRA-imposed fare ceiling on the operator. Because our price elasticity is less than -1, the lower fares would stimulate more demand and the operator would need to offer more services to capture additional passengers and make up the revenue loss. This would, in turn, put more demand on the limited Peninsula infrastructure. Similar results are obtained for a broad range of fare elasticity values: lower elasticity representing business users willing to pay high fares to ride convenient CHSR services, and higher elasticity representing additional users that start to ride CHSR instead of other transportation alternatives.

4.12 Results and Implications: The Commuter Rail Operator's Perspective

Next, we will take a look at a slightly different scenario for a commuter rail operator's perspective. Here we assume fares are constant either because demand is very elastic to fares, i.e., almost all the demand is lost if a user's fare is above certain fare threshold, or fares are set by the government(f_0)) Instead of demand being dependent on fares, demand depends on level of service.

In this scenario, the elasticity to the level of service can be defined as $e_n = -\frac{\Delta d / d_0}{\Delta h / h_0}$ where h is the average headway between consecutive trains. Since the headway is proportional to $1/n$, the elasticity can also be computed as $e_n = -\frac{(d-d_0)\cdot n}{(n-n_0)\cdot d_0}$. Therefore, the demand can be determined by $d(n) = (1+e_n)\cdot d_0 - \frac{e_n \cdot d_0 \cdot n_0}{n}$.

4.12.1 Calculations:

The optimal level of service and fare (n^*, f^*) to maximize profits can be determined repeating the same type calculations carried out in the high-speed operator example. Assuming again that track-access charges are linear ($ac(n) = ac_f + ac_v \cdot n$), it is determined that the optimal level of service that a TO can operate would be either:

$$n^* = \sqrt{\frac{f \cdot e_n \cdot d_0 \cdot n_0}{vc + ac_v}},$$

$$n^* = \frac{(1+e_n) \cdot d_0 \cdot n_0}{2 \cdot c} - \frac{\sqrt{(1+e_n)^2 \cdot d_0^2 \cdot n_0^2 - 4 \cdot c \cdot e_n \cdot d_0 \cdot n_0}}{2c}, \text{ or} \tag{4-16}$$

$$n^* = 0$$

The operator's choice of one level of service over the other would depend on how revenues and cost compare. If revenues obtained from fares are much higher than variable costs, then the optimal strategy to maximize profit would be to maximize revenues. If revenues are comparable to variable costs, the optimal strategy would be to ensure that there is no excess-capacity on the trains. Finally, if variable costs are higher than the revenues per train, the TO should not operate any trains.

Note that this level of service is independent of the level of subsides and the fixed costs (from operations and access-charges). These values would only affect to whether the TO's cash flow are positive and hence the TO can sustainably operate these level of service.

4.12.2 Implications

This scenario is representative of the situation of the commuter rail train operators, including an operator such as Caltrain. Caltrain faces fixed operational (direct) costs of $fc = \$142{,}614$ per day and variable operational costs of $vc = \$2{,}406$ per train and per day. Fixed and variable costs were determined by checking Caltrain historic service levels and plotting against operating costs from Caltrain operating budgets using the assumption that the relationship is linear as follows:

$$Total\ costs = fc + vc * trains/day$$

Given that this is an oversimplification (variable costs are also dependent on passenger demand, staffing levels, etc.), we adjust fixed costs so that Caltrain runs its services with a balanced operating budget (as it does today).

The elasticity of the demand with respect to the headway (the inverse of frequency) is estimated to be equal to $e = 0.41$ (Lago et al 1981). In 2014, Caltrain's average fare was \$4.62 (for simplicity, operating revenues divided by ridership), the level of weekday service averaged $n_0 = 92$ trains per day, with a realized demand (daily rideship) of $d_0 = 52{,}611$ passengers per day. Each train's seated capacity is $c = 650$. Again, we realize that Caltrain has the potential to carry much more than its seated capacity (several weekday trains today do in fact have loads as high as 120% of seated capacity and seats do "cycle" as average trip length on the 51-mile corridor is just over 20 miles), but we simplify to reach an interpretable model. Subsidies are $s = \$121\ thousand$ per day and are based on historical operating budgets.

Figure 4-3 compares current Caltrain operating profits with the expected profits when the profit maximizing strategy presented in equation 4-16 is used to determine the level of service. The results show that higher profits can be unlocked by reducing the number of services, especially when variable costs increase due to track-access charges. Please note that even under the profit maximizing strategy, despite the subsidy, Caltrain would not be able to operate if access charges exceed \$575 per train per day, since the variable costs of operating the train would be higher than the revenues obtained. As a result, operating a train would only increase the cost burden for the system.

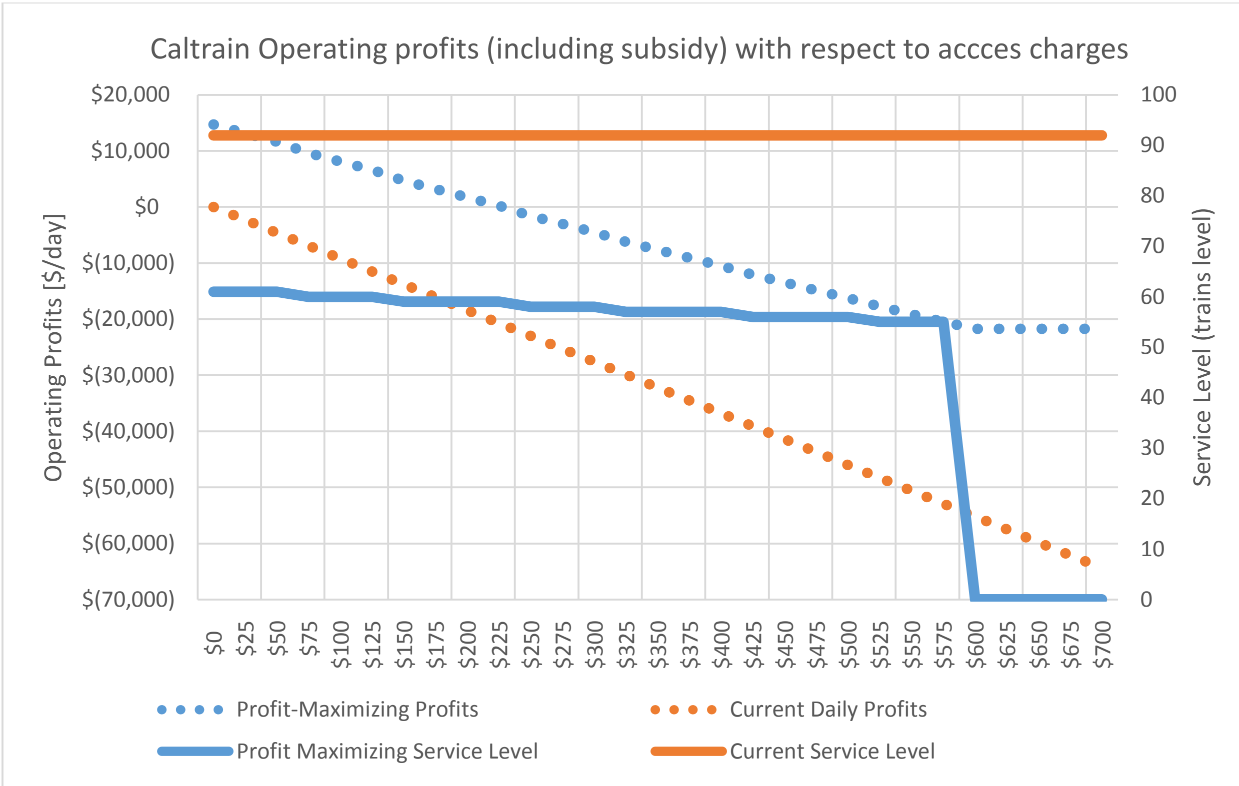


Figure 4-3: Caltrain Response to Access Charges

This model validates what we already know to be true: Caltrain operates a lot of trains that serve a public-utility benefit. Mid-day and late night trains are unlikely profitable, but Caltrain's mission is to meet the growing mobility needs of the San Francisco Bay Area region, so these trains are operated in spite of the loss to the agency.

Unlike the model for the high-speed operator, we hold fares constant and only assume an elasticity to travel time under the assumption that 1) the commuting public likely values this travel time, and, by extension, frequency (see Chapter 3) enough that fares have a minimal effect on ridership choices[13], and 2) significantly raising fares is politically challenging for a government agency due to intense public opposition to fare increases.

As the access charge to run trains increases, the "Caltrain-for-profit" strategy ceases to be sustainable either. At approximately $250 per train per day, the access charges force the already-subsidized operator into operating losses. While these values are approximate given the simplifications we make for the two models, we see an order-of-magnitude difference between the high-speed rail operator's and the commuter rail operator's willingness to pay. The California HSR operator has two orders of magnitude greater the ability to pay for an access charge to San Francisco or the Peninsula. How will an infrastructure manager react to this knowledge? We will now discuss the impact of this disparity from the infrastructure manager's point of view.

[13] The *Silicon Valley Business Journal* reported that the average annual income of a Caltrain rider is $117,000 suggesting that time is likely a more important consideration than fare (Weinstein 2014)

4.13 The Infrastructure Manager's Perspective

As noted earlier, the benefit of an independent infrastructure manager such as the fictitious "PIMO" or the planned Transbay Joint Powers Authority or the Transbay private-public partner is that independence lessens the likelihood of a Penn Station scenario where one operator gets preference over the other. However, even with a lack of institutional bias, any third-party operator would likely prefer to do business with an operator with a two orders of magnitude greater willingness to pay than a competing operator. Before we continue, however, we will perform a quick estimation of the Transbay Joint Powers Authority's (or PIMO's) need in terms of access charge revenue.

We will use cost data from the CHSRA's 2012 business plan report and Caltrain's 2015 operating cost data to derive cost estimates for the infrastructure manager's costs:

Table 4-2: Operating Cost Estimate for Infrastructure Manager

Infrastructure Manager Cost Estimate			Transbay JPA		PIMO (SF Peninsula)	
		Cost/Unit	Count	Total	Count	Total
Shared Station	Each	$4.1M	1	$4,100,000	3	$12,300,000
Commuter Station	Each	$116,000	-	-	27	$3,132,000
Track Maintenance	Route Miles	$200,000	2	$400,000	110	$22,000,000
Traction Power	Train-Set Miles	$7.45	147,570	$1,099,393	5,789,265	$43,130,024
Administration & Support	8% of cost	NA	-	$447,951	-	$6,444,962
Contingency	5% of cost	NA	-	$279,970	-	$4,028,101
			Total Annual Cost	**$6,327,314**		**$91,035,087**

Sources: CHSRA Operation and Maintenance Methodology from 2012 Business Plan, PCJPB, Author's Calculations

Using this simple cost estimate, we can see how many trains per day the infrastructure owner needs to schedule given a certain access charge. Keep in mind that the values shown in the next table are only the access charges needed to recover enough to cover costs; that is, at these service levels, the infrastructure manager would not be able to make investments in infrastructure expansion. Also, this table assumes that each train is charged an equal price for using the infrastructure at certain times. In Europe, capacity is often priced more expensively at peak periods and we might expect the same to hold true at the Transbay Transit Center.

Table 4-3: Estimated Trains/Day for an Infrastructure Manager to Fully Recovery Operating Costs

Access Charge per train	Transbay	PIMO
$50	347 trains/day	4988 trains/day
$125	139	1995
$250	69	998
$500	35	499
$1,000	17	249
$2,500	7	100
$5,000	3	50
$10,000	2	25
$15,000	1	17
$20,000	1	12
$25,000	1	10
$30,000	1	8
$35,000	0	7
$50,000	0	5
$75,000	0	3
$100,000	0	2

Source: Author's Calculations

Assuming neither operator has a budget constraint and desires to run the services outlined in their respective future operating plans, Table 4-3 shows that an infrastructure manager at the Transbay Transit Center would need to charge an average per train access fee of approximately $125 per train to recoup annual infrastructure costs. These charges are in line with similar charges on a per-train-mile basis to those in Europe according to a 2014 UIC report (Prodan and Teixiera). An infrastructure manager for the entire Peninsula would need to charge a fee much closer to $2500. We determined earlier that $2,500/train is out of Caltrain's price range given current costs, but current costs would be much lower if Caltrain did not have to maintain the 51-miles of infrastructure and stations it does today[14].

Returning to the $125 value, from an order of magnitude standpoint, we find that that access charge is well-within the capabilities for a high-speed rail operator, though it would be a significant burden for Caltrain at current subsidy levels. Even if we were to assume, however, that Caltrain could receive additional subsidies so that it could compete with a high-speed rail operator, there would need to be some form of check on the Transbay JPA to keep charges reasonable. A Caltrain operator with seemingly bottomless subsidies and a high-speed operator with a large willingness to may lead to both operators paying higher access charges. In his thesis, Sakamoto expressed a similar concern with Trenitalia, the state-owned railway in Italy, which could conceivably cover any losses with increased

[14] The author is not able to estimate Caltrain's costs if it were an operations-only entity. However, at an author-estimated revenue of about $4,000 for a peak hour train (average fare x ridership), $2,500 would not be an insignificant about for the agency.

subsidies (2012). This "unbalanced competition" as Sakamoto warns, will be felt by the passengers in the form of increased ticket prices.

4.14 Implications of our Train Operator and Infrastructure Manager Models

Since we have determined it would be difficult for the high-speed rail operator and Caltrain to compete on a level playing field for access to the Transbay Transit Center due to the fiscal strength of the high-speed rail operator, perhaps there are other methods for allocating space. Why is it important that Caltrain have access to the Transbay Transit Center? If the high-speed operator can afford it, should it not have as much access as it wants? This author's response to that premise is that Caltrain service generates many of positive externalities including travel time and savings for individuals driving on adjacent freeways, the environmental and public health benefits of less congestion, and the agglomerative benefits of connecting San Jose and Silicon Valley with San Francisco. In a pure-willingness to pay (monetary) access charging scheme, those externalities are difficult to measure. And while it is true that high-speed rail also offers some of these positive externalities, we assume that high-speed rail riders will have other choices (e.g. take Caltrain from San Jose as a "last leg") that Caltrain riders may not necessarily have.

As an alternative to a monetary access charge, instead, for example, capacity could be allocated on a points instead of monetary basis. This would mean giving each operator a set number of "points" and then allowing operators to place bids for specific train using those points. This would conceivably allow a commuter rail operator like Caltrain to have a better opportunity in securing train-paths into the Transbay Transit Center than if it is only based on a pay-for-access policy. This would require some form of auction to allocate train paths according to an operator's interest in accessing the Transbay Transit Center at a particular time. However, because of the interdependence of one train path on the train paths of the other operators, there is potential for "gaming" an auction system by protecting certain time windows with high bids. Also, as Maite-Pena Alcaraz points out in her thesis, there is an inherent uncertainty associated with auctions (2015). This uncertainty means that operators will not know their rolling stock or staffing needs until the timetable is set. And for the commuters, this uncertainty will invariably be passed on in the form of changing timetables and non-uniform headways.

In Chapter Two, we reviewed European capacity allocation policies. In general, most European states create their timetables by negotiating conflicts and then referring to some sort of priority rule scheme if the conflicts cannot be resolved. Priority rules (such as HSR takes priority during peak times) would undoubtedly solve conflicts between PCJPB and CHSRA and provide the California HSR operator with a better sense of the revenue risks associated with the blended system, but the fact remains that capacity into the Transbay Transit Center and along the line is constrained no matter how trains are scheduled.

The author would like to emphasize that freight access is not even considered in this model. While freight on the Peninsula appears to not be concerned with rail access during the peak period, it does create certain constraints during the midday that will be detrimental to the service quality provided by either Caltrain or HSR unless addressed.

4.15 Conclusions

In this chapter, we took an in-depth look at the levels of coordination between the CHSRA and PCJPB in developing the operational aspects of the blended system on the Peninsula. In short, given how high-speed rail will radically and forever change rail service on the Peninsula, there remains much work to be done in terms of capacity coordination between the two agencies. Though we reviewed some of the physical challenges of sharing track in Chapter Two, aside from the brief section on platform sharing and its effect on capacity, this chapter purely addressed capacity along the line and into and out of the Transbay Transit Center. Aside from access to the corridor and the terminal, the two agencies need to coordinate on other issues such as positive train control, California Public Utilities Commission regulations on freight traffic on electrified corridors, additional safety precautions and maintenance required for 125mph track, maintenance windows for track repairs, etc. In its comments on the 2014 CHSRA business plan, the California HSR Peer Review Group noted the PUC regulations for electric catenary and the potential redundant positive train control system as two key non-capacity related issues. The Peer Review Group goes on to say that these represent "near term decisions" that could be "made by the parties acting separately that would ultimately compromise the performance of the system." In July 2013, PCJPB published a Caltrain/HSR Blended System Planning Process chart, which is depicted in Figure 4-4

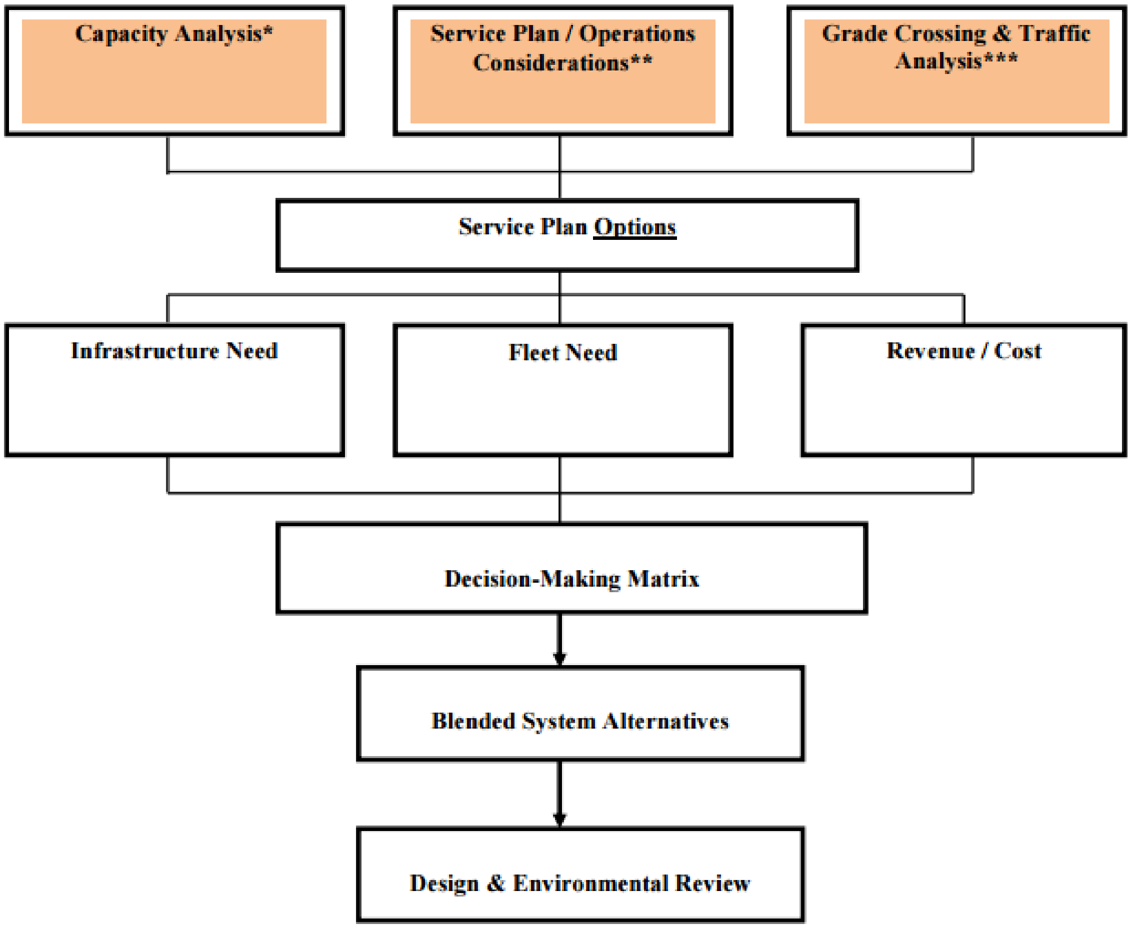


Figure 4-4: Caltrain/HSR Blended System Planning Process
Source: PCJPB

The chart lists the three documents produced by LTK Engineering thus far, implying that the next step in the process is the Service Plan Options. Caltrain has not yet published service plan options, but is planning on issuing a request for proposals for trainsets in July 2015 and award a contract in the winter of 2015/2016. This suggests that the agency has skipped level two ("Service Plan Options") at this point and is proceeding with fleet procurement (step 3, "fleet need"). This step, as we will discuss later in this thesis, is critical to achieving a truly integrated system and a step both agencies skip at their own peril. In March 2015, the PCJPB hired a new CEO after their previous CEO retired. Their choice, former Redwood City councilman, Jim Hartnett, served previously on the boards of both the CHSRA and the PCJPB. Hartnett helped implement the 2009 MOU between the two agencies; writes in the *Palo Alto Weekly:*

> "When high-speed rail officials attended a meeting in Mountain View in November 2011 to discuss their new vision for the rail line, it fell to Hartnett to make the case for what is now known

> as a ‘blended system.’ . . .Hartnett called the new approach a ‘rethinking of the whole high-speed rail approach.’”

The hiring of Hartnett reflects the increased importance of the blended system in the eyes of the PCJPB board of directors and inspires hope for even higher levels of collaboration between the agencies.

In reviewing the blended service feasibility study, we conclude that the presence of high-speed rail, as planned, severely degrades the service quality experience by Caltrain riders. Users experience increased travel times and highly variable headways between trains that lead to gaps in service and crowding. Adequate commuter access to the Transbay Transit Center has not been considered (the author does not consider two trains per hour per direction “adequate” given the concentration of residences and jobs noted in Chapter Three).

This discussion brought us to the Transbay Transit Center, a vital station for both operators. Fortunately, unlike Penn Station in New York, neither operator is going to outright own the station—it will be owned and managed by a third-party, the Transbay Joint Powers Authority. However, it is quite possible that the TJPA eventually cedes control to one of the operators or at least, prioritizes one operator over another. We employ a train operator financial model to emphasize that the high-speed rail operator will likely have a much higher willingness to pay for access to the terminal than Caltrain. Given the planned third-party arrangement, there is also an opportunity for a transition to a third-party operator for the entire Peninsula corridor. There is a lot of uncertainty in the ultimate management arrangement of the terminal; and regardless of the ultimate structure, unless there are codified capacity access rules, this uncertainty will remain.

This uncertainty might be enough to drive away a potential private investor in the project. Because the CHSRA’s plan is to sell the right to construct (and then operate for profit) to a concessionaire, there needs to be significant revenue potential. Without the opportunity to fully capitalize on the prime location of the San Francisco station, this private investor takes on a revenue risk. Without a clear plan for the Peninsula Corridor, the CHSRA will have to finance that revenue risk; and potentially, the list of qualified private investment interest will shrink.

Finally, any kind of capacity allocation mechanism has network ramifications regarding service patterns and service levels for the rest of the high-speed rail operator’s network. Access to the Peninsula Corridor or Transbay Transit Center will dictate timetables customers experience on the rest of the network.

This thesis suggests that coordination and *integration*, in the spirit of the blended system as written in the 2012 CHSRA Business Plan, and not competition, is paramount to the success of the shared-use concept on the Peninsula. When CHSRA and Caltrain compete against each other for access to track, whether it is on the Peninsula or only at the Transbay Transit Center, both operators lose. We want to emphasize the importance of planning service before making large infrastructure investment decisions such as platform heights or shared facilities. Because of the high capacity utilization of the Peninsula Corridor, the blended service concept demands this approach. In the next chapter, we will examine how certain infrastructure and service decisions impact the long term service goals of Caltrain, the high-speed rail operator, and the rest of the operators (i.e. Amtrak, Metrolink, and COASTER) in the Golden State.

5 Southern California Blended Service—A (Relatively) Blank Slate

In the third and fourth chapters, we discussed the blended system in Northern California. We now turn to Southern California where the CHSRA also plans to blended services with local commuter rail agencies. While both system "bookends" have many of the same issues, the ultimate form of the blended system in Southern California is much less defined than its northern counterpart

5.1 Introduction: Southern California Rail Overview

Like Chicago, Southern California is a rail transportation hub for both freight and passenger services. Because of the strength of the Ports of Los Angeles and Long Beach, both BNSF and Union Pacific have large rail yards and intermodal facilities in the region.

Los Angeles Union Station just north of downtown serves as the nexus of passenger rail service in the region: Four Amtrak long distance trains and the majority of regional commuter rail lines originate or terminate in the historic station. Additionally Los Angeles is the main hub for Amtrak California's Pacific Surfliner, the busiest Amtrak route outside of the Northeast Corridor (Malouff 2013). The owner of the station, the Los Angeles County Metropolitan Transportation Agency, runs three rail transit lines through the facility as well. A beautiful California Mission-Revival rail terminal, Union Station hosts more rail services than any other station in California and is the second busiest Amtrak station outside of the Northeast Corridor.

In this chapter, we will review the rail network in Southern California. We will discuss challenges that the commuter rail players face in the present, as well as ones that are anticipated in the future. We will discuss the importance of Los Angeles Union Station to the CHSRA and regional railroads as well as the opportunity presented by the Southern California Regional Interconnector Project.

Southern California faces many of the same issues that we see on the Peninsula Corridor in Northern California. Freight and passenger rail share tracks in many corridors and the California High-Speed Rail Authority plans to operate "blended service" on approximately the same length of corridor. While no single passenger line experiences the demand seen by Caltrain in Northern California, long single-track segments and high-levels of freight constrain capacity. In 2008, a collision between a Metrolink commuter train and a Union Pacific freight train on a single track section in northwest Los Angeles County led Congress to require railroads to implement positive train control on shared corridors by the end of 2015; the Southern California Regional Rail Authority, appropriately, leads most of the nation on this front (Stagl 2013). Los Angeles, along with Chicago, should be considered a national hubs of freight-passenger rail interaction.

This chapter is shorter than the chapter looking at Northern California blended service for the simple reason that most of the blended service planning has yet to be completed at the time of writing. In fact, at the time of writing, not even the route is set: the CHSRA is currently studying a new route alternative between Burbank and Palmdale, California through the Angeles National Forest (Weikel 2015).

5.2 The Commuter Rail Players: SCRRA (Metrolink) and NCTD (COASTER)

The Southern California Regional Rail Authority (SCRRA), another California joint powers authority, is responsible for the planning, design, and operation of Metrolink, the largest commuter rail service in Southern California. Governed by representatives from five of the six counties in which it operates—Los

Angeles, Orange, Riverside, San Bernardino, and Ventura, SCRRA operates Metrolink services on a 512-mile network[15]. However, Caltrain, in the north, continues to have higher annual ridership on its Peninsula Corridor, which is 1/10 of the size of the Metrolink network. Metrolink carries fewer passengers for several reasons. First, jobs and housing in the region are not as concentrated around stations as they are on the Peninsula; last-mile transit connections are a challenge for many riders. Secondly, Metrolink's schedules provide less service frequency than Caltrain—its relatively minimal "reverse commute" service make it an unattractive service for commuters travelling away from downtown Los Angeles in the morning. Finally, because Metrolink runs a majority of its trains on a network owned by freight railroads (a significant portion of which is single-tracked), delays can create reliability and service challenges, though Metrolink has improved on-time performance—in part due to capacity improvements—in recent years (Gbenekama 2012).

In February 2014, Metrolink became the first commuter rail in the United States to use a positive train control system on its network (SCRRA 2014). The project uses Wabtec Corporation's Interoperable Electronic Train Management System (I-ETMS), a vendor agreed upon by the four Class One freight railroads, Amtrak (outside of the Northeast Corridor), and North County Transit District (NCTD) in San Diego, but interestingly, not the PCJPB (ibid). While the initial PTC implementation is on BNSF's track, Metrolink expects to add PTC capability in its own rail territory in 2015 (ibid)

In the south of the region, connecting with Metrolink in Oceanside, is the NCTD's COASTER. The other commuter rail service in the region runs between Oceanside and San Diego. The connections between Metrolink's Los Angeles-Oceanside line and Coaster's Oceanside-San Diego line at the Oceanside Transit Center are not very well coordinated. COASTER, while operating on its own corridor and one of comparable size to Caltrain's SF Peninsula Corridor, has lower ridership and service levels than Caltrain. As with Caltrain, the Union Pacific Railroad operates freight service along the corridor.

[15] Even though SCRRA operates Metrolink service into San Diego County to Oceanside, San Diego County is not represented on the Board of Directors

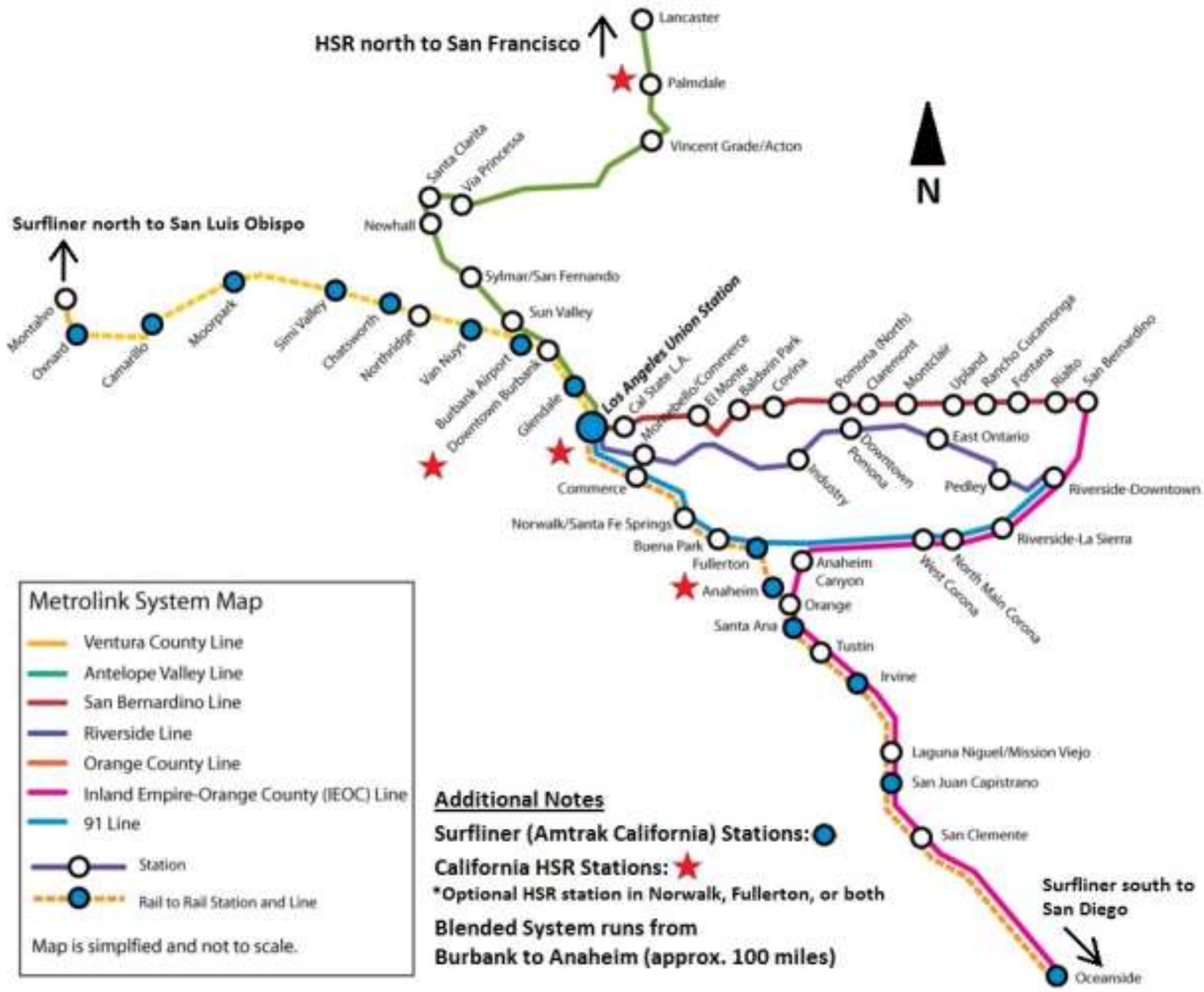


Figure 5-1: Metrolink System Map
Source: SCRRA, CHSRA, "Additional Notes" section added by author

5.3 The San Luis Obispo-Los Angeles-San Diego Corridor: Amtrak as Commuter and Rail2Rail

The other commuter rail passenger service in the region is Amtrak California's *Pacific Surfliner* (or "Surfliner"). Running over 300 miles between San Luis Obispo, Los Angeles, and San Diego, the Surfliner provides the one-seat ride between Los Angeles and San Diego that Metrolink and Coaster do not provide on their own. The Pacific Surfliner is managed by the LOSSAN (Los Angeles-San Luis Obispo) Joint Powers Authority with nine counties sitting on the board and staffed through the Orange County Transportation Authority. This switch from state management to local governance occurred in 2012 with the supposition that local management would provide—to quote the bill's sponsor, state senator Alex Padilla, "greater administrative, procurement and operational efficiencies that come with integration" (Gabbard 2012).

5.3.1 The Rail2Rail Program

Integration has thus far been fairly minimal with the exception of the Rail2Rail Program and a joint LOSSAN-specific timetable. While many of the Surfliner trains skip minor stops, it acts as a supplementary commuter service for both local Metrolink and COASTER commuters as well as those traversing across the boundary of the two networks at Oceanside. Metrolink and Amtrak California have negotiated a program in which Metrolink monthly pass holders can ride the Amtrak service on the LOSSAN corridor at no charge. NCTD and Amtrak California have taken Rail2Rail a step further: 6 of the 24 daily Pacific Surfliner trains stop at all of the COASTER stations and any type of passenger (single ride or monthly) can pay COASTER fare to ride on Amtrak (NCTD 2015)[16].

5.3.2 The Missed Opportunity at Oceanside

SCRRA's Metrolink and NCTD's COASTER both end their service at Oceanside, a station in the northern part of San Diego County. The trains operate the same Bombardier bi-level equipment and share platforms at Oceanside, yet through-running is rare; only during horseracing season at Del Mar south of Oceanside do Metrolink trains cross into NCTD territory (Hymon 2011). On top of the lack of through running, it is very difficult to make connections between the two systems. Commuters wanting to transfer northbound from a COASTER train to a Metrolink train bound for Los Angeles find that only two Metrolink trains meet with one of the 11 daily COASTER trains that arrive at Oceanside from San Diego. Commuters wanting to transfer southbound from a Metrolink train to a COASTER train bound for San Diego find that only two COASTER trains meet with one of the 6 daily Metrolink trains that arrive at Oceanside from Los Angeles. Displayed in small text at the corner of the LOSSAN – specific timetable is the warning that even those few transfer opportunities between Metrolink, and COASTER "are not guaranteed" (LOSSAN 2015).

Figure 5-2: The Oceanside Transit Center is a terminal for both Metrolink (M) and COASTER (C); Only Amtrak California Surfliner trains (A) run through the station
Source: LOSSAN

Figure 5-3: The Oceanside Transit Center is a terminal for both Metrolink (M) and COASTER (C); Only Amtrak California Surfliner trains (A) run through the station
Source: LOSSAN

[16] NCTD pays Amtrak California $4.28 for each COASTER passenger that uses the service. SCRRA has a similar agreement in place for a single roundtrip each day on the Ventura county line as well as trips between Los Angeles and Bob-Hope Airport

5.4 Freight Presence

Freight has a large presence in Southern California, and with the large port complex of Los Angeles and Long Beach coupled with the low-costs of long-distance rail freight transportation, rail freight volumes in the region continue to grow. The blended corridor in Southern California will run along the BNSF's San Bernardino Subdivision from Hobart Yard near Union Station to Fullerton. According to the Southern California Association of Governments (SCAG), this corridor saw 45 freight trains per day in 2010 and is projected to grow to 90 freight trains per day in 2035 (2012). The line from Burbank to Union Station is owned by SCRRA, but Union Pacific operates about 10 trains per day on that section as well via trackage rights as it is the link between Los Angeles and the Central California coast (Leachman 2011)

While the CHSRA's relationship with freight will to be important across the state, it is on these blended corridors that it is critical. The Peninsula Corridor sees low (but continuous) freight traffic and freight is a tenant on the rail line. In Southern California rail goods movement is a vital part of the regional economy and high-speed rail will operate on freight-owned infrastructure. Any decisions made regarding service on the blended corridor in Southern California will need to have Union Pacific and BNSF at the negotiating table.

5.5 Los Angeles Union Station

Los Angeles Union Station is a critical piece of passenger rail infrastructure in California. With 14 tracks used by three rail operators (Metrolink, Amtrak, and Amtrak California), it will be an important hub for a high-speed rail operator and its future demands careful consideration.

5.5.1 Transit Hub

One of the reasons Union Station is so critical to high-speed rail is that, like the Transbay Transit Center, it is a transit hub in the Los Angeles region. It is best connected to Los Angeles' population centers and will continue to serve as a regional transportation hub regardless of the ultimate success of high-speed rail. Metrorail, the Los Angeles subway, operates on 7-minute headways during the rush hour peak. A project is under construction to bring two more of Los Angeles' heavily-patronized light rail lines (in addition to the existing Gold Line) into the terminal as well (LACMTA 2015). For a high-speed rail passenger without a car, these connections are critical and will make the train much more competitive with the automobile.

5.5.2 Run-Through Tracks

One of the regional rail projects with the greatest potential to change service patterns in Southern California are run-through tracks at Union Station.

Union Station is currently a "stub-end" terminal, meaning that trains must leave and enter on the same tracks. This causes both congestion on the tracks leading into the station as well as operational delays as trains must either "back in" or "back out" of the station.

Figure 5-4: Los Angeles Union Station run-through tracks
Source: RailPAC/L.A. Times

Figure 5-5: Los Angeles Union Station run-through tracks
Source: RailPAC/L.A. Times

The run through tracks are known as the Southern California Regional Interconnector Project (SCRIP)[17] This $350 million effort will save through travelers 15-20 minutes of travel time and increase Union Station's rail capacity (definition of capacity unknown) by 40-50% according to Los Angeles Metro, the leading agency on the project (Wiekel 2014). Currently, all trains arriving and departing from and to San Diego to the south, San Luis Obispo and Santa Barbara to the north, and San Bernardino County to the east all use the same approach tracks to the north of the terminal. The four run-through tracks (some of which will be used by high-speed rail trains) will add a high degree of flexibility for express services and inter- and intra-agency transfers and coordination. Construction is scheduled to be completed in late 2019 or early 2020 (ibid).

5.6 Adding HSR to the Mix: The Southern California Blended System

As part of their new business plan in 2012, the CHSRA chose to pursue a blended system in Southern California conceptually similar to the blended system in Northern California. As in Northern California, freight rail will remain on the corridor. At the time of writing, this blended system runs approximately 50 miles from Burbank in the San Fernando Valley through Los Angeles Union Station and on through to Anaheim's newly-built Anaheim Regional Transportation Intermodal Center (ARTIC). Currently, electrification in Southern California is solely for high-speed rail. Metrolink and Amtrak California have no plans to electrify their systems. From 2022 to 2028, riders would transfer from high-speed rail at Burbank to diesel powered trains for the ride southward to Los Angeles and Anaheim. When the CHSRA completes Phase 1 in 2028, HSR trains would share tracks, but not stations, with Metrolink and the Pacific Surfliner south through Los Angeles and onwards towards ARTIC. Metrolink and the Surfliner, though, would continue conventional rail operation, though possibly at higher speeds than today.

Metrolink and Amtrak California also have no plans to change the specifications in terms of door height or floor height on their operating train sets. This means that high-speed rail will have to use separate platforms even if tracks are shared in between stations. This could limit the capacity and benefit of Los Angeles Union Station because the run-through tracks need to be assigned specifically to high-speed rail or conventional rail.

A December 2014 *Los Angeles Times* article by Ralph Vartabedian discusses the fogginess of the blended system in Southern California. Writes Vartabedian, "Metrolink hasn't had to think about sharing rail because, unlike the Bay Area, the bullet train ultimately is supposed to have its own tracks all the way to Union Station" (2014). The plan to have trains terminate in Burbank for a six-year period (or more as some project followers fear) could, as RailPAC president Paul Dyson notes, "severely crimp

[17] The Southern California Regional Interconnector Project (SCRIP) is not to be confused with the Regional Connector project which is the aforementioned light-rail connection. Both projects will be transformational to Los Angeles' regional transit system.

ridership" (ibid) As one critic points out, the Burbank terminus would "require major investments in parking lots and other maintenance operations" that are normally built at a rail system's endpoints" (ibid)

The blended service in Southern California is not as well defined as it is in Northern California; in the words of project spokesman Lisa Marie Alley: "We are looking at all of the options." However, this means there are opportunities for creativity and integration.

5.7 Conclusions

In this chapter, we reintroduce the reader to the Southern California rail network and the issues it is facing in regards to capacity constraints. We discuss the CHSRA's relatively nascent plans for a blended corridor in Southern California between Burbank and Anaheim, a distance of 50-miles, similar to the 51-mile Peninsula Corridor. The Authority will face many of the same challenges as it is facing on the Peninsula, but to varying degrees. For example, passenger rail demand is lower in the south than on the Peninsula, but freight demand is higher. The corridor is owned by multiple operators, but one of those operators is the financially powerful BNSF Railway. Both corridors host a hub station on the HSR network: San Francisco on the Peninsula and Los Angeles Union Station in the Southland. The level of coordination at this point is low, but there is lots of opportunity for creative solutions in bringing improved passenger rail service—both high-speed and commuter—to the region.

In the next chapter, we will merge our knowledge of North and South and discuss in broad terms a "wish-list" for the California rail network, a network composed of myriad commuter agencies, freight railroads, California HSR, and even a private high-speed rail venture. We will look at the local decisions made in Northern California and Southern California and evaluate their overall network impact.

6 Measuring the Statewide Impact of Local Decisions

We thank the reader for reading this thesis so far and we hope we have adequately presented the challenges that California will face in the implementation of its high-speed rail line on the blended corridors. Now we move onto an important part of the thesis in which we first describe a dream for the California rail network and then ask ourselves how design and implementation decisions made on the local level impact this dream.

6.1 Putting it all together: Inferring a "wish-list" for California

Based on our research of planning documents and board meeting minutes issued by the railroad agencies and metropolitan planning organizations in California, we compile a "wish list", or rather a summary of goals for commuter and intercity rail agencies across California. While this list is not exhaustive, we believe it represents a broad set of goals that will be impacted by decisions made regarding blended HSR-commuter service.

6.1.1 Level Boarding and Interoperability

Level boarding presents a large operational advantage for commuter rail agencies in that passengers do not need to ascend or descend steps to board a train. Level boarding reduces both station average dwell time length and dwell time variation. In systems with high bicycle ridership, dwell time length will be shortened as bicyclists can now "roll" on board the train. Wheelchair users require ramps to board trains at non-level platforms. If ramps are not present, time-intensive wheelchair lifts are required. Agencies need to budget for a worst-case scenario in terms of wheelchair delay lest these delays cause on-time performance to suffer. This dwell time "padding" gets added into the published timetable, increasing crew costs and making the service less attractive to customers.

	Median^	High^
TOTAL STUDY	:48	7:35
Bicycles	:50	7:35
Regular Passengers	:48	6:23
Passengers Needing Assistance	1:58	5:05
No Passengers or Bikes Boarding	:40	5:25

^ Dwell time is defined as the amount of time a train is stopped at a station.

Figure 6-1: 2010 Caltrain Study on station dwell (listed in "mm:ss" time format) times in 2011. Note the impact of passengers needing assistance on dwell times and the high levels of dwell time variability.
Source: PCJPB, 2010

Level boarding is relatively rare on U.S. commuter passenger rail systems outside of the Northeast Corridor. The new Eagle P3 project out of Denver, Colorado is one of the first modern commuter rail systems designed to have level-boarding at all doors. Caltrain has expressed a strong desire for level boarding as its high bicyclist volumes increase station dwell times significantly.

Metrolink, COASTER, and Amtrak California have not pursued level boarding. Metrolink and COASTER use cars with the floor 25" above the top of railroad rail; Amtrak California uses mostly cars that are 18" above the rail (Parsons Brinckerhoff 2012). As mentioned earlier, because of the California Public

Utilities Commission General Order 26-D which requires certain horizontal clearance minimums, level boarding on shared freight infrastructure is legally impossible. The difference between Caltrain and other agencies in California is that Caltrain has identified GO 26D as a necessary hurdle while the other operators have cited it as a reason not to pursue level boarding. However, to the author’s knowledge, neither agency has yet to take steps to seek a waiver for GO-26D.

Interoperability here means the ability of one system to serve passengers of another system. Passengers travelling on a corridor would not need to wait for a specific train operator, but could board the first train that arrives that serves their destination. This allows operators to complement each other’s services instead of being competitors. Interoperability goes a step beyond commuter operators being simple “feeders” to the HSR system; instead, commuter operator trackage can be served by HSR trains to provide a “one-seat ride” and HSR trackage could be used by commuter rail to provide intra-regional “express service” The following operators have potential for interoperability:

- Amtrak California’s Surfliner and SCRRA’s Metrolink (already partially exists through Rail2Rail)
- Amtrak California’s Surfliner and NCTD’s COASTER (already partially exists through Rail2Rail)
- CHSRA and PCJPB’s Caltrain
- CHSRA and Metrolink (between Palmdale and Los Angeles and Anaheim)
- CHSRA and Amtrak California (between Burbank and Los Angeles and San Diego
- Metrolink and COASTER (between Los Angeles and San Diego)

If Metrolink and Pacific Surfliner service was fully interoperable with high-speed rail service, customers could make use of interlined ticketing and trains as well as timed transfers to make connections across Southern California. Shared platforms would allow ease of access between systems and reduce infrastructure costs. However, there are sections of the Surfliner’s and Metrolink’s networks that see very low levels of passenger demand and that operate on aging, single-track infrastructure; the benefits of electrification might outweigh the costs.

The PCJPB believes the Baby Bullet service was instrumental to its ridership growth in the last decade; to quote the Caltrain operations manager, “the Baby Bullet is part of our branding.” However, the heterogeneous service adds complexity to the mainly two-track system: train meets and passes have to be precisely scheduled to avoid delays. Caltrain’s future partner, the CHSRA, also needs to decide what kind of service they want to offer commuters on the Peninsula. Currently the CHSRA plans for a minimum of three Peninsula stations (San Jose, Millbrae/SFO, and San Francisco) with the option of a 4th at either Redwood City or Palo Alto. The typical Baby Bullet train stops at six or seven stations between San Jose and San Francisco (inclusive). Given the similarities of Baby Bullets with Peninsula high-speed rail service from a stop-pattern perspective, there is potential for a merging of the two services or provide timed transfers at San Jose or mid-corridor.

6.1.2 Ability to modify service levels as needed

As noted earlier in this thesis, one of HSR’s main competitive advantages versus the airlines is the ability adjust service levels to adjust to consumer travel demand (the marginal cost of an additional train is lower than that of an additional flight plus airlines face capacity constraints of their own). This is only true, however, when the infrastructure is available to add services.   Frank Vacca, the program manager of the CHSRA, admitted at the 2015 ASME Joint Rail Conference that capacity enhancements would be needed if a high-speed operator determined it needed more service than the current plan of two high-speed trains per hour per direction on the Peninsula (four per hour per direction with a midline overtake section).

On the commuter rail side, agencies often provide additional services for special events. For example, Caltrain provides additional train service or additional stopping patterns for large events along the Peninsula such as the annual "Bay to Breakers" Race, San Francisco Giants games (and World Series victory parades as of late), or Stanford football games. In Southern California, Metrolink has offered similar additional trains for sporting events and county fairs. Additionally, as demand for commuter rail service grows, agencies would likely be able to add trains to the timetable to avoid crowding.

6.1.3 Shared corridor and success of Xpress West

The CHSRA is not the only entity planning a high-speed rail line in California. "Xpress West", a private venture backed by Las Vegas hotel developer Tony Marnell, is a planned 185-mile rail line between Palmdale and Las Vegas. The line has been supported by LACMTA as well as the CHSRA, though those agencies do not plan to offer financial assistance (Xpress West 2014). Xpress West would operate in a dedicated right of way at speeds of up to 150mph providing service to Las Vegas at a minimum of every 20 minutes during operating hours.

Because Palmdale is in the far northeast corner of Los Angeles County, in the relatively-isolated Antelope Valley, the Xpress West project is going to rely on high-speed rail, Metrolink, and personal vehicles to draw ridership from the Los Angeles Basin. This would mean entail the creation of a Palmdale transfer hub. It is safe to assume that, ideally, the Xpress West line could be interoperable with the high-speed rail line so that instead of a transfer, travelers could enjoy a one-seat ride between Downtown Los Angeles (or San Francisco) and Las Vegas. Both San Francisco-Las Vegas (#17) and Los Angeles-Las Vegas (#10) are among today's top 20 airport-pair markets in terms of passengers served (Bureau of Transportation Statistics 2014). And on the surface side of the transportation network, the Interstate 15 corridor between the Los Angeles Basin and Las Vegas is a highly congested automobile corridor, especially at peak weekend travel periods (Brennan 2006). This interoperability could help foster what Xpress West has envisioned as a "Southwest HSR Network" connecting San Francisco, Los Angeles, Las Vegas and eventually, San Diego (via California HSR), Salt Lake City, Phoenix, and Denver (Xpress West 2014). While there is considerable doubt as to whether the Xpress West system will ever come to fruition, this link would represent a pivotal step in in bringing HSR across state lines.

6.1.4 Integrated Southern California Rail Network

While the Southern California rail network is impressive on a track-mile basis, the network is splintered and ridership has not reached expectations. While Caltrain in the north has seen unprecedented ridership growth, Metrolink's has lost nearly 600,000 annual riders since 2008. As discussed earlier in the section, there are missed opportunities not only for institutional cooperation between Amtrak California, SCRRA and NCTD, but also within agencies themselves. Increased integration has been discussed in a positive light at both LACMTA board meetings and in the LOSSAN JPA's 2012 strategic implementation plan board meetings, but no integration aside from Rail2Rail and the Del Mar train have been implemented (LACMTA 2012, LOSSAN 2012). In his thesis, Ulrich Leister hypothesizes why the current system in place in Southern California has a low market share:

> Most rail lines are targeted for the commuter market, with rail service only during peak hours. Usability of the rail system is low because departure times and stopping patterns are usually not standardized and therefore customers need good knowledge of "their" rail line. On top, infrequent service leaves passengers without flexibility and, in the worst case, forces customers to structure their day according to a train's timetable (Leister 2011).

In an ideal Southern California rail system, riders could count on reliable and smooth connections between systems and "one-seat rides" between hubs. A single ticketing system would reduce complexity for riders and encourage transfers to local transit systems. With an integrated system, true headways would decrease as train operators could complement each other's services. The arrival of HSR to the region promises lots of opportunity to take a serious look at the rail system California has and the system it wants and deserves.

Connecting San Diego and Los Angeles with a one-seat commuter rail ride is an oft-discussed goal, but an institutional challenge—both Metro and the LOSSAN JPA have stated it in their near-term ambitions. The biggest challenge largely institutional: there are two existing commuter railroad owners and operators in SCRRA and NCTD and a new Los Angeles-San Diego commuter service would directly compete with Amtrak California. Aside from slightly more comfortable seats, Wi-Fi, on-board snack purchases, and slightly faster travel time (due to less station stops), Amtrak is a direct substitute for commuter service. Today's LOSSAN provides users with a joint timetable that lists Metrolink, COASTER, and Amtrak services on the corridor, but higher levels of integration will provide a more seamless customer experience.

6.1.5 High-frequency and uniform HSR and commuter service

In their 2008 published preliminary operating plan, the CHSRA scheduled eight trains per hour on the Peninsula. Before the blended service concept surfaced, the idea of ten Caltrain trains per hour per direction during peak periods was proposed by Caltrain in their Caltrain 2025 draft service plan. This ten train timetable was also reported in the CHSRA's preliminary alternatives analysis document in 2010. These ten trains included four trains per hour terminating at the Transbay Transit Center. It is reasonable to assume that Caltrain's capacity needs have not decreased since the report was written and may likely have grown (based on ridership outpacing expectations). According to the 2013 State Rail Plan, Metrolink, Amtrak California, and COASTER all expect to increase service levels as well.

As discussed earlier in this thesis, uniform headways are advantageous to both intercity travelers as well as commuters. Uniform, "clockface" (trains leave at the same minute each hour) headways not only make it easier to for customers to memorize schedules, but also result in less crowding on individual trains (under the assumption of uniform passenger arrival rates at stations). Transit agencies around the world, operate on uniform headways and clockface timetables when practical. And again, before the blended service concept appeared, both the CHSRA and the Caltrain published uniform, "clockface" timetables in service planning documents.

6.1.6 Bond Measure Satisfied

Finally, it is important that the requirements of Proposition 1A, the bond measure that voters passed authorizing funds for high-speed rail, are met. Proposition 1A mandates a maximum designed trip time of 30 minutes from San Francisco to San Jose and 160 minutes from San Francisco to Los Angeles. The CHSRA's program management team issued a memo stating that even in the blended system those requirements could be reached if the Peninsula is upgraded to 125mph track (CHSRA 2014b). As noted in chapter 2, the FRA only permits 125mph operations if an "impenetrable barrier" blocks traffic at grade crossings. These impenetrable barriers will inevitably increase “gate-down time” and intersection delay along the Peninsula.

Additionally, the bond measure calls for achievable operating headways of 5 minutes or less. This currently runs contrary to the blended service analysis which stated that the Peninsula Corridor is capable of operating at most 10 trains per hour per direction (6 minute headways); and this headway is contingent upon significant new construction. In the 2014 Business Plan, the CHSRA showed an operating run time of 180 minutes between San Francisco and Los Angeles (as opposed to 160) and 50 minutes between San Francisco and San Jose (as opposed to 30).

It has become clear that the CHSRA would like to differentiate between what the system is capable of and what will happen once the system begins operating in revenue service. This distinction has already become the subject of a lawsuit between two farmers in Central California and the CHSRA. Frank Vacca, the CHSRA's program manager, in a declaration to the court argued the following, making clear the CHSRA's distinction:

> For the purposes of the Business Plan, the operating plan described that shows a travel time between San Francisco and Los Angeles of 180 minutes (or three hours) . . . was representative of the information provided for the ridership forecasting model to forecast ridership levels based on specific patterns and frequency of train service. These service patterns were designed to achieve maximum commercial yield and were in no way tied to the ultimate performance capabilities for the travel time along the Phase 1 corridor (Vacca 2013).

For this thesis, we will agree with the CHSRA's approach and evaluate the ability of the Authority to meet “theoretical” design criteria outlined in Proposition 1A. The three main requirements that we will examine are 1) travel time, 2) headway, and 3) the ability of the project to be operationally self-sustaining (revenue-neutral at worst).

Furthermore, it is worth noting that there is no timeline required in the Proposition for satisfying the bond measure. One argument the CHSRA could make is that this is a phased project and that the bond measure requirements will ultimately be met at some unspecified date in the future.

6.1.7 Minimize Costs and Project Timeline across California

Californians are naturally suspicious of large-scale infrastructure projects. In 1989, the Loma Prieta Earthquake caused a section of the upper deck of the San Francisco-Oakland Bay Bridge to collapse onto the lower deck. An analysis done by the California Department of Transportation determined the bridge was seismically unsound (Mladjov 2011) and that a new eastern span would be necessary. It took the state over 12 years to begin construction of that span.

When construction commenced in January 2002, the project was slated to be complete in 2007 with costs estimated at $1.4 billion (ibid). The bridge finally opened in 2013 at a cost of $6.4 billion (Associated Press 2013). Even after the bridge opened, there has been ongoing concern that certain anchor rods built installed within the bridge are deficient (ibid). If Caltrans cannot build a ½ mile span to replace a structurally unsound bridge without a 900% cost overrun and a 24-year timeline, Californians might justifiably wonder how realistic the estimates are for $68 billion, 520-mile rail line to be completed by 2028.

Cost minimization and construction expediency are critical for not just the CHSRA, but for the entire state. Caltrain is on the cusp of electrifying its corridor, a project that was first proposed in 1992 (Morrison Knudsen Corporation 1992). Freeway and airport congestion are nearing their limits today, and with the state projected to add 10 million people by 2050, adequate rail capacity will only become more critical. While there is an impetus to build projects fast, there is also a need to build projects right. Short-term costs need to be weighed against long-term benefits, not just for individual regions or agencies, but for the wellness of the Golden State as a whole.

6.2 Upcoming Local Design Decisions

We will now discuss four key design choices that are upcoming in the next few years involving the CHSRA and local rail agencies and operators. Several of these local decisions will not only impact the rest of the California rail network, but will also set a precedent for future decisions made along the HSR corridor. Complicated negotiations taking place in Northern California on the more-developed blended corridor will undoubtedly have an impact on negotiations that occur in Southern California. Furthermore, the Southern California-Northern California rivalry will continue to play a role in the state's politics. Politicians in both regions will be on the lookout for special benefits afforded to their counterpart region and not their own. The California High-Speed Train Project is the largest truly cross-regional project to take place in the Golden State and no local decision will be allowed to exist unnoticed in its regional bubble.

6.2.1 Decision A: Platform Height and Equipment Floor Height

In Chapter Four, we discussed the coordination between Caltrain and the CHSRA in procuring equipment with similar door heights in order to facilitate common-use platforms. Common-use platforms are possible without having matching door heights: as long as the platform is below the floor of the vehicle, mini-high platforms can be constructed to accommodate both wheelchair users and passengers now needing to make a large step-up to a higher vehicle floor. However, there is no known instance of mini-low platforms where a ramp down to a lower door exists. This means that low-floor vehicles would not be compatible with platforms built for level-boarding with high-floor vehicles (e.g. the CHSRA's trainsets).

Figure 6-2: Example of mini-high platforms on MBTA system
Source: Flickr

Figure 6-3: Example of mini-high platforms on MBTA system
Source: Flickr

The CHSRA has been adamant thus far about having a nominal 50" vehicle floor. A 2009 technical memorandum from project consultant Parsons Brinckerhoff (PB) advocates for a platform height between 45.47" and 51.18" based on trains in existing service (CHSRA 2009b). According to PB, only the Alstom AGV Duplex operates with low platforms today (12.36" floors); however, that train can only operate up to 200 mph which falls short of the 220 mph requirement of Proposition 1A. Having a lower platform height would undoubtedly facilitate level boarding; for example, CHSRA can adapt to the existing Caltrain system and not the other way around. While the CHSRA would like to use a "service-proven" HSR system that has been in operation for at least 5-years, it would be worth examining the price-premium manufacturers would ask for a low-floor, high-speed train that has better compatibility with the existing system. For now, however, we will assume that CHSRA will adopt a 50" platform.

Design Decision	Explanation
1—Caltrain acts alone	Caltrain selects an EMU car compatible with existing diesel fleet
2—CHSRA coordinates with Caltrain	Caltrain selects an EMU car compatible with HSR fleet
3—CHSRA coordinates with Caltrain and Southern California railroads	There is a standard vehicle door height across CHSRA, Caltrain, Metrolink, the Pacific Surfliner, and possibly COASTER
4—CHSRA coordinates with Caltrain, Southern California Railroads, and other California rail agencies	In addition to the standard described in Choice 3, other agencies such as the San Francisco Municipal Transit Authority, Bay Area Rapid Transit, Amtrak California (Capital Corridor and San Joaquin trains), or the Valley Transportation Authority standardize as well.

6.2.2 Decision B: Capacity Allocation Strategy

In Chapter Four, we discussed the gulf between the CHSRA's willingness and ability to pay for access to the Transbay Transit Center versus Caltrain. Given the importance the terminal station to both operators, a method of determining who gets access and at what time will be necessary. This could come in the form of integrated planning or some sort of capacity allocation mechanism.

Design Decision	Explanation
1—Do not develop a capacity allocation strategy	Build infrastructure first with general service plan assumptions and wait to negotiate particular train slots when all parties are ready
2—Create a codified capacity allocations strategy	Develop a formal set of rules to allocate capacity on the Peninsula and access into the Transbay Transit Center
3—Negotiate capacity	Agree on a service plan prior to putting HSR operating contract out for bid

6.2.3 Decision C: Southern California Electrification Timeline and Scope

Though Metrolink has come out against electrification, rail advocates such as the Rail Passengers Association of California and Nevada (RailPAC) have pointed out many potential benefits to electrification of the entire blended corridor in 2022 prior to the CHSRA's plan to electrify in 2028 (McCallon 2012).

Design Decision	Explanation
1—Conventional (Diesel Corridor)	Maintain Amtrak California and Metrolink service as diesel powered operations ; truncate HSR in Burbank from 2022-2028
2—Electrification	Convert the blended corridor to all-electric operation (aside from freight) and commence Los Angeles HSR service in 2022

6.2.4 Decision D: Two Track Corridor on the Peninsula

In Chapter Four we discuss LTK's Blended Operations analysis done on behalf of the PCJPB where they verified the performance of different track configurations on the blended system. We will examine the impact of three different design choices on the performance of the corridor and the HSR system.

Design Decision	Explanation
1—Keep corridor as is	Do not add additional passing tracks
2—Expand the corridor to include passing tracks	Build LTK's recommended "midline overtake" section on the corridor, adding about 10 miles of quadruple track
3—Revert to the four-track option	Build HSR on the Peninsula as originally planned with two dedicated tracks for HSR use

6.3 Measuring Network Impact

In this section, we are going to take a look at these four major upcoming decisions and discuss the impact of each design decision from the viewpoint of the California rail network.

6.3.1 Decision A: Platform Height and Equipment

Choice 1—Railroads Act Alone

If Caltrain acts alone on platform height, they will likely select a 25" floor height to maintain compatibility with their diesel-electric rolling stock (PCJPB 2013a). Metrolink and COASTER will continue to maintain their fleets at the 25" door height as well. The CHSRA will continue forward with its planned 50" floor height.

	Railroads Act Individually
Level Boarding and Interoperability	Door heights for Caltrain, Metrolink, COASTER, and Amtrak California will be below HSR platforms. HSR trains will require mini-high platforms to use commuter rail stations since there will be a minimum of 25" step.
Ability to modify service levels	HSR will be limited by its four-track terminal at Transbay Transit Center and Caltrain by its two track terminal at all times. In Southern California, run-through capacity for non-HSR passenger railroads may be limited at Los Angeles Union Station where high-speed rail would need two of the four run-through tracks.
Shared corridor with Xpress West	In order to have an opportunity for a shared system, Xpress will likely specify same vehicle floor height at HSR to ensure interoperability. However, Xpress West will not be able to stop at non-HSR stations without constructing mini-high platforms
Integrated Southern California Rail Network	Metrolink and Amtrak California are likely limited to two through-tracks at Union Station. Cross-platform, timed-transfers at Union Station between regional and high-speed rail are impossible.
High-frequency, uniform HSR and commuter service	According to LTK's blended service plan (which makes an assumption of separate facilities), Caltrain will have uneven headways and limited access to Transbay Transit Center. Unless politically-challenging passing tracks are constructed, high-speed rail will not function beyond two trains per hour per direction on the corridor which is a far-cry from HSR's original 12 trains per hour goal. Frequency and uniform headways for HSR and commuter service in Southern California will depend mainly on the degree of track sharing between HSR, freight, and other passenger rail agencies as well as the ability of all operating railroads to coordinate service planning.
Bond Measure Satisfied	Theoretical travel times and headways are satisfied with 125mph on the Peninsula, however satisfying the revenue-neutral requirement and securing a private operator will be challenging.
Minimize costs and build system quickly	Metrolink and Amtrak California save time and money by not changing vehicle floor heights or platforms for interoperability. However, CHSRA will need to construct new stations in its shared corridors.

Choice 2—California HSR and Caltrain Act Together

If Caltrain and HSR act together, Caltrain will likely procure a vehicle with two door heights—one compatible with its current diesel fleet and one that matches HSR floor heights. Amtrak California and Metrolink would likely keep their existing 25" and 18" floor heights respectively. This analysis assumes Caltrain will eventually convert its platforms to the same height as HSR since not doing so would defeat the purpose of buying the dual floor height cars.

	Caltrain and HSR Act Together
Level Boarding and Interoperability	Caltrain will be able to stop at any HSR station and vice versa. Even if stations are segregated, HSR trains could use Caltrain platforms (or vice versa) in the event of an emergency. HSR trains could make stops at commuter stations for special events.
Ability to modify service levels	HSR and Caltrain could use each other's spare platforms at the Transbay Transit Center, however, limited line capacity on the Peninsula would still be a challenge. Caltrain and HSR would have increased flexibility to create merged service plans (see fifth box in matrix). In Southern California, run-through capacity for non-HSR passenger railroads may be limited at Los Angeles Union Station where high-speed rail would need two of the four run-through tracks.
Shared corridor with Xpress West	Even though, it is currently only a Southern California system, Xpress West would have full access to Peninsula (and CHSRA would have access to Las Vegas), but this might be financially impractical since Xpress West would have to pay access charges to Caltrain and CHSRA—a timed transfer at Palmdale with CHSRA might be preferable. Xpress West will not be able to stop at Southern California commuter (non-HSR) stations without constructing mini-high platforms.
Integrated Southern California Rail Network	As with Choice 1, Metrolink and Amtrak California are likely limited to two through-tracks at Union Station. Cross-platform, timed-transfers at Union Station between regional and high-speed rail are impossible. However, a successful negotiation between Caltrain and HSR regarding platform heights might pave the way for a similar arrangement in Southern California.
High-frequency, uniform HSR and commuter service	With HSR and Caltrain having the same floor height, services on the Peninsula could be interchangeable; that is, HSR could run a Caltrain-like service plan with multiple stops or Caltrain could run a HSR-like service plan with few stops. Increased heterogeneity in service patterns during a single time period, however, will limit the practical capacity of the corridor. Frequency and uniform headways for HSR and commuter service in Southern California will depend mainly on the degree of track sharing between HSR, freight, and other passenger rail agencies as well as the ability of all operating railroads to coordinate service planning.
Bond Measure Satisfied	Theoretical travel times and headways are satisfied with 110mph on the Peninsula. If Caltrain and CHSRA interline services, the two agencies would need to negotiate a joint-venture revenue and cost-sharing agreement so a private investor in the system can expect to generate revenues on the corridor even if it is not operating the trains.
Minimize costs and build system quickly	Caltrain will have increased expense by ordering non-standard vehicles with two door heights. HSR may be able to avoid building separate facilities at its Peninsula stations, but will need to build its own facilities in Southern California. Construction time would be accelerated on the Peninsula because of reduced scope.

Choice 3—California HSR, Caltrain, and Southern California Rail Agencies Act Together

If Caltrain and HSR include Amtrak California's Pacific Surfliner, SCRRA (Metrolink), and possibly NCTD (COASTER) in the vehicle floor height decision, additional opportunities for level boarding and interlining emerge. Level boarding has the highest benefit for Amtrak California and Metrolink on routes shared with HSR[18]. All Metrolink routes besides the Inland Empire-Orange County Line are technically shared with HSR's blended system for a certain distance outside of Los Angeles Union Station, but in particular, the Ventura County Line and the Antelope Valley Line north of Los Angeles and the Orange County Line south of Los Angeles together cover the entire blended corridor between Burbank and Anaheim. The Pacific Surfliner covers the entire blended corridor from Burbank to Anaheim. This will facilitate platform and station sharing, and at a minimum, cross-platform transfers.

For the purposes of this thesis, let us assume that ultimately the entire Southern California rail network adopts a HSR-compatible floor height. This could mean building "mini-high" platforms at stations without high-platforms or purchasing railcars capable of using two different platform heights as Caltrain is currently exploring.

The benefits described in "Choice 2" will be extended to Southern California. Metrolink and Amtrak would provide higher-quality "feeder service" to the HSR trunk. Xpress West will have access to all stations on the shared corridor in Southern California. All four run-through tracks at Union Station could be used by any rail provider allowing for higher returns on investment. Additional negotiation will be required to guarantee that Metrolink and Amtrak services are not competing with high-speed rail for revenue; that is, in order to satisfy the revenue-neutral requirement of the bond measure, Amtrak and Metrolink need to be feeding the HSR network, not stealing passengers from it. Costs would increase in that Metrolink and Amtrak would need to purchase new equipment and raise their existing platforms, but costs might decrease in that stations could be shared and costly new HSR station infrastructure could be eliminated.

[18] Amtrak California's *Capitol Corridor* (as well as SJRRC's *Altamont Commuter Express* and Amtrak's *Coast* Starlight) share with Caltrain (and California HSR) a 3-mile piece of the Peninsula Corridor. However, at this part of the corridor there is a third track we expect that these services will operate on the additional track and not share tracks with HSR or Caltrain (though they sometimes share one of Caltrain's two mainline tracks today.

Choice 4 —Bringing the SFMTA and BART to the platform height discussion

In his TRB paper that we discussed in Chapter 2, Reinhard Clever presents a creative proposal in which Caltrain would use outbound tracks on the San Francisco Municipal Transportation Agency's Market Street Subway through downtown San Francisco. The Market Street Subway is a light-rail subway; in the inbound direction, five lines converge; in the outbound direction, Clever argues that a coupling operation at the end of the subway could increase the capacity and allow room for Caltrain. A one-mile single track construction along Seventh Street in San Francisco to complete a Caltrain loop would allow for Caltrain trains to continue back onto the main Peninsula Corridor and serve the Peninsula. The two main advantages of this system are:

1. Caltrain would no longer need access to the Transbay Transit Center to serve downtown San Francisco while Peninsula commuters would still enjoy a one-seat ride to key San Francisco destinations
2. Light-rail lines and BART share several of these key downtown stations with Caltrain enabling easy connections for San Francisco residents commuting southbound and Peninsula residents commuting outside the San Francisco CBD

Figure 6-4: Reinhard Clever's proposed Caltrain-SFMTA Market Street subway integration
Source: Clever (2013)

Figure 6-5: Reinhard Clever's proposed Caltrain-SFMTA Market Street subway integration
Source: Clever (2013)

This system would free capacity in the Transbay Transit Center and set a helpful precedent for integration across the state. CHSRA could add services into Transbay Transit Center if necessary since Caltrain would have less requirements for track. The largest challenges to this plan are institutional in nature. SFMTA is expecting its new Central Subway to provide a light-rail connection between Caltrain and downtown and has used Caltrain transfer traffic as a large component of ridership (SFMTA 2008). There is the technical challenge of bringing a heavy rail system into a light rail system regarding horizontal and vertical clearances, platform heights (SFMTA's Market Street Subway platform height is about 36") and different power systems (600V DC in Market Street Subway vs 25 kV HSR/Caltrain), but Clever points to systems in Europe (e.g. Karlsruhe, Germany) where these challenges have been overcome and where the ridership gains have been on the order of 400% (Clever 2013).

Clever takes his idea of system "convergence" a step further by suggesting that the HSR system could run on underutilized BART right-of-way between the Peninsula Corridor and SFO Airport. BART operates on Indian Broad-gauge track which is 5 feet, 6" between rails and incompatible with the 4 feet, 8.5" standard gauge on the Peninsula Corridor and the future HSR network (ibid). The BART track between the BART-Caltrain transfer station at Millbrae is only operable after 8pm during the week and on weekends; writes Clever, “Demand was so low [on the Millbrae-SFO BART shuttle]--it was known as the ‘ghost train!’” (5).

If the BART track were replaced with standard gauge track, HSR trains could provide a one-seat ride to SFO complete with checked baggage and through-ticketing from points across the Central Valley and San Jose. The BART SFO airport station is under-utilized: it has three tracks, one of which is never used; this third track could serve as a terminal for high-speed rail. Sending one HSR train out of every three would free up space north of Millbrae on the Peninsula. And though Clever does not go this far, Caltrain could reduce service on the Peninsula south of Millbrae as HSR could shuttle some commuters from San Jose to the Millbrae station where Caltrain could provide a timed-transfer for its short loop into and through San Francisco. While this depends on careful schedule planning, the returning southbound Caltrain could meet the airport HSR train returning southbound to provide a seamless connection to the southern half of the state.

Again, this would entail further institutional challenges and construction costs. BART would need to release its right-of-way and station platform at SFO and infrastructure costs would increase in the short term. For truly blended integration, participating agencies need to act as blended entities. Clever warns the reader, “[Without integration], the California HSR system will almost certainly not reach its full potential, and will instead degrade into a very fast connection between huge parking lots” (13).

Figure 6-6: The BART SFO Station “platform not-in-service” cones (which incidentally have their own Flickr photo page) at top and today’s BART map showing limited scheduled service on the Millbrae-SFO leg at bottom
Source: BART, Flickr

6.3.2 Decision B: Capacity Allocation Strategy

Choice 1—Do Not Develop a Capacity Allocation Strategy

This choice means that infrastructure decisions will be made prior to service planning decisions. Agencies have a general idea of their capacity needs in terms of trains per hour per direction. CHSRA wants at least four trains per hour per direction. Caltrain plans on operating six (but has planned for up to 10) with two serving Transbay Transit Center. In the South, Metrolink, COASTER, Amtrak have expansion plans as well. According to the 2013 California State Rail Plan, non-HSR passenger rail volumes on the blended corridor sections are going to increase significantly between 2014 and 2030:

Table 6-1: Forecasted 2040 non-HSR train volume increases on Southern California blended corridor

Blended Section	Owner	2014 Daily Round Trips	2040 Daily Round Trips	Percent Increase
Palmdale-Burbank*	SCRRA	15	23	53.3%
Burbank-Los Angeles	SCRRA	36	53	47.2%
Los Angeles-Fullerton	BNSF	29	49	69.0%
Fullerton-Anaheim	SCRRA	29	39	34.5%

**Palmdale-Burbank will not likely be shared for its entire length*
Source: California State Rail Plan/Author's Calculations

	Do Not Develop a Capacity Allocation and Capacity Pricing Strategy
Level Boarding and Interoperability	While the lack of a capacity allocation scheme does not eliminate the possibility of level boarding and interoperability, interoperability is by definition, a capacity consideration, so it is unlikely that interoperability will occur in an environment that does not consider capacity before infrastructure decisions are made.
Ability to modify service levels	Absent a capacity allocation plan, adding frequency will be easy when capacity is abundant, but capacity will become congested more quickly than without centralized planning. A "buffet style" approach to track access in which operators take capacity without regard for other operators capacity needs will quickly congest available train slots. Adding services will require coordination among all affected operators and will be institutionally challenging and time-consuming.
Shared corridor with Xpress West	Xpress West will have no capacity challenges on their track since they are operating in a dedicated corridor. However, being a private operator trying to compete for track access with public agencies such as SCRRA or CHSRA, Xpress West will likely have last priority to access the Palmdale-Los Angeles section of the network.
Integrated Southern California Rail Network	Because of the joint powers authority setup of the SCRRA/Metrolink and the unidirectional nature of commute patterns (inbound from outlying counties to Downtown Los Angeles in A.M., outbound in P.M.), the "confederacy of counties" will be resistant to any changes that affect services in that county. Because service changes will have a rippling effect (positive or negative) across all lines in and out of Los Angeles Union Station, it will be difficult to coordinate and alter Metrolink service without inconveniencing members of the JPA.

High-frequency, uniform HSR and commuter service	Initially, operators can deploy high-frequency, uniform service, but as capacity gets consumed, it becomes difficult to continue that trend. For example, the LTK blended operations analysis assumes HSR has the first opportunity on the Peninsula for capacity and schedules trains with uniform headways; as a result, reasonable Caltrain frequencies to the Transbay Transit Center are not implemented and operating headways are highly variable. While the LTK analysis was conducted to verify broad feasibility of the blended system, it is apparent that service uniformity becomes an increasingly complex exercise under the assumption of not developing a capacity allocation policy.
Bond Measure Satisfied	Adherence to the bond measure requirements is dependent on whether or not the HSR operator has first access to train slots on parts of the corridor it does not own. Otherwise, HSR will find its trains "stuck" behind slower moving commuters or freight services and the time requirements may not be satisfied. If service quality suffers, revenue will suffer as well and the revenue-neutral requirement may not be met.
Minimize costs and build system quickly	If careful planning of capacity needs can minimize infrastructure costs, then not developing a capacity allocation and pricing strategy will result in unnecessary/redundant rail infrastructure. If capacity is allocated inefficiently with a first-come, first-serve mentality, then agencies could find themselves in a situation where it is politically easier (yet more expensive) to build more capacity than to renegotiate with multiple host railroads. The State of California will also receive less competitive bids from private operators due to the uncertainty related to track access.

Not developing a capacity allocation scheme or negotiating capacity prior to relatively precise service planning decisions is high-risk, especially to a private investor in the HSR system. The State will pay a risk-premium for not working out capacity agreements especially on the congested Peninsula Corridor and the BNSF section of the corridor between Los Angeles and Anaheim. In her dissertation Maite Pena-Alcaraz notes how lack of capacity planning has made modification of Northeast Corridor services an extremely difficult exercise (2015).

The National Cooperative High Research Program Report 773 (2014) describes the current method of adding service, which is the likely outcome of waiting to implement a capacity allocation policy: "On corridors they own, freight carriers fully control the technical assessment of the operations for proposed and existing shared-use territories even when the passenger rail sponsor underwrites the cost of such analysis" (14). It is unlikely that any private investor will be willing to risk potentially lucrative Los Angeles-Anaheim service to that level of capacity uncertainty.

Choice 2—Create a Codified Capacity Allocation Strategy

This choice requires agencies to develop a codified policy for allocating and pricing capacity. Again, this is only relevant to corridors where HSR is sharing track or station access (i.e. the blended corridors in Northern or Southern California). There are network challenges, however, with a capacity allocation and pricing mechanism. Take for example the Transbay Joint Powers Authority (TJPA). If the TJPA, through any allocation mechanism, awards an HSR train the right to depart at a certain time, Caltrain needs to allow that train to continue to move through the corridor and continue southward. When that train arrives in Metrolink territory, it needs to be accepted to move towards Los Angeles Union Station.

	Create a codified capacity allocation and pricing procedure
Level Boarding and Interoperability	If agencies work together to try to formulate an approach to allocating capacity, the benefits of level boarding and interoperability will be quickly realized as level boarding and interoperability minimize on-track competition and a capacity allocation mechanism emphasizes the trade –offs necessary with on-track competition.
Ability to modify service levels	While adding frequency may not be easy, a codified capacity allocation procedure will make it transparent so operators will know the necessary steps to add services.
Shared corridor with Xpress West	If California develops a capacity allocation mechanism, it will need to consider the potential of Xpress West or other private operators seeking access to the track. In this sense, a capacity allocation mechanism will be beneficial to Xpress West and any other private operators evaluating the commercial viability of a new rail enterprise.
Integrated Southern California Rail Network	The Peninsula Corridor is relatively simple compared to the network in Southern California. Agencies will have to decide the scope of any capacity allocation and pricing mechanisms. If the mechanism only applies to corridors with HSR, operations outside the corridor will be subject to decisions made within the corridor; for example, if Metrolink is limited to two trains per hour by the capacity allocation mechanism, should those two trains continue on to Ventura to the west, Oceanside to the south, or San Bernardino or Riverside to the east? Furthermore, unless a capacity allocation procedure takes into account the effects of network integration (e.g. connections between HSR and Metrolink), it is unlikely to lead to coordinated timetables.
High-frequency, uniform HSR and commuter service	As we discuss in Chapter Four, a high-speed operator has a much higher willingness to pay for access to infrastructure so a capacity allocation mechanism could put commuter rail agencies at a disadvantage in securing high frequencies and uniform headways. Also, because train paths are not independent of one another (a high-speed train could disrupt the paths of multiple commuters and vice versa), it is unlikely that a capacity allocation mechanism will result in uniform headways or produce high levels of track utilization.
Bond Measure Satisfied	A HSR operator with a higher ability to pay for infrastructure access might be able to guarantee itself the capacity needed to meet the headway and travel time goals defined in the bond measure. However, if there is significant expense in securing access to the track, this will impact an operator’s bottom line and the revenue-neutral requirement of the bond measure will not be satisfied.
Minimize costs and build system quickly	With a capacity allocation mechanism in place, a private HSR operator will have a much better understanding of the risks associated with operating in a shared-use environment and the risk premium that the operator demands might be lessened.

Choice 3—Negotiate Service

With this option, railroad agencies work together to develop a timetable. Like the discussion on platform and vehicle floor height, the number of included parties increases the complexity of conversations but also could potentially yield a better outcome. The parties would agree on a preliminary timetable, build infrastructure to match said timetable, and then make changes at a later date if necessary. The timetable itself could be part of the concession contract for the private high-speed rail operator.

	Negotiate service
Level Boarding and Interoperability	Level boarding and interoperability will increase the ability for operators to mix and match services and remove constraints on the negotiating process. If service negotiations occur before agencies make design decisions affecting level boarding and interoperability, it is more likely the agencies will reach design decisions facilitating these goals.
Ability to modify service levels	Like Choice 1, no capacity allocation strategy, adding service will be easy when capacity is available, but difficult once capacity is saturated. At saturation, more and more entities will be affected by small changes in the timetable and adding services will become a challenging and time-consuming exercise. At some point, if demand patterns change enough, an entire re-evaluation of the timetable may be necessary.
Shared corridor with Xpress West	Xpress West will need to be involved in the timetable negotiation discussion if the CHSRA would like to integrate Xpress West service on the corridor. Again, however, the addition of Xpress West potentially puts five operators (CHSRA, Amtrak California, Metrolink, and BNSF) on the Burbank-Anaheim corridor and could make negotiations extremely complicated.
Integrated Southern California Rail Network	This choice perhaps leaves California with the best opportunity of integrating the Southern California rail network. Transfers could be carefully timed and freight rail demand could be managed in windows that avoid conflicts with passenger trains. Cuts on some lines could be justified with enhanced connections at transfer stations like Anaheim, Oceanside Burbank, Fullerton, or Los Angeles Union Station.
High-frequency, uniform HSR and commuter service	Much like the ability of negotiated service plan to create an integrated Southern California rail network, careful service planning could also lead to a high-frequency and even headway rail service. This will be achieved with well-timed transfers and removal of redundant services.
Bond Measure Satisfied	During the service negotiation period, the CHSRA could use the bond measure requirements as a hard or soft constraint. The CHSRA could perform a financial analysis of any proposed timetables and understand the revenue potential to ensure that the revenue-neutral requirement is satisfied. If capacity improvements are needed, the necessity of said improvements might very well be realized during this timetable negotiation process.
Minimize costs and build system quickly	Having a more definitive operating plan in place and knowing the infrastructure necessary to meet that operating plan will reduce the risk for a private HSR operator even more than a defined capacity allocation mechanism. This will minimize the risk costs borne by the State. Also, a better understanding of infrastructure needs will help avoid excessive construction and lead to lower costs and a shorter project timeline.

Careful service planning (negotiated service) might very well be welcomed by the freight railroads. Freight railroads are also capacity constrained and long-standing arrangements with passenger trains pre-date some existing capacity constraints. If freight operators are guaranteed slots to operate trains throughout the day, they may be more hospitable to increase passenger operations in the blended corridors. As long as it does not cause traffic delay, freight railroads have an interest in more passenger operators since additional train movements typically results in higher access fee revenues. Detailed discussions with freight railroads may reveal necessary capacity improvements as well.

Freight railroads operate on networks that cross state lines; the California network effects discussed in this thesis might pale in comparison to the network effects felt across a multi-state, multi-hub freight network. NCHRP 773 notes this fact and admits that host freight railroads are often unwilling to “bear the disruptions associated with an embargo of freight operations over a shorter section of track during, for example, commuter rush hour periods” (15) Because of the location of BNSF’s large Hobart yard (several miles from Union Station and on the future blended Anaheim-Los Angeles corridor), the CHSRA might find that separate railroad infrastructure is a necessary requirement to ensure smooth, profitable operations for the private operator.

There are certain institutional challenges in moving towards a capacity allocation mechanism. For the multiple infrastructure managers—the TJPA, the PCJPB, CHSRA, SCRRA, and possibly the BNSF—to cede control of capacity and break current capacity contracts and switch to a formalized out-of-headquarters mechanism. All operators will have to perceive any capacity mechanism as unbiased and result in a net positive for their respective operation.

6.3.3 Decision C: Southern California Electrification Timeline and Scope

Choice 1—Maintain Diesel Rail Service

Here Metrolink and the Pacific Surfliner continue diesel operation on the corridor. Between 2022 and 2028, high-speed rail passengers alight at the Burbank Station and then transfer to a diesel train for the ride to Los Angeles or Anaheim.

The Transfer from Burbank to Los Angeles Union Station

Currently the Surfliner does not stop at the station, but assuming it did, Burbank-Los Angeles sees 38 passenger trains per day and the timetable is concentrated around the peaks (Amtrak, SCRRA 2015 timetables). The San Fernando station will see 50 trains per day or one train every 19 minutes (CHSRA 2014b). Again, these trips would be concentrated, albeit slightly less so, around the peak times—high speed rail is expected to have a minimum of 30-minute headways throughout the day; Metrolink has a 60-minute headway midday from the Burbank Station.

In his January 2015 presentation to the CHSRA, East Japan Railway Company’s vice chairman, Masaki Ogata, stressed the importance of total trip time and the importance of shortening all pieces (door-to-door) of the HSR journey. The total trip time from Burbank in a scenario with conventional rail service is as follows:

$$Total\ Trip\ Time = Transfer\ Time\ at\ Burbank + Diesel\ Trip\ to\ Destination\ South\ of\ Burbank + Transfer\ Penalty \qquad 6\text{-}1$$

Though Mr. Ogata does not define it, the transfer penalty is an unknown, yet non-zero value of time (often expressed in minutes) that represents the customer's disutility of transferring. It is based on the following items:

- Quality of transfer station—how difficult is it for customers to transfer between services? Will bags be transferred automatically? Is there an enclosed waiting area for customers?
- Uncertainty in connections—is there any chance of missing connections? Will the customer need to purchase another ticket, and if so, does the customer have assurance that there will be adequate ticketing machines and staff available to avoid missing a connection? Is there enough space on the next train?
- Reliability of connections—What is the on-time performance of connecting trains?[19] Will connecting trains (HSR or commuter) wait for a customer's train if the customer's original train is late?

While it is difficult to find a value for this transfer penalty for high-speed rail services, Guo estimates it at 9.52 minutes for the MBTA (2008). For example, the Toronto Transportation Commission uses a coefficient of 10, suggesting that each transfer is 10 times more painful for a customer than time spent travelling in-vehicle (Wilson 2014)

Table 6-2: Travel time via conventional rail (Source: SCRRA, Author's Calculations)

Burbank to:	Distance	Best Travel Time	Avg. Speed	% trip time increase on top of a 158-minute San Jose-Burbank HSR trip[b]	% trip time increase on top of a 62-minute Fresno-Burbank HSR trip[b]
Los Angeles	13 miles	27 minutes	35mph	17%	44%
Anaheim	44 miles	65 minutes[a]	44mph	41%	105%

[a] Author used best time of Pacific Surfliner and Metrolink and subtracted lay-over time at Union Station under assumption that run-through tracks would reduce this layover to 1-2 minutes.
[b] Using travel times from all-stop HSR train in 2014 Business Plan, Author assumes five-minute transfer at Burbank and 100% on-time departures from Burbank
[c] In the 2014 Business Plan, the CHSRA schedules approximately 10 minutes travel time between Burbank and Los Angeles after Phase 1 is complete

Table 6-2 puts into numeric terms the inconvenience of a transfer at Burbank. An HSR passenger adds 12 minutes of in-vehicle travel time versus a one-seat HSR ride; the additional 13 miles (even assuming a 5-minute seamless transfer at Burbank) adds 17% to the total trip time of a San Jose-Burbank trip and 44% to a Fresno-Burbank trip. While it is expected that improvements will be made to increase speeds on the diesel portion, the train averages 35-45mph during the route compared with an average speed of 139 mph between San Jose and Fresno and 147 mph between San Jose and Burbank, a difference which might be psychologically frustrating for a potential HSR user.

[19] Metrolink's on-time performance (defined as arriving within 5 minutes of scheduled time) was 94.9% in February 2015 (SCRRA 2015). The Pacific Surfliner's on-time performance in all of 2014 was 80.5% (Amtrak 2015).

	Maintain conventional diesel service
Level Boarding and Interoperability	Since diesel power has no impact on the door height of the trailer cars, whether or not to maintain diesel service has no impact on level boarding. Between 2022 and 2028, high-speed rail commuters would have to transfer at Burbank for trips south to Los Angeles (24 minutes from Burbank) and Anaheim (67 minutes from Burbank). With diesel service maintained, it would be difficult for Antelope Metrolink trains to use the upgraded high-speed rail infrastructure between Palmdale to Burbank (which cuts travel time between Palmdale and Burbank from 80 minutes to 15).
Ability to modify service levels	Metrolink and Amtrak California would face the same issues they do today in adding frequency until 2028. Once HSR service is extended to Los Angeles, HSR trains will have to navigate around slower moving and slower-accelerating diesel passenger service and freight trains.
Shared corridor with Xpress West	Xpress West will likely have less competition (since Metrolink will likely remain on their own non-HSR tracks) on the Palmdale-Burbank section of a route into Los Angeles, but will face higher congestion between Burbank and Los Angeles for reasons stated above.
Integrated Southern California Rail Network	HSR would essentially be run as its own separate system outside of the blended corridor. However, outside of that, integration would still be possible with timed transfers at key stations. The distinct propulsion systems would give agencies less incentive, however, to pursue compatible platforms (just as a lack of compatible platforms would give agencies less incentive to adopt electric operation).
High-frequency, uniform HSR and commuter service	With diesel service, Metrolink and Amtrak California trains cannot easily intermix with HSR trains and the opportunity to offer supplemental HSR via commuter connections and overlapping service diminishes. Unlike Amtrak California today, HSR will be a premium service in Southern California and thus unlikely to be part of a "Rail2Rail"-type program. Run-through tracks at Union Station would need to be segregated (two for HSR, two for diesel service) unless all four were electrified. This could tighten capacity.
Bond Measure Satisfied	Sharing tracks with slower diesel service might slow down actual travel times, but theoretical travel times will not be affected. To meet the theoretical headway requirement, the signal system will need to be upgraded to accommodate high levels of mixed and variable traffic. In terms of meeting revenue-neutrality, having Metrolink and Amtrak California provide slow, diesel-powered connections (24 minutes + Transfer Time + Transfer Penalty) at Burbank to the hub at Union Station might cut into ridership and revenue for HSR.

Minimize costs and build system quickly	Keeping the Surfliner and Metrolink on diesel operation moves the expense of electric catenary infrastructure to a later date and saves the cost of buying new locomotive equipment. The timeline for a one seat ride from Northern California and the Central Valley remains as scheduled in 2028. There is the additional cost of hosting an HSR terminal in Burbank from 2022 to 2028 before the terminal moves south to Los Angeles Union Station.

Choice 2— Convert the Blended Corridor to All-Electric Passenger Operation

Upgrading Amtrak California and/or Metrolink to electrified propulsion will not be cheap. Also, there is an issue of electrification outside of the corridor—since all Metrolink and Amtrak California trains operate on segments outside the corridor as well as within the corridor, there is the question of whether to electrify only the shared HSR portion of the corridor, electrify the LOSSAN corridor, or electrify the entire Southern California Passenger Rail network. The last two options are likely cost-prohibitive and the utility of electrifying tracks that have relatively low passenger usage is minimal[20].

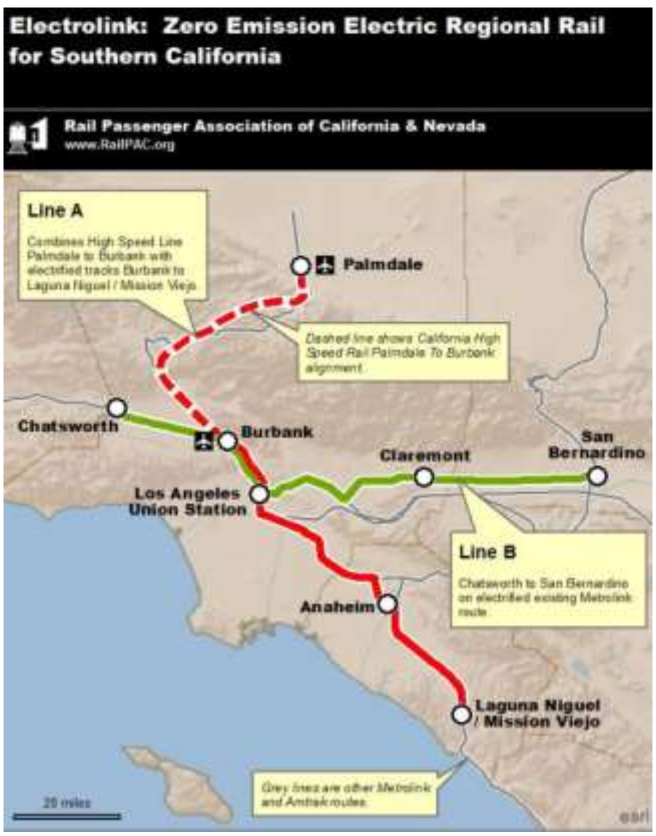


Figure 6-7: RailPAC's proposed electrified Metrolink system that could interoperate with HSR.
Source: RailPAC

In Figure 6-7, Paul Dyson illustrates the Rail Passenger Association of California and Nevada's plan to electrify part of the blended corridor; Dyson refers to the project as "Electrolink" (2014). This takes advantage of the existing and under construction double-track sections of railroad that could sustain high levels of electric service. In this scenario, the Surfliner would maintain diesel operation, but conceivably could be run less frequently since the electric service provided by Metrolink would be more frequent.

Between Union Station and Fullerton, CA, the corridor is owned by the BNSF railway. This might make electrification more institutionally challenging. Unlike on the Peninsula, the freight railroads in Southern California operate double-stack cars that require high overhead catenary clearance.

Amtrak California or Metrolink could run with dual-mode locomotives paid for by connectivity funding from HSR. Alternatively, the entire Southern California passenger rail network could feed into a dedicated "electric

[20] For example, Metrolink operates just six daily round trips on its Riverside line

shuttle" that runs exclusively on the blended corridor. This, however, would necessitate smooth timed transfers that would likely need to be facilitated by shared platforms.

	Convert Metrolink (and potentially the Pacific Surfliner) to blended service on the Burbank-Anaheim corridor by the time HSR reaches Burbank
Level Boarding and Interoperability	Metrolink trains can enjoy benefits of electrified system including reduced travel time from Palmdale to Los Angeles on the Antelope Valley Line. Metrolink trains could provide transfers from HSR to smaller stations with reduced travel times.
Ability to modify service levels	Adding frequency would be easier because of increased homogeneity of service characteristics (speed and acceleration) on the corridor. Metrolink would be able to run express trains that provide HSR-like travel times within the region.
Shared corridor with Xpress West	With faster Metrolink service from Palmdale to Downtown Los Angeles, Xpress West will have less incentive to seek through-service on to Los Angeles, but if they do, there are less "slow-moving trains" in their path to Union Station.
Integrated Southern California Rail Network	With similar train operating characteristics and infrastructure requirements, it is much simpler for HSR to share track with electrified Metrolink and Surfliners. This will enable better use of capacity at Union Station and smoother operations along the blended corridor. The electrified blended corridor will not improve the connection at Oceanside between Metrolink and COASTER.
High-frequency, uniform HSR and commuter service	With electric service, Metrolink and HSR trains can intermix and provide a more comprehensive service plan. A program similar to, but more expansive than, Rail2Rail will allow for passengers use both systems. Speed homogeneity will allow for better use of available track capacity. The Burbank-Union Station trunk may need capacity increases to accommodate higher levels of Metrolink and HSR services, especially when freight continues to operate on the line.
Bond Measure Satisfied	Metrolink and Surfliner electrification will not negatively impact the ability of the CHSRA to meet Proposition 1A requirements, but In terms of meeting revenue-neutrality, electrification of the corridor will allow for a one-seat ride from the Bay Area to Los Angeles and Anaheim as early as 2022. Metrolink service can act as a more effective feeder service for HSR by reducing total trip time.
Minimize costs and build system quickly	There might be savings in accelerating the construction of the catenary system between Burbank and Los Angeles and Anaheim. By extending to Los Angeles, the CHSRA avoids the prospect of a temporary terminal in Burbank. The largest additional expense will be converting Metrolink and the Surfliner to electric operation in the corridor. Institutional hurdles will need to be addressed, especially the issue of interacting with freight on both publicly-owned and freight rail-owned infrastructure.

6.3.4 Decision D: Tracks on Peninsula

Choices 1 and 2—Two Track Corridor or Two Track Corridor with Midline Overtake

We will compare the two-track corridor and the two-track corridor with a midline overtake in the same table. The two track corridor is the existing system (plus electrification, positive train control, and the downtown extension) which actually has two four-track areas meant for Baby Bullet overtakes. The midline overtake option includes building an additional four-track section on the middle of the corridor that allows for HSR overtakes of Caltrain services.

	Two Tracks or Two Tracks with midline overtake
Level Boarding and Interoperability	Two Tracks—Since the two-track corridor constrains capacity, this drives the CHSRA and Caltrain to pursue level boarding. The lack of capacity afforded to the high-speed rail on the Peninsula will mean that interlining HSR passengers onto trains might become a priority. This, in turn, will dictate the importance of a smooth transfer at San Jose and again encourages the concept of interoperability. Midline Overtake—Level boarding is less critical with the increased infrastructure, but the transfer at San Jose might be important if the demand for HSR services grows
Ability to modify service levels	Two Tracks—With a two-track corridor, it will be very difficult to add service. LTK estimates the most that the corridor can handle "as is" is 8 trains per hour with even 30- minute headways for HSR. If it becomes apparent that HSR needs more service to match demand, it will be very difficult and costly to build midline overtake tracks without disrupting service on the Peninsula. In 2004, when overtake tracks were built for Caltrain's Baby Bullet project, the agency suspended weekend service—this would likely be financially unviable for high-speed rail and weekend travel demand. Midline Overtake --Slightly easier with more track infrastructure, but signal and run-time delays already surfacing in LTK analysis. Grade crossing delay will be exacerbated.
Shared corridor with Xpress West	Two Tracks—This design choice sets a precedent for the idea of "common infrastructure." However, if the HSR operator starts to experience loss of revenues due to inadequate service on the Peninsula and into San Francisco, the likelihood of sharing revenues with Xpress West on the Palmdale-Los Angeles portion diminishes Midline Overtake —both effects are diminished in comparison to the two-track option
Integrated Southern California Rail Network	Two Tracks—Limited infrastructure requires careful planning of transfers in San Jose. This could create down-line scheduling conflicts in Southern California and require trains to be truncated at Burbank to avoid slot conflicts with other passenger rail or freight. Midline Overtake —the effect is diminished in comparison to the two-track option

High-frequency, uniform HSR and commuter service	Two Tracks—LTK analysis reveals that high-frequency, uniform-headway service very difficult with two-track system (see Chapter 4). Like the effect on level-boarding, this might encourage more serious discussion on interlining and cooperation between CHSRA and Caltrain. Baby Bullet service is probably not feasible because of timetable disruption it causes on other Caltrain services. Ten Caltrain trains per hour is not feasible. Again, in Southern California, HSR has to take precedence to ensure well-timed connections at San Jose. The limited ability to add HSR service possibly makes it easier for Caltrain to access the Transbay Transit Center. Midline Overtake —Baby Bullet service might be feasible (according to LTK analysis). Baby Bullet trains could be used as a superior substitute for HSR service than local Caltrain services making a transfer at San Jose more palatable for a time-sensitive HSR customer.
Bond Measure Satisfied	Both options can only theoretically satisfy the bond measure if the tracks are upgraded to 125mph operation. Two Track—Limited service HSR trains during peak hours could take away ridership from system. Given the importance of San Francisco to intra-California traffic, airlines will likely continue to provide capacity on the market and take away pricing power of an HSR operator. Midline Overtake —More HSR trains per hour would allow for better competition with airlines and allow for more ridership/revenue capture.
Minimize costs and build system quickly	Two track—Minimizes infrastructure cost on Peninsula and avoids likely political battles with expansion and decreases construction timeline. This is only true if HSR never determines that it needs to expand, because building the midline overtake tracks after operation begins will be expensive, time-consuming, and politically challenging. Since Baby Bullet service is infeasible, Caltrain now has more incentive to switch to an all-EMU fleet (Caltrain has planned to use diesel trains to continue Baby Bullet service). This might increase costs in the short-run since the diesel fleet is retired earlier than the expected useful lifetime, but long-run benefits of single fleet type might outweigh costs. Midline Overtake —political opposition to adding tracks will prolong timeline and there is extra cost associated with more tracks.

Choice 3—Four Track Corridor

The four-track option is very unlikely, but should be examined in order to contrast the results with the two-track options. Legislators and their constituents on the Peninsula, despite overwhelmingly being in favor of Proposition 1A, made their voice heard in Sacramento. The four-track option, with its trenches and viaducts cutting through the neighborhoods along the Peninsula Corridor, is a threat to land values on the Peninsula and the least preferable option.

	Four Tracks
Level Boarding and Interoperability	Level boarding for Caltrain is unlikely because HSR will have dedicated tracks and no incentive to integrate and cooperate. Caltrain would lose incentive to procure compatible trains. Caltrain loses benefit of shared platforms at Transbay Transit Center Level boarding in Southern California unlikely because Northern California would be getting dedicated stations (sets precedent).
Ability to modify service levels	Adding service is easiest for HSR on the Peninsula. Caltrain is still capacity constrained and might have difficulty accessing HSR tracks for passing (Baby Bullet overtakes) In Southern California, there is more flexibility to add frequency in the capacity constrained environment since schedule choices in the South do not need to be coordinated as carefully with timetables on the Peninsula Corridor.
Shared corridor with Xpress West	Sharing corridor is probably easier because of less northern timetable constraints, but CHSRA will lack framework for sharing infrastructure in Northern California. Higher San Francisco revenues for CHSR might encourage political leaders to advocate for Xpress West service through to Los Angeles (since the competition would not interfere as much with California HSR operator revenues)
Integrated Southern California Rail Network	There is a lack of a framework for sharing infrastructure and a dedicated corridor in Northern California might encourage a similar dedicated corridor in Southern California. This separate HSR system will leave little incentive for integration among other Southern California passenger rail providers.
High-frequency, uniform HSR and commuter service	For HSR service, high-frequencies and uniform headways are much easier due to lack of Caltrain interference. Caltrain will likely loses opportunity to run as many Baby Bullets as HSR track will be “reserved” for HSR
Bond Measure Satisfied	Best opportunity for bond measure to be satisfied since there is new infrastructure to allow for upgraded signals, fast speeds, and revenue-optimal HSR service levels in Northern California.
Minimize costs and build system quickly	Costs will escalate well-above $68B since this requires two additional tracks (likely above grade or in trench) in very dense urban corridor Politically challenging as the reversal to a four-track system requires reversal of nine-party MOU explicitly calling for a predominantly two-track corridor

6.4 Effect of Decisions on Other Local Decisions

Not one of these design decisions is completely independent of other choices that will be made in the next few years. In this section, we will assume a certain design choice gets made first and then examine its impact on the rest of the design decisions. In each of the following matrices, we look at one design decision and speculate as to the likely effect that decision has on other design choices.

6.4.1 Decision A—Platform Height and Equipment Coordination

<table>
<tr><th></th><th>Capacity Allocation Process</th><th>Southern California Electrification</th><th>Tracks on the Peninsula</th></tr>
<tr><td>1—Railroads acts alone</td><td>A lack of coordination between railroads regarding platform height might imply that there will be a similar lack of coordination regarding service planning until absolutely necessary</td><td>Since there is no chance of interoperability with distinct platform heights, It is very unlikely that the blended corridor will be electrified earlier than 2028 or that Metrolink would ever electrify its trains</td><td>Since separate platforms for Caltrain and HSR creates a distinct HSR service pattern, a midline overtake will likely be necessary</td></tr>
<tr><td>2—CHSRA coordinates with Caltrain</td><td rowspan="3">With separate entities behaving as “one railroad system,” it becomes increasingly likely that precise service planning and capacity negotiations can take place before construction</td><td>Caltrain coordination with CHSRA might set a precedent for Southern California to attempt to coordinate with CHSRA regarding roll-out of electrification.</td><td rowspan="2">Depending on the level of interlining and integration between HSR and Caltrain, a midline overtake may not be useful</td></tr>
<tr><td>3—CHSRA coordinates with Caltrain and Southern California railroads</td><td rowspan="2">The benefits of interoperability would be fully realized if the entire corridor is electrified as soon as possible</td></tr>
<tr><td>4—CHSRA coordinates with Caltrain, Southern California Railroads, and other California rail agencies</td><td>With such high levels of integration, keeping the corridor on two tracks is much more feasible</td></tr>
</table>

6.4.2 Decision B—Capacity Allocation Strategy

	Participants in Platform Height Discussion	Southern California Electrification	Tracks on the Peninsula
1—Do not develop a capacity allocation strategy	Without a capacity allocation strategy, railroads may not realize their true capacity constraints and will be less likely to pursue coordination on platform height and interoperability	Combining HSR with an electrified corridor through to Union Station would require careful capacity planning, so it would be easier to avoid interlining the railroads and initially truncating HSR service at Burbank	The exact needs of HSR will not be clear so it is less likely that Caltrain and the CHSRA will try and justify a mid-line overtake expansion
2—Create a codified capacity allocations strategy	A codified capacity allocation mechanism reveals the challenges of segregating some infrastructure and blending other infrastructure, so this might facilitate increased coordination between all passenger railroads.	Because Metrolink would need to provide higher service levels to facilitate a Burbank transfer, capacity would need to be completely re-negotiated or re-allocated twice (once in 2022 and once in 2028 when Phase 1 is complete) with freight railroads. It would be politically easier to integrate (i.e. electrify) immediately and negotiate only one time.	With a better understanding of 1) which operator gets access to the track at what time and 2) what kind of integration there will be between CHSRA and Caltrain, the specific needs of the Peninsula in terms of infrastructure will be realized
3—Negotiate capacity	Careful service planning will reveal the benefits of high levels of integration		

6.4.3 Decision C—Southern California Electrification

<table>
<tr><th></th><th>Participants in Platform Height Discussion</th><th>Capacity Allocation Process</th><th>Tracks on the Peninsula</th></tr>
<tr><td>1—Conventional (Diesel Corridor)</td><td>With slower diesel service, the only advantage of a similar platform height is a quicker HSR-Metrolink transfer, decreasing the incentive to collaborate</td><td>A capacity allocation process is less likely because Metrolink, UP, Amtrak, and BNSF already have capacity agreements in place and HSR initially stays out of this shared corridor</td><td rowspan="2">On one hand, a slower trip (i.e. transferring) into Los Angeles could justify a slower trip into San Francisco (fewer tracks), but at the same time , the delay experienced in Southern California could encourage better performance on the Peninsula (more tracks)</td></tr>
<tr><td>2—Electrification</td><td>This large investment in Metrolink will encourage CHSRA and Metrolink to seriously consider converting the Metrolink system so it is HSR-compatible</td><td>The investment required in electrifying early will encourage the CHSRA and Metrolink try and maximize utility of the infrastructure. This will encourage new capacity allocation agreements.</td></tr>
</table>

6.4.4 Decision D—Tracks on the Peninsula

	Participants in Platform Height Discussion	Capacity Allocation Process	Southern California Electrification
1—Keep corridor as is	With a two-track corridor, Caltrain and HSR will practically be forced into collaborating on platform height since capacity is so limited. This might encourage similar collaboration in Southern California	With increasing capacity on the Peninsula (from constrained two track corridor moving towards dedicated HSR capacity), there is less incentive to create a capacity allocation procedure or carefully plan service	Since not all HSR trains will be able to serve San Francisco due to line capacity constraints, it is likely that the same strategy could be applied in Southern California and Los Angeles, reducing the need for early electrification
2—Expand the corridor to include passing tracks	Increased capacity on the Peninsula removes pressure for platform sharing and integration		Increased one-seat rides in San Francisco increase pressure for one-seat rides into Los Angeles, making the case for early electrification
3—Revert to the four-track option	Platform sharing unlikely with 4-track option because the only benefit is increased flexibility at the Transbay Transit Center		Because platform sharing is unlikely, it is also unlikely to electrify Southern California early because the utility of an electrified Metrolink decreases

6.5 Conclusions

In this chapter, we take a step back and ask what needs to happen to bring California the rail network it needs to sustain its future economic prosperity. We identify seven "wish list" items ranging from interoperability to a train to Las Vegas to high-frequency, uniform-headway commuter rail service. We then review four key design decisions that are going to be made by the CHSRA and its commuter rail agency partners in the next few years of project development. For each of these decisions, we evaluate how a certain design decisions affects the probability of one of these wish list aspirations to be realized.

Agreement on platform height, as mundane as the topic appears at the surface, unlocks much capacity in terms of integration between commuter and high-speed rail systems. However, this requires careful planning of revenue splits and service patterns across the system. Service levels cannot be planned one system at a time as has been done in the past—capacity in California is too precious and high-speed rail needs adequate rail capacity to be successful. Without a guaranteed access plan, a high-speed rail investor will demand a risk premium to operate the service. Revenue neutrality will be put at risk, a risk ultimately absorbed by the taxpayers of California.

In Southern California, we examine the impact of a temporary terminal in Burbank. We agree with the Rail Passenger Association of California and Nevada that there are significant ridership risks to forcing passengers to transfer to conventional diesel service to reach Los Angeles and Anaheim. However, there is also a risk in converting Metrolink (and possibly the Pacific Surfliner) to electrified service. One possibility is simply accelerating construction phasing so that a one-seat ride to Los Angeles on electrified track comes on-line in 2022 along with Burbank, but in this case, high-speed rail might lose an important feeder system in Metrolink.

The elephant in the room in Southern California is the freight presence in the blended corridor. Unlike in Northern California, where freight is a tenant, in Southern California, between Los Angeles and Anaheim, the freight operator—specifically BNSF—is an owner. Furthermore, this subdivision is vital to BNSF as it is a link between the Ports of Los Angeles/Long Beach and its sprawling Hobart Intermodal Yard. Before any kind of blended service expansion gets implemented in Southern California, the BNSF Railway's needs will need to be addressed.

On the Peninsula, in their blended service analysis, LTK Engineering stressed the importance of a long, mid-line overtake track. Leaving the corridor as is has implications that will be felt across the state. Interregional travelers will have limited service into Los Angeles and capacity negotiations will be strained. While the limited capacity on the line will undoubtedly push the Caltrain and CHSRA to collaborate on level boarding and integration. However, without level boarding and with the corridor remaining as is, the service quality experienced by both the HSR traveler and the Caltrain commuter will be hamstrung.

Having the same vehicle floor height is only the first step. For instance, Caltrain and high-speed rail could have the same platform height and share platforms in the Transbay Transit Center which would reduce the impact of delays or mechanical failures in either system. However, the two operators could go further. High-speed rail could offer customers the opportunity to transfer to a Caltrain train with a simple cross platform timed transfer at San Jose to a Caltrain express. As long as baggage could be quickly transferred, this would practically be a pure substitute for a high-speed rail ride into the Transbay Transit Center. Reinhard Clever challenges California to take integration a step further. His proposal for Caltrain to share tracks and platforms with the San Francisco Municipal Transportation Agency and share stations BART is bold and creative yet requires significant institutional coordination and acceptance of one standard over another and ceding of institutional jurisdiction, a non-trivial hurdle for agencies with clear definitions of scope.

In the last section of this chapter, we examine design decisions on other design decisions—in this complex rail network, no one single decision can be made without having some impact on other choices to be made in the future.

In 2009, the CHSRA, in coordination with Parsons Brinckerhoff, developed a comprehensive set of technical standards that define how high-speed rail will function. This includes everything from platform height to cabin layout to station security. Of course, 2009 is prior to 2012 when the blended system philosophy was laid out in the CHSRA Business Plan. It would be worthwhile for the CHSRA to revisit these standards now that integration is more important than ever to a successful California network.

We thank the reader for continuing with us through this exploration of the challenges and opportunities that California's present and future rail network faces. In our concluding chapter, we will review these challenges and opportunities and offer a path for California to proceed, both on the corridor and statewide level.

7 Conclusion

As we arrive at our conclusion, we thank the reader for their continued attention and hope that they have found this to be a valuable reading thus far. Supposing that the reader is just joining us or is reading this thesis intermittently, we will briefly review the topics we covered in the first five chapters. Finally, we will discuss our findings, conclusions, and recommendations, and review the contributions we have made to the story of high-speed rail implementation in the context of California.

Without the California High-Speed Rail Authority's radical departure from the dedicated high-speed system to a blended line shared with the region's commuter railroads, a decision that was urged by the governor, this thesis would not exist. Legislators determined that the dedicated line was no longer feasible due to costs and local opposition to a high-speed rail line slicing through communities. Moreover, the blended system creates many new opportunities for the State to take a new look its rail network beyond the high-speed line.

7.1 Brief Review of First Five Chapters

7.1.1 Chapter One: Introduction to Railroad Capacity, HSR, and California

In this chapter, we discuss the importance of rail capacity management as the demand for passenger and freight rail grows. In the second half of the chapter, we introduce California and its rail geography. We end the chapter by explaining the motivation behind this research: to improve capacity management, and to understand how local decisions regarding capacity affect the California rail network's ability to move both intraregional and interregional travelers as well as freight.

Importance of Capacity Management

The railroad is anything but an antiquated 19^{th} century technology. America's freight rail network is prevailingly relevant as it carries 40% of the nation's freight (as measured by ton-miles carried). Not only does rail provide a "green" alternative to carrying freight by truck, it also reduces congestion on our nation's highways. Ton-miles carried per mile of track have more than tripled since 1980--meaning our track networks are busier than ever. Simultaneously, passenger rail traffic has increased by all measures. These two growth trends have led to a proliferation of shared track corridors where freight lines and passenger lines share rail infrastructure. It is important to study capacity on shared corridors because the congestion and delay costs affect both freight operators and passenger rail agencies. Furthermore, we are finding it difficult to increase capacity through adding infrastructure because 1) urbanization of the country has created a scarcity of adequate right of way for railroads, 2) finding funding for these megaprojects has become politically and financially infeasible.

California is finding itself as "Exhibit A" in representing the trends of passenger and freight rail growth. In Southern California, the Ports of Los Angeles and Long Beach are a massive origin and destination of freight rail traffic for the entire country. The BNSF and Union Pacific Railroads share tracks with local commuter rail and Amtrak service as they move goods across the Los Angeles Basin. In Northern California, Caltrain finds itself in a capacity crunch on the Peninsula, as it confronts the mixed blessing of standing-room only trains and year-over-year ridership increases. California, the world's 8^{th} largest economy, is experiencing transportation capacity challenges on all fronts. The Los Angeles-San Francisco short-haul air market is both one of the busiest and most delay-prone in the U.S. Expanding runway capacity is both politically and financially infeasible. Because of the urbanization of the state, adding freeway lanes is also a costly task; the recent expansion of the I-405 freeway in Los Angeles cost the state $1.1 billion for 20 lane-miles of highway.

High-speed Rail and California

California, along with some other states, views high-speed rail as one of the most effective alternatives to meet rising transportation demand. We discuss why California and its voters believed that an investment in high-speed rail was the right choice for the state in 2008 and the advantage that high-speed rail has over air transportation, its main source of ridership.

Introduction to California's Rail Geography

We conclude Chapter 1 with an introduction to California and its current rail geography. California hosts a wide array of passenger rail services as well as being a freight transportation hub. Amtrak California operates three intercity routes, of which the *Pacific Surfliner*, running in the San Luis Obispo-Los Angeles-San Diego (LOSSAN) corridor, enjoys the highest ridership of any Amtrak line outside the Northeast Corridor. In Northern California, two commuter rail lines (PCJPB's *Caltrain* and SJRRC's *Altamont Commuter Express)* carry passengers into and within Silicon Valley and the San Francisco Peninsula. In Southern California, the Southern California Regional Rail Authority (SCRRA) operates a web of Metrolink commuter lines reaching across the region from its Los Angeles Union Station hub, and the North County Transportation District's *COASTER* provides coastal commuters service into San Diego's Santa Fe Depot. Finally, Amtrak operates four long-distance trains across the state, connecting points as far away as Chicago.

A main theme of California's rail network, is "one line, multiple owners." Though California commuter rail agencies own nearly 50% of the track on which they operate their networks, virtually 100% of the network is shared with freight railroads that operate freight traffic 365 days per year. This creates scheduling challenges for both freight and passenger railroads now and into the future. Because the California High-Speed Rail Authority has elected to share track and corridor with these commuter railroads, the future high-speed rail operator will not escape the complex negotiation process with California's freight railroads.

7.1.2 Chapter Two: California HSR and Sharing Capacity—Literature and Practice

In this chapter, we review literature regarding sharing capacity, capacity allocation mechanisms, and the California high-speed train project. We then discuss the practical challenges of sharing capacity whether between high-speed rail and conventional passenger rail or between conventional passenger rail and freight. We end the chapter with an overview of European shared corridors, where separation of infrastructure, ownership, and train operations has been mandated by the European Commission.

Capacity Allocation and Pricing

In this section of the literature review, we review different forms of capacity allocation discussing Stephen Gibson's three distinct mechanisms in practice today—administered, cost-based, and market-based—as well as Patricia Perennes' discussion of rail-specific challenges in managing capacity. We look at novel proposals for capacity allocation mechanisms and how they might be applied on all, or part of the California system.

Integration and Institutions

We then introduce the concept of integration, using Reinhard Clever's TRB paper on the "six levels of integration." This theme of integration is important throughout the remainder of this thesis. We also introduce the concept of competition versus collaboration in public agencies through a paper written by Meyer et al. While the CHSRA is not, per se, competing with any of the other passenger rail agencies in the state, it will inadvertently, by nature of rail capacity, be competing for access on shared corridors.

California HSR Research

There is a great deal of literature previously written on the California high-speed train project, though not that much research has been performed since 2012 when the CHSRA radically changed their project delivery approach from fully-dedicated line to blended system. We categorize the current research into three groups: 1) studies regarding the project's feasibility, revenue, and ridership, 2) the relationship between California HSR and the state's air transportation network, and 3) novel approaches to high-speed rail service in the state.

7.1.2.1 Shared Corridor Challenges

There are numerous challenges to sharing track, which we separate into physical, operational, and institutional challenges. Physical challenges include rail geometry constraints, and clearance issues for platforms and overhead catenary. Operational challenges include the difficulty of accommodating heterogeneous train speeds, implementing positive train control among different railroad operators, and finding time to perform on-track maintenance on busy corridors. Lastly, institutional challenges include priority rules for operators and the competition versus collaboration for railroads providing passenger service.

7.1.2.2 Vertical Separation versus Integration

In final section of the literature review, we review the multitude of research looking at the effects of unbundling (vertical separation) versus traditional vertically integrated railroads. Both sides have advocates and detractors, with the general consensus being that "the jury is still out" on the optimal institutional structure. What is certain, however, is that the European Union is performing a grand experiment on unbundling with its railway directives.

7.1.2.3 European Union Case Studies

The European Union's directive to separate railway services from railway infrastructure ownership with minimal further instructions to member-states has led to a variety of institutional arrangements between infrastructure managers and operators across the European Union. In this section, we examine the "network statements" of different infrastructure managers which govern access to the railway network. In particular, we look at managers in Belgium, Germany, the Netherlands, Portugal, Spain, Switzerland, and the United Kingdom. Much of the competition thus far, has been "off-track," but in Italy, we discuss on-track competition between high-speed rail operators. We discuss the relevance of the European Union experience to California and conclude that, while current institutional arrangements preclude vertical separation in California, European models could serve as models for new capacity allocation mechanisms.

7.1.3 Chapter Three: Northern California Blended Service

In this chapter, we discuss the past, present, and future of the Peninsula Corridor in northern California. The blended service on the Peninsula is going to be capacity constrained and the San Francisco northern terminus of the high-speed rail line is critical for both Peninsula commuters and intrastate high-speed rail travelers.

History and Today's Peninsula Corridor Joint Powers Board

In this section, we provide a brief history of the San Francisco-San Jose rail line and introduce the institution that has managed the rail service—branded as *Caltrain*— on the Peninsula for nearly 30 years: the Peninsula Corridor Joint Powers Board. The PCJPB, made up of the three counties served on the 87-mile network, owns the northernmost 51-miles of track between San Francisco 4th and King Station and San Jose Rod Diridon Station; Union Pacific uses the corridor and maintains perpetual trackage rights. The PCJPB and its relationship with Union Pacific, the CHSRA, and the private operator on the corridor is already and will continue to be instrumental in the ultimate form of high-speed rail in California.

Current and Future Ridership Growth (Electrification and Transbay Transit Center)

We then discuss a "state of the system" for Caltrain. The railroad is enjoying huge ridership growth due, in part, to the thriving economic conditions in Silicon Valley and San Francisco and the millennial generations' desire to leave the car at home or not own a car at all and be productive on the daily commute. The Baby Bullet express service has provided reasonable travel times, but has also drawn many commuters to bring their bikes on-board—Caltrain sees more bicyclists on-board than any other transit agency in the nation.

We discuss two projects that have the potential to change commute patterns and drive ridership even higher. First, an electrification of the corridor will allow for more local services--making the train a more convenient option. Second, the extension of Caltrain to the Transbay Transit Center (the Downtown Extension) will bring Caltrain riders much closer, via a one-seat ride to San Francisco's job center.

"The Blended System"

After a review of Caltrain and its ridership growth, we introduce the implications of welcoming high-speed rail to the corridor as part of a "blended system." In this blended system, high-speed trains will share tracks with commuter rail agencies on the north and south "bookends" of the line; aside from track speed upgrades and potential construction of passing sections, the Peninsula Corridor will remain very much the same as it is today. The change from separated to shared infrastructure was made in response to ballooning costs and public outcry from residents in affluent Peninsula communities who felt the construction of a dedicated high-speed line would destroy property values. The switch has implications for some of the requirements of the bond measure: that a high-speed train can travel from San Francisco to San Jose in 30 minutes, that it can operate at 5-minute headways, and that the operation will require no public subsidy.

The Importance of the Transbay Transit Center and Peninsula to HSR

In the last section of the chapter, we discuss criticality of the Transbay Transit Center to Caltrain as a ridership source and destination and to the high-speed operator as a revenue generator. The two operators will compete both spatially for the six-track terminal and temporally during the rush hour peak. Currently, the plan is to have two dedicated Caltrain tracks and four dedicated HSR tracks, but the Transbay Joint Powers Authority is urging the two agencies to consider adopting standard vehicle height to allow for platform sharing.

7.1.4 Chapter Four: Current Levels of Coordination and Train Operator Model

In Chapter Four, we review publically available documents regarding the partnership between the California High-Speed Rail Authority and the Peninsula Corridor Joint Powers Board. We then turn to the Transbay Transit Center, which will be owned by the Transbay Joint Powers Authority, a third-party entity with no formalized allegiance to either of the two rail operators. We apply the train operator model previously developed for the Northeast Corridor and apply it to the Transbay Transit Center and Downtown Extension. We conclude that a high-speed rail operator would have a much higher willingness than a commuter rail operator to pay for access to the important San Francisco station.

LTK Blended Operations Analysis and Memorandum of Understanding

We review two significant documents regarding blended operation: the memorandum of understanding between the PCJPB and the CHSRA and the blended operations analysis performed by LTK Engineering. The Memorandum of Understanding highlights that 1) freight will remain operating on the blended corridor, 2) the track configuration, aside from a few passing tracks, will remain the same, 3) Caltrain service will remain operational during the construction of the blended system, and 4) the PCJPB will retain ownership of the corridor assets (aside from to-be-construction Downtown Extension and Transbay Transit Center). LTK's blended service analysis shows that headways for Caltrain become very uneven with the addition of just one HSR train on the corridor, and that more than two HSR trains per hour will require the construction of a midline overtake track.

The Transbay Transit Center—Comparisons to Penn Station

In this section, we compare the Transbay Transit Center to Penn Station, an existing terminal with multiple operators. The Hudson River tunnels that bring New Jersey Transit and Amtrak trains into the station are at capacity, making peak hour schedule changes difficult for both operators. One key difference between Penn Station and the planned Transbay Transit Center is that, while Amtrak owns Penn Station and operates trains in and out of the terminal, the Transbay Joint Powers Authority will not operate any trains. We also discuss the challenges of scheduling commuter rail with high-speed rail on the Northeast Corridor and review the institutional arrangement between Metro North Railroad and Amtrak.

Application of TRB Paper Model

Using this knowledge that the northernmost 1.3 miles of the high-speed rail line will be a vertically separated structure, we apply the vertically-separated train operator model developed in our TRB paper. We determine that it would be difficult for the high-speed rail operator and Caltrain to compete on a level playing field for access to the Transbay Transit Center due to the fiscal strength of the high-speed rail operator. We conclude that it is much more likely that capacity will need to be negotiated between all parties, rather than auctioned to the highest bidder.

7.1.5 Chapter Five: The Southern California Network and Blended Plans

In Chapter Five we introduce the Southern California rail network and the planning that is underway for the arrival of high-speed rail. We discuss the Los Angeles Union Station terminal and the upcoming Southern California Regional Interconnector Project that will add four run-through tracks for HSR and commuter rail. As in Northern California, high-speed rail operations will be blended with commuter rail operations. However, in Southern California, there are more operators, freight-owned right-of-way, and no plans to electrify non-HSR operations. The development of blended service plans is nascent in Southern California, even more so than the Northern California system.

7.1.6 Chapter Six: Measuring the Statewide Impact of Local Decisions

In Chapter Six, we amalgamate our research on shared system challenges and the northern and southern ends of the California HSR network and construct a "wish-list" for the future California rail network. We then identify four upcoming decisions that are likely to be made on the local level—the platform height standard, the decision whether to electrify Metrolink and phase the project in Southern California, whether or not to adopt a formal capacity allocation mechanism (at the Transbay Transit Center or system wide), and whether to construct additional tracks on the Peninsula Corridor. We then evaluate the impact of each choice on the "wish-list" as well as the impact of each choice on the other choices. We find that items as mundane as platform height can have powerful impacts on the ultimate performance of the California passenger rail network.

This concludes our brief review of this thesis. We now move into the conclusions section of this chapter where we present the results of our analysis of the California rail system and provide recommendations to passenger rail agencies across the state.

7.2 Conclusions

7.2.1 Conflicting institutional priorities stand in the way of a unified California rail network

The California rail network is currently fragmented and there is much opportunity for interagency coordination. The Rail2Rail program in Southern California is a positive first step, but that program could be improved through expansion. The Southern California Regional Rail Authority (SCRRA) could work together with the North County Transit District (NCTD) to ensure timed transfers at Oceanside, or better yet, through-run trains to provide commuters options that are more affordable than buying an Amtrak California ticket. Agencies are often protective of their own assets and there is no overseeing agency that implores agencies to work together; as Clever notes in his paper on integration, "By dividing up project planning into separate professional disciplines studying engineering/capital costs, ridership/operating costs, and environmental impacts, sight of the system as a whole is lost. System wide ridership studies are completed without knowing the exact station locations or the level of integration with other modes" (Clever 12). This individualistic agency mindset will not work in a blended system in the future.

7.2.2 Northern California is further along in the planning process than Southern California

While the CHSRA announced the change to a blended system for both Northern and Southern California at the same time, the southern blended system lags the northern counterpart in definition. Granted, the Southern California network is much more complex than its northern counterpart; but since the Los Angeles Basin will see high-speed rail service six years before the Bay Area does, it is surprising that the north leads the south in this regard. Perhaps this is due to higher levels of political pressure in Northern California, but the fact remains that there is no blended operations analysis or significant memorandum of understanding signed between SCRRA, the CHSRA, Amtrak California, or the Class I freight railroads. In Northern California, this early planning has been beneficial because it has brought to the forefront questions such as platform compatibility and ultimate track layout. However, the current fuzziness of the Southern California system is also an opportunity, since all options are still available for consideration.

7.2.3 Shared corridor challenges most important to California

Congestion and Delays

The blended system will put high demands on the existing infrastructure. Commuter rail or freight delays can propagate to the HSR system. As the ratio of service volume to capacity tends towards 1, the system loses stability and on-time performance suffers. With degraded on-time performance and uncertainty regarding arrival times, schedule padding becomes necessary and makes rail as a mode less attractive to time-sensitive consumers.

The Caltrain corridor today experiences delays due to two main factors: aging equipment malfunctions and on-track suicides[21]. While some of the oldest equipment will be retired once the electric equipment arrives in 2020, Caltrain plans to continue operating some diesel-electric equipment concurrently with the electric vehicles. Aside from the two different fleet types making maintenance more time-consuming, this could lead to delays when aging equipment breaks down and a specific fleet type needs to be substituted. And since grade crossings will not be eliminated, on-track suicides will continue to cause significant delays, though ongoing prevention programs could help minimize this impact.

CPUC Requirements

There are two major California Public Utility commission regulations that stand in the way of an integrated rail system. The first is a regulatory framework for high-voltage operation on shared corridors. The CHSRA developed a framework for high-voltage operations on its dedicated corridors, but operations in blended corridors with freight and grade crossings have yet to be addressed. If this fails to be resolved, the CHSRA would be forced to either build dedicated right-of-way as originally planned or truncate its operations in Burbank and San Jose and forced travelers to transfer to commuter rail systems.

Overhead catenary wire presents clearance issues for freight railroads in Southern California. Freight railroads cannot operate in certain tunnels with double-stack containers if overhead catenary wires are not high enough to provide adequate clearance. It will also be challenging to construct the improvements necessary for the high-speed rail system on the BNSF-owned right of way in Southern California as freight railroads demand high levels of track availability.

The second CPUC requirement is the freight train lateral clearance requirement. This standard requires adequate lateral clearance for freight trains at platforms. The platforms of the SPRINTER light rail system in San Diego County are evidence of this requirement in action. The SPRINTER shares track with freight railroads but also uses high platforms. To meet the ADA maximum 3" gap requirements and satisfy the CPUC minimum gap requirements, the SPRINTER employs mechanical platform "gangways" that descend during light-rail operation during the day, and retract at night to allow for freight trains to pass. The CHSRA has opted for separate stations to avoid this CPUC requirement. Using the same stations as the commuter rail lines would mean that the CHSRA must find a compatible platform height and urge for CPUC rule changes. Freight railroads will likely contest rule changes because it will limit their operational flexibility to haul wide loads. However, the cost savings of not having to build HSR-

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[21] Though the suicide rate fluctuates from year-to-year, Caltrain claims it has the highest suicide rate in the nation (Brotherhood of Locomotive Engineers and Trainmen 2003)

specific stations are substantial and the rule changes are something the author believes are worth working hard to achieve.

Track Ownership and Priority

The blended system dictates that the CHSRA will operate on a multi-owner network, much like Amtrak does today. Instead of having sole control of its infrastructure, the CHSRA will have to work with the TJPA, PCJPB, SCRRA, and BNSF Railway to ensure smooth operation. As a result, the CHSRA will face many of the issues Amtrak faces today regarding train priority. The ability for the CHSRA to operate in a reliable fashion will depend on the priority rules that the CHSRA can negotiate with its host railroads on the blended corridors.

7.2.4 The blended service on the Peninsula as it stands today is infeasible

While neither agency would describe their relationship as a competitive one, the HSR operator and Caltrain will be competing for track access and access to the downtown San Francisco terminal. The blended operations analysis, though PCJPB emphasizes that it is a feasibility study, not a service plan, shows that Caltrain will likely have limited access to its most important station and that the HSR operations create uneven headways on the corridor. Furthermore, without passing track construction on the mid-peninsula (through the very same communities that fought against the four-track corridor), CHSRA can only operate two trains per hour, per direction into the terminal. The separate stations for high-speed rail up and down the Peninsula will make it difficult for passengers to “interline” or use both systems as envisioned in the 2012 CHSRA Business Plan describing blended service. A renewed dedication to blended operations is beginning to form with the current discussion on Caltrain’s new electric equipment; the two agencies need to keep this momentum while moving forward towards a true shared system.

7.2.5 The blended system as planned does not match the former aspirations of Caltrain or HSR

The blended system was a significant scale-back of the high-speed rail system sold to voters in 2008, and it is evident that both the service plans of Caltrain and the CHSRA are nowhere nearly as customer-friendly as they were before 2012. Caltrain has shared aspirations of 10 trains per hour, per direction on the corridor, while the high-speed rail authority has shown service frequency as high as eight trains per hour per direction The LTK engineering study reported that six Caltrain trains per hour was feasible and four HSR trains was possible only with significant construction. Due to the importance of Caltrain to everyday commuters, significant construction of passing tracks is exceptionally challenging: the Ponderosa Project to build the passing tracks for Baby Bullet service required weekend shutdowns of the Caltrain system for two years This means that once a high-speed operator is running revenue service along with increased Caltrain service, performing track construction to expand capacity on the line or in the Transbay Transit Center will be more challenging than ever before.

The CHSRA asserts that they are still meeting the bond measure requirements that were approved by voters in 2008. However, the language of the measure suggests a very different system than what is on the table today. When the voter read the text “Achievable operating headway (time between successive trains) shall be five minutes or less” it would have been reasonable for the voter to assume that service levels would be somewhat higher than two high-speed trains per hour (30 minute headway) into San Francisco.

7.2.6 The impact of the phased approach has consequences that go beyond the phase

Truncating the initial operating segment in the San Fernando Valley for six years is a hugely important decision, especially if the CHSRA chooses to operate in separate station facilities than Metrolink. Metrolink service will need to match high-speed rail trains with much higher off-peak service levels than today to ensure a timed transfer. Even so, a smooth transfer will be very difficult because Metrolink will be at a separate platform, meaning that without costly facilities, baggage transfer will be difficult. Because transit connections are poor in the San Fernando Valley, the high-speed operator will demand high levels of parking to enable access for residents across the Southland. Building these parking facilities for a temporary terminal will impact land-use around the station site; the positive impacts of transit-oriented development, a key driver in ridership, will not be realized. This could affect long term ridership and the ability of the high-speed rail operator to generate revenues to cover operating costs.

7.2.7 Freight Impacts

It could be argued that a strong rail freight network is just as important to California's economy and congestion mitigation as a strong passenger one. The freight railroads provide a key role in transcontinental goods movement and one freight train removes hundreds of trucks from our nation's highways. It is for this reason that the freight railroads cannot be "pushed aside" for passenger service. On the Peninsula Corridor, freight will seek to continue operation on the corridor; however, increased corridor use from high-speed rail will narrow operating windows for freight service and finding time for track maintenance will be more difficult than it is today. In Southern California, BNSF will likely require high-speed rail to expand capacity on BSNF's San Bernardino subdivision between Los Angeles and Fullerton, CA. Negotiations for capacity with freight railroads can become contentious when freight railroads feel that they are losing flexibility to run trains efficiently through their network when necessary. However, if passenger rail can use freight infrastructure in a way that does not impede freight trains from operating efficiently, freight railroads would stand to benefit financially from increased access charges.

7.3 Contributions

This thesis contributes in two main ways to the development of shared corridors in California. First, it presents a way forward for the California rail network that will satisfy passenger rail agencies, freight operators, and both intraregional and interregional travelers. Second, it creates a framework for reviewing the system impacts of seemingly local choices; these local decision decisions ultimately impact the realization of this future California rail network.

It would be unfair to write that California has not done significant planning for its rail future. The 2013 California State Rail Plan, a requirement of the 2008 Passenger Rail Investment and Improvement Act (PRIIA) acts as a vision statement for the future of rail transportation in the Golden State. The plan provides a broad overview of potential challenges and the expected capacity requirements of future passenger and freight rail service. The 400-page plan emphasized integration and coordination across passenger rail agencies and between passenger rail agencies and freight rail operators. The plan lists proposed service levels as well as goals for new passenger rail routes such as, an Amtrak *Coast Daylight* operating between San Francisco and Los Angeles or new intercity service connecting the Coachella Valley with Los Angeles. While this thesis does not aim to validate or invalidate the feasibility of individual service level goals, it does draw broad conclusions regarding goals for the California rail network as a whole.

Based on planning documents and board meeting minutes of those individual passenger rail agencies, the seven "wish-list" items we identify, like the State Rail Plan, reflect the importance of coordination and integration among railway operators. These seven "wish-list" items, while not self-evident, would generally be agreed upon by most passenger rail agencies in the state, though some items are more important to certain agencies than others. We believe that if all seven "wish-list" items were realized, California could boast both a politically popular and cost-effective statewide rail service. Some of these "wishes" are correlated with one another; for example, if passenger rail agencies pursue interoperability, an integrated Southern California network is much more likely. On the other hand, some of these goals conflict with one another to a certain extent as well: high-frequency, uniform-headway HSR and commuter rail will likely cost more due to increased infrastructure costs. The aim of this thesis is not to state whether or not one goal is superior to another, but rather to understand the impacts of design decisions

The second contribution of this thesis is a developing a process for looking at local impacts of design decisions. It is difficult to quantify flexibility, nor would any quantification have very much inherent value—in the end, there will be one operating plan and to have more infrastructure than necessary would be wasteful (just as having less infrastructure than necessary will be costlier in the future). However, we do observe how each decision affects future decisions and whether or not the decision takes certain rail goals "off the table." California agencies could work together to refine their priorities instead of using our inferred priorities and could apply other larger-scale design decisions to this process as well.

7.4 Recommendations

7.4.1 Agency-specific

California High-Speed Rail Authority

Procure low-floor vehicles if manufacturers can supply them

The CHSRA is currently committed to purchasing service-proven technology. There are no high-speed trains currently in service that are 1) capable of 220mph operation and 2) a low-floor vehicle. If the commuter rail agencies are to pursue level boarding and compatibility with high-speed rail, having a low-floor vehicle has the potential to reduce cost across the network. This is because Caltrain and Metrolink currently operate the same Bombardier equipment and could simply raise platforms to accommodate their existing equipment[22][23]. If funding for level boarding falls short, it could be implemented at individual stations that would stand to benefit the most from its implementation. Even

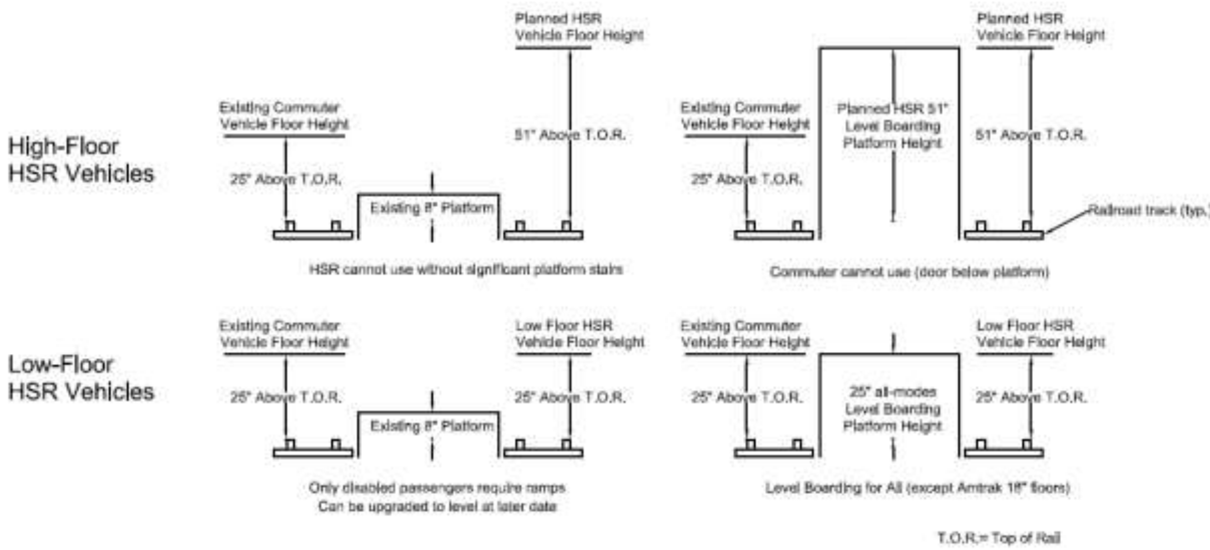

Figure 7-1: Low floor HSR vehicles would allow for shared infrastructure and allow for gradual transition of existing commuter rail platforms to level boarding. Amtrak California's 18" floors would require car reconstruction or a step system for higher platforms
SOURCE: Diagram by Author, Floor heights from PCJPB,

[22] Metrolink's new Hyundai Rotem equipment that is replacing the Bombardier equipment has the same 25" floor height

[23] The *FrontRunner* commuter rail service in the Salt Lake City, Utah area currently operates the same Bombardier coaches and has level boarding.

if Caltrain and Metrolink never raise platforms, high-speed rail could operate at commuter rail stations (without level boarding). This will save Caltrain the expense of procuring specialized electric vehicles with two sets of doors that match both existing and future platform heights.

There are clear risks for the CHSRA to try and conform to existing California vehicle floor heights as opposed to existing HSR vehicle floor heights. Vehicle costs of a new technology could be much higher due to reduced competition of vehicle suppliers. Lack of service-proven technology means that California would be the “guinea pig;” that is, they would be the first to experience any issues with reliability and safety of new equipment.

The Parsons Brinckerhoff technical memorandum advocating for high platforms for high-speed rail was released in 2009 when the plan for HSR service was to operate in a completely dedicated right-of-way. Since that time, the blended system demands a fresh approach and vision for the entire system and how it will integrate with existing rail services. By adopting a low-floor vehicle specification for its trainsets, the CHSRA will show its agency partners that it is committed to the success of blended operations and encourage them to follow suit and develop a similar attitude. Some risks like new low-floor high-speed rail vehicles would be worth taking.

Avoid terminating service temporarily in Burbank

The CHRSA’s plan of terminating service from 2022 to 2028 before extending service to Anaheim and Los Angeles poses a risk. We show in Chapter Five that the transferring to conventional diesel service from Burbank to Los Angeles and Anaheim will add a non-trivial amount of time in addition to a perceived “transfer penalty.” There are also associated costs with operating a temporary terminal station. Maintenance and baggage transfer facilities will be necessary; and because a Burbank/San Fernando Valley station has relatively minimal transit connectivity, the station will require a lot of additional parking for high-speed rail customers. The relative lack of access from the southern portion of the Los Angeles Basin might initially crimp ridership and revenue. Either a private investor or the CHSRA (i.e. the State) itself will have to fund the cost of additional time for ridership and revenue to materialize after the section to Anaheim and Los Angeles is finished (presumably in 2028).

The CHSRA will have project acceleration costs if it chooses to build the initial operating segment system to downtown Los Angeles. The additional cost will have to be borne by the Authority and not a private investor, since the Authority claims that investment is contingent upon successful revenue service. At the time of writing, the Authority has only $12.5 billion in committed funding (in addition to carbon tax revenues, which were $250 million last year). This means the CHSRA only currently has 40% of the Phase 1 cost, estimated at $31 billion. Pursuing more public funding on top of the $31 billion to finish the railroad to Los Angeles might be political infeasible. However, if the CHSRA determines it is possible, it should prioritize completing the connection into Los Angeles Union Station.

Formulate a coherent blended service strategy at both ends of the line

In order to reduce the risk for the private operator that will ultimately run the system, the CHSRA needs to understand exactly what blended will entail. Will there be a Metrolink train meeting every HSR train in Burbank and will that train continue on to Anaheim from Los Angeles? Will Caltrain customers be able to use HSR trains instead of Caltrain trains between San Jose and San Francisco? How many HSR trains per hour will the high-speed operator be allowed to run during the peak hour into downtown San

Francisco? The CHSRA needs to resolve these questions before making infrastructure decisions such as passing tracks in Northern California or a temporary Burbank Terminal, and definitely before it tries to seek a private operator to invest in the capital construction costs.

Peninsula Corridor Joint Powers Authority

Consider the impacts of competing for access with a statewide HSR operator

The Peninsula Corridor Joint Powers Board owns the right-of-way and track between San Francisco's 4th and King Station and San Jose and the Transbay Joint Powers Authority will own 1.3-mile Downtown Extension into the Transbay Transit Center. This seemingly puts the PCJPB/Caltrain on "home turf" when it comes to access negotiations since they represent San Francisco's 150-year old commuter railroad. However, the CHSRA serves a much larger, statewide constituency, than the three-counties that enjoy Caltrain service. Furthermore, the PCJPB structure is a weak because it requires voluntary contributions from the three counties; it has no dedicated funding source. The PCJPB and CHSRA currently have a healthy partnership, but ultimately, Caltrain will be working in partnership with the private HSR operator, not the CHSRA. Since the operator will be facing revenue and ridership pressure, and since Caltrain operates at their peak service levels at the most valuable times for high-speed rail, this relationship could potentially become more adversarial. In order to avoid this, the PCJPB and CHSRA need to carefully negotiate access, or at a minimum, agree on a method for objectively allocating and pricing capacity.

Grow stronger working relationship with Southern California

Whether or not Metrolink or Amtrak California decide to electrify operations on the blended corridor in Southern California, they will encounter many of the same issues faced by the Caltrain in the north. For example, there will be negotiations regarding service levels and access to railroad assets such as the run-though tracks at Los Angeles Union Station. As owners of tracks and right-of-way that will see frequent use from high-speed rail, both the Caltrain and Metrolink stand to benefit by sharing effort in developing the ultimate form of the blended system. Both agencies have overlapping interests: they want to protect rail service for the everyday commuter, they want to maximize the benefit of HSR connectivity funding, and they want to keep positive relationships with the freight railroads and other passenger railroads with whom they share infrastructure. Man-hours could be saved by working through HSR compatibility challenges together.

Service plan as soon as possible (try examples of better integration) and develop metrics to evaluate output timetable

In their blended service planning document, Caltrain writes that their next step is to look at service plan potions prior to fleet need. However, Caltrain is already beginning the procurement process for their vehicles. Service planning needs to come first and Caltrain needs to develop these service plans with the CHSRA. Planning should include multiple levels of integration, from shared platforms all the way to shared trainsets so the two agencies can understand the value of integration investments. For example, some HSR trains could replicate Caltrain's Baby Bullet service and stop a five or six intermediate stations between San Francisco and San Jose instead of two. Even though HSR trains acting as "Baby Bullets" making limited stops would hurt the utility of the high-speed service, it is the superior alternative to truncating service in San Jose and forcing HSR travelers to transfer to commuter rail. As LTK concluded, the capacity is simply not there for greater than two HSR trains per hour and Caltrain Baby Bullet service.

To evaluate the timetable from a customer perspective, the CHSRA and Caltrain should develop metrics which factor customer travel time, headway uniformity, and passenger residential and job data among other measures. Caltrain's origin-destination data is not reflective of consumers' preferred stations; rather, it is reflective of a Baby Bullet service which pulled riders to high-service stations. Timetable metrics would allow the two agencies to objectively compare one service plan to another and quantify the benefits of one timetable that may require the construction of passing tracks versus another.

Address the freight issues—CPUC horizontal clearance and operating windows

The freight issues are not going to disappear any time soon—the PCJPB has affirmed through its statements and in the memorandum of understanding with the high-speed rail authority that freight is going to remain on the Peninsula Corridor. By not addressing the freight issues, the PCJPB is implicitly encouraging the CHSRA to use separate facilities since the waiver is a necessary condition for Caltrain to have level boarding, but not one for HSR if it believes that separate facilities are sufficient for its own operation.

Currently Union Pacific is guaranteed one 30-minute window between 10:00 A.M. and 3 P.M. each day to run freight trains on each of the northbound and southbound tracks of the Peninsula

Corridor. Between midnight and 5:00 A.M., one main track is reserved for freight use. With increased service due to HSR, these window capacity allocations may need to be revisited. As owner of the right of way, it is the PCJPB's responsibility to manage these operating window constraints before these issues affect Caltrain and HSR's service commitments.

Transbay Joint Powers Authority

Consider impact of reduced Caltrain service to Transbay Transit Center

Limited Caltrain service to the Transbay Transit Center will be as painful to the developers and the Transbay Transit Center as it will to the commuters themselves. Being able to boast a frequent one-seat ride to the points south on the Peninsula will raise rents for the property owners and developers as well as revenues for retail spaces, and as a result, revenue for the City of San Francisco. It is in the best interest of the developers at Transbay Transit Center to ensure that Caltrain has adequate access to the terminal.

Ensure there is a path for improvements to the Downtown Extension

One of the primary concerns raised in the environmental impact report for the Transbay Transit Center was the small size of the six track terminal. For a terminal station, six tracks is minimal—Los Angeles Union Station has 14 tracks and Penn Station in New York City has 21. In the 2002 Environmental Impact Report/Environmental Impact Statement, the Transbay Joint Powers Authority wrote that "additional turnaround or "tail" tracks will greatly assist in relieving congestion at the platform tracks." In 2008, the Transbay JPA announced that the "tail tracks would be deferred until operationally required." This means that the TJPA anticipates a need for track capacity, but will seek funding sources later. This raises interesting questions about who will be responsible for increasing capacity and who will fund that additional capacity. Will one operator be forced to choose between a large capital expenditure and service reductions, and if so, which operator? Because the TJPA is a separate entity, neither the CHSRA nor Caltrain has a "right" to access the vital terminal. If the CHSRA is required to fund capacity improvements, should the cost fall on the private operator or the public? The Transbay Transit Center should answer these questions sooner rather than later to help both the Caltrain and the CHSRA plan for service and future expansions of service.

Rail Agencies in Southern California

Quantify to the greatest extent possible, the benefits and costs of level boarding, platform sharing, electrification, and increased integration in terms of increased ridership and connectivity

The Southern California Regional Rail Authority, Amtrak California (the LOSSAN JPA), and even NCTD should, along with the CHSRA, evaluate the benefits and costs of level boarding, platform sharing, electrification, and increased integration across the greater Los Angeles area. Level boarding and platform sharing clearly provide a benefit for transfers to-and-from high-speed rail and allow for maximum use of limited capacity at Union Station, but the benefits of level boarding outside the blended corridor are markedly less. Increased integration could result in benefits such as a one-seat ride between Los Angeles and San Diego or Las Vegas, and could help commuter rail serve as a better first-mile and last-mile connection for high-speed intercity travelers; that is, both modes will see ridership gains with an integrated system. If "Blended Service" means integration between HSR and commuter rail operators, can Southern California operators integrate non-HSR service as well? Perhaps cooperation with the high-speed rail authority can help foster increased cooperation between Metrolink, Amtrak California, and COASTER.

Protect the run-through tracks at Los Angeles Union Station

In the author's opinion, the run-through tracks at Union Station will be a hugely important asset. In terms of cost per minute of travel time saved for through trains, the Southern California Interregional Connector Project is one of the most cost-effective rail projects under construction in the state. Unfortunately, only four tracks of the 14 at Union Station are going to "run-though" and it is likely that high-speed rail will need to use at least two of them. These tracks are going to be more valuable for regional commuter services as well: overnight, Metrolink will gain much more flexibility with service planning and timed-transfers and Amtrak California can now offer customers travelling from the northern half of the LOSSAN corridor to the southern half nearly 15 minutes off of their trip. It is important that the return on this $350 million capacity investment is maximized; CHSRA should demonstrate their plan to achieve high levels of track utilization before LACMTA (the owner of Union Station) allows high-speed rail to monopolize half of the run-though track improvements. However, it would be ideal to maintain all four tracks for general use through a consistent low-floor platform height.

7.4.2 General Recommendations

Integrated operations have a potential to bring HSR a revenue source; like regional airlines feed into international hubs, so too can commuter rail services feed into interregional high-speed rail services. To that end, service planning should drive infrastructure decisions; in an era where infrastructure such as new HSR stations or electrification are expensive and the public is leery of megaprojects, California can set an example with a well-conceived (i.e. well service planned), integrated rail system.

This integration is important from a risk management perspective as well. The CHSRA is fortunate to have their lead cheerleader in the statehouse: Governor Jerry Brown is the by far the most important political ally that the Authority has at its disposal. Unfortunately for the CHSRA, Governor Brown concludes his term in 2018 and it is unlikely that his successor—whether Democrat or Republican—will be such an ardent supporter of the project. At the time of writing, there are court cases that threaten the CHSRA's ability to use Proposition 1A funding on the grounds that the current system is not what was promised to voters. If the funding were to evaporate, it would be much better to be left with a useable system than a standalone section of high-speed track in the Central Value with little independent utility. The CHSRA was right to start construction in the Valley as they are filling key a rail gap between the Central Valley and the Los Angeles Basin; however, if this piece does not fit into the rest of the California network; this will truly be a "train to nowhere" as project critics attest.

7.5 Future academic research

In this section we will identify future academic research that would benefit both the rail stakeholders in California, but also future high-speed rail projects across the United States

7.5.1 Combine with research on stakeholder analysis to look at feasibility of certain institutional cooperation in California (and possibly generalize to other corridors)

In this thesis we have identified areas where coordination and integration would have great benefits, but we did not evaluate how likely it is that certain entities will cooperate with one another. Research that evaluated the feasibility and likelihood of cooperation based on characteristics of each entity in California would be beneficial as it would identify less-than-obvious institutional synergies. There is current research in M.I.T.'s Regional Transportation/High-speed Rail group that is looking at stakeholder analysis on the Northeast Corridor. This research, could of course, be expanded into a broad evaluation tool for stakeholder willingness to cooperate.

7.5.2 Revenue sharing and Integration between public and private sectors

One of the challenges with a blended system is how to share passenger fare revenues, especially between a private operator and a public agency. For example, if Caltrain transports a high-speed rail passenger who came from Fresno between San Jose and San Francisco, what share of that total fare revenue should Caltrain receive? Should Metrolink collect an additional fare (e.g. baggage fees) from a connecting HSR passenger between Los Angeles and Burbank in addition to the basic one-way fare it already collects? Though the idea of offering multi-agency tickets exists today in the U.S., the degree of complexity that the CHSRA is discussing in terms of interlining and through-ticketing does not yet exist in the U.S. rail market. Airlines already practice some form of fare proration between operators in offering code share flights, but this is between two private companies. Research that identifies some of the institutional and regulatory challenges of cooperating with a private for-profit operator would be useful and valuable for both the CHSRA and its public agency partners.

Outside of the CHSRA, high-speed rail is an attractive concept that has garnered private sector interest. The Texas Central Railway Company is currently planning on constructing a fully-private high-speed line between Houston and Dallas. Xpress West is a private company, yet is hoping to receive some federal loans to complete construction of a Palmdale-Las Vegas HSR link. We noted earlier how Las Vegas and Los Angeles would both stand to benefit from a one-seat ride between the two cities, however this would require the CHSRA to allow Xpress West to access tracks in between Palmdale and Los Angeles. CHSRA may be interested in running trains on Xpress West's infrastructure between Palmdale and Las Vegas as well. This type of private HSR/public HSR coordination is unique and will require a new institutional paradigm. Research examining how this relationship might work best from a political, legal and customer-satisfaction standpoint would be valuable and applicable across the country.

7.5.3 California Rail Authority

Japan is frequently cited as a leader in high-speed rail technology. Unlike California, however, Japan's institutional structure is one that is fully integrated. Each of the four "JR" companies that operate high-speed service, operate unprofitable commuter rail service as well. Timed transfers are commonplace and on-time performance is high, and operations on the system level are profitable. One potential avenue of research would be to see how well the Japanese model could be exported to California. This would reduce the complexity of capacity allocation as well as challenges associated with revenue sharing interlining and platform compatibility. However, it would require local authorities to cede control. The Peninsula Corridor Joint Powers Board, which lacks a dedicated source of funding might be amenable to being folded into the CHSRA; however, some politicians and constituents would be wary of ceding local control to a state agency[24].

7.6 Final Thoughts

We thank the reader for joining us by reading this thesis. We hope it has been a fulfilling experience and one that has sparked interest in the evolving California high-speed rail project. We hope that public

[24] The PCJPB depends on contributions from the three counties in which it operates service.

officials in leadership positions at the passenger rail agencies we discuss in this thesis have the opportunity to read and understand the gravity and impact of their decisions on the future of the state of California. The blended system was a radical change, but also one that presents a Golden State opportunity. Instead of building the California high-speed rail *line*, we have the opportunity to optimizing the California rail *network*.

California needs to take a “top-down” approach to high-speed rail, asking “what do we want as a state and how do we get there?” rather than a bottom-up approach which asks “how does this part of the system need to work for high-speed rail to be successful?” Taking this top-down approach has a huge impact on the system the state ultimately delivers. Optimizing locally constrains the system optimal solution; and as California agencies make decisions regarding vehicle fleets and track investments with Proposition 1A connectivity funding, we can see that the local optimizing is already beginning. Decisions made on the Peninsula Corridor can create capacity bottlenecks that affect HSR trains on an interregional level. And since these blended issues are being addressed presently on the Peninsula Corridor with the concurrent electrification of Caltrain, a precedent is being set for their southern neighbors. The Peninsula Corridor, therefore, is an important proving ground for whether or not blended operations can work.

The high-speed line from San Francisco to Los Angeles has a price tag of $68 billion. The CHSRA’s business model depends on over half of that money—$37 billion—coming from a private operator bidding for a concession contract after the initial operating section from Merced to Burbank via Fresno and Bakersfield operates profitably. However, much of this blended uncertainty creates risk that will cost the state when the time comes to seek investors. The risks include not gaining access to key track stations, political opposition to new construction, and poor regional rail feeder connectivity. The CHSRA should focus on reducing the risk when it comes time to find a private operator. Investments made by the CHSRA and partner agencies in integration will pay dividends as the high-speed rail project moves forward. California is a land of dreamers, but in reality, it will be small and seemingly mundane decisions, like platform height and shared facility use, that will bring this project to a successful conclusion.

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