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GETTING BACK *On* TRACK

Policy Solutions to Improve California Rail Transit Projects

JANUARY 2022
Policy Report

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16. Abstract
This report combines a cost baseline analysis with five case studies of California rail projects (four local transit projects and California's High-Speed Rail project) to identify the causes of high project costs, slow deployment, and overruns/delays beyond initial project estimates. Baselines were developed from an analysis of two prominent transit cost databases, and case studies were developed through review of the historical record and expert interviews. Key findings include lack of transit agency experience and expertise; insufficient cross-agency coordination; costly stakeholder outreach; inefficient procurement and contracting methods; and project overdesign. The report proposes a set of recommendations for transit agencies and state policymakers to overcome these challenges, including the creation of regional project delivery consultant teams, legal authorization and use of alternative contracting methods, and new agency coordination and communication structures.

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GETTING BACK ON TRACK

Policy Solutions to Improve California Rail Transit Projects

Berkeley Law | Center for Law, Energy, & the Environment

Berkeley Institute of Transportation Studies

ABOUT THIS REPORT

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The University of California Institute of Transportation Studies (UC ITS) is a network of faculty, research and administrative staff, and students dedicated to advancing the state of the art in transportation engineering, planning, and policy for the people of California. Established by the Legislature in 1947, ITS has branches at UC Berkeley, UC Davis, UC Irvine, and UCLA.

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LIST OF ACRONYMS

AB	Assembly Bill
ARRA	American Recovery and Reinvestment Act
AUR	Advance utility relocation
BART	Bay Area Rapid Transit
Cal/OSHA	California Division of Occupational Safety and Health
Caltrans	California Department of Transportation
CEQA	California Environmental Quality Act
CHSRA	California High-Speed Rail Authority
CLEE	Center for Law, Energy & the Environment at UC Berkeley School of Law
CMGC/CMAR	Construction manager/general contractor or construction manager-at-risk
CPUC	California Public Utilities Commission
CTC	California Transportation Commission
EIR/SEIR	Environmental impact report or supplemental/subsequent EIR
EIS/SEIS	Environmental impact statement supplemental/subsequent EIS
FTA	Federal Transit Administration
FY	Fiscal year
HSR	High-speed rail
km	Kilometer
M&E	Maintenance and engineering
Metro	Los Angeles County Metropolitan Transportation Authority
MOA	Memorandum of agreement
MOU	Memorandum of understanding
MTA	New York Metropolitan Transportation Authority
MTC	Bay Area Metropolitan Transportation Commission
MTS	San Diego's Metropolitan Transportation System
Muni	San Francisco Municipal Railway
NEPA	National Environmental Policy Act
NIMBY	"Not in my backyard"
P3	Public-private partnership
PPP	Purchasing power parity
RFP	Request for proposals
RSD	Revenue service date
SANDAG	San Diego Association of Governments
SB	Senate Bill
SFMTA	San Francisco Municipal Transportation Agency
TAP	Tunneling advisory panel
TBM	Tunnel boring machine
TIFIA	Transportation Infrastructure Finance and Innovation Act
TJPA	Transbay Joint Powers Authority
UC ITS	University of California Institute of Transportation Studies
USD	U.S. dollars
UTC	San Diego University Town Center
VA	U.S. Department of Veterans Affairs
VTA	Santa Clara Valley Transportation Authority


ELEVATOR
EXIT
East Bay
PLATFORM 1

I. EXECUTIVE SUMMARY AND INTRODUCTION

California spends billions of federal, state, and local dollars on rail transit projects, which are central to improving mobility and meeting long-term climate and environmental goals. Yet these projects, like others in the United States, tend to take more money and time to build than similar projects in other advanced economies. For example, completed U.S. heavy rail projects (with trains powered from below via an electric "third rail") cost more than twice as much on average than their European, Canadian, and Australian counterparts, while U.S. light rail projects (powered by overhead electric lines) cost around 15 percent more than similar projects in Europe, Canada, and Australia.[1]

Scholarship demonstrates that cost and delay are intimately related; any issue that results in a project delay also increases project costs, and some aspects of high costs (like complicated station designs) also precipitate project delays. Once construction is underway, delays are quite costly. For example, every month of delay on Boston's Green Line Extension would cost between $1-2 million after construction has started because of equipment rental, storage, and contractors on call.[2]

The causes of these nationwide higher costs and delays are myriad, owing in part to the decentralized nature of land-use and infrastructure governance in the United States (with regional rail project leaders often facing dozens of permitting agencies, powerful stakeholder groups, and potentially multiple political jurisdictions with de facto power to block a project).[3] These fragmented decision-making processes—and the litigation (or threat of it) that often accompanies environmental reviews and other land-use approvals in California and other states—can contribute to an especially slow and costly transit development environment in the U.S.

Yet several of the factors that account for these discrepancies, from project design to contract structure and stakeholder outreach, are potentially within the control of local transit leaders—creating opportunities for more efficient project delivery. For example, according to a McKinsey analysis, 73 percent of time and budget overruns stem from poor project execution, including "incomplete design, lack of clear scope, ill-advised shortcuts, and even mathematical errors in scheduling and risk assessment."[4] This report aims to identify the aspects of project delivery that California officials and local transit leaders have the power to improve and to provide recommendations of how to do so.

California has a relatively mixed record in delivering rail transit projects compared to national and international average costs. The four California rail transit case studies studied in this report (excluding high-speed rail, the subject of the fifth case study) were roughly two to three times more expensive per kilometer than expected compared to international averages. They tended to be closer to national cost expectations, with one project delivered below the expected cost based on U.S. averages, two completed within 20 percent of expected U.S. costs, and one exceeding expected costs by a factor of two. The four projects tended to perform better on the speed of delivery than on cost when compared to peer projects, although some case study projects faced substantial delays. While this report excludes the case study projects from baseline estimates (to avoid self-comparison and incomplete information), if those projects were included, the California baselines for both light and heavy rail would be higher.[5]

In general, rail projects have become slower and costlier to build compared to previous decades, which harms the public acceptance of future investment.[6] The problem may worsen, given that several currently planned California megaprojects are anticipated to be among the most expensive in the country.[7] Some driving factors behind high costs and lengthy completion schedules can be addressed through an agency or state action—the focus of this report—while other factors may be primarily outside of agencies' control and therefore difficult to change (e.g., changing economic conditions, costs of materials or land, labor availability).

The stakes are high for California rail leaders to address the challenges and work to reduce costs and time of delivery, considering the state's ambitious climate change goals and pronounced urban mobility and housing density needs. Furthermore, transit agencies and the constituencies they serve are also eager to understand the drivers behind inefficient project delivery and options for overcoming them. For example, the San Francisco County Transportation Authority identified the need to "restore public confidence in the ability to deliver transportation projects" and proposed a resolution directing $180,000 toward a capital project delivery review and best practices study.[8]

Given the high stakes and challenging environment, what steps under their control can California transit leaders and state officials take to improve rail transit project delivery? What are some of the best practices to adopt more widely, and what changes need to be made at the state and local levels to improve project delivery?

This report seeks to answer these questions based on five case studies of California rail transit projects and a review of other scholarship on this topic. Funded by a research grant through the University of California Institute of Transportation Studies under Senate Bill (SB) 1, the Center for Law, Energy and the Environment (CLEE) at UC Berkeley School of Law compiled these case studies and findings through research on the transit projects, outreach to key personnel involved in implementation, and interviews with project leaders, California transit experts, and national and international transit scholars. The target audience includes leaders at federal, state, and local transit agencies; elected officials at all three levels; and other stakeholders in the public transportation investment process.

The remainder of this introduction describes the case study selection process and previews the research's key findings and policy recommendations. Section II provides an overview of the cost baselines used to assess case study project performance. Section III includes a discussion of the report's five key findings and associated policy recommendations for transit agencies and state leaders, with supporting examples from the case studies and a literature review. Section IV contains the five complete case studies, and Section V is the conclusion.

SELECTING FIVE CASE STUDIES

To develop an understanding of challenges and successes in California transit project delivery, CLEE selected five projects to analyze via case studies, expert interviews, and cost baseline comparison. A description of the cost baseline comparison methodology is available in Section II, and the complete case studies and interview findings are available in Section IV.

To select these California projects for analysis, CLEE first identified California rail transit projects over $500 million in cost and either completed after 2010 or currently in progress.[9] CLEE then selected four transit projects based on diversity of location within California, project environment, and construction type; and an anticipated completion date within one to three years of the research project. These criteria were selected to ensure that the case studies were all accurately considered "mega-projects" and comparable in terms of scale; near enough to completion to provide robust analysis, but not outdated; and reflective of a variety of community goals, agency strategies, and project environments. The four transit projects include:

- San Francisco Central Subway
    - Project location: Downtown San Francisco
    - Project environment: High-density urban
    - Project type: Light rail, tunneled, and surface

- San Diego Mid-Coast Corridor Trolley
    - Project location: Downtown to Mid-Coast San Diego
    - Project environment: Medium-density urban and suburban
    - Project type: Light rail, surface, and elevated

- Los Angeles Purple Line
    - Project location: North and West Los Angeles
    - Project environment: Medium-density urban
    - Project type: Heavy rail, tunneled

- Bay Area Rapid Transit (BART) Berryessa Extension
    - Project location: South Bay Area
    - Project environment: Medium-density urban and suburban
    - Project type: Heavy rail, elevated

In addition to the four rail transit projects, CLEE also evaluated the California High-Speed Rail project. The project is not directly comparable to the other four case studies in terms of cost, technology, or project structure, but its high profile and potential impacts on the future of large-scale transit investment in California rendered it a valuable point of analysis and comparison. Expert outreach in the project-scoping stage confirmed that analysis of high-speed rail could complement and benefit from the transit case study analyses.

KEY FINDINGS AND RECOMMENDATIONS

The key findings include the following themes as primary factors determining cost-effective and timely deployment of rail transit projects:

1. Building megaproject management capacity and expertise: The unique demands and expertise of multi-billion-dollar projects pose a potential challenge for agencies that rarely build them.

2. Maintaining project scope and right-sizing design: Requirements to identify necessary project enhancements and high cost-items early in the design process, and avoid unnecessary enhancements during construction, could significantly improve delivery.

3. Conducting advance and ongoing multi-agency coordination: Agencies that prioritized coordination with stakeholder entities and jurisdictions were better able to overcome barriers.

4. Using appropriate project delivery methods: Choice of project delivery method proved central to the success of multiple projects, with structures that emphasized early collaboration and placed greater risk on the contractor delivering greater accuracy in designs and timelines.

5. Facilitating comprehensive stakeholder outreach: Developing strong relationships with neighboring communities and “anchor tenants” can smooth project roll-out.

Based on these themes, transit agency and state leaders could make the following policy reforms and investments to advance project delivery in California and beyond:

Capacity and Expertise

Transit agencies could:

- **Form regional collaboratives** (where applicable) to house permanent expertise not tied to any individual local project, with staff available to consult with or contract out to projects when needed.
- **Ensure internal staff and management capacity is adequate to the scale of the project**, including the task of negotiating with and managing contractors, before the bid process.
- **Hire or retain staff with expertise in the selected procurement method** so that they can manage the project appropriately.

State leaders could:

- **Create state and/or regional transit megaproject delivery teams** available to consult with local agencies.
- Provide funding specifically to **enhance staff capacity and conduct more extensive advance planning**.

Project Scope and Design

Transit agencies could:

- Work with contractors and stakeholders in the planning stage to **identify additional project elements vital to the project's success** (for engineering, ridership, or stakeholder acceptance reasons) to limit the risk of unnecessary modifications, which can create delays and cost overruns.
- **Avoid the addition of significant, non-essential betterments and limit bespoke design** for extraneous station elements (e.g., complex facades), particularly after the design stage.
- **Factor site-specific challenges into route design** prior to setting time and cost estimates, such as by conducting advance geotechnical surveys.
- **Account for the tradeoff between the efficiency of building projects in existing rights of way and alignments that maximize access and ridership.**

State leaders could:

- Encourage more efficient project design by **conditioning state funding of local projects on avoidance of over-designed elements**, using performance metrics such as cost-per-anticipated-rider criteria to determine access to certain funds (potentially via California Transportation Commission guidance on State Transportation Improvement Program funds or legislative action).

- **Dedicate state funds specifically for enhanced project design** to minimize the risk of "surprise" factors that increase costs or create delays during construction and reduce transit leaders' ability to present overly optimistic budget and timeline estimates.

- **Update state law to allow all transit agencies statewide to employ construction manager/general contractor or construction manager-at-risk and other alternative contracting methods** (see Section III.4 on procurement methods).

Agency Coordination

Transit agencies could:

- **Develop permanent, ongoing structures to coordinate communications among agencies** when projects are co-managed or co-dependent, such as selecting a neutral third party to arbitrate disputes whenever issues arise, and/or housing agency representatives at partner agencies to facilitate coordination, conversation, and timely resolution of conflicting viewpoints.

- **Engage with local governments and enter memoranda of agreement/understanding to set expectations** at the appropriate stage in the construction process.

State leaders could:

- **Create an office within the California Department of Transportation (Caltrans) to provide dedicated staff support/ technical assistance** to facilitate coordination among local and regional agencies or offer additional funding to agencies that provide detailed plans for addressing any in-house staffing needs, as applicable.

- **Condition state funding based on detailed local agency plans**, as needed, for coordination and partnerships on project implementation.

- **Consider legislatively granting master permitting authority to transit agencies with priority rail transit projects** (including engineering, street closure, and similar project completion-critical permits) to reduce delays and costs imposed by local governments or large or powerful stakeholders along the route.

Project Delivery (Procurement and Contracting)

Transit agencies could:

- **Break apart project tasks among multiple, smaller contractors** where possible to avoid ceding too much leverage to one contractor.

- **Consider advance utility relocation (AUR) contracts** to expedite utility-related work in tunneled areas or around stations.

- **Consider using construction manager/general contractor or construction manager-at-risk (CMGC/CMAR) and other alternative project delivery methods with early contractor involvement** to ensure the total cost of building expensive projects in dense, complex areas is identified before construction begins.

State leaders could:

- **Update state law (which currently authorizes only select counties to employ project delivery methods like CMGC/CMAR contracting on a pilot basis) to allow all transit agencies statewide to employ these methods.**

- **Structure or create state grants to reward transit agencies that prioritize and use efficient procurement strategies.**

Stakeholder Outreach

Transit agencies could:

- **Target major new routes and extensions to areas with a single stakeholder** such as a university or hospital (where appropriate with ridership, accessibility, and equity goals) or form an early stakeholder coalition to build support for the route/design, streamline negotiations, and minimize the risk of costly delay.

- **Enter legal agreements with cities or other parties as needed to avoid potential conflict and clarify expectations before the design is finalized** (including selecting appropriate procurement methods).

- **Prioritize clear and timely communication**, even when communicating unpopular information like road closures, so that affected parties may plan ahead and build trust in the transit agency's communication process.

State leaders could:

- **Create guidelines, host workshops, and/or provide direct funding to local agencies to develop and disseminate guidelines on stakeholder outreach** best practices, or provide additional funding to local agencies that offer detailed plans for conducting this outreach, as needed.

II. COMPARING CALIFORNIA TO THE UNITED STATES AND OTHER ADVANCED ECONOMIES ON RAIL TRANSIT DELIVERY

Using databases compiled by the Marron Institute and the Eno Center for Transportation, CLEE examined the costs and construction times associated with different transit projects across modes, grade alignment, and geographies to estimate how four California case studies compared to expected cost outcomes based on averages of similar completed projects. Using that guidance, CLEE found that the four California rail transit case studies (excluding high-speed rail, the subject of CLEE's fifth case study) were roughly two to three times more expensive per kilometer than expected when compared to international averages and tended to be closer to national expectations on cost delivery. The four projects tended to perform better on construction time compared to peer projects internationally and nationally, as well as past completed projects within California, although some case study projects faced substantial delays. Project delivery comparisons to expectations provide a robust set of themes and through-lines (both negative and positive) for analysis (see Table 1 for more detail). This review indicates that California transit agencies can still make significant progress reducing time and costs to deliver more value for public dollars, keeping pace with state, national, and international track records and bringing project delivery costs and times down further, as the projects used to inform baseline estimates are not necessarily exemplary in their own cost and construction time outcomes. This exercise was not a formal statistical analysis but was meant to provide a rough idea of whether a project performed as expected.

Researchers at the Marron Institute of Urban Management at New York University (NYU) estimate that the global median cost of a kilometer of subway is approximately $250 million.[10] What does that number look like for light-rail projects or in different regions? What costs or construction schedules would be expected for projects with different amounts of tunneling or elevated track?

CLEE utilized the Eno and Marron Institute databases because they are similar in their overarching goal, their release date (late 2020), the metrics they include, and the types of projects they cover.[a] Using information from both databases, CLEE sought to ensure that the estimates offered here are as robust as possible.[b]

CLEE calculated different estimates depending on a project's extent of tunneling or elevated track, as these appear to be leading factors in cost overruns and time delays. CLEE then grouped projects from the consolidated database into bins ranging from 0% to 100% tunneling and compared the case study projects to the average cost or time in the appropriate bin.[c] In some cases, no comparison project existed. Next, CLEE calculated the expected cost or time for each case study based on the average cost or time of projects with similar amounts of tunneling or elevation.[d] The decision to differentiate based on grade alignment does not indicate that the amount of tunneling or elevation drove each project's delays or budget overruns. However, there is evidence that grade alignment substantially

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a Both databases also present the length of time from initial project construction (rather than the year of initial project design) to the year the project began operation. The Eno Center's database focuses more on projects that have completed construction and includes only three projects slated to open in 2021 (Boston's Green Line Extension, San Francisco's Central Subway, and the Metro Line B extension in Rennes, France). In contrast, the Marron Institute database includes transit projects scheduled for completion through 2030. For consistency and in the interest of learning primarily from completed projects, this report does not include future projects from the Marron Institute database with opening dates after 2021 (projects expected to open in 2021 are included, where cost data is available). This report also does not include projects for which no end date was specified. The report does not include in these calculations any projects without cost estimates (some projects in the databases did not have cost estimates associated with them), or projects for which the start and end year of construction was unknown, as this made it impossible to determine a midpoint with which to calculate inflation.

b The Marron Institute database includes a broader range of international examples, while the Eno Center's data focuses on the U.S., Canada, and Europe "because of their comparable political culture, government structures, and infrastructures development and age." (See Five Takeaways from Eno's Transit Capital Construction Database – The Eno Center for Transportation) Both exclude the costs of rolling stock, such as passenger cars or on-track maintenance vehicles. The Marron Institute specifies that "costs include all construction and construction-related expenditures, but not rolling stock or sales taxes. In some cases, rolling stock costs are included in the headline numbers, and we have tried to subtract them whenever possible; in some remaining cases, it was not possible, and we note that the costs include the equipment." (See NYU Marron Institute Transit Cost Database). The Eno Center notes that its database also excludes maintenance facilities where possible. (See Eno Transit Construction Cost Database - December 2020 - Google Sheets).

c By grouping projects into 10 buckets ranging from 0% to 100% tunneled, CLEE aimed to add a layer of specificity that acknowledges the significant impact of tunneling on project cost. However, CLEE recognize that this bucketing approach results in some small sample sizes, or even yields zero similar projects for some comparisons. Although larger sample sizes are more desirable, grouping the projects together without accounting for tunneling would erase a level of detail that the authors feel is important to understanding project costs. Please see Appendix A for a summary of sample sizes by category.

d For a hypothetical project with 100% tunneling, one would take the average cost per kilometer for other projects in California, the U.S., and internationally with 90-100% tunneling and multiply it by the number of kilometers of the case study project to find the total cost that would occur if the case study project fell exactly at that average.

contributes to high costs relative to other countries. (For example, the Eno Center finds that "grade alignment has a stronger impact on costs than mode [does].")[11] CLEE then divided the resulting amount by the actual total project cost for the case study project to find a multiplier—for example, a project with an actual cost of 200% of the average or baseline cost of comparable projects is twice as expensive as expected. It should be emphasized that these are "back of the envelope" calculations and are meant to be approximate estimates. The goal of providing these comparisons is to offer a general sense of a project's performance relative to peer projects in California and other comparable settings. Because conditions differ in each of the three geographic areas used for comparison, the projects completed in these regions will not have the same cost or schedule; however, the goal of comparing expectations across these three geographic groupings is to help determine where there are differences in project delivery outcomes and how these differences can be explained by issues specific to a given project versus broader systemic issues.

TRANSIT PROJECT BASELINES

Based on this rough analysis, CLEE found that the four rail transit case studies (excluding the high-speed rail case study) performed as follows, in terms of cost and time of construction compared to a statewide, nationwide, and international baseline.[12] All project cost estimates are current as of September 2021; cost values are rounded to the nearest whole number. For a visual depiction of underlying baseline data, please see Appendix B.

Percent of case project's cost or time compared to baseline
0-49%
50-100%
101-150%
151-200%
201-250%
251%+

Below 100% means a project performed better than expected, 100% = exactly as expected, >100% worse than expected.[e]

e The analysis in this section refers to a project's performance compared to the expected cost or time for similar projects, derived from an analysis of comparable projects in three geographic categories. The percentages in Table 1 indicate how each California case study project performed relative to a baseline expectation composed of its peer projects, so 200% would indicate that the case study project cost two times as much as expected. Values in Table 1 should not be interpreted to mean a project went 200% over its original budget. This analysis examines only the magnitude of costs or construction time relative to other projects; it does not describe the extent to which a project went over budget or schedule.

Table 1. Comparison of Actual and Expected Project Costs and Timelines for Four California Rail Transit Case Studies Based on Amount of Tunneling

	TOTAL COST ($ MILLIONS)	YEARS OF CONSTRUCTION	COST PER KM ($MILLIONS/KM)	YEARS OF CONSTRUCTION PER KM (YR/KM)
SAN DIEGO MID-COAST CORRIDOR TROLLEY				
Expected[13]	CA - $826 U.S. - $1,090 Int'l. - $661	CA - 8.6 U.S. - 7.9 Int'l. - 8.8	CA - $47 U.S. - $62 Int'l. - $38	CA - 0.50 U.S. - 0.50 Int'l. - 0.50
Actual	$2,171	5.0	$124	0.3
Comparison to Baseline			CA – 260% U.S. – 200% Int'l. – 330%	CA – 60% U.S. – 60% Int'l. – 60%
SAN FRANCISCO CENTRAL SUBWAY				
Expected	CA - n/a U.S. - $1,570 Int'l. - $620	CA - n/a U.S. - 4.7 Int'l. - 4.0	CA - n/a U.S. - $574 Int'l. - $227	CA - n/a U.S. - 1.7 Int'l. - 1.5
Actual	$1,891	12.0	$691	4.4
Comparison to Baseline			CA – n/a U.S. – 120% Int'l. – 300%	CA – n/a U.S. – 250% Int'l. – 300%
LOS ANGELES PURPLE LINE SECTION 1				
Expected	CA - $1,393 U.S. - $4,757 Int'l. - $1,380	CA - 4.2 U.S. - 12.5 Int'l. - 14.2	CA - $221 U.S. - $754 Int'l. - $219	CA - 0.7 U.S. – 2.0 Int'l. - 2.3
Actual	$3,504	9.0	$555	1.43
Comparison to Baseline			CA – 250% U.S. – 70% Int'l. – 250%	CA – 210% U.S. – 70% Int'l. – 60%
BART BERRYESSA EXTENSION				
Expected	CA - $1,709 U.S. - $2,240 Int'l. - $1,409	CA - 12.7 U.S. - 7.7 Int'l. - 22.5	CA - $105 U.S. - $137 Int'l. - $86	CA - 0.8 U.S. - 0.5 Int'l. - 1.4
Actual	$2,330	8.3	$143	0.5
Comparison to Baseline			CA – 140% U.S. – 100% Int'l. – 170%	CA – 70% U.S. – 119% Int'l. – 40%

HIGH-SPEED RAIL BASELINE

California's ongoing high-speed rail project is one of the five case studies included in this report. However, because there are no comparable high-speed rail projects in the United States, the process for estimating a baseline was slightly different. CLEE used the Marron Institute's high-speed rail cost database to estimate an international baseline.[f] However, this comparison of California's progress on high-speed rail to completed international projects does not account for cost differentials or elements of the system that add costs, such as viaducts, tunnels, and other components.

Table 2. Comparison of Average Cost per Kilometer and Average Years of Construction Time per Kilometer for High-Speed Rail in Europe and All Countries

	AVG. COST PER KM ($ MILLIONS)	AVG. YEARS OF CONSTRUCTION PER KM
ALL COUNTRIES (NOT INCLUDING U.S.)	$60	0.06
EUROPE	$57	0.07
CALIFORNIA—ENTIRE ROUTE	$82 (projected average cost across all sections); $90 (estimated for total project upon completion) Approximately 1.4 times as expensive as expected compared to all country baseline, and 1.5 times as expensive as expected compared to European baseline	N/A – only one portion of route has begun construction
CALIFORNIA—SEGMENT CURRENTLY UNDER CONSTRUCTION	$72 Approximately 1.2 times as expensive as expected compared to all country baseline, and 1.3 times as expensive as expected compared to European baseline	0.04 (estimate for completion of the initial 119-mile [192-km] portion by 2023). On track to complete construction approximately 30% more quickly than all country baseline and 40% more quickly than European baseline

Source: Marron Institute High-Speed Rail Cost Database, with analysis by authors.

f The Marron Institute's high-speed rail database includes cost and time information from 17 countries. First, CLEE removed any entries that did not have a start date or an end date for construction, as well as any projects completing in 2021 or later years so that only completed projects are considered. CLEE adjusted the data for inflation to 2019 U.S. dollars (USD) and calculated an average cost and construction time per kilometer. Unlike the estimates for light- and heavy-rail, this estimate includes all countries rather than narrowing down the estimate to only reflect Canada, Europe, and Australia. Two averages are presented: one for all countries in the Marron Institute data, and one focusing only on Europe. Cost per kilometer estimates for the ongoing California project account for the projected costs for the entire project (in terms of cost per kilometer averaged across each segment as well as the total project cost vs. total kilometers of the project). In contrast, the years of construction per kilometer estimate only reflects the expected construction completion timeline for the initial 119-mile segment currently under construction. It is too early to estimate construction times for any of the other segments. Marron Institute, Transit Costs Project, High-Speed Rail Database, available at https://transitcosts.com/high-speed-rail/.

III. SUMMARY OF KEY FINDINGS AND POLICY RECOMMENDATIONS

The review of literature, comparison of rail transit delivery databases, and case studies revealed several central themes in hindering or supporting low-cost, on-time project delivery; five of these emerged with the greatest prominence and consistency across the analysis. This section describes those findings and offers associated policy recommendations to promote best practices and overcome barriers.

The literature review revealed numerous factors contributing to cost and time overruns. There is some overlap between causes—for example, an issue that results in a project delay also increases project costs, and some aspects of high costs (like complicated station designs) also precipitate project delays. In general, core drivers of costs and delays can include contract, bidding, and procurement practices; labor and management; government organization and funding source restrictions; technical aspects, such as the use of bespoke designs versus standardized or prefabricated components, or the project location; and regulatory or legal factors, such as the cost of conducting environmental impact studies or procuring property.[14] In the California projects selected for review, key barriers (and opportunities for improvement) focused on contracting and procurement, agency coordination, agency expertise, project scope, and stakeholder outreach.

1. BUILDING MEGAPROJECT MANAGEMENT CAPACITY AND EXPERTISE

Inefficient labor, staffing, and management practices can hinder a project's ability to complete on time and within budget. Some assert that profits fall into the hands of construction companies, consulting firms, and "politically connected labor unions."[15] Companies are also ramping up costs while politicians have not implemented reforms to reduce excessive costs.[16] In some U.S. cases, such as New York's Second Avenue Subway, the project site sometimes had twice or even three times as many supervisors and workers on duty as required.[17] Rules preventing work from occurring around the clock, or preventing certain streets from being blocked off, can also slow project completion and lead to higher costs.[18] Productivity also plays a role in potential cost savings; research from McKinsey links substantial cost savings to infrastructure productivity improvements, finding that "better choices about which projects to execute, streamlining the delivery of projects, and making the most of existing infrastructure" and other best practices could generate trillions of savings globally.[19]

However, labor productivity and cost issues may relate to the broader question of institutional knowledge and project staff capacity. Significant work is required to manage a complex construction project safely, on time, and on budget; in many cases, rail megaprojects arrive only once every few decades at a given transit agency, leading to few repeat projects of similar scale and staff diaspora after project completion. As a result, despite significant planning and engineering expertise, these agency staff may require substantial time to familiarize themselves with megaproject negotiation and development—and may be at a strategic disadvantage compared to contractor staff who exclusively work on projects of a similar scale. Design errors, contracting issues, management mistakes, labor inefficiencies, and stakeholder coordination problems can arise as a result. Multiple expert interviews conducted in the research process for this report emphasized a lack of adequate agency staff capacity as a contributing source of delays and overruns.[20] The Eno Center also identifies insufficient staff capacity and lack of adequate training as factors contributing to cost and time overruns. For example, Eno proposes the creation of "small, multidisciplinary teams of high-quality, experienced executives with control over on-the-spot decisions, and enough junior staff to support them."[21]

Large-scale rail projects require a series of adaptive management decisions. When faced with challenges, an agency team with limited capacity may not adapt management structures effectively and commit to significant or risky decisions.[22] Limited teams may also struggle to shift practices when faced with new or unfamiliar technology. Agencies could benefit from consultation or support at the regional or state level to help bring project teams up to speed at the early stages of a megaproject.[23]

Boston's Green Line Extension provides an example of a project that suffered from a dearth of management employees in the project's early days. Massachusetts had cut many employees in the decades leading up to the project, and as a result, agencies lost vital institutional knowledge about managing large transit projects. The lack of dedicated employees caused project delays, as the few staff assigned to the project were simply unable to manage a workload of the scale associated with the project. When the project rebooted after 2015, the transit agency hired more staff to oversee the project.[24]

The case study research for this report yielded two especially instructive examples of the impact of staff expertise and capacity on project delivery:

California High-Speed Rail: The California High-Speed Rail Authority (CHSRA) was short staffed at the outset of the project's development. Although the agency was created for the sole purpose of executing the high-speed rail project, staff lacked the capacity and resources to oversee all required tasks, especially during the earlier phases of the project. Transit agencies can experience limited capacity in terms of both staff time and staff expertise. The latter is especially true for large-scale or novel technology projects like high-speed rail. CHSRA lacked the institutional knowledge to manage a 500-mile (approximately 800-kilometer) high-speed rail project in part because such a project had never been constructed before in the United States. CHSRA relied—and continues to rely—heavily on contractors who offer expertise from international high-speed rail projects. Contractors can also alleviate time burden for agency staff by completing tasks like environmental review. However, CHSRA contractors eventually outnumbered internal staff, and, in some cases, contractors spoke on behalf of the agency without the authority to do so. Agencies must balance the need for external expertise with their own internal capacity, especially given that private consultants and contractors may not have the same incentive to conserve public dollars as public agency staff. Recently, CHRSA has reduced the ratio of contractors to internal staff and has increased internal capacity. See page 72 for the complete case study and detailed analysis.

San Francisco Central Subway: The project was the first major subway construction in San Francisco in 40 years, meaning that even the well-staffed agency lacked in-house experts with significant experience working on major subsurface projects in the city.[25] This dynamic likely contributed to early delays in the environmental review process and to some of the issues that resulted from the single large contract employed for the station work, a significant source of delays and extra cost. See page 49 for the complete case study and detailed analysis.

RECOMMENDATIONS:

Based on the literature review and case studies presented here, transit agencies could:

- Form regional collaboratives (where applicable) to house permanent expertise not tied to any individual local project, with staff available to consult with or contract out to projects when needed.
- Ensure internal staff and management capacity is adequate to the scale of the project, including the task of negotiating with and managing contractors, before the bid process.
- Hire or retain staff with expertise in the selected procurement method so that they can manage the project appropriately (and, where possible, delegate those staff maximum authority to make non-mission-critical decisions without multiple reviews).

To support these steps, state leaders could:

- Create state or regional transit megaproject delivery teams available to consult with local agencies.
- Provide funding specifically to enhance staff capacity and conduct more extensive advance planning.

2. MAINTAINING PROJECT SCOPE AND RIGHT-SIZING DESIGN

A project's design and specific components can influence cost and time overruns in several ways, from decisions about the mode of transit (e.g., light vs. heavy rail) and the extent of tunneling or elevated track to decisions about station design or the overall route of the project. High costs for U.S. tunneled projects have been attributed to the complexities of navigating dense cities, such as moving utility lines or passing over waterways. But complexity does not fully account for high costs, as other parts of the world—including historic and dense metropolises like Paris and Madrid—overcome similar challenges at lower costs.

Communities engaged in the project may desire certain features or design modifications. In some cases, these modifications create value for the community and may enhance cultural and artistic resources in a particular neighborhood; in others, they may bolster access or rider experience. Some of these modifications may be appropriate for a project, but determining who will pay for the addition is a crucial decision point that can push a transit project over budget and behind schedule, if not appropriately managed—including, potentially, for modifications that are important to stakeholders but not critical to reaching the project's service date. The responsibility for the impact of these modifications ultimately falls not with the community but with public agency staff and decision makers that fail to set adequate boundaries on project expectations.[28] There is no generally applicable approach for determining whether a request should be incorporated into a project, and if so, who should cover the cost. Agencies and communities must use their discretion to decide which modifications are worth pursuing within the project's scope and under the transit agency's authority and should carefully consider the associated impact on budget and timeline. If a modification is not essential or beneficial to the user experience, it may be worth considering delaying the action until trains are operating and/or delivering it through a different entity and funding source.

Engaging local communities too late in the design and planning process can lead to a disconnect between a community's priorities and project feasibility. Transit leaders could potentially mitigate conflict by engaging communities from the outset of a process.[29] Drawn out review processes and disorganization between political leaders and government agencies also can cause budget and scope to expand beyond the threshold of a realistically deliverable transit project. At the same time, elected officials may present overly optimistic budget and timeline projections without having done the planning and engagement necessary to determine more realistic estimates.

Agencies should differentiate between transit-facilitating and non-transit-facilitating modifications, and limit all modifications as the project progresses past the planning stage.[30] Accessory modifications and amenities may benefit the project and the community, but should not necessarily fall under the purview of the transit agency and/or may be completed after transit

BETTERMENTS AND MODIFICATIONS

Several different terms and definitions exist to describe externally-requested project modifications. "Betterments" is a common term, defined by the Los Angeles County Metropolitan Transportation Authority (Metro) as "an upgrade of an existing city or utility's facility or the property of a Third Party, be it a public or private entity, that will increase or upgrade the service capacity, capability, appearance, efficiency or function of [the facility]."[26] Metro differentiates betterments from "project revisions," which it defines as "potential revisions to a Project's Scope of Work that may or may not have been originally considered during the environmental review process, but were either rejected or were raised after the Project's Notice of Determination or after the issuance of a Project's Record of Decision. Project Revisions may or may not ultimately be classified as Betterments depending upon what kind of infrastructure is identified in the request for inclusion."[27]

service commences where they are not vital to transit functions. However, agencies should account for equity when determining how to allocate the costs of community-requested modifications. For example, Los Angeles's Metro implemented a consistent process for evaluating, selecting, and allocating costs for community-requested project modifications, including consideration of equity.[31]

Research shows that land acquisition and permitting is a significant driver of time overruns worldwide.[32] Instead of prioritizing new infrastructure, planners and policymakers could refurbish existing infrastructure or use it more efficiently. Simply selecting suitable projects can be challenging but can offer tremendous benefits.[33] However, while using existing infrastructure and rights of way can offer cost and time savings, doing so may locate project routes outside the highest priority transportation corridors. Transit agencies should select routes that maximize transportation network connectivity. In addition, agencies may want to focus on system accessibility (i.e., valuable connections between residents and destinations) rather than anticipated ridership when selecting routes. High accessibility likely will lead to high ridership and is more straightforward to estimate.[34]

An analysis of transit costs by the Eno Center for Transportation concluded that a project's grade alignment (i.e., whether it is tunneled or elevated versus at ground level) was a better indicator of project cost than whether the project was light rail or heavy rail. The United States has a higher percentage of heavy rail at-grade than peer countries (U.S. around 20%, non-U.S. around 8%) but has a slightly smaller portion of light rail constructed at-grade (U.S. approximately 80%, non-U.S. around 90%).[35] At-grade project costs in the U.S. tend to be more consistent with at-grade projects in Canada and Europe.[36] However, once U.S. projects include above-grade (elevated) or below-grade (tunneled) components, costs begin to rise more dramatically than comparable projects in Europe and Canada. Increases are particularly notable when tunneling is involved. Tunneled projects in the U.S. experience more variability in costs.[37] Transit cost researcher Alon Levy recommends that cut-and-cover should be used in place of tunnel boring whenever possible to keep costs down.[38]

Station construction and design can also add costs. Spain has kept prices down in part by adopting a standardized station design that is replicated across all stations constructed on a line.[39] This uniformity allows for bulk purchasing and minimizes design costs while allowing construction workers to apply learned expertise to each subsequent station's construction. When Boston's Green Line needed substantial cost cuts to stay afloat, station modifications were among the first line items to be slashed, saving the project millions.[40]

Design inevitably will change throughout a project's planning phase. Still, drastic modifications or "scope creep" (the addition of new project elements) may make a project so bulky that it cannot timely achieve its fundamental mission of providing transit service to surrounding communities.[41] Modifications can also cause initial project budget and timeline estimates to be overly optimistic and inaccurate, leading to public cynicism and

STAKEHOLDER-DRIVEN PROJECT MODIFICATIONS

Communities engaged in the project development process may request modifications to the design or construction that fall into various categories. These can include:

- Construction parameters: To limit disruptions, residents and businesses may demand that construction activities only occur in specific locations or at certain times (e.g., barring nighttime activity).
- Transit-facilitating modifications: Communities may request infrastructure linking the transit project to the rest of the area (e.g., bike paths and parking infrastructure) to increase accessibility and ridership.
- Accessory modifications: Communities may request beautification or surface amenities adjacent to stations that are not directly linked to ridership or accessibility.

future shortfalls. Agencies may be able to better serve communities by significantly redesigning projects in response to community requests, but the cost of doing so (both direct expenditures and expensive delays) can render some modifications and redesigns impractical, and will require agencies to consider major tradeoffs. The Minneapolis Green Line light rail project, for example, included a thorough community engagement process that resulted in the relocation and addition of multiple stations to better serve the predominantly minority and immigrant communities along one section of the route, contributing to significant cost increases—demonstrating some of the tradeoffs that may be necessary to deliver a project that meets community accessibility needs.[42]

The case study research for this report yielded four especially instructive examples of the impact of project scope and design on project delivery:

BART Berryessa Extension: A former Union Pacific railroad right of way provided BART's Berryessa Extension route. Although not an appropriate choice for every project, relying on an existing railroad right of way expedited permitting and environmental processes, reduced disruption to local communities, and leveraged existing infrastructure as much as possible to reduce construction time and cost. Utilizing an existing right of way also enabled the project's mostly at-grade construction, thus avoiding the cost challenges typically associated with elevated or tunneled track. Additionally, the selected route considered equity of transit service and access, and project planners sought extensive buy-in from local neighborhoods when selecting the route. Treating community priorities as central to the decision allowed the project to avoid much of the conflict that has delayed or derailed other projects. See page 63 for the complete case study and detailed analysis.

San Diego Mid-Coast Corridor Trolley: Two components of the project design—a significantly elevated section through the University of California, San Diego (UCSD) campus and construction of two new parking lots at station sites—were responsive to the challenge of designing a project through multiple communities including a variety of stakeholder groups, potential project veto points, and barriers to land access. These elements added to the project's relatively high cost but were viewed as essential to achieve stakeholder buy-in, speed construction, and secure commuter ridership from suburban neighborhoods. In particular, elevating the UCSD section of the route minimized potential conflicts with university and hospital operations and eliminated the need to acquire a full surface right-of-way. While these features proved expensive and may be less preferable than lower-cost surface construction and density-promoting transit-oriented housing development, identifying the need at early stages helped ensure that they were included in the original scope and did not contribute to delays or overruns. See page 42 for the complete case study and detailed analysis.

San Francisco Central Subway: The project's significant delays and cost overruns (over three years and more than $300 million) have occurred almost entirely in the station construction and completion phase, in large part due to the mismatch between lowest-cost bid contracting and the highly complex nature of deep excavation station work in a dense urban environment (as well as the mid-construction addition of station-related surface improvements to surrounding parks and plazas, which earned support from community members but added complexity in new design, permitting, and stakeholder engagement, resulting in additional delay). See page 49 for the complete case study and detailed analysis.

Los Angeles Purple Line: According to agency officials, the project's design required tunneling rather than cut-and-cover construction through geologically challenging areas in Los Angeles, encountering tunneling anomalies ranging from abandoned oil wells and tar formations to steel beams. While certain route and tunneling design elements may have been unavoidable, project leaders could have built more time and cost contingency into their estimates to account for the route and tunneling design challenges. Tunneling anomalies accounted for a substantial portion of the project's cost overruns and delays. On the other hand, Metro achieved cost and time efficiencies in its application of a standardized station design. Limiting bespoke station design resulted in more efficient construction and permitting for each of the three stations. See page 55 for the complete case study and detailed analysis.

RECOMMENDATIONS:

Based on the literature review and case studies presented here, transit agencies could:

- Work with contractors and stakeholders in the planning stage to identify additional project elements vital to the project's success (for engineering, ridership, cost or time savings) to limit the risk of unnecessary modifications, which can create delays and overruns.
- Avoid the addition of significant, non-essential betterments and limit bespoke design for certain station elements (e.g., facades or modular components), particularly after the design stage.
- Factor site-specific challenges into route design prior to setting time and cost estimates, such as by conducting advance geotechnical surveys.
- Account for the tradeoff between the efficiency of building projects in existing rights of way and alignments that maximize access and ridership.

RIGHT OF WAY

Future projects should consider the tradeoffs between cost savings and project usability when determining a route along an existing right of way. While selecting a route along an existing right of way can reduce costs and decrease permitting and review requirements, these corridors may not always contain locations conducive to maximizing accessibility for riders. For example, if an existing right of way is along a highway or an old railroad route, it may not align with population areas and may be inconvenient for riders to access, defeating the primary purpose of any transit project. However, where an existing right of way is drastically more affordable to build than other project alternatives—or where it is the only alignment that can avoid unacceptable equity or environmental justice impacts—it may be the best option.

To support these steps, state leaders could:

- Encourage more efficient project design by conditioning state funding of local projects on avoidance of over-designed elements through cost-per-anticipated-rider criteria. For example, CTC or the legislature could require local transit agencies to meet specific design performance standards, such as cost-per-anticipated-rider and/or regional vehicle miles traveled reductions, to access State Transportation Improvement Program funds.
- Dedicate state funds specifically for enhanced upfront project design to minimize the risk of "surprise" factors that increase costs or create delays during construction and reduce transit leaders' ability to present overly optimistic budget and timeline estimates.
- Update state law to allow all transit agencies statewide to employ CMGC/CMAR and other alternative procurement methods (see Section III.4 on procurement methods).

3. CONDUCTING ADVANCE AND ONGOING MULTI-AGENCY COORDINATION

Government agencies juggle multiple priorities, constituencies, and regulatory requirements—from meeting communities' needs to conducting environmental impact assessments—but often fail to avoid cost and schedule overruns in the process. Different authorities (e.g., city, state, or federal) have overlapping or conflicting powers related to transit projects, which sometimes manifest as project delays or inefficiencies. Inconsistencies both within agencies and between agencies can be detrimental to project management. For example, a Regional Plan Association report cites a lack of vertical integration within New York's Metropolitan Transportation Authority (MTA) as a critical factor in project management inefficiencies, as multiple divisions and subdivisions within the MTA each have to communicate throughout the pre-construction and construction processes, adding unnecessary complexity.[43]

Transit projects that intersect multiple jurisdictions (e.g., crossing city lines) create additional coordination challenges.[44] The patchwork system of decision-making authorities means that coordination across governments adds costs, time, and complexity, including a lengthy permitting process.[45] In some regions and cities, several transit authorities operate with systems that do not align or complement each other, making transit planning much more difficult.

The case study research for this report yielded three especially instructive examples of the need for agency coordination strategies on project delivery:

BART Berryessa Extension: Two separate transit agencies—BART and Santa Clara Valley Transportation Authority (VTA)—co-managed the Berryessa Extension's planning, construction, and operation. VTA managed design and construction, while BART maintained responsibility for ongoing operations. The agencies' coordination could have been improved through greater integration of team members, including the potential for on-site staff representatives housed at each agency. For example, to facilitate interagency collaboration, the Berryessa team's end-of-project analysis proposed that some BART staff share VTA offices to speed testing implementation.[46] Housing staff representatives in agencies' respective offices could bolster interagency communication and reduce obstacles by holding discussions in a timelier manner. Additionally, where agencies experience miscommunications or disagreements, disputes could be resolved by a neutral third party identified at the project's outset. Appointing such an arbitrator may have been beneficial towards the end of the Berryessa project's construction when there were inconsistencies in agencies' and contractors' interpretation of the punch list. Assigning a neutral third party to help decide where to prioritize limited resources could be valuable for future rail projects. See page 63 for the complete case study and detailed analysis.

California High-Speed Rail: California's envisioned high-speed rail line spans roughly 500 miles (approximately 800 kilometers), crossing through a diverse patchwork of urban and rural communities. Such an expansive project requires close coordination with local governments, both at the city and county level and within and between state and federal agencies. The legislature created CHSRA to oversee project delivery and manage coordination with other government agencies. CHSRA frequently coordinates with local jurisdictions, other California state agencies, and the federal Department of Transportation for permitting, environmental review, land acquisition, and funding. At the beginning of the project, CHSRA lacked coordination with other state and local agencies due to inadequate staff capacity and resources. However, coordination improved over time as the agency found its footing and increased staff capacity. See page 72 for the complete case study and detailed analysis.

Los Angeles Purple Line: The project team regularly met with the Los Angeles Mayor's Office to provide transparent and timely updates to City government staff. Metro also entered a Memorandum of Agreement (MOA) with the City of Beverly Hills—a key jurisdiction on the route with potentially significant leverage over project outcomes—to define the parties' respective responsibilities and expected actions before construction began within the City's boundaries. In each case, early information-sharing and establishment of roles helped avoid obstacles to project delivery in later stages. See page 55 for the complete case study and detailed analysis.

RECOMMENDATIONS:

Based on the literature review and case studies presented here, transit agencies could:

- Develop permanent, ongoing structures to coordinate communications among agencies when projects are co-managed or co-dependent, such as selecting a neutral third party to arbitrate disputes whenever issues arise, and/or housing agency representatives at partner agencies

to facilitate coordination, conversation, and timely resolution of conflicting viewpoints.[47]
- Engage with local governments and enter memoranda of agreement/understanding to set expectations at the appropriate stage in the construction process.

To support these steps, state leaders could:

- Create an office within Caltrans to provide dedicated staff support/technical assistance to facilitate coordination among local and regional agencies or offer additional funding to agencies that provide detailed plans for addressing any in-house staffing needs, as applicable.
- Condition state funding based on detailed local agency plans, as needed, for coordination and partnerships on project implementation.
- Consider legislatively granting transit agencies with priority rail transit projects master permitting authority to reduce delays and costs imposed by local governments or large or powerful stakeholders along the route.[48] Such permitting authority could be granted to a single local agency on a pilot basis, or conditioned on transit agency applications to a state agency demonstrating project achievement of strict performance criteria on greenhouse gas emissions, vehicles miles traveled, equity, and other key metrics.

4. USING APPROPRIATE PROJECT DELIVERY (PROCUREMENT AND CONTRACTING) METHODS

Across the case studies examined in this report, the method of procuring a third-party contractor or set of contractors to construct the rail transit line loomed largest to determine cost and time of performance. The literature supports the importance of a sound procurement process. Many U.S. projects suffer from project delivery methods ill-suited to the project's realities, and even appropriate project delivery methods are poorly executed. Typical project delivery methods include Design-Build, Design-Bid-Build, CMGC/CMAR, and Public-Private Partnership (P3). Some government and transit agencies have established limitations on project delivery methods allowable for different contracts. As one finding, a Regional Plan Association report on New York's high transit delivery costs recommended using design-build for all future rail projects.[49]

PROJECT DELIVERY STRUCTURES

Primary project delivery structures for the design and construction of transit projects include:

- Design-build: The project owner (i.e., transit agency) enters a single contract with a single general contracting firm for both design and construction work.
- Design-bid-build: The project owner contracts with a design firm for a complete project design, then solicits bids from contractors to build the design. The selected contractor completes construction with no contractual relationship to the designer.
- CMGC/CMAR: The project owner engages a designer and a construction manager separately during the design phase, with the construction manager providing input on the design. Prior to design completion, the owner and the construction manager negotiate a guaranteed maximum price for construction, and the construction manager becomes the general contractor for the build phase.

Each structure carries different advantages, but a few key characteristics distinguish them:

- Risk and responsibility: Typically, a design-bid-build arrangement places the most contractual risk on the project owner (since neither the designer nor the builder is responsible for the complete project, or to each other), while design-build and CMGC/CMAR arrangements place more completion risk with the general contractor.
- Design and collaboration: Design-build and CMGC/CMAR structures can promote greater collaboration with the project owner and may deliver better early information on project design, scheduling, and constructability, leading to higher project quality and fewer disruptions.
- Cost: Design-bid-build contracts typically deliver the lowest bid cost since multiple contractors compete to win the bid based on the final design. Design-build and CMGC/CMAR are more likely to carry accurate final cost projections since the builder is involved in the design and bears more responsibility for project completion and risk in case of delays.

Design-bid-build has been a traditional project delivery method for transit agencies in most of the country, likely because its sequential structure facilitates the largest bid pool and lowest bid prices; however, design-build and CMGC/CMAR structures have been gaining popularity for complex megaprojects with a high risk of cost overruns, delays, or construction challenges.[50]

The procurement process begins by developing an accurate assessment of the project scope to get an accurate bid. Otherwise, over- or under-estimations of cost and schedule can contribute to overruns. If early cost estimates are too optimistic (i.e., too low), the project could face slowdowns as the money runs out sooner than anticipated.[51] Assessments that are too high might include inefficient designs or construction approaches, which likely will delay a project. Projects that fail to include an adequate contingency in their initial budget also run the risk of exceeding cost.[52] Bidding processes can contribute to poor scope definition and unrealistic project expectations. Governments are often required to select the lowest bidder. Adopting different bidder selection methods, such as those that reward value rather than purely low costs, could help projects avoid detrimental barriers later in the process.

As a cautionary example from the literature, Boston’s Green Line Extension suffered from vastly underestimated bids, design changes, and a suboptimal contract structure. Combining these factors led the transit agency to cancel the project in 2015 after officials set a cost estimate threshold of $2.3 billion. Above that amount, the officials reasoned, the project would not be worth constructing. Estimates exceeded that threshold, putting the project at risk of surpassing the initial budget by nearly $1 billion. According to research by the Marron Institute, "in the span of three years, [the Green Line Extension's] projected costs increased by nearly a billion dollars, or 79%," primarily attributed to scope changes.[53] Despite $700 million in sunk costs, the project was canceled and eventually rebid at a lower price after simplifying several design features.[54]

Ultimately there are benefits to each procurement approach, depending on the specific conditions and structure of the project. Agencies should select the procurement method based on project characteristics rather than defaulting to the lowest cost contracting option. At the same time, agencies must ensure that their staff members are sufficiently familiar with the selected procurement method to manage the contract appropriately and efficiently.[56] (For example, while design-build and CMGC/CMAR can both help mitigate the risk of late-process modifications and cost increases, they require distinct negotiation and project oversight approaches to avoid higher overall costs and slow contracting processes.[57]) In addition, separating projects into smaller contract units can yield benefits over the entire construction timeline but may also increase the agency's oversight costs—so it may be most appropriate for the largest project components.

The case study research for this report yielded three especially instructive examples of the impact of procurement practices on project delivery:

San Diego Mid-Coast Trolley: Use of CMGC/CMAR was a cornerstone of the project's timely and on-budget delivery (though that budget was ultimately significantly higher than for comparable national and international projects). CMGC/CMAR allows the project owner to involve the contractor early in both the design and third-party outreach/land acquisition processes, reducing the potential for delays to arise during the construction process by conducting comprehensive outreach and constraint/conflict identification during the planning process. This method proved particularly valuable for the project given its overall physical footprint (nine new stations and two highway crossings), budget (over $2 billion) and mix of residential, commercial, and university stakeholders. See page 42 for the complete case study and detailed analysis.

Los Angeles Purple Line: In addition to the primary design-build contract, Metro issued smaller AUR contracts to expedite construction at the line's three underground stations. The AUR's finite scope reduces additional high-risk work for the design builder and provides essential information about the location of underground utilities. The Purple Line's AUR activities uncovered some previously unknown utilities and allowed the contractors to relocate those utilities safely. Procuring smaller and more specific AUR contracts before the design builder began station construction and tunneling allowed cost savings and

LOW-BID CONTRACTING

Maryland's Purple Line project adopted an innovative 36-year P3 structure but faced cost and time overruns that could prove fatal to the project. Described as a "cautionary tale," the 16-mile (approximately 26-kilometer) light rail project is nearly $755 million over budget and two years behind schedule.[55] Low initial bids from contractors and Maryland's decision to select the lowest bidder are cited as causes of the overruns. The contractors also note that the state's delay in land acquisition, environmental review modifications, and design changes led to overruns.

efficiency. See page 55 for the complete case study and detailed analysis.

San Francisco Central Subway: While station work was initially set to be completed via four separate design-bid-build contracts, the decision to instead procure a single contract for all four stations significantly reduced the agency's leverage in negotiation once delays and overruns began to arise for each station, and the lowest-bid approach left the project more subject to initial underestimation of costs. If four separate contracts were involved, the San Francisco Municipal Transportation Agency (SFMTA) might have been better positioned to respond to new conditions, but the single-contract arrangement left delivery of the entire project at risk whenever a new overrun or delay arose and limited SFMTA's ability to negotiate the cost of contract modifications. In addition, if SFMTA had used a project delivery method with a greater emphasis on early contractor involvement (such as progressive design-build or CMGC/CMAR), the agency could have had a better original estimate of costs, a strategy the Transbay Joint Powers Authority (TJPA) is now considering for the Downtown Rail Extension project in San Francisco. See page 49 for the complete case study and detailed analysis.

RECOMMENDATIONS:

Based on the literature review and case studies presented here, transit agencies could:

- Break apart project tasks among multiple, smaller contractors where feasible to avoid ceding too much leverage to one contractor.
- Consider AUR contracts to expedite utility-related work in tunneled areas or around stations.
- Consider using CMGC/CMAR and other alternative project delivery methods with early contractor involvement to ensure the total cost of building expensive projects in dense, complex areas is identified before construction begins.

To support these steps, state leaders could:

- Update state law (which currently authorizes select counties to employ project delivery methods like CMGC/CMAR contracting on a pilot basis) to allow all transit agencies statewide to employ these methods.
- Structure or create state grants to reward transit agencies that prioritize and use efficient procurement strategies.

5. FACILITATING COMPREHENSIVE STAKEHOLDER OUTREACH

Environmental review and other permitting or pre-construction requirements can constitute substantial undertakings for government agencies and their contractors.[58] These processes require significant time and cost resources—sometimes years and millions of dollars—before the project can even break ground, including multiple rounds of stakeholder review and comment. While environmental, social, cultural, and economic impacts must be considered, there may be opportunities for greater efficiency in these processes without cutting corners or sacrificing project quality.

The American (and Californian) legal systems also tend to facilitate litigation and delay of project developments, perhaps more so than in other countries, primarily due to the extensive public review, comment, and participation processes afforded by environmental review and land use permitting laws.[59] Opposition is often related to a project's location; many individuals would like access to transit or other beneficial amenities but do not want projects sited in their neighborhood, giving rise to the term "not in my backyard" (NIMBY). But permitting and environmental review processes can also give rise to litigation from interest groups ranging from competing developers to organized labor. Legal challenges brought against transit projects often lead to delays.[60] Comprehensive and early stakeholder outreach can help incorporate public perspectives into project design and construction plans, minimizing litigation and delay risk.

Agencies could differentiate between large, organized stakeholder groups and smaller groups or individuals that lack the resources or capacity to participate in the engagement process. Agencies could tailor engagement strategies to reach all relevant stakeholder groups, especially individuals and community groups whose voices may not be as present as larger, more powerful entities.

The case study research for this report yielded two strong examples of the impact of stakeholder engagement practices (primarily with large institutions) on project delivery:

> Los Angeles Purple Line: Metro's MOA with the City of Beverly Hills serves as an example of pre-construction coordination between parties to address local concerns before an issue arises. Parties may not always agree on project decisions, so transit leaders could create a mechanism to align expectations and resolve disputes to help reduce (costly and time intensive) conflict. Metro also established guidance for reviewing stakeholder requests for project modifications at different project phases.[61] While not specific to the Purple Line project, Metro's process establishes consistent review mechanisms for requests, which in some cases may reduce conflict by creating fairer and more transparent processes for modification petitions. See page 55 for the complete case study and detailed analysis.

San Diego Mid-Coast Corridor Trolley: The project included six stations located in or around the UCSD campus, serving a growing commercial and educational hub that was a core motivator of the selected route. Participation and approval of the project design by UCSD leaders—who had potentially significant leverage over project outcomes—proved vital to completing the project on time. The project team engaged UCSD leadership throughout project planning, development, and construction to ensure that the design met university community needs and minimized disruptions, achieving buy-in for the project and minimizing the risk of conflicts and litigation (in particular for land acquisition/access and interactions with state and federal leaders). See page 42 for the complete case study and detailed analysis.

RECOMMENDATIONS:

Based on the literature review and case studies presented here, transit agencies could:

- Target major new routes and extensions to areas with a single stakeholder such as a university or hospital (where appropriate with ridership, accessibility, and equity goals) or form an early stakeholder coalition in order to build support for the route/design, streamline negotiations, and minimize the risk of costly delay.
- Enter legal agreements with cities or other parties as needed to avoid potential conflict and clarify expectations before the design is finalized (including selecting appropriate procurement methods).
- Prioritize clear and timely communication, even when communicating unpopular information like road closures, so that affected parties may plan ahead and build trust in the transit agency's communication process.

To support these steps, state leaders could:

- Create guidelines, host workshops, and/or provide direct funding to local agencies to develop and disseminate guidelines on stakeholder outreach best practices, or provide additional funding to local agencies that offer detailed plans for conducting this outreach, as needed.

IV. CASE STUDIES

This section presents five California rail transit case studies and examines lessons that can improve future projects.

1. SAN DIEGO MID-COAST CORRIDOR TROLLEY

Project Overview

KEY THEMES: *Higher initial budget estimate leads to on-budget delivery; the right contract mechanism can support project success; partnership with non-governmental entities can create mutually beneficial outcomes.*

The Mid-Coast Corridor Trolley project extends the San Diego Metropolitan Transportation System (MTS) Blue Line Trolley, managed by the San Diego Association of Governments (SANDAG) metropolitan planning organization. The project consists of 11 miles (approximately 17.5 kilometers) of new surface light-rail service, including nine new stations (plus additional connecting service on existing track), linking downtown San Diego with the U.S. Department of Veterans Affairs (VA) Medical Center and UCSD to the north. The route primarily follows an existing railroad right-of-way. The project's $2.17 billion budget is funded in nearly equal shares by the Federal Transit Administration's New Starts program and funds from a local transportation improvement sales tax measure known as TransNet. Construction began in 2016 and service is anticipated to begin in late 2021, serving approximately 20,000 riders per day.[62]

The project is located entirely in the City of San Diego, originating in the Downtown core and running north-south along the Interstate 5 corridor through the Pacific Beach and La Jolla areas to the UCSD campus and University Town Center (UTC) employment/commercial hub and shopping center. (The project connects to an existing line that runs from San Ysidro to Downtown, providing a one-seat ride from the border to UTC.) It consists of light rail/trolley service on a combination of existing track (3.5 miles, 5.6 kilometers), new at grade track (6.9 miles, 11.1 kilometers) and new elevated track (4 miles, 6.4 kilometers) on existing railroad right-of-way, with one 0.03 mile (0.05 kilometers) cut-and cover-undercrossing; of the nine new stations four are at grade and five are elevated.

The project team conducted expert interviews with Ron Roberts (former San Diego County Supervisor and SANDAG Board Chair), Gary Gallegos (former SANDAG Executive Director and Caltrans District Director for San Diego County), and Jim Linthicum (SANDAG Chief of Capital Programs and Regional Services), each of whom were extensively involved in the project's planning, funding, and implementation, to inform this analysis.

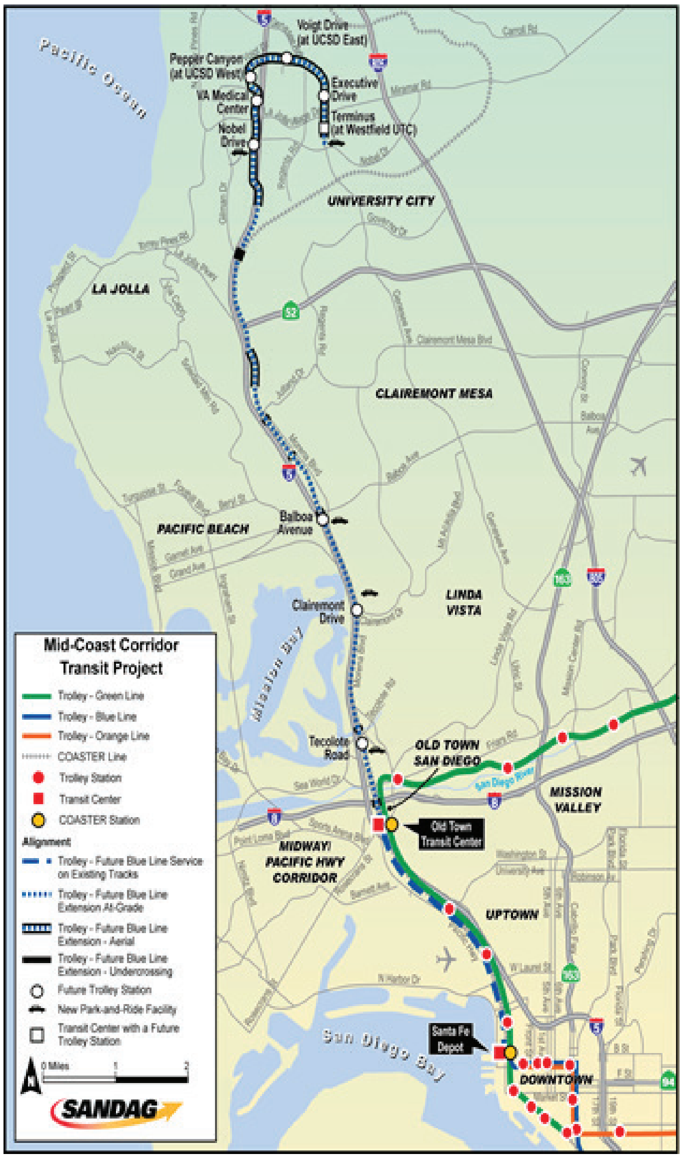

Figure 1. Map of San Diego Mid-Coat Corridor Route.
Source: SANDAG.

SAN DIEGO MID-COAST CORRIDOR TROLLEY

Location: San Diego, San Diego County

Lead project agency: San Diego Association of Governments (SANDAG)

Rail/construction type and number of stations: Light rail; elevated and at-grade; nine new stations

Length: approximately 11 miles (17.5 kilometers)

Cost: $2.17 billion (expected final)

Contracting structure: CMGC/CMAR

Timeline: 1987 (initial project proposal); 2004 (initial public funding approval); 2014 (federal funding and environmental review approval); 2016 (construction start date); 2021 (expected service date)

Cost per km: $123.77M/km

Time per km: 0.29yr/km

Table 3. Comparison of San Diego Mid-Coast Corridor Trolley Cost and Timeline to Expectations Based on Averages of Similar Completed Projects

	TOTAL COST ($ MILLIONS)	YEARS OF CONSTRUCTION	COST PER KM ($MILLIONS/KM)	YEARS OF CONSTRUCTION PER KM (YR/KM)
Expected[63]	CA - $826 U.S. - $1,090 Int'l. - $661	CA - 8.6 U.S. - 7.9 Int'l. - 8.8	CA - $47 U.S. - $62 Int'l. - $38	CA - 0.50 U.S. - 0.50 Int'l. - 0.50
Actual	$2,171	5.0	$124	0.3
Comparison to Baseline			CA – 260% U.S. – 200% Int'l. – 330%	CA – 60% U.S. – 60% Int'l. – 60%

Background and History

San Diego voters approved the regional TransNet transportation funding program in 1987, instituting a ½-cent sales tax to generate 20 years of revenue for public transit, local road, and highway projects, with one third of funds dedicated to each category.[64] The funding is primarily administered by SANDAG, with participation from MTS and Caltrans. SANDAG is the metropolitan planning organization for San Diego County, a consolidated regional transportation planning agency created by state law in 2003.[65] When created, SANDAG assumed all public transit project development and construction authority in the county, including design, permitting, environmental review, and funding streams.[66] SANDAG's board includes representatives from city councils throughout the county, plus advisory members from Caltrans, the U.S. Department of Defense, port and airport authorities, local tribes, and neighboring jurisdictions. SANDAG created a project working group to lead public involvement in the Mid-Coast Corridor Project, consisting of local community, business, and institutional representatives.[67] MTS, which is a joint powers authority representing jurisdictions throughout the county (and which had planning and construction responsibilities prior to the SANDAG consolidation) operates transit services in the central and southern portions of the county.

The Mid-Coast Corridor Trolley was included in the initial set of Early Action Projects targeted for funding under TransNet.[68] The Metropolitan Transit Development Board (a predecessor to SANDAG's post-2003 authority) initiated planning studies in 1991, resulting in the 1995 Draft Environmental Impact Statement (EIS) which outlined a trolley extension from Old Town to University City, identifying congestion along the Interstate 5 corridor, anticipated population and employment growth, and a lack of current public transit options.[69] (SANDAG estimated the project could cost $130 million in its initial TransNet expenditure plan, and $350 million in the 1995 environmental documents.[70])

However, the project was not funded in the first round of TransNet transit projects, which focused on station and car improvements for the existing trolley network, bus rapid transit lines, and improvements to the San Diego-Los Angeles-San Luis Obispo commuter rail corridor.[71] Between the 1995 EIS and the 2003 SANDAG restructuring, the project was divided into two separate segments (Old Town-Balboa Avenue and Balboa Avenue-University City). When San Diego voters approved Proposition A in 2004, extending the TransNet tax and program through 2008-2048, the Mid-Coast Corridor Trolley was identified for receipt of $660 million in funding (to be paired with federal matching funds), and in 2005 SANDAG voted to re-combine the two segments into a single project.[72] SANDAG prioritized the project following the start of the second phase of TransNet in 2008; initial environmental review documents were finalized in 2010 and 2011, with a Final Supplemental Environmental Impact Statement/Subsequent Environmental Impact Report (prepared under California and federal environmental review statutes, California Environmental Quality Act (CEQA) and National Environmental Policy Act (NEPA)) issued in September 2014 that selected a project alternative including 3.5 miles (5.6 kilometers) of existing track, 10.9 miles (17.5 kilometers) of extension on new track, and 9 new stations.[73]

In May 2014, SANDAG selected Mid Coast Transit Constructors, a joint venture firm of Stacy & Witbeck, Inc., Skanska USA, and Herzog Contracting Corporation, to serve as the construction manager for the project. The contract was arranged via a CMGC/CMAR structure, a form of general contracting approach in which the project developing agency contracts with a single construction entity that offers a total guaranteed maximum price for the project and procures/manages all subcontracts for project elements. The CMGC/CMAR structure can help limit the risk of budget overruns and change orders by holding the construction manager responsible for procuring subcontracts and managing project implementation within the agreed total budget, contractually relieving the agency of most overrun risk. When managed appropriately, this approach can result in more accurate (and potentially higher) initial budgets, improving both financial and public relations performance.[74] Expert interviewees indicated that the procurement structure was one key to on-time, on-budget project delivery.

A pilot program created under 2015 legislation (SB 762, Wolk, Chapter 627) authorized certain counties to use “best value” contracting based on evaluation of “objective criteria,” enabling SANDAG to enter a CMGC/CMAR contract rather than a low-bid contract as typically required by state law for county construction contracts.[75] This legislation created the opportunity for SANDAG to test a previously unused structure, and SANDAG held “CMGC 101” training sessions for agency leadership and construction managers to familiarize themselves with the model and best practices for planning and risk management.

In October 2014, the Federal Transit Administration issued a NEPA Record of Decision approving the project alternative, and in September 2016 the FTA approved a Full Funding Grant Agreement to provide $1.04 billion of the total $2.17 billion project budget via federal New Starts funding, with $590 million anticipated from TransNet funds and $538 million anticipated from a local Transportation Infrastructure Finance and Innovation Act (TIFIA) loan.[76]

In 2015, SANDAG, UCSD, MTS, and Caltrans entered a Memorandum of Understanding (MOU) outlining their obligations related to the project, including SANDAG's and Caltrans' funding of at least $45 million in bridge and road improvement projects on the UCSD campus; UCSD's agreement to provide all necessary easements and land transfers for the project; and commitments among all the parties to enter necessary construction, operation and maintenance, and real estate contracts.[77] Construction started in October 2016, and as of August 2021 the project was set to begin revenue service in late 2021. The Final Supplemental EIS and Subsequent EIR (SEIS/SEIR) projected a total budget of $2.11 billion ($1.04 billion in FTA funding), with construction starting in 2015 and revenue service beginning in spring 2019.[78]

Analysis

The project is scheduled to enter service in late 2021 on a total budget of $2.17 billion. The final budget and five-year construction timeline represent a cost increase of approximately $60 million and a completion delay of approximately one year as compared to projections in the 2014 final environmental documents, but align with the budget and service date projections contained in the last SANDAG annual program budget and work program issued prior to construction start in 2016.[79]

The average cost per kilometer was $123.77 million and the average time per kilometer was 0.29 years. As compared to the estimated baseline cost and time for similarly designed projects detailed in Section II, these averages are greater than the expected cost for California, US, and international projects (260%, 200%, and 330% respectively), yet shorter than the expected time (60%, 60%, and 60% respectively).

Review of the historical record and expert interviews identified the following main drivers behind this relatively high-cost, on-budget, rapid-deployment outcome:

University partnership. The UCSD/UTC northern project terminus is a major employment, commercial, and medical center in the San Diego area and a key driver of anticipated ridership on the project. Six of the project's nine new stations are located in the greater University City area. SANDAG worked directly with UCSD leadership throughout the project planning and development process, culminating in the 2015 MOU which cemented the parties' commitment to work together to facilitate the construction phase of the project. This collaboration helped to achieve maximum buy-in from the university community, which was initially skeptical of a transit connection to downtown San Diego but eventually embraced the increased connectivity between housing and employment opportunities. The "virtual partnership with UCSD" (according to one interviewee) also helped to ensure buy-in from local Congressional representatives and the state's Senate delegation, and likely earned rating points in the FTA New Starts application process, securing essential federal funding. The

LEGISLATIVE AUTHORIZATION FOR ALTERNATIVE PROCUREMENT METHODS

SB 762 (Wolk), which authorized certain counties to use "best value" contracting based on evaluation of "objective criteria," enabled pilot programs in Alameda, Los Angeles, Riverside, San Bernardino, San Diego, Solano, and Yuba counties but expired in 2020. In 2019, the program was extended to Monterey and Santa Clara counties and through 2025 (SB 128, Beall, Chapter 501). The 2019 extension shifted the determination of best value from "evaluation of objective criteria that relate to price, features, functions, life-cycle costs, experience, and past performance" to "on the basis of objective criteria for evaluating the qualifications of bidders" including "financial condition, relevant experience, demonstrated management competency, labor compliance, and safety record."

existence of a single “anchor” stakeholder along a significant portion of the planned route, and SANDAG’s successful engagement at the senior leadership level, helped ensure smooth passage through the potential barriers of land acquisition, access, and construction.

Contracting structure. All three interviewees cited SANDAG’s use of the CMGC/CMAR contract structure as a cornerstone of the project’s timely and on-budget delivery. CMGC/CMAR allows the project owner to involve the contractor early in both the design and third-party outreach/land acquisition processes, reducing the potential for delays to arise during the construction process by conducting comprehensive outreach and constraint/conflict identification during the planning process.[80] This method proved particularly valuable for the project given its overall physical footprint (nine new stations and two highway crossings), budget (over $2 billion) and mix of residential, commercial, and university stakeholders. The project’s anticipated on-time, on-budget delivery is evidence of the contracting model’s effectiveness in risk allocation.

Elevated track design. The high overall project cost was in part due to the exclusive use of elevated track in the UCSD area, which was a basic condition of routing the project through the university campus and VA medical center (due to a combination of community preference and a lack of available ground real estate/rights-of-way), a key source of project ridership and key factor in obtaining FTA funding. While the construction of 4 miles (6.4 kilometers) of elevated track (including highway crossings) added significant cost versus at-grade alternatives, it also eased a number of land acquisition and community conflicts. In addition, the project team elected to use precast construction for bridge sections, rather than onsite box-girder construction —an additional cost increase that spared time (and construction-related environmental impacts identified in CEQA reviews) by limiting the total amount of disruptive work done onsite.

Parking structures. The project included development of two new parking structures at station sites (in addition to an agreement for private construction of parking spaces at the Westfield UTC shopping center lot as a CEQA mitigation measure,[81] and an easement for spaces at the Clairemont station, which a private developer may later convert into an elevated parking structure), meeting approximately 85% of anticipated parking demand.[82] These parking structures added to the overall project cost and may not represent the highest and best land use for boosting ridership or improving equitable access to the line, but project leaders considered them necessary to secure ridership (and federal grant dollars) and serve the suburban communities in which the stations along the middle of the project route were located (the Interstate 5 corridor portion between downtown and University City). In addition, open-air parking lots potentially can be repurposed for development in the future, allowing transit agencies to procure station-adjacent property that can contribute to transit-oriented development.

Lessons Learned

The key determinants of the project's relatively successful delivery appear to be the use of CMGC/CMAR contracting and the early, leadership-level engagement between SANDAG and UCSD to identify and address potential stakeholder conflicts in advance of construction. Each of these aspects of the project enabled greater accuracy in budget and timeline estimates and facilitated land access/acquisition, minimizing the risk of holdouts and unforeseen new costs. In addition, project experts cited SANDAG's advantageous refinancing of the project's federal Transportation Infrastructure Finance and Innovation Act (TIFIA) loan in early 2021—which will save approximately $100 million in costs over the 25-year life of the loan—as a vital, but not necessarily replicable, element of project success.[83]

Counties currently authorized to use CMGC/CMAR through 2025 under SB 762 and SB 128 (Alameda, Los Angeles, Monterey, Riverside, San Bernardino, San Diego, Santa Clara, Solano, and Yuba) could consider using the project delivery method in future projects if possible. And state legislators could consider extending the pilot program beyond 2025, and to counties statewide, to allow more projects to reap similar benefits. However, as noted in Section III, this procurement method may not be appropriate for all project types—and agencies should ensure that staff have experience in negotiating and overseeing CMCG/CMAR contracts in order to avoid high overall costs and slower design and contracting.

In addition, while future transit project developers may not always be able to replicate the project's location in a dense, university-centered corridor—and thus the existence of an "anchor" stakeholder with concentrated authority over land and construction decisions—they can try to identify stakeholder groups that together form this type of "anchor" and craft memoranda of understanding to detail mutual commitments and obligations in advance of construction. And, where possible, they could target new projects toward routes that overlap with such stakeholders, with the knowledge that such overlap is likely to support successful deployment.

2. SAN FRANCISCO CENTRAL SUBWAY

Project Overview

The Central Subway project is an extension of the San Francisco Municipal Railway Metro light-rail system (Muni), managed by the San Francisco Municipal Transportation Agency (SFMTA). The project consists of a 1.7-mile (2.7 kilometer) extension of the existing Muni T line into downtown San Francisco. The Central Subway includes four new stations, one at street level and three below grade. The majority of project funding (approximately $950 million of the original $1.58 billion estimate) is provided by the FTA's New Starts program; additional funds are from the State of California (approximately $470 million), the Bay Area Metropolitan Transportation Commission (MTC), the San Francisco County Transportation Authority, and the City and County of San Francisco (approximately $120 million through a local sales tax measure). Initiated in 2009 after completion of the Third Street T line, the project is expected to open for service in early 2022, serving approximately 35,000 riders per day.[84] Situated in a dense urban area and crossing the existing subsurface Muni and BART tunnels beneath Market Street, the project has progressed relatively slowly and carries a relatively high (but accurately estimated) price tag, garnering some public concern and opposition even prior to construction.[85]

KEY THEMES: *High cost and slow project delivery in densely populated residential/commercial district; challenging overrun/delay containment with single low-bid contractor overseeing all stations and systems work; expensive delays associated with complex station construction.*

The project is located entirely in the City of San Francisco, connecting the surface-level service along Third Street in the Bayshore and Mission Bay neighborhoods through the SOMA, Downtown, and Chinatown business districts. The project is considered Phase 2 of the T/Third Line; Phase 1, a surface trolley line between Bayshore and the city's Caltrain station, entered revenue service in 2007. (Proposed Phases 3 and 4 would extend the line from Chinatown to residential and tourist areas in North Beach and beyond.) The project includes four new stations, one at surface in the SOMA neighborhood and three underground in the northern sections at depths of 40 to 120 feet below grade. The new Union Square station is linked to the existing Muni Powell station, linking the project to the rest of the Muni system servicing the western and southwestern areas of the city. (The existing T/Third Line currently connects to the rest of the system through additional stations along the Embarcadero and Market Street). The light-rail trolley service extends approximately 0.7 miles (1.1 kilometers) at grade before entering twin tunnel bores that pass through 1 mile (1.6 kilometers) of dense sand clay (the "Colma" complex beneath downtown and Market Street) and bedrock (the "Franciscan" complex beneath Nob Hill and Chinatown).[86]

The project is managed by SFMTA, a department of the City and County of San Francisco with full planning, financing, construction, and operational/maintenance responsibility for San Francisco's rail and bus systems.[87] Project funding partners include the FTA, State of California, MTC, and San Francisco County Transportation Authority.

The project team conducted expert interviews with John Funghi (former SFMTA Central Subway Project Director) and Albert Hoe (SFMTA Central Subway Program Manager) and email communication with Sandeep Ghosh (Contract Administrator, SFMTA Central Subway Project) and Luis Zurinaga (Project Management and Oversight Consultant, San Francisco County Transportation Authority).

Figure 2. Map of San Francisco Central Subway Route.
Source: SFMTA.

SAN FRANCISCO CENTRAL SUBWAY

Location: San Francisco, San Francisco County

Lead project agency: San Francisco Municipal Transportation Agency (SFMTA)

Rail/construction type and number of stations: Light rail; tunneled and at-grade; four new stations

Length: 1.7 miles (2.7 kilometers)

Cost: $1.891 billion

Contracting structure: Design-bid-build

Timeline: 1993 (initial project proposal); 2008 (environmental review approval); 2010 (federal funding approval and construction start); 2022 (expected service date)

Cost per km: $626.9M/km

Time per km: 4.39yr/km

Table 4. Comparison of Central Subway Cost and Timeline to Expectations Based on Averages of Similar Completed Projects

	TOTAL COST ($ MILLIONS)	YEARS OF CONSTRUCTION	COST PER KM ($MILLIONS/KM)	YEARS OF CONSTRUCTION PER KM (YR/KM)
Expected	CA - n/a U.S. - $1,570 Int'l. - $620	CA - n/a U.S. - 4.7 Int'l. - 4.0	CA - n/a U.S. - $574 Int'l. - $227	CA - n/a U.S. - 1.7 Int'l. - 1.5
Actual	$1,891	12.0	$691	4.4
Comparison to Baseline			CA – n/a U.S. – 120% Int'l. – 300%	CA – n/a U.S. – 250% Int'l. – 300%

Background and History

SFMTA first identified the Bayshore-to-Downtown area as a transit priority in the 1980s, developing initial project alternatives including a Third Street Muni light rail line (with multiple alignments including both the Bayshore-SOMA segment and the SOMA-Chinatown segment) in a 1993 transit corridor study.[88] While the initial environmental documents for the Third Street Corridor included both segments, FTA did not include the Central Subway in its 1999 Record of Decision approving federal funding for Phase 1. Construction on the 5.4-mile (8.7 kilometer), 18-station, surface-only Phase 1 began in 2001 and concluded in 2007. Planning for the Phase 2 Central Subway proceeded, with initial FTA approval of preliminary engineering in 2002, preparation of draft and final NEPA/CEQA environmental impact statements/environmental impact reports (EIS/EIR) in September 2007 and 2008, and FTA approval of the final EIS in November 2008.[89] FTA approved the final project design in January 2010 and construction started in February 2010. Tunnel boring began in July 2013 and was completed in June 2014; station and track construction began in September 2013, with major excavation completed at the Moscone/Yerba Buena and Union Square stations completed in 2017. As of summer 2021, station completion work was ongoing and the expected revenue service date (RSD) was spring 2022.

The project underwent multiple significant design changes between its initial conception and selection of the deep tunnel alternative in the Final SEIS/SEIR. These included:

- An alignment consisting of a deep-bore tunnel, which was initially deemed too expensive;
- A shallower alignment with a combination of cut-and-cover trench work and tunneling work, which would have caused significant construction-related disruptions to businesses and traffic congestion in the Market Street and Union Square areas; and

- An all-surface alignment, which significantly reduced construction costs but was not projected to generate additional ridership (relative to the existing bus network in the highly congested area) sufficient to meet the minimum ridership benefit requirement for federal New Starts funding.[90]

When the 2008 Final SEIS/SEIR was prepared, the cost of deep tunneling work had decreased to the extent that it represented both the least-cost and least-disruption alternative with adequate ridership and transit-oriented development benefits.[91] While this alignment proved to be the preferred alternative in terms of costs and impacts, it also relied on relatively deep subsurface stations that were associated with significant cost overruns and delays in the construction phase.

The FTA approved a New Starts Full Funding Grant Agreement for the project in October 2012, providing $942 million of the estimated $1.58 billion budget. The remainder of the budget included $471 million in State of California funds ($328 million in Proposition 1B state infrastructure funds, $68 million in Regional Transportation Improvement Program funds, $61 million in Proposition 1A high-speed rail connectivity funds, and $14 million in traffic congestion relief funds), $124 million in city/county Proposition K sales tax funds, and $41 million in Federal Highway Administration flexible funds.[92] (By contrast, the 2008 Final SEIS/SEIR had estimated a $1.24 billion budget, including $762 billion in federal funds, $306 million in state funds, and $167 in local funds.[93]) By the end of 2020, the project had spent $1.635 billion, and by mid-2021 it had spent $1.845 billion.[94] In March 2021, SFMTA approved $147 million in contract modifications and change orders sought by contractor Tutor Perini, covering a range of mechanical, electrical, fire safety, train control, and communications system changes and associated construction delays totaling over 365 days.[95]

The project contract for stations, surface, track, and systems is more than $300 million over budget, including approximately $150 million over budget for Chinatown station, $20 million for Union Square station, $5 million for Yerba Buena station, and $120 million for Fourth and Brannan station, and associated surface and systems (e.g., electrical, communications, ventilation, drainage, fire suppression, and elevator) work. The stations have taken over 8 years to complete, with nearly 3 years of delays.[96] These issues are largely due to the mismatch between the project's low-bid contracting (which has a higher propensity to underestimate costs) and complex, high-cost station excavation and systems work in a dense urban environment with old subsurface infrastructure (which had a higher propensity for change orders, unanticipated challenges, and increased costs), resulting in an arrangement ripe for delays and additional costs. Delays at the Chinatown station also relate in part to the construction of the surface Chinatown Plaza park at the station entrance—a new open space specially requested by community stakeholders and the Mayor's office but, according to expert interviews, a more delay-prone (and thus cost overrun-prone) alternative to the housing structure originally planned for the parcel. However, with special funding from the Mayor's office, the plaza contributed less than five percent of the station's total cost overrun. (Chinatown Station won a 2020 "Project of the Year" award from the International Tunneling and Underground Space Association for the innovative methods employed to overcome challenging engineering.[97])

Analysis

The project is scheduled to enter service in spring 2022 (more than three years after its original anticipated completion date of late 2018) at a final cost of $1.891 billion (a cost overrun of $313 million as compared to the final pre-construction estimate, or approximately 20 percent).[98] Compared to expected baseline estimates for similar project profiles, the per-kilometer construction time is between two and three times longer than anticipated compared to similar U.S. and international projects, and the construction cost is approximately three times greater than anticipated on a per-kilometer basis compared to similar international projects (see Table 4). Review of the historical record and expert interviews revealed the following main drivers of this relatively high-cost/slow-construction project with significant construction delays and cost overruns:

Contracting structure. Expert interviews indicated that the contract structure with Tutor Perini has been a major impediment to on-time and on-cost delivery. Tunneling work was completed largely at-cost and on-time via a design-bid-build project delivery method, and work for the four stations was initially set to be completed via four separate design-bid-build contracts. However, SFMTA elected to instead procure a single design-build contract for all four stations (and associated surface and systems work), which significantly reduced the agency's leverage in negotiation once delays and overruns began to arise for each station. If four separate contracts were involved, SFMTA would have been better able to change direction in response to new conditions. As it stood, the "too big to fail" arrangement left delivery of the entire project at risk whenever a new overrun or delay arose and limited SFMTA's ability to negotiate the cost of contract modifications at the tail end of the project. And, more broadly, the lowest-bid design-bid-build structure – which provides initially competitive bids but may not account well for major changes – was perhaps not the best fit for a project of such high cost and in such a complex, dense environment, particularly for the stations work. The decision to include system work as part of the large civil construction contract was also a major source of conflicts and delays.

Project location and depth. The project is located in one of the densest neighborhoods of the second-densest major city in the US. This was both one of the project's major upsides—high ridership in a busy residential and commercial district without further surface congestion—and one of its challenges, as the alignment selection and station construction were substantially affected by a high level of stakeholder input and business disruption. The depth of the underground portion of the project (40-120 feet) also appears to have been a major driver of high overall costs, but tunneling and excavation were not a major source of delays or overruns, and were necessary to achieve the desired ridership and congestion relief.

High-cost, slow-deployment stations. While the station completion work did not begin until 2017—seven years after initial construction began and five years after the FTA funding agreement—the $313 million cost overrun and three-year delay for stations comprise nearly all of the project's total cost and time overrun described above. In particular, the Chinatown station has posed a number of additional cost drivers, reflecting the challenge of building a new station in a highly dense neighborhood at great subsurface depth, as well as difficulties with the contracting structure.

Lessons Learned

The key determinants of the project's high-cost, long-delayed deployment appear to have been the project's location in a dense, historic commercial and residential corridor, which inherently led to complex and expensive deep tunneling and station construction plans; and the single contractor, lowest-bid design-bid-build approach for stations and systems work, which experts suggested left the project significantly exposed to additional delays and overruns. Combining systems work with a heavy construction contract, while reducing contract interfaces, resulted in owner/contractor conflicts, cost overruns, and delays. The mismatch between lowest-bid contracting and highly complex station work has led the TJPA to consider a shift to alternative procurement methods, with early contractor involvement and contractor selection weighted toward qualifications and experience, not on low bid, for the upcoming Downtown Rail Extension project. TJPA anticipates bringing its preliminary assessment of procurement methods to its board later this year

San Francisco's density and geography are relatively unique within California, suggesting that transit planners may not confront the same location-based challenges in future projects. However, future Muni extensions within San Francisco will confront such challenging geography, and if density increases in other major urban centers their downtown cores may approximate San Francisco's. Where possible, projects in these areas could engage "anchor" stakeholders as early as possible and utilize CMGC/CMAR or Progressive Design-Build project delivery methods, both of which are based on early contractor involvement to ensure the full cost of building in dense, complex areas is identified before construction begins.

3. LOS ANGELES PURPLE LINE

Project Overview

KEY THEMES: *Subsurface and geotechnical challenges can cause delays or expenditures beyond expectations and beyond project management's control; maintaining open communication among transit agencies, host cities, and contractor(s) is critical for success.*

Los Angeles County Metropolitan Transportation Authority's (Metro) ongoing Purple Line (D Line) Extension Project will connect the line's existing terminus at Wilshire/Western with LA's Westside through 9.1 miles (14.6 kilometers) of new heavy rail construction. The extension includes seven new stations at Wilshire/La Brea, Wilshire/Fairfax, Wilshire/La Cienega, Wilshire/Rodeo, Century City/Constellation, Westwood/UCLA, and Westwood/VA Hospital, the line's new endpoint.[99]

The Purple Line Extension Project consists of three separate sections, which will be constructed and completed at different times. Section 1 carries passengers 3.92 miles (6.31 kilometers) from Wilshire/Western to Wilshire La/Cienega. Section 2 covers 2.59 miles (4.17 kilometers) to Century City/Constellation. Section 3 will add 2.56 miles (4.12 kilometers) for the final stretch of the line from Century City to Westwood/VA Hospital. All three sections are under construction as of early 2021.[100] Section 1 is expected to open in 2024, followed by Section 2 in 2025. Section 3 is scheduled to open in 2027. Sections 1 and 2 are funded partially by the 2008 Measure R transportation sales tax measures, while Section 3 funding comes from the 2016 Measure M transportation sales tax measure.[101] All three project sections contain federal funding contributions. This case study focuses specifically on Section 1 as it will be the first to complete construction and open to the public. As of 2021, this section of the project is approximately 70 percent complete.

Table 5. Comparison of Purple Line Section I Cost and Timeline to Expectations Based on Averages of Similar Completed Projects

	TOTAL COST ($ MILLIONS)	YEARS OF CONSTRUCTION	COST PER KM ($MILLIONS/KM)	YEARS OF CONSTRUCTION PER KM (YR/KM)
Expected	CA - $1,393 U.S. - $4,757 Int'l. - $1,380	CA - 4.2 U.S. - 12.5 Int'l. - 14.2	CA - $221 U.S. - $754 Int'l. - $219	CA - 0.7 U.S. – 2.0 Int'l. - 2.3
Actual	$3,504	9.0	$555	1.43
Comparison to Baseline			CA – 250% U.S. – 70% Int'l. – 250%	CA – 210% U.S. – 70% Int'l. – 60%

The project team conducted expert interviews with Rick Clarke, Retired Chief Program Management Officer at Metro, as well as a panel of current Metro employees: Dave Sotero (Communications Director), Salvador Chavez (Deputy Executive Officer, Program Control), Jim Cohen (Executive Officer for Program Management), Sameh Ghaly (Executive Officer for Transit Project Delivery), and Julie Owen (Senior Executive Officer, Program Management Oversight).

Figure 3. Map of Los Angeles Purple Line Route.
Source: Metro.

LOS ANGELES PURPLE LINE

Location: City of Los Angeles and City of Beverly Hills, Los Angeles County

Lead project agency: Los Angeles County Metropolitan Transportation Authority

Rail/construction type and number of stations: Heavy rail, tunneling, 3 new stations

Length: 3.92 miles (6.31 kilometers)

Cost: $3.504 billion

Contracting structure: Design-Build

Timeline: Roughly 9.0 years from groundbreaking to anticipated RSD. Contract awarded in 2015, construction began in 2015, tunneling began in 2018, tunneling completed in 2021, construction expected to complete in 2023, revenue service expected to start in 2024.

Cost per km: $555.49 million per km

Time per km: 1.43 years per km

Background and History

Los Angeles leaders had envisioned a subway down Wilshire Boulevard, the most densely populated corridor west of the Mississippi River, since some of the original rail plans for the region dating back to at least the 1960s. Despite local leaders raising sales taxes and federal funds for such a route starting in the 1980s, the entire route was stopped after a 1985 methane gas explosion on nearby Fairfax Avenue, which galvanized opposition by local, state, and federal leaders. Though some concerns were motivated by fears of transit-induced gentrification in the local neighborhoods, opponents used the prospect of tunnel safety to halt the project by banning the use of federal funds on this route.

By the mid-2000s, the idea crystallized again in part to then-mayoral candidate Antonio Villaraigosa's "Subway to the Sea" slogan to relieve congestion along the Westside and connect areas currently underserved by transit with central employment and economic areas. In 2005, an independent American Public Transportation Association Peer Review Panel concluded that tunneling could be performed safely underneath the Wilshire Corridor using modern-day tunneling technology and appropriate mitigations. Federal leaders, primarily Rep. Henry Waxman, relented on the ban on tunneling in this corridor, allowing the project to proceed if local leaders could raise sufficient funds. In November 2008, Los Angeles County voters approved Measure R, implementing a half-cent sales tax per dollar to raise funds for transportation projects in the County, including partial funding for the proposed Purple Line, which would eventually connect riders to the city's Westside.[102] The tax increase took effect in 2009 and was slated to sunset in 2039. Notably, it built upon two prior sales tax measures passed by county voters in 1980 and 1990, respectively. Voters approved the Measure M sales tax in 2016. Measure M eliminated the sunset on the previous Measure R and provided the remaining local funding to complete the entire Purple Line.

The Purple Line Extension Project faced several design and route conflicts before construction began. Metro held public meetings in 2009 regarding the location of the proposed Crenshaw station, one of the points of conflict along the proposed line's route. Communities near the proposed Crenshaw stop strongly opposed adding a station, raising concerns about noise and traffic congestion. Opponents also questioned the need for the station given the area's residential nature, particularly in the upper-income Hancock Park neighborhood immediately to the north. Proponents noted that there would be a gap in the line's connectivity without any station between Western and La Brea.[103] Avoiding construction on major streets was a critical factor in finalizing the route at 2010 public meetings.[104] Ultimately, the Crenshaw station was not included in the final design.[105] In September 2010, the Draft EIR was released.[106]

In 2010, Metro announced that construction on the first segment of the Purple Line Extension would break ground in 2012, with an expected 2018 opening date to Fairfax.[107] However, construction did not start until 2015 and the line is expected to begin revenue service in late-2024.[108] The March 2021 Monthly Monitoring Report notes that "[t]he previous and current impacts will move the forecasted [revenue service date (RSD)] to late 2024, beyond [Metro]'s current target RSD of November 2023 and potentially surpassing the [Full Funding Grant Agreement] RSD of October 31, 2024."[109]

Metro is delivering the Purple Line Extension through a design-build contracting structure for Section 1 tunnels, stations, trackwork, and systems. The contractor has employed a joint venture structure with Skanska, Traylor, and Shea. The final design contract is through Parsons Transportation Group.[110]

Tunneling for the 3.92-mile (6.31-kilometer) segment began in October 2018 and concluded in spring 2021.[111] The project encountered several challenges while boring under the La Brea Tar Pits and surrounding areas famous for the sticky natural tar that bubbles up from the ground and the millions of Ice Age fossils unearthed in the area. These difficult geologic conditions—including encounters with methane gas deposits and abandoned, unmarked oil wells—delayed tunneling and required additional mitigations, increasing the project's costs.[112] By February 2021, the first Tunnel Boring Machine (TBM) reached the Wilshire/La Cienega station, and the second machine reached the station in March 2021.[113] TBM mining was completed in May 2021. The TBMs operated five days per week, working 20 hours each day. At that pace, the two machines excavated about 60 feet per day.[114]

Analysis

Compared to the estimated baseline cost and time for similarly designed projects detailed in Table 5, the project's $555.49 million/km cost is roughly 2.5 times greater than the expected cost for both California and international projects, but about 30 percent less than the expected cost of similar U.S. projects. The Purple Line Section 1's construction time (1.43 years per kilometer) is approximately 2.1 times greater than the expectation when compared to similar California projects, but construction time has been shorter than expectations when compared to similar U.S. and international projects (see Table 5 above).

Metro's February 2021 Monthly Report notes that "[t]o date, the project has experienced higher than expected differing site conditions, increase in third party and safety requirements, and changes in scope."[115] In August 2020, Metro increased the project's budget by $200 million after the project's contingency was depleted to less than the 3 percent minimum.[116] The total capital cost forecast is $3.29 billion after the $200 million increase.[117]

A review of the historical record and expert interviews identified the following primary drivers behind the Purple Line's deployment outcome:

Honest relationship with contractors and key project partners: Transparent and regular communication with core project partners—including contractors, city governments, and federal funders—reduced challenges that could lead to project delays. Metro cites its positive contractor relationship as a driving force behind the project's progress.[118] On a project of this scale, delays and change orders are inevitable. Dealing honestly and openly with the contractor furthers trust and reduces delays caused by friction in the contractor-agency relationship.

Open and timely communication between transit agencies and a project's host city (or cities) is essential for project success. Metro coordinated with the City of Los Angeles regularly throughout the planning and construction process. Monthly meetings between Metro and the Mayor's office allowed the project team to provide updates and ask for specific assistance from the City. For example, when road closures were required for station construction, the collaboration between Metro and the Mayor's Office allowed for fewer conflicts with residents and businesses and fewer overall project delays. Similarly, the Purple Line Extension Project team meets with the FTA regularly to share any updates or projections.[119]

In some cases, transit agencies may wish to enter into a Memorandum of Agreement (MOA) or Memorandum of Understanding (MOU) with partners to resolve potential areas of disagreement before they arise. These agreements clearly define each party's responsibilities before construction begins. An MOU or an MOA can reduce project time and cost by minimizing conflict, setting expectations early on, and reducing the risk of litigation. For example, Metro and the City of Beverly Hills entered an MOA regarding the construction of the Wilshire/La Cienega Station and associated tunnels and infrastructure. This particular station is the only portion of the Purple Line's Section 1 within the City of Beverly Hills. The MOA outlined obligations for each party, including when parties should share certain information or when there may be restrictions on construction per the City's policies.[120]

Tunneling through challenging terrain/differing site conditions: The two TBMs encountered several anomalies and challenging site conditions while excavating Section 1.[121] The type of impediment varied for each of the anomalies. For example, Metro suspected that an anomaly along San Vicente Boulevard was an old railroad trestle or similar structure. In March 2021, an anomaly intervention was conducted for the south tunnel approaching Wilshire/La Cienega station for one TBM.[122] Certain portions also encountered underground water, which required the project team to dewater two of the stations. When tunneling encountered hazardous, naturally occurring underground substances like gas, additional mitigation measures were necessary to ensure the safety of workers and the structural integrity of the tunnels.

Encountering anomalies during the tunnel boring process caused unanticipated delays and costly mitigations.[123] Certain types of anomalies, like steel structures, could damage the boring machines themselves and require special precautions. Encounters with significant anomalies could cause delays of over a year. Extensive pre-tunneling work was performed to remove the anomalies; however, the forecasted opening was partially delayed due to TBM encounters with anomalies.[124]

Although site analysis conducted in advance of tunneling included several investigations, reports, and preliminary borings, Metro believed it impossible to discover all underground obstacles before tunneling commences. The maps that informed tunneling operations were old and created without the benefit of modern technology, and therefore may not have represented all obstacles present in the ground.

When preparing for a project with such difficult terrain, agencies face a tension between spending more money and time on upfront investigation of tunneling conditions before the contract is awarded versus doing a less comprehensive investigation but beginning the tunneling contract sooner. To address this tension, Metro instituted a tiered investigation approach. Tier 1 involved a preliminary investigation. If no critical issues were uncovered, the project team would continue with a standard investigation. If issues did arise during Tier 1, the project team would advance the investigation to Tier 2, a more thorough analysis of specific conditions. Metro engaged a Tunneling Advisory Panel (TAP) to develop and execute the tiered investigation. The TAP consists of three professionals experienced in all aspects of tunneling. It was formed after a major tunnel construction collapse in the 1990s and has proven to be a valuable resource to address the technical complexity of tunneling.

Station cost and time efficiencies: The project's three new stations were constructed relatively efficiently because of advance decisions about their design and contracting structure. On the design side, stations were built modularly with an efficient design that allowed cost and time efficiencies, compared to other U.S. and international projects with highly designed stations that can cause delays or cost overruns. On the contracting side, Metro performed AUR before building all three stations. This smaller contract allowed for work within the station's footprint to relocate utility lines and infrastructure away from the pile line before the larger contractor entered the picture to complete construction.[125]

Third-party and safety requirements: Communication with state agencies like the California Division of Occupational Safety and Health (Cal/OSHA) was crucial when determining project risk and contingency plans. Challenges encountered in tunneling included elevated levels of methane gas. Cal/OSHA required that work stop in the tunnels to ensure worker safety and vent the gas. However, Cal/OSHA also required that the previous station evacuate work, and therefore Metro had to suspend work at the station frequently. Metro successfully communicated with state agencies overall, especially given the complexity of the tunneling and design. For example, Metro shared the design with permitting agencies well in advance so that agencies were aware of the project's details. However, not all agencies are involved in the design phase of the project. Transit project managers, contractors, and agencies should maintain constant communication to ensure that all parties understand requirements and plan accordingly.[126]

Local requirements also influenced the Purple Line Extension's construction. Tunneling is more expensive than a cut-and-cover construction approach but greatly minimizes disruption to the streets above. Given the density of Los Angeles's commercial and residential areas, especially along the Wilshire Boulevard corridor, this tunneling approach reduced substantial disruption to businesses and residents and avoided extensive utility relocation close to the surface. When constructing in dense cities, transit agencies may have little choice in their construction methods and may need to select higher cost and more time- and labor-intense approaches like tunneling.

Lessons Learned

Tunneling in a geologically complex area means that unknown challenges will occur; however, one interviewee noted that additional contingency could have been built into budget and timelines given the known challenges of boring in geologically unique areas.[127] A more conservative estimate of the potential risk could have increased the likelihood of staying on time and within budget. Contractors noted that techniques to locate anomalies should be deployed earlier in future project timelines to reduce the risk of substantial delays.[128] Agencies face a tradeoff between spending more time and money before tunneling to ensure the best available information informs the tunnel boring process and relying on a preliminary investigation to unearth any significant issues, leaving additional unknowns for the tunneling process. The former option requires more spending upfront with the hopes of reducing spending later. In contrast, the latter option would require more contingency built into the budget and schedule to manage issues that the machines encounter, but avoids additional upfront investigation costs.

Other transit agencies facing similar challenges could consider adopting the tiered investigation approach used for the Purple Line Extension. Similarly, transit agencies can learn from the project's use of a TAP and consider ways to incorporate expert advice throughout the decision-making process, primarily when a site is known to have highly complex geologic conditions.

Issuing smaller AUR contracts for stations helped create a more efficient workstream during station construction. The AUR's finite scope has two primary benefits. First, it minimizes additional, high-risk work for the design builder early on. Second, it offers a sense of what utilities exist underground that may not have appeared on the utility matrix, which could be incomplete or out of date. During the Purple Line Extension Project's AUR activities, the project team became aware of some utilities that had not been known previously, which helped the design builder work more safely and efficiently once construction was underway.[129] Other transit agencies could consider issuing AUR contracts for stations in advance of pile line construction.

Transit agencies should also take proactive measures in their relationships with contractors, cities, and communities. By communicating clearly and frequently with all partners and stakeholders, agencies can avoid or mitigate conflicts that cause public mistrust and construction-related penalties that could adversely affect the schedule. Several tools and strategies can improve communications and reduce potential conflict. For example, agencies can coordinate with city government to plan road closures, proactively inform the public about potential construction impacts well in advance, participate in regular meetings with local government officials, and consider an MOA or MOU to ensure that the parties' expectations are aligned and resolution processes are understood in advance of construction.

4. BAY AREA RAPID TRANSIT BERRYESSA EXTENSION

Project Overview

KEY THEMES: *Selecting a route that aligns with an existing railroad right of way can facilitate permitting and construction processes in some instances, but planners should weigh accessibility tradeoffs; unexpected events in the post-construction testing phase can add time and cost, and therefore testing should be built into contingency estimates; multi-agency oversight of different project elements can work well but requires dedicated coordination and communication.*

The Berryessa Extension project expanded BART's rail service south to Santa Clara County for the first time in BART's nearly 50-year history. The heavy rail project is primarily at-grade and carries riders 10 miles (16 kilometers) south from the Warm Springs/South Fremont station to North San José, with two new stations at Milpitas and Berryessa/North San José. The new stations are robust transit centers with connections to other area transit options, such as buses, employer shuttles, bicycle facilities, and light-rail connections.[130] Existing Union Pacific railroad tracks and rights of way were utilized along the route to expedite the permitting and construction processes.[131] The Berryessa Extension opened to the public on June 13, 2020, after approximately eight years of construction. By 2030, the new Berryessa station is expected to serve 25,000 daily passengers, and the new Milpitas station is expected to serve 20,000 daily passengers.[132]

Table 6. Comparison of Berryessa Extension Cost and Timeline to Expectations Based on Averages of Similar Completed Projects

	TOTAL COST ($ MILLIONS)	YEARS OF CONSTRUCTION	COST PER KM ($MILLIONS/KM)	YEARS OF CONSTRUCTION PER KM (YR/KM)
Expected	CA - $1,709 U.S. - $2,240 Int'l. - $1,409	CA - 12.7 U.S. - 7.7 Int'l. - 22.5	CA - $105 U.S. - $137 Int'l. - $86	CA - 0.8 U.S. - 0.5 Int'l. - 1.4
Actual	$2,330	8.3	$143	0.5
Comparison to Baseline			CA – 140% U.S. – 100% Int'l. – 170%	CA – 70% U.S. – 119% Int'l. – 40%

The project extended BART's Green and Orange Lines through the City of Fremont in Alameda County and the City of Milpitas in Santa Clara County, running roughly parallel to Interstate 680 and Interstate 880. The Berryessa Extension is part of BART's larger 16-mile Silicon Valley Extension. A second phase of the Silicon Valley Extension will extend BART six additional miles (approximately 9.7 kilometers) to downtown San José. This case study focuses only on Phase I, the Berryessa Extension.

The $2.3 billion Berryessa Extension was funded in part through Measure A ($107 million), the State of California Traffic Congestion Relief Program ($363 million), and the Federal Transit Administration's New Starts program ($900 million).[133] BART and Valley Transportation Authority (VTA) co-managed the project. VTA oversaw design and construction, and BART

Figure 4. Map of Bay Area Rapid Transit Berryessa Extension Route.

Source: VTA.

BAY AREA RAPID TRANSIT BERRYESSA EXTENSION

Location: Santa Clara County

Lead project agency: BART and VTA

Rail/construction type and number of stations: At-grade and grade-separated heavy rail; 2 new stations

Length: 10 miles (16 kilometers)

Cost: $2.33 billion

Contracting structure: Design-build

Timeline: 8+ years from groundbreaking to opening

Cost per km: $142.68 million per km

Time per km: 0.51 years per km

is responsible for ongoing operations and maintenance. VTA provides some funding to support BART's operation and maintenance activities. BART had experience managing projects of a similar scale using similar technology, while VTA only had light rail experience but could navigate the local landscape important to design and construction phases.

The CLEE team conducted expert interviews with former Mayor of San José Ron Gonzales and California State Senator Dave Cortese. Mr. Gonzales served as Mayor from 1999 to 2006 and previously served as a Santa Clara County Supervisor between 1989 and 1996. Senator Cortese previously served on the Santa Clara County Board of Supervisors, the San José City Council, and the Metropolitan Transportation Commission. Both Mr. Gonzales and Senator Cortese were foundational to the early phases of the larger Silicon Valley BART extension, including the Berryessa extension project. The CLEE team also received feedback from Stuart Cohen (Principal, Stuart Cohen Strategies).

Background and History

The Berryessa Extension marked BART's first entrance into Santa Clara County, but the expansion into Silicon Valley had been several decades in the making, originating in the late 1960s.[134] Initial studies began in 1984 to expand BART service south into Santa Clara County. Former mayor of San José Ron Gonzales revitalized the project when he joined the Santa Clara County Board of Supervisors in 1989, before he served as Mayor.[135]

Early advocacy was fundamental in steering the project towards its current route and service areas. Mayor Gonzales noted that the Board had a 20-year master plan for transportation, but plans for service expansions fell short in the communities most dependent on public transit. For example, he envisioned rail service benefitting the east side of San José, one such underserved transit-dependent area. However, others raised concerns regarding the project's potential to exacerbate environmental justice issues. For example, if high project costs reduced resources for existing transit services like bus routes, communities of color and lower-income residents would face the most significant burden from ensuing service reductions.[136] Early project observers also noted that the project was underfunded and cost overruns were likely. They further reported that cost estimates for the full extension into San José (as the project was not divided into two phases until later) failed to account for "operating costs, bond financing, assistance in covering BART maintenance shortfalls, [and] a potential buy-in fee to existing BART counties."[137]

At the outset of the Berryessa project, planners and communities decided between two routes, both along existing rights of way—one owned by Union Pacific and the other owned by Southern Pacific. At the time of the project's initial conception, Union Pacific and Southern Pacific railroads had not yet merged and therefore were operating different tracks with different rights of way (Southern Pacific would become part of Union Pacific in 1996).[138] The Southern Pacific route offered a more direct north-south pathway into the city but would require tunneling under historic neighborhoods like Japantown. Planners favored this route, but the decision of the preferred route had not received much public input. A second option was the Union Pacific route, which provided a less direct east-south route, but avoided some historic neighborhoods and provided better accessibility for underserved communities.[139]

As the route began to take shape, uncertainty remained about the appropriate mode of transit given local funding constraints. Funding was unavailable for a major BART extension, so advocates proposed light-rail instead. When California Governor Gray Davis announced support for extending BART, approximately $760 million in state funding became available, reviving discussions of a full BART extension and catalyzing the project's next development phase.[140] MTC narrowly approved the Union Pacific route and certified EIR for the right of way with a 6 to 5 vote in favor. If the council had not voted to select the route and certify the EIR, the project would have never gotten off the ground, demonstrating the importance of early political support.[141]

Scoping studies continued through 2000, at which time an analysis of alternatives began. In 2000, federal policy required local entities to provide 50 percent of project funds in return for receiving the other half of project funds from the federal government.[142] However, the county targeted an 80:20 local to federal cost share ratio to increase the likelihood of securing federal support for the project.[143] Santa Clara County voters passed Measure A in 2000, approving a half-cent sales tax over 30 years to raise funds for transit projects, including the proposed BART extension project.[144] Measure A passed with more than 70 percent of voters in favor of the proposed revenue increases.[145] Support was not limited to those directly served by the proposed BART extension; voters in areas not served by the project, like Gilroy and Palo Alto, approved the measure by some of the widest margins.[146] During these early stages of project planning, local officials underestimated total costs and overestimated the target project opening date. According to one advocate, politicians initially campaigned on a 2010 opening date for San José service.[147] Passengers will not have service to San José until the late 2020s.[148]

In November 2001, VTA's board of directors adopted a Major Investment Study for the project. By March 2004, the environmental clearance process was underway and the Final EIR was certified later that year, followed by certification of the Final Supplemental EIR in 2007. The project later faced challenges with securing federal funding. In 2008, Santa Clara voters narrowly passed Measure B, with approximately 67% voting in favor to add a one-eighth cent sales tax over the following three decades. The revenue would enable BART to operate the planned extension, contingent upon securing state and federal funds to match the local contribution.[149] As a result of financial limitations and lack of federal and local support for funding the whole project at once, the Silicon Valley extension was split into two distinct phases in February 2009: 10 miles (16 kilometers) from Warm Springs to Berryessa (Phase I, complete as of 2020), and a separate six miles (9.7 kilometers) from Berryessa to downtown San José (Phase II, not yet completed).

The Berryessa Extension used an uncommon co-management structure between two separate transit agencies, with VTA responsible for design and construction and BART responsible for ongoing operations and maintenance. The co-management arrangement between VTA and BART was a byproduct of Santa Clara County's decision to opt out of the BART District upon its creation in the 1960s.[150] By opting out, Santa Clara County residents did not have to pay taxes into the BART system but also did not receive BART service.

Construction began on the Berryessa Extension in April 2012 and was expected to be completed in 2018. The RSD was then postponed to 2019 when VTA petitioned the FTA for an extension.[151] System testing occurred between 2016 and 2020.[152] The project suffered significant delays during the testing phase, after construction was complete. Software malfunctions prevented train doors from aligning with the correct locations on the platform during tests.[153] Installation of non-compliant communications equipment, such as keypad entries and train signaling equipment, delayed the project further.[154] VTA's contractor took responsibility for the improper equipment installation and replaced the faulty parts. These errors delayed the opening date by approximately one year beyond the already adjusted 2019 target date, a total delay of two years beyond the originally scheduled RSD.

When the project was near completion, the agencies encountered discrepancies in the prioritization of remaining tasks on the punch list. Discussing the issues in more detail enabled the project team to delete several items from the punch list and expedite project completion.[155] An example punch list item was the mitigation of "excessive temperature in room C115," which was resolved by fixing the HVAC system in the room.[156]

According to the September 2020 Project Monitoring Report, "all safety critical items were cleared by the California Public Utilities Commission (CPUC) on June 3, 2020. ... All test documentation has been completed, verified, and turned over to BART as the operator and BART initiated service on June 13, 2020. The PMOC continues to maintain periodic contact with CPUC coordinating close out of punch list items...."[157] The December 2020 Monitoring Report noted that a "BART-generated [list of] discrepancies and contract punch list items were consolidated in [fall 2019]," and that "the last of all punch list items were closed out as of September 29, 2020," a few months after the June 2020 RSD.[158]

The December 2020 Project Monitoring Report also indicated that VTA had "expended more than their respective original estimates by the following amounts: $4.1 million in Sitework, $38.6 million in Systems, and $117.3 million in Professional Services" but forecasted "$44.7 million remaining in unallocated contingency remaining at the project's end."[159]

Analysis

As compared to the estimated baseline cost and time for similarly designed projects detailed in Table 6, the project's cost per kilometer of $142.68 million is approximately on par with or slightly greater than the expected cost for California, U.S., and international projects, and construction time of 0.51 years per kilometer is similar to or less than the expected time for California, U.S., and international projects (see Table 6 above).

A critical component of the project's relatively on-budget delivery is that nearly all of the track was constructed at-grade and within existing right of way. Constructing the track predominantly at-grade avoided the high costs and delays typically associated with both tunneled and elevated track construction. Selecting a route with existing right of way also minimized the time and resources required for permitting and land acquisition.

The success of the Berryessa Extension—and the broader Silicon Valley Extension—relied on a seamless connection with BART stations to the north. The Berryessa Extension connects with the rest of the BART system at Warm Springs/South Fremont Station, a linkage designed to provide a seamless, convenient trip for riders. However, construction of the extension from Fremont Station to Warm Springs/South Fremont coincided with the Berryessa Extension's construction, creating interdependence between the two extensions and their respective construction timelines. Delays in the Warm Springs/South Fremont Station's construction precipitated setbacks for the Berryessa Extension prior to the Warm Springs/South Fremont Station's revenue service opening on March 25, 2017.[160]

From the initial idea and preliminary studies to its opening day, the Berryessa extension spanned more than 30 years and overlapped the careers of dozens of public servants, advocates, engineers, and transit professionals. Interviewees cited several causes for the multidecadal timespan of the Berryessa project, which is only the first phase of the larger Silicon Valley extension—and the most difficult portions from an engineering and construction perspective are still to come in Phase II. First, the project evolved under several federal administration shifts, precipitating substantial swings in transit funding priorities. State and local priorities also influenced the speed of project development. For example, when Governor Davis announced state support and funding, focus intensified on the project and it progressed more quickly than in previous years. At the local level, changes in mayors, city council members, or VTA staff meant that the attention on the project fluctuated over time, depending on local priorities and attention on other projects. Second, support (or lack thereof) from the community was critical to the project's outcome. In some cases, portions of the community preferred one alternative, or local needs and opinions shifted over time, especially over an extended timeframe.[161] According to one interviewee, when project planners were deciding between the Southern Pacific and Union Pacific routes at the outset of the project, roughly a dozen neighborhood associations eventually backed the Union Pacific route, demonstrating significant community buy-in for the route and the project.[162]

On the technical side, once the project construction was well underway in the late 2010s, VTA contractors cited tie-in issues with the ongoing Warm Springs Extension as a risk for the Berryessa Extension in multiple quarterly risk summaries.[163] Warm Springs Extension testing delays also halted progress for Berryessa and were identified as a priority risk. Coordination between the two projects was made more complicated by the separation of lead agencies. BART oversaw Warm Springs Extension construction, while VTA led construction on the Berryessa Extension. The February 2016 PMOC remarked that "[VTA] and BART should be commended for their ability to facilitate restricted access … to the [Warm Springs Extension project] which have somewhat eased consumption of schedule buffer float."[164] Nevertheless, differentiation of responsibility between VTA and BART exacerbated several delays and resource shortages.

The Berryessa Extension experienced its own testing and equipment delays, leading to a revenue service date postponement of nearly a year, not accounting for delays precipitated by other factors. Installation of improper network and communication equipment caused schedule setbacks, delaying the project's opening initially to 2019, but the project missed this deadline due to pre-revenue testing delays.[165] According to the October 2018 progress report, VTA and BART "discovered the receipt and installation of non-conforming, used network equipment…said equipment is to be removed, replaced, and tested with certified components…[the finding of] used network equipment is now determined to have a significant impact on schedule, albeit not fully known."[166] Around the same time, communications testing progress slowed as software had to be reconfigured to account for operations requirements.[167] The used network equipment was expected to delay testing by at least several months.

In addition to opening date delays, the project experienced several substantial change orders throughout the construction process. The most prominent change order was for $65.4 million in August 2016, allocated to "Balancing and Settlement." Other substantial change orders included "Purchase and Use of Tamper & Stabilization Equipment," "MCI/Verizon Utility Relocation Work," and "Hazmat Materials & Soil Management." VTA's total expenditures on professional services exceeded the initially budgeted amount by approximately $117 million, and finance charges exceeded initial allocations by roughly $38 million.[168]

A review of the historical record and expert interviews identified the following primary drivers behind this relatively at-expectation deployment outcome:

Route selection and grade alignment: By weighing the pros and cons of various route options early on, project planners could proceed with a route that met community needs while utilizing preexisting right of way to minimize permitting burden. In some cases, selecting the existing right of way for the sake of cost savings or permitting convenience may come at the expense of accessibility for users and may not be advisable for every project; however, the Berryessa planners were selecting between two existing rights of way, rather than proposing a new right of way. Additionally, selecting an at-grade alignment expedited construction by avoiding the difficulties of tunneling or elevation.

Interdependence among ongoing construction efforts and multiple agencies: The Berryessa Extension experienced delays due to station completion and testing setbacks at the Warm Springs station. The Berryessa Extension connects with the Warm Springs station at its northern end, so certain construction tasks for the Berryessa Extension were contingent upon completing the Warm Springs station, which opened to the public in 2017. Appointing a central agency to coordinate interdependent projects may be a realistic option for other California transit projects in the future to ensure timely communication and limit the number of obstacles to project delivery.

To facilitate interagency collaboration, the Berryessa team's end-of-project analysis proposed that "BART Maintenance and Engineering (M&E) staff [should be allowed] to populate [VTA] offices and become engrained into day to day of test implementation so that they might exert a timelier influence into O&M discussions."[169] The September 2018 monthly report mentions that "BART M&E staff are now resident in the SVBX Project Office and at the [contractor's] facility and are meeting regularly with [VTA] regarding systems anomalies and gaps between operational requirements and the original systems specifications."[170] Integrating staff representatives in agencies' respective offices could bolster interagency communication and reduce obstacles by holding discussions in a timelier manner.

Political priorities and alliances: The Berryessa Extension spanned several presidential and California gubernatorial administrations, each with its own transportation funding priorities. The project was subject to significant shifts in federal and state funding agreements, sometimes to its benefit and sometimes to its detriment. For example, early support from Governor Davis enabled the project to access approximately $750 million in state funding, which proved crucial to maintaining its momentum in the early planning and design phases. Santa Clara County also leveraged public support to secure additional local revenues and increase their portion of the cost share so that the federal government was more likely to allocate funding to the project. The project offers an example of successfully maneuvering through political shifts and finding ways to gain support from key funding sources.

The project owed a portion of its success to strong political alliances within the Bay Area. Early political support ensured that the MTC approved initial actions crucial to the project's survival, like the approval of the Union Pacific route. As the project advanced, solid alliances between Santa Clara County and Alameda County officials kept the project afloat. Alameda County recognized the value in extending BART to the South Bay. Connecting the South Bay with the East Bay would create economic development opportunities for Alameda County, even though the Berryessa Extension did not have any stations in Alameda County. Political support for the project sometimes came at the expense of other regional priorities. The Warm Springs station nearly ran out of funding, which would have delayed the project further and threatened the BART extension's connectivity to the rest of the East Bay.[171] But MTC diverted funds from the other projects to the Warm Springs station, enabling connectivity between the existing BART line to the north and the new Berryessa segment.[172]

Technical challenges: The Berryessa Extension experienced delays and cost setbacks even after project construction was completed due to unforeseen difficulties during the testing phase and a contractor mistake that required the replacement of communications equipment. Specific challenges included rail activation; traction power testing; railroad intrusion detection system; short stopping and invalid excessive speed codes; a high voltage electrical fault; and non-conforming network equipment. While these challenges were unexpected, project managers could have built additional buffer into planning estimates to alleviate cost and time overruns. At the project's closeout, the Berryessa project team suggested that "[VTA]/BART should purchase system components directly rather than relying on contractors or sub-contractors. Also, [VTA] or specialty consultant should conduct receiving inspection for all components to certify authenticity and quality…."[173] Additionally, the Berryessa team noted that "systems design, procurement, and testing should be separate from other contracting and the direct responsibility of BART," as "BART is the most familiar with the various operating systems…and should be in direct charge of systems from design through testing. This approach minimized gaps in understanding and application of systems requirements."[174] Project managers could have engaged a neutral third party to settle disputes around the final punch list, as disagreements about specific non-testing-related punch list items threatened to precipitate budget overruns.

Lessons Learned

Selecting a project that maximizes existing right of way is a simple method of reducing cost and time burden. While it will not always be possible or desirable to utilize former railroad routes or similar existing infrastructure, transit planners and communities should consider options that allow for overlap whenever possible. This could reduce permitting time and reduce impacts to local communities and the environment because existing routes may have already been cleared through environmental review processes (in some but not all cases). Regardless of the selected route, agency leaders need to build trust with local communities and gain their support. Although not every community member or group will be a project proponent, understanding community concerns early on and ameliorating them before and through the design phase is essential for a project's success.

When co-managing a project among multiple transit agencies, project leaders could assign lead agencies for project design, construction, operations, and maintenance, in order to allow a clear delineation of responsibilities and to help facilitate communication and coordination. Any project that connects with another station or line under construction simultaneously should ensure regular communication between lead agencies (and their contractors) for each of the lines or stations in question. This communication is vital when progress on one project (such as completing the line or beginning testing) is contingent upon the completion of the other project. When the Warm Springs Extension experienced delays, the Berryessa Extension suffered setbacks because contractors could not proceed with certain tasks until the Warm Springs station was complete. While delays are inevitable, tying the fate of one transit project to another amplifies the need for contingency in the project budget and schedule. The Berryessa Extension experienced its own delays because of testing and equipment malfunction. Building additional contingency during the testing phase could be wise for future transit projects.

Major transit projects rely on state and federal funding, but administrations and funding priorities change when projects take several decades to design and complete. The federal government could enter multi-year contracts with funded projects to mitigate the impacts of shifting political administrations and reduce uncertainty. The ideal timeframe for a contract would span multiple presidential terms, so a minimum of five years up to nine or ten years.[175]

When a project is nearly complete but punch lists seem insurmountable, agencies may wish to engage a neutral party to serve as a decision maker. This neutral party can determine which tasks are worth additional time and resources, and which should be dropped from the punch list. By the time a neutral third party is advantageous, conflict may make it difficult for parties to reach agreement about the need for and selection of the neutral entity. Therefore, agencies should consider writing the selection of a neutral party into their initial contract agreements, before work commences. Agencies should consider issuing a request for proposal (RFP) early on to select the neutral entity, even if they are engaged much later in the process.[176]

5. CALIFORNIA HIGH-SPEED RAIL

This case study examines the ongoing development of high-speed rail along the corridor from San Francisco to Southern California through the San Joaquin Valley (Phase 1). High-speed rail does not directly compare to other transit projects, including the projects covered in the four other case studies, because of the substantial differences in technology, the lack of precedent for high-speed rail, and the massive scale of the high-speed rail project—much larger in terms of budget and geographic expanse than the other four projects considered in this report. Nevertheless, high-speed rail faces similar management and political issues, and therefore lessons learned from this project can inform future transit undertakings in California and beyond. California is developing the only high-speed rail project in North America, and one of the most ambitious intercity rail undertakings in U.S. history. Lessons learned from this 21st century project especially can inform future U.S. high-speed rail development.

The CLEE team conducted expert interviews with Jeff Morales, former CEO of the California High-Speed Rail Authority, and Brian Kelly, current CEO of the California High-Speed Rail Authority. The team also received input from Lou Thompson, chairman of the California High-Speed Rail Peer Review Group and Melissa Figueroa of the California High-Speed Rail Authority..

HIGH-SPEED RAIL COSTS

Average cost per km high-speed rail (Europe): $57.40 million per km[177]

Average cost per km high-speed rail (California): $82.47 million per km projected average across sections; $89.82 million per km estimated for total project upon completion

Entire system total cost: at least $71.5 billion[178]

Table 7. Comparison of High-Speed Rail Costs and Construction Time Per Kilometer[g]

	AVG. COST PER KM ($ MILLIONS)	AVG. YEARS OF CONSTRUCTION PER KM
ALL COUNTRIES (NOT INCLUDING U.S.)	$60	0.06
EUROPE	$57	0.07
CALIFORNIA—ENTIRE ROUTE	$82 (projected average cost across all sections); $90 (estimated for total project upon completion) Approximately 1.4 times as expensive as expected compared to all country baseline, and 1.5 times as expensive as expected compared to European baseline	N/A – only one portion of route has begun construction
CALIFORNIA—SEGMENT CURRENTLY UNDER CONSTRUCTION	$72 Approximately 1.2 times as expensive as expected compared to all country baseline, and 1.3 times as expensive as expected compared to European baseline	0.04 (estimate for completion of the initial 119-mile [192-km] portion by 2023). On track to complete construction approximately 30% more quickly than all country baseline and 40% more quickly than European baseline

Source: Marron Institute High-Speed Rail Cost Database, with analysis by authors.

g Comparison of California's progress on high-speed rail to completed international projects does not account for cost differentials or elements of the system that add costs, such as viaducts, tunnels, and other components.

Table 8. Length and Cost for Each California High-Speed Rail Segment[179]

SEGMENT	MILES	KILOMETERS	CAPITAL COST ($ MILLION)	COST PER KM (MILLION $/KM)
San Francisco to San José	43	69	$1,600	$23.19
San José to Carlucci Road	88	142	$13,600	$95.77
Madera to Merced	33	53	$2,300	$43.40
Madera to Poplar Avenue (Segment under construction)	119	192	$13,800	$71.88
Poplar Avenue to Bakersfield	19	31	$1,200	$38.71
Central Valley Wye Balance	28	45	$2,200	$48.89
Bakersfield to Palmdale	79	127	$15,700	$123.62
Palmdale to Burbank	41	66	$16,800	$254.55
Burbank to Los Angeles	13	21	$1,400	$66.67
Los Angeles to Anaheim	31	50	$2,900	$58.00

Background and History

In the early 1980s, initial proponents of California's high-speed rail project envisioned quick connections between major population centers, drawing inspiration from existing high-speed trains in Japan and across Europe. By 1982, Amtrak and a Japanese development partner announced their intent to construct a high-speed rail line between Los Angeles and San Diego.[180] The project was canceled in 1985 after failing to raise the necessary private funding and facing opposition from local communities along the proposed route.[181] Although the Los Angeles to San Diego route was discarded, interest in California high-speed rail kept growing, especially as populations expanded and highway demand increased. By 1989, following project announcements in Florida and elsewhere, California and Nevada legislators proposed high-speed rail connecting southwest population centers.[182] The California-Nevada Super Speed Train Commission—an entity created by state legislatures in 1988 to oversee cross-state rail development—reviewed a report recommending Anaheim as the end-point of the rail line from Las Vegas to California.[183]

At that time, construction on the Nevada-California segment was expected to conclude in 1998, but the larger goal of a complete regional high-speed network was expected to take up to 50 years.[184]

Throughout the late 1980s and early 1990s, plans proceeded slowly but gained support and attention. Early visions centered on privately-funded projects, but as envisioned projects like the Nevada-California rail line fell through due to insufficient funds, more project proponents advocated for government subsidization.[185] In October 1992, as part of the federal Intermodal Surface Transportation Efficiency Act, the Department of Transportation authorized several California corridors for high-speed rail development, leading to the approximate route under evaluation today—between San Diego and Los Angeles, and Los Angeles to Sacramento and the Bay Area.[186] State senator Quentin Kopp spearheaded a 1993 bill requiring a long-term high-speed rail plan for California and specifying that construction on the network should begin by the year 2000 to serve Californians by the year 2020 (Senate Concurrent Resolution 6).[187] Senate Concurrent Resolution 6 also specified that the Los Angeles to San Francisco corridor should be developed first, although the specific route was still under evaluation.[188] A 1995 report compared three route options: the Route 99 corridor, which served the Central Valley while connecting Los Angeles and the Bay Area; the Interstate 5 corridor, which provided the fastest travel time between Los Angeles and the Bay Area; and a coastal route, which required slower speeds.[189]

The legislature created the California High-Speed Rail Authority (CHSRA) in 1996 to oversee the project's development, outreach, and funding. Throughout the mid-to late-1990s, California's Intercity High-Speed Rail Commission (a separate entity from CHSRA) reviewed plans for routes, competing technologies, construction timelines, and budgets. The project was never free from conflict. With its multibillion-dollar cost estimates and uncertain route, the project drew criticism from those who felt that high-speed rail was an inappropriate use of public funds, while others supported the concept but wanted to see certain regions served first or wanted stations placed in certain cities. The project would need to secure support from the public before it could gain funding and move forward with planning. Voters were supposed to decide on a bond measure allocating funding for high-speed rail in the November 2000 election, but the measure was delayed and modified multiple times. A $9.95 billion bond measure was scheduled to appear on the November 2004 ballot, but was again delayed to 2006 and then 2008.[190] Cost estimates for the project had fluctuated over the years, and by 2004 the system was expected to cost $37 billion.[191] By 2007, CHSRA reported that $30 million had been spent on route planning and environmental reviews since 1996.[192] The ballot packet voters received for the 2008 election reported that the Authority had spent $60 million on pre-construction activities between 1996 and 2008.[193]

In 2008, after much uncertainty, California voters approved Proposition 1A, authorizing funding for the project. Assembly Bill 3034, which put Proposition 1A on the 2008 ballot, stipulated several conditions for high-speed rail development, including a requirement that passengers can travel between Los Angeles and San Francisco in two hours and 40 minutes or less, as well as a requirement that the service does not receive an operating subsidy.[194] To achieve the required travel times between each station, trains would need to reach or exceed 220 miles per hour (354 kilometers per hour), which was technologically challenging. California's flat Central Valley was the most likely area to achieve such speeds.[195] Proposition 1A was never intended to provide full funding for the project. Ultimately, the state received $3.5 billion in federal grant funding through the American Recovery and Reinvestment Act of 2009 (ARRA) and a Congressional appropriation in fiscal year 2010 (FY10).

Federal officials required that construction begin in the San Joaquin Valley (in part to help address regional unemployment issues) as a condition of receiving funds. However, the initial Valley section would not connect major coastal population centers. As funding for the remainder of the project became uncertain, critics and representatives of these unserved areas expressed concern that the initial construction phase would become a "bridge to nowhere."[196] Proposition 1A's prohibition on any local, state, or federal operating subsidy would also make it difficult for the system to support itself via an initial operating segment in the Valley, before it could gain sufficient passengers by reaching major population centers. Project opponents also called into question CHSRA's estimates of ridership, costs, and travel time.

Even with the bond measure passed, high-speed rail's fate was still uncertain. A 2010 report by the California State Auditor cited problems with the system's planning, funding, and administration. The report concluded that CHSRA "has not adequately planned for the future development of the program" and that "the program risks significant delays without more well-developed plans for obtaining funds," among other significant flaws threatening the Authority's ability to operate and complete the project as planned.[197] Nevertheless, the Authority maintained that the present-value benefits of the project, estimated at greater than $150 billion in 2008, would far outweigh capital and operational costs over a 4-decade period, justifying the project and its high upfront costs.[198]

Positions of project opponents and proponents have remained relatively unchanged throughout the project's history. Project proponents highlight high-speed rail's potential to increase connectivity and mobility for Californians, reducing dependence on other modes of transportation like driving or short-haul flights, which generate substantial air pollution and greenhouse gas emissions. Proponents also see an opportunity for job growth in underserved regions of the state. On the other side, opponents raise concerns about the project's high costs and cost growth over time, and question whether it should be the role of the government to build such a project. Opponents also cite negative impacts to communities, such as through land acquisitions, and are skeptical that the project will deliver on its promises of economic growth and improved connectivity.[199]

At the beginning of the 2010s, construction had not yet begun. Mehdi Morshed, the longtime executive director of CHSRA, cited political disagreements between elected officials as the primary factor causing construction delays at the time.[200] In 2015, construction began on the system at a location in Fresno.[201] As of early 2021, 119 miles (192 kilometers) in the Central Valley were under construction, and the Central Valley segment was environmentally cleared (See Table 9 and Figures 5 and 6 below for more detail on each segment). Three

Design-Build contracts were awarded for the 119-mile (192-kilometer) stretch of construction between Fresno and Bakersfield (contracts were awarded in August 2013, June 2015, and February 2016). The three design build contractors were Tutor-Perini/Zachry/Parsons, a Joint Venture; Dragados/Flatiron, a Joint Venture; and California Rail Builders, a Joint Venture of Ferrovial-Agroman West, LLC and Griffith Company.[202]

Phase 1 will ultimately connect Los Angeles and Anaheim via San José, Gilroy, Merced, Madera, Fresno, Kings/Tulare, Bakersfield, Palmdale, Burbank, and Los Angeles. Phase 2 is envisioned to stretch north from Merced to Sacramento, and extend south and east from LA to reach San Bernardino and Riverside, terminating in San Diego. High-speed rail will also allow other rail systems to electrify and connect with the system. For example, Caltrain is electrifying 51 miles (82 kilometers) of existing rail between San Francisco and San José, which will share tracks with the high-speed rail system. High-speed rail will also share tracks with Metrolink in the Los Angeles area.[203] Future stations in San Francisco, San José, and Los Angeles have already received significant funding.

Proposition 1A specified that no bond funding could be used for construction until project leaders secured a match from a local, private, or federal source.[204] As noted above, California's high-speed rail project eventually received approximately $3.5 billion in federal funding commitment. The money would support completing the environmental review for Phase 1 of the system and constructing the 119-mile (192-kilometer) Central Valley segment. Of this amount, $2.5 billion came from ARRA, while Congress appropriated another $929 million from FY10 Transportation, Housing and Urban Development funds.[205] California could be required to pay back the federal government for grant funding received if it does not meet the agreed-upon construction deadline.[206]

Access to federal funding has fluctuated over the course of the project due to shifts in presidential administration priorities, and the project's timeline and budget have suffered due to this funding uncertainty.[207] The Obama administration first awarded ARRA funding to CHSRA in FY10. In 2019, The Department of Transportation under the Trump administration rescinded the existing agreement between the federal government and CHSRA, de-obligating the $929 million awarded in 2011 and describing options for California to pay back its ARRA funding.[208] The Federal Railroad Administration's letter to CHSRA detailed the Authority's violations of the agreement, including management failures and missed deadlines, and described unsatisfactory progress on the project.[209] The State of California and CHSRA then sued the U.S. Department of Transportation, "alleg[ing] that the FRA's May 2019 termination of the Fiscal Year 2010 Cooperative Agreement (the FY10 Agreement) violated the Administrative Procedure Act, 5 U.S.C. § 706, because it was arbitrary, capricious, an abuse of discretion, or otherwise not in accordance with law."[210] The parties settled, and the Biden Administration reinstated $929 million in federal funding. Uncertainty from administration to administration may also contribute to a lack of private investment support, an inability for agencies and communities to plan for the long term, and increased concern about stranded assets if the project cannot be completed.

Table 9. High-Speed Rail Phase 1 Funding and Completion Status by Segment as of 2020[211]

	SEGMENT	LENGTH	EIR/EIS COMPLETION[212]	CAPITAL COST[213]
NORTHERN CALIFORNIA	San Francisco to San José	43 miles 69 kilometers	Q2 2022	$1.6 billion
	San José to Carlucci Road (Merced)	88 miles 142 kilometers	Q1 2022	$13.6 billion
CENTRAL VALLEY	Merced to Madera	33 miles 53 kilometers	Complete	$2.3 billion
	Madera to Poplar Ave. (Fresno)	119 miles 192 kilometers	Complete	$13.8 billion
	Poplar Ave. (Fresno) to Bakersfield	19 miles 31 kilometers	Complete	$1.2 billion
	Central Valley Wye Balance	28 miles 45 kilometers	Complete	$2.2 billion
SOUTHERN CALIFORNIA	Bakersfield to Palmdale	79 miles 127 kilometers	Q2 2021	$15.7 billion
	Palmdale to Burbank	41 miles 66 kilometers	Q4 2022	$16.8 billion
	Burbank to Los Angeles	13 miles 21 kilometers	Q4 2021	$1.4 billion
	Los Angeles to Anaheim	31 miles 50 kilometers	Q4 2022-Q2 2023	$2.9 billion

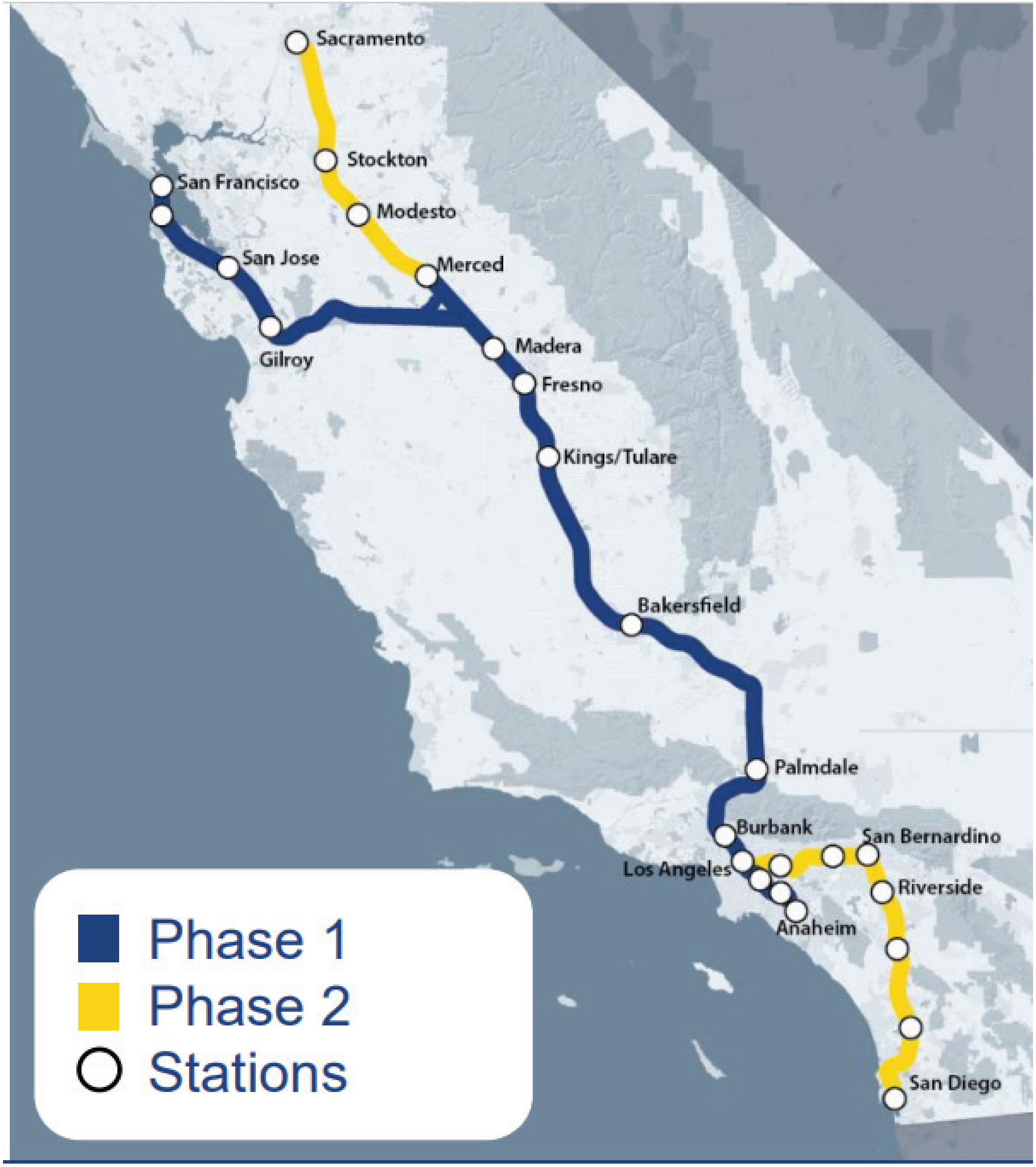

Figure 5. Map of Phase 1 and Phase 2 Segments and Stations.

Source: Boris Lipkin, California High-Speed Rail Authority, "California High-Speed Rail: Northern California Region" (Presentation, December 2020), available at https://www.codot.gov/about/southwest-chief-commission-front-range-passenger-rail/meetings/december-4h-2020/20201204-front-range-passenger-rail-commission-vf.pdf.

Figure 6. Map of Segments under Environmental Review or Development as of August 2021.

Source: Map provided by California High-Speed Rail Authority, September 2021.

By 2020, the 171-mile (275-kilometer) stretch between Merced and Bakersfield was ready for construction.[214] The remainder of the planned Phase 1 route was either under environmental review or approved for future development. Sections under environmental review include San José to Merced/Madera via Gilroy; Bakersfield to Palmdale; Palmdale to Burbank; Burbank to Los Angeles; and Los Angeles to Anaheim. By 2023, all sections should have environmental clearance, but even then, funding may not be available to begin construction right away.[215] In Southern California, the line will connect with the proposed privately-owned Brightline West high-speed rail project, eventually carrying passengers across the California-Nevada border to Las Vegas. The Brightline West segment is not included in the scope of this case study.

Analysis

High-speed rail has struggled with funding stability since its inception. Proposition 1A authors never intended to give the project full funding; instead, the measure was supposed to jumpstart funding, while the Authority planned to pull from other sources as available. For example, CHSRA's 2008 business plan targeted funding from federal, state, local, and private sources.[216] Private sector operating support may become available once the project is completed, but to date the entire pre-operational phase of the project—including design, environmental review, and construction—has been publicly funded. Private sector interest is likely contingent upon the state shouldering more demand risk and stabilizing emissions permit funds.[217]

Segmenting the 500-mile (800-kilometer) Phase I high-speed rail corridor—from San Francisco to Anaheim—into roughly ten sections created opportunities and challenges for environmental review, pre-construction, and project delivery. The 2012 Business Plan described broad support for a phased implementation approach and noted two benefits to project funding and finance from this approach. First, the costs of phased implementation were substantially lower per section than construction of the whole system at once.[218] Second, successful construction and operation on early sections would allow subsequent sections to benefit from lessons learned and proof of concept, thereby reducing risk for investors and communities.[219] Segmentation and phased implementation also enabled environmental review and design specifications to be tailored to a local level, taking into account specific needs of cities or metropolitan regions and accounting for NEPA impacts (including socioeconomic, cultural, and environmental) at a more precise level of granularity. Segmentation also allowed multiple review and engagement processes to proceed concurrently, mitigating schedule delays. If the entire review had been conducted at a full-project scale, it likely would have taken much longer to complete.

In terms of challenges, splitting the project into segments meant that some segments were cleared for development sooner than others, as was the case with the segment under construction in the Central Valley at the time of this report's publication, while other segments were still undergoing review. When the Authority completes the initial sections, these operational portions might benefit local commuters and residents traveling within the Central Valley, but the full network-wide benefit of the high-speed rail system will not be realized until more connections to major metropolitan areas are available across a wider geography. In the meantime, CHSRA will also be responsible for the upkeep of the completed track sections even if no trains are running, and it could be years before soon-to-be-completed sections are operating.

Unlike most other local transit projects, the high-speed rail project emerged from a statewide ballot initiative, not an initial proposal from a transit agency. This setup allowed less flexibility as conditions changed. Proposition 1A arrived on the ballot through legislative enactment, and the legislature reviewed, discussed, and approved the bond measure, offering a clear vision for constructing a high-speed, electric train between Northern and Southern California using technology already proven internationally.[220] However, the bond measure itself was not passed as legislation—voters decided based on the legislature's referral—leaving the legislature unable to modify the specifications in the measure once approved.[221] Because the project's approval came through Proposition 1A rather than a traditional review by federal agencies and the state legislature, high-speed rail did not receive typical assessments afforded to other projects and did not benefit from legislative oversight in the same way that other projects do.[222] Ultimately, Proposition 1A and Assembly Bill 3034 led to several of high-speed rail's core challenges because the plans themselves—enacted via relatively inflexible means—were not rooted in an agency's institutional knowledge or imperative to serve the local area. Specifications that voters approved in 2008 without the benefit of environmental review or agency design became defining characteristics of the project.

In some cases, specifications helped to ensure that funding would not be diverted to other transit projects and would be used for electric high-speed rail only.[223] In practice, some of these specifications led to challenges. Most prominently, Proposition 1A specified that high-speed rail must be designed to connect San Francisco and Los Angeles in less than two hours and forty minutes.[224] According to some experts, three hours would be a more reasonable time estimate.[225] While the technology was available to achieve this connection, cost estimates to achieve it varied considerably over time, and the requirement may have guided decision-making when other factors (such as maximizing ridership or minimizing need to acquire right-of-way) could have better served efficient and beneficial deployment. Some experts also noted that the two-hour and forty-minute requirement would assume a non-stop train and that a more reasonable interpretation of this provision is that the system must instead be designed to this standard but not necessarily operate at it.[226] Ultimately, the actual operating time between San Francisco and Los Angeles is expected to be closer to three hours.[227] As a result, a key legal challenge to the program claimed that the Authority needed to demonstrate that the two hour-forty-minute requirement was being met, even in the early stages of the program.

Proposition 1A also included a provision that high-speed rail cannot receive an operating subsidy (i.e., funding towards the operation of the rail service; only funding towards construction is allowed). The "no operational subsidy" provision may make it difficult for high-speed rail to function under the phased implementation structure, where certain parts of the line are completed first, beginning with those in the Central Valley. Until trains can carry passengers along the entire stretch of the proposed route, gaining revenue to cover operating expenses will be difficult. Additionally, Californians will not adopt high-speed rail for personal and commercial transit needs overnight; use of the system will likely gain momentum over time, adding to near-term operational revenue woes until a critical mass of riders can benefit from the system, given that a substantial proportion of these riders will want to travel between Los Angeles and the Bay Area.

Staffing is another challenge for the high-speed rail project. Such a massive project required hundreds of consultants, tasked with completing everything from NEPA and CEQA review to physical construction; however, consultants cannot complete some tasks, and consultants need management guidance to ensure alignment with the project's overarching details and goals. According to recent leadership, CHSRA was chronically understaffed at the beginning of the project, making it challenging to keep up with the workload associated with such a massive project. Authority leaders now believe that staff capacity is much improved. Adding to the challenge, few people in California (or even the U.S.) have managed a transit project at this scale and using this technology. Consultants, some of whom have completed comparable projects overseas, have in some cases made decisions on behalf of the state when lacking guidance from the agencies overseeing the project. The current state staff-to-consultant ratio is around 55 percent state staff to 45 percent consultants, which is lower than in past phases when consultants outnumbered state staff.[228] Future projects should establish a clear line delineating decisions made by agency authorities and the consultants executing those decisions. [229]

Federal requirements also created complications. The law required that CHSRA spend the federal funding by the end of September 2017. The Authority met this requirement because they were able to spend these funds before spending state dollars.[230] However, federal funding requirements caused the project to enter construction before it was ready to do so, as well as obligating the project to start construction in the San Joaquin Valley.[231] Agency leaders established design-build contracts and selected contractors before the state had acquired any right of way, which is in itself a complicated, multi-year process. No right of way can be purchased until the environmental clearance process is complete—another complicated, multi-year process. This delay meant that contractors were hired but unable to commence work until agency leaders completed environmental review and acquired right of way.[232] The scope of property acquisitions also challenged the project team's capacity. For example, the 119-mile (192-kilometer) stretch of track currently under construction required the acquisition of 2,300 parcels, far exceeding the 500 parcels acquired statewide by Caltrans in a typical year.[233] The State Auditor's 2018 report cited the early construction start in the Central Valley as a critical factor in cost overruns of $600 million at the time of the report, while contributing to another $1.6 billion in costs to complete the Central Valley projects.[234]

Lessons Learned

Establishing more realistic and flexible expectations at a project's outset can help improve the accuracy of budget and schedule estimates. Project managers should build in flexibility and review checkpoints so that plans can adjust to changing conditions. Along these lines, California High-Speed Rail Authority leaders began instituting a new "Stage Gate" management approach, which they hope will improve "rigor, oversight, accountability, and transparency to project development and delivery."[235] "Stages" refer to project development phases, while "gates" align with "major milestones at which a formal decision is made on a project's readiness to advance to the next stage and inform financial affordability."[236] Before projects can advance to the next stage, they must meet certain requirements. Authority leaders noted that they "developed [their] Stage Gate process, in part, in response to the lessons learned from advancing Central Valley construction before appropriate pre-construction activities were completed."[237] Future projects could implement a stage gate approach from the project's outset, building on the Authority's lessons learned from the Central Valley construction challenges. (SPUR has also recommended the use of stage gate processes for Bay Area transit agencies.)[238]

California's high-speed rail project was constrained by stringent requirements from the ballot measure that initiated state funding (Proposition 1A). The project also had to adhere to federal funding requirements. Because funding was linked to a voter-approved measure, the project needed to meet certain expectations, even when those expectations made it difficult to meet budget and timeline expectations. Future project proponents should consider in advance how rigid design specifications can lead to cost and time tradeoffs. Proponents of other large rail projects that may be funded through a similar voter-approved measure could consider allowing subsequent review phases and technical input to modify those plans so that project implementers have room to adjust the budget and schedule estimates as conditions change. This process is especially crucial for mega-projects that develop over many years, as planning conditions and technology inevitably change during these extended construction periods. Future large-scale projects could also include legislative and federal review processes that can modify project requirements after voter approval. While Proposition 1A and AB 3034 did unfold from legislative processes, once voters approved the measure, the legislature could not modify the requirements based on changed conditions, constraining the project to an early phase of development.[239]

At the time the legislature approved the bond bill, project proponents estimated the total cost to be much lower than current projections, demonstrating the difficulty of accurately estimating a project's total cost prior to environmental review and more detailed planning. In response, CHSRA has since begun to estimate costs within a range, rather than attempting to identify a specific dollar value.[240] Future projects relying on similar bond measures for funding could make several adjustments based on California's experience. First, future bond measures could be introduced for voter approval later in a project's design process, in order to provide more accurate accounting. Second, future bond amounts could be greater (if politically feasible) to match project needs more realistically, especially if introduced later in the project timeline, as planners would have a more complete understanding of the total amount of funding required and how much of the total budget a bond measure could cover.

To remain eligible for federal funding, the California high-speed rail project was forced to begin construction before right of way acquisition had been completed. Future projects may face similar constraints, and agency leaders may have difficulty adapting to changing federal requirements at a project level. Federal leaders could ensure that future funding for regional and state-scale mega-projects allows for more flexibility on timing and location. Project leaders could also work to secure a more diverse array of funding sources to help prevent dependency on any single source. The California high-speed rail project faced funding uncertainty largely out of its control. However, future project proponents could consider ways to secure funding as far in advance as possible and leave sufficient time and budget for pre-construction activities like environmental review processes or right-of-way acquisition. In addition, the federal government could increase its commitment to passenger rail, on par with funding allocated to the highway system.

Transit agencies or local governments planning similar large-scale projects could consider bolstering and securing adequate staff capacity during different project phases, from permitting to operations. Agencies could plan well in advance to increase staff capacity during heavy review phases and build institutional knowledge into the team. Because few people in the United States hold high-speed rail expertise, agency leaders will need to work hard to recruit those who understand how to manage a rail project as complex as this one in terms of budget, geographic scale, technology, and timeline. Therefore, agencies could consider methods of retaining the expertise accumulated during the California high-speed rail project and applying lessons learned to future U.S. high-speed rail undertakings. This staff retention may help reduce cost and schedule overruns in future projects.


Hollywood / Highland

V. CONCLUSION

California's mobility, climate, and equity goals all depend to varying degrees on the state's ability to build rail transit projects quickly and cost-effectively. To date, the state has not been able to exceed expectations and still lags other advanced economies around the world in terms of project delivery.

At the same time, cost-effective and timely rail transit project delivery is a national problem, primarily due to the decentralized nature of the country's governance structure which provides multiple veto points over projects of regional significance. Multiple small cities or powerful stakeholders often have leverage to exact changes to project design and implementation, with often devastating consequences for project delivery. In addition, many U.S. transit agencies lack the dedicated in-house expertise to manage these projects effectively. As a result, reforms at the federal level may be needed to address this issue more comprehensively.

Yet while many of these underlying factors are largely beyond the control of state and local transit leaders, this report outlines lessons learned that can benefit future projects operating in this national context. State and local leaders can take steps under their control to improve project delivery through procurement and contracting, project selection and design, coordination and outreach, and other strategies.

Ultimately, as transit agencies begin delivering these projects more quickly and efficiently, they will help ensure that transit dollars deliver more benefits to the public through more projects. They will also bolster the case for the state and local jurisdictions to dedicate more resources to climate-friendly projects. Only through a reinvigorated push for more transit and associated infrastructure can state and local leaders begin to meet the mobility and access needs of all Californians.


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APPENDIX A: DATABASE SAMPLE SIZES

Table 10. Sample Sizes of Database Categories (Mode, Geography, Percent Tunneled)

	LIGHT RAIL			HEAVY RAIL		
Percent Tunneled	Europe, Australia, Canada	U.S.	California	Europe, Australia, Canada	U.S.	California
0% - <10%	38	44	10	3	4	1
10% - <20%	4	3	0	0	1	1
20% - <30%	1	1	1	1	0	0
30% - <40%	1	0	0	1	0	0
40% - <50%	0	1	0	3	0	0
50% - <60%	0	0	0	1	0	0
60% - <70%	2	0	0	3	2	1
70% - <80%	1	0	0	4	0	0
80% - <90%	1	0	0	1	0	0
90% - 100%	4	1	0	44	6	2
Total	52	50	11	61	13	5

APPENDIX B: TUNNELING COSTS

The graphs in this appendix depict the relationship between a project's amount of tunneling and its cost per kilometer (in millions of dollars). These graphs are not the product of a formal regression analysis—limitations in the underlying data made it difficult to ensure the quality of such an analysis. However, they offer some visual trends that can help inform readers' understanding of the relationship between tunneling and cost.

The first two figures are scatterplots showing this relationship for heavy rail and light rail. The heavy rail graph shows a very slightly positive trendline (R-squared value = 0.041). It should be noted that many projects are clustered around zero or 100 percent tunneling, and the two data points above $1,500/km represent New York City's 7 Subway Extension and Second Avenue Subway (Phase I). The light rail graph also shows clustering around zero and 100 percent tunneling, and shows a more positive correlation between tunneling and cost (R-squared value = 0.412).

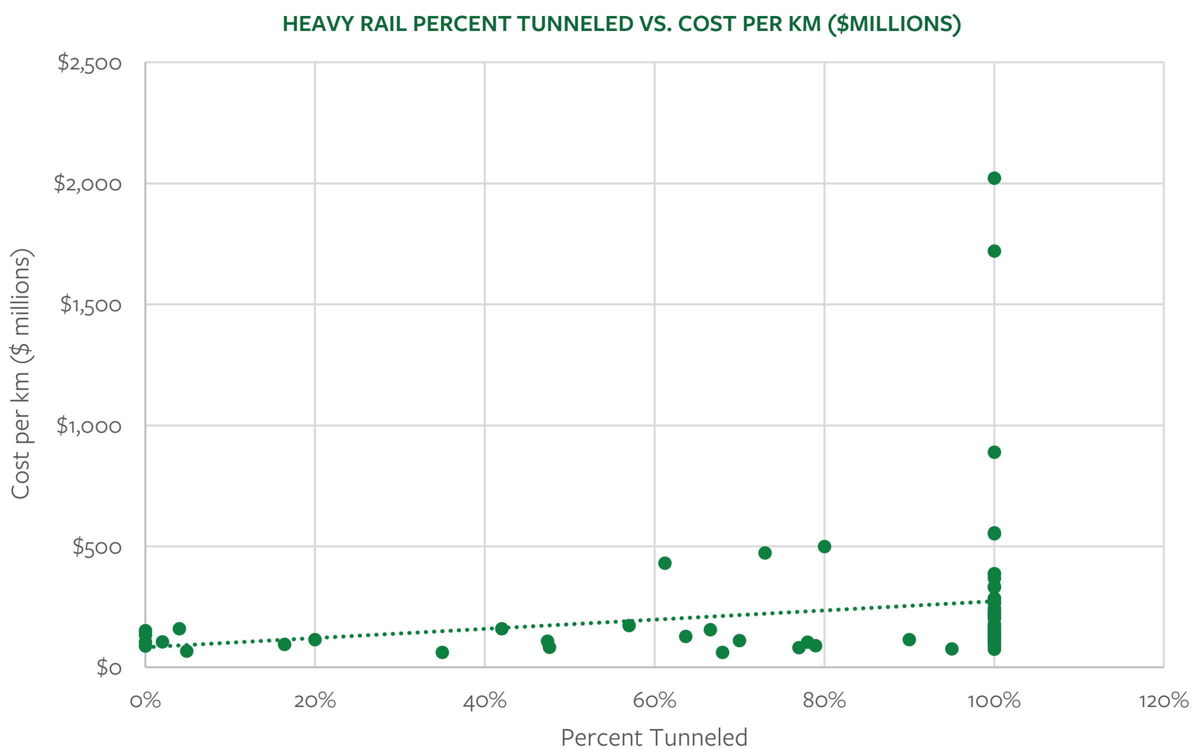

Figure 7. Heavy Rail Percent Tunneled vs. Cost per Kilometer ($ Millions), U.S. and International Subgroup

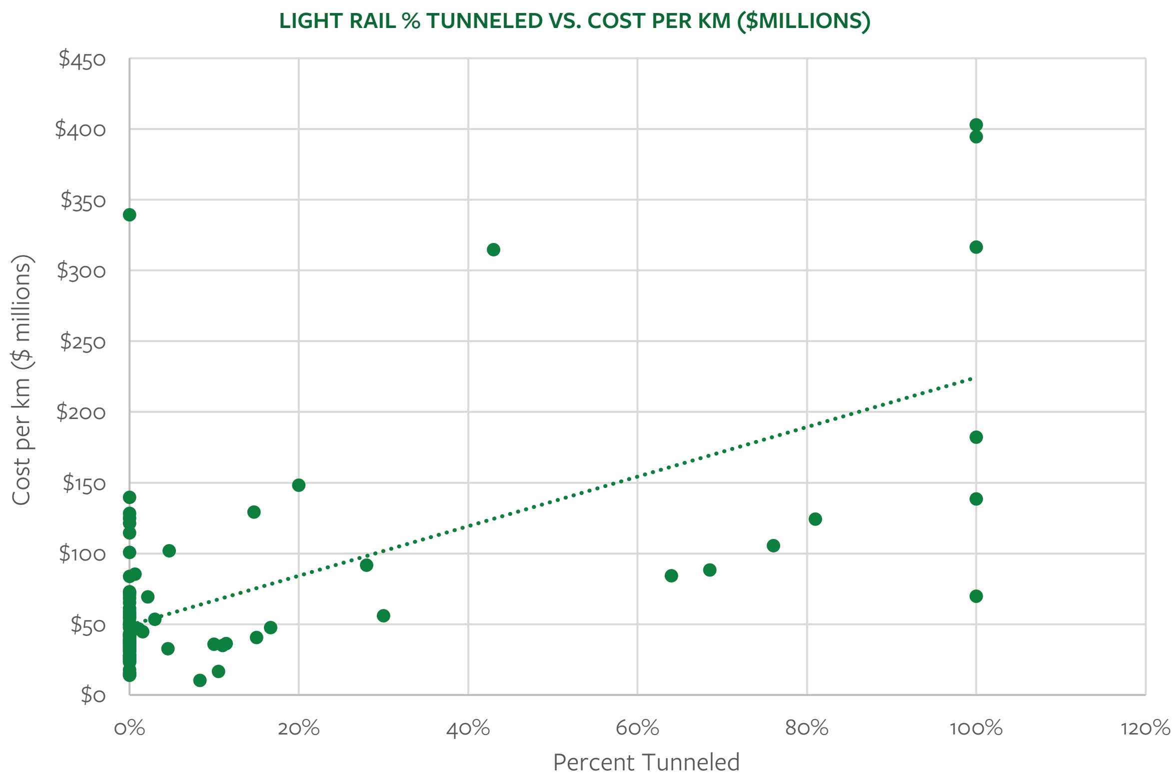

Figure 8. Light Rail Percentage Tunneled vs. Cost per Kilometer ($ Millions), U.S. and International Subgroup

The next two graphs are box and whisker plots depicting the spread of cost data for projects with different amounts of tunneling (grouped into bins from zero to 100 percent tunneled). These graphs show the minimum, median, and maximum data points in each bin, as well as the lower and upper quartiles associated with each set.

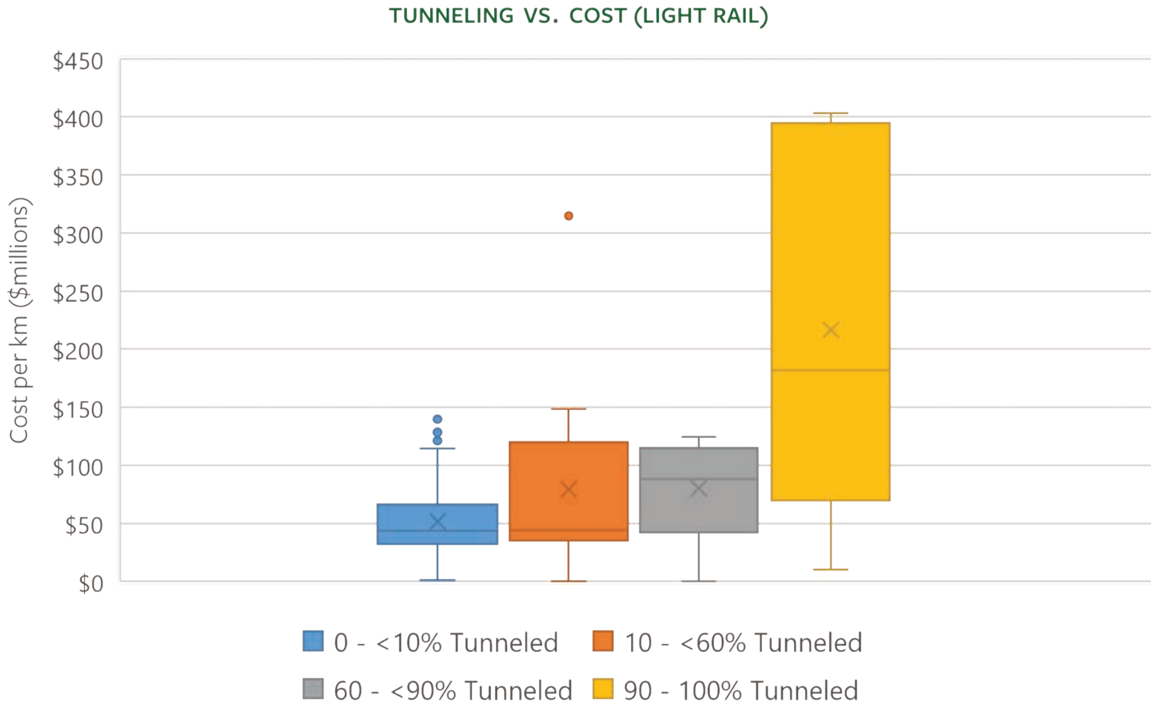

Figure 9. Tunneling Percentage vs. Cost per Kilometer ($ Millions), U.S. and International Subgroup

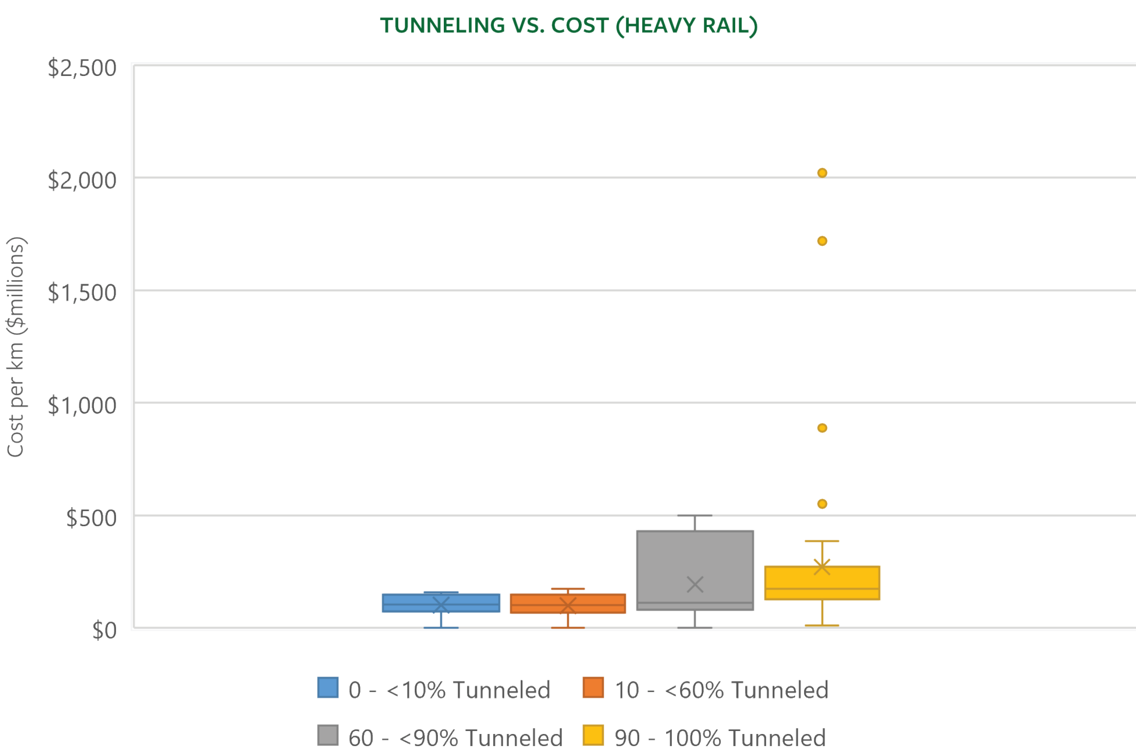

Figure 10. Light Rail Percentage Tunneled vs. Cost per Kilometer ($ Millions), U.S. and International Subgroup

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