Title

Modeling and Analyzing Cost Overruns, Delays, and Cancellations in Senate Bill 1 Projects

Authors

Yu, Jiangbo, PhD
Bahk, Younghun, PhD
Hyland, Michael F., PhD

Publication Date

2024-10-01

DOI

10.7922/G2F47MHJ

RESEARCH REPORT

Institute of Transportation Studies | UNIVERSITY OF CALIFORNIA

Modeling and Analyzing Cost Overruns, Delays, and Cancellations in Senate Bill 1 Projects

Jiangbo Yu, Ph.D., P.E., Postdoctoral Researcher, Department of Civil & Environmental Engineering, University of California, Irvine

Younghun Bahk, Ph.D. Candidate, Department of Civil & Environmental Engineering, University of California, Irvine

Michael F. Hyland, Ph.D., Assistant Professor, Department of Civil & Environmental Engineering, University of California, Irvine, Institute of Transportation Studies

October 2024

ITS·IRVINE
INSTITUTE of TRANSPORTATION STUDIES

Report No.: UC-ITS-2023-39 | DOI: 10.7922/G2F47MHJ

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UC-ITS-2023-39	N/A	N/A

4. Title and Subtitle	5. Report Date
Modeling and Analyzing Cost Overruns, Delays, and Cancellations in Senate Bill 1 Projects	October 2024
	6. Performing Organization Code ITS-Irvine
7. Author(s) Jiangbo Yu, Ph.D., P.E. https://orcid.org/0000-0002-4525-4640 Younghun Bahk, https://orcid.org/0000-0001-5233-1563 Michael F. Hyland, Ph.D. https://orcid.org/0000-0001-8394-8064	**8. Performing Organization Report No.** N/A
9. Performing Organization Name and Address Institute of Transportation Studies, Irvine 4000 Anteater Instruction and Research Building Irvine, CA 92697	**10. Work Unit No.** N/A
	11. Contract or Grant No. UC-ITS-2023-39
12. Sponsoring Agency Name and Address The University of California Institute of Transportation Studies www.ucits.org	**13. Type of Report and Period Covered** Final Report (Oct. 2022 – Dec. 2023)
	14. Sponsoring Agency Code UC ITS

15. Supplementary Notes
DOI:10.7922/G2F47MHJ

16. Abstract
In 2017, California passed Senate Bill 1 (SB1) to bolster transportation infrastructure funding. Using data primarily from the California Department of Transportation (Caltrans)'s official SB1 progress reports, we analyze the severity of cost overruns, delays, and cancellations across SB1 Transportation Projects. Although events such as the COVID-19 pandemic likely caused some of these negative outcomes, our statistical models show consistent patterns of overruns associated with fiscal periods, programs, and geographic locations. Our results indicate that the common 20% contingency is generally insufficient, indicating the need for better risk estimation in project planning. We also suggest amplifying data transparency on project performance and re-evaluating project selection criteria to avoid rewarding underestimation of project costs and duration and penalizing accurate estimation.

17. Key Words		18. Distribution Statement	
Project management, cost overruns, construction scheduling, project delivery, risk analysis		No restrictions.	
19. Security Classification (of this report) Unclassified	**20. Security Classification (of this page)** Unclassified	**21. No. of Pages** 46	**22. Price** N/A

Form Dot F 1700.7 (8-72)

Reproduction of completed page authorized

About the UC Institute of Transportation Studies

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.

Acknowledgments

This study was made possible with funding received by the University of California Institute of Transportation Studies from the State of California through the Road Repair and Accountability Act of 2017 (Senate Bill 1). The authors would like to thank the State of California for its support of university-based research, and especially for the funding received for this project. The authors would also like to thank Caltrans staff, especially Patrick Lo and Sreedevi Ponduri, for help with accessing and understanding SB 1 project report data, and for their feedback on the tool developed as part of this project. Their kind and invaluable feedback were pivotal during this research study and their time and expertise significantly enriched this work, illuminating paths we might not have traversed independently. Any mistakes or inaccuracies found within this report are entirely the responsibility of the authors.

Disclaimer

Modeling and Analyzing Cost Overruns, Delays, and Cancellations in Senate Bill 1 Projects

Jiangbo Yu, Ph.D., P.E., Postdoctoral Researcher, Department of Civil & Environmental Engineering, University of California, Irvine
Younghun Bahk, Ph.D. Candidate, Department of Civil & Environmental Engineering, University of California, Irvine
Michael F. Hyland, Ph.D., Assistant Professor, Department of Civil & Environmental Engineering, University of California, Irvine, Institute of Transportation Studies

October 2024

ITS·IRVINE
INSTITUTE of TRANSPORTATION STUDIES

Report No.: UC-ITS-2023-39 | DOI: 10.7922/G2F47MHJ

Table of Contents

Table of Contents

List of Tables

List of Figures

Executive Summary

Executive Summary

In 2017, the California State Legislature passed (and the Governor signed) Senate Bill 1 (SB1), also known as the Road Repair and Accountability Act of 2017, to increase funding for maintaining and enhancing transportation infrastructure. According to the California Transportation Commission, SB1 provided the first significant, stable, and ongoing increase in state transportation funding in more than two decades.

This research project examines the severity of cost overruns, delays, and cancellations in SB1 projects thus far. We conducted the study primarily using the official SB1 quarterly progress reports released to the public by the California Department of Transportation (Caltrans) between 2018 and 2023. As an intermediate output, we also developed a data informatics and visualization tool[1] that processes raw project data into a standard format to facilitate data analysis and insight development. We further developed statistical models for conducting quantitative analysis and deriving insights.

The results reveal a concerning overall pattern of cost overruns, delays, and cancellations. However, the severity varies greatly by fiscal period, program, and location. Below, we highlight some key findings:

- Around 37 percent of the transportation projects experienced cost overruns. The average cost overrun (across all projects, not just projects with overruns) was $1.8 million with large variations. Cost overruns are particularly severe in the State Highway Operation and Protection Program (SHOPP) and Active Transportation Program (ATP) as well as in in District 1 (Eureka Valley area), District 10 (Stockton area), and District 75 (railroad-related projects that might cross two or more areas). Causes of overruns include unforeseen site conditions, contractor conflicts, increased scope of work (e.g., sudden request to add Complete Street elements). Although the cost overruns in Fiscal Year 2021-2022, Quarters 3-4 were $2.5 million (probably due to the COVID-19 pandemic) and then declined back to 1.6 million in Fiscal Year 22-23, Quarter 3, overruns have steadily increased since then.
- Over 60 percent of the projects experienced delays, with an average delay (across all projects, not just delayed projects) of around 1.5 years with large variations. Causes of delays include weather conditions, right-of-way acquisition issues, and unforeseen site conditions (e.g., need for additional utility relocation). Furthermore, the delays have been increasing since 2018. The COVID-19 pandemic only appears to explain a limited amount of the severe increase in average delays.
- Cancellations: Our analysis found that around 373 projects (or project segments), or around two percent of all projects, were canceled. Major reasons for project cancellations included budget constraints, changes in project scope, and changes in priority.

[1] Here is the link to the data informatics and visualization tool.

- With the aid of statistical models, we find that overruns are positively associated with fiscal period, program, and spatial location. Compared with other SB1 programs, the Trade Corridor Enhancement Program (TCEP) performs the best in terms of budget control.

Despite our best attempts, we could not complete a comprehensive factor analysis to determine the common causes of cost overruns and project delays, because insufficient data is released related to the reasons for overruns and delays. It is possible that the necessary data is not even being collected.

Below, we list some implications and policy suggestions based on our findings:

- Program managers should investigate the significant performance differences among programs, districts, and implementation phases. We encourage managers responsible for different programs, districts, and implementation phases to communicate, provide good/best practices, and help solve each other's challenges.
- Despite data quality concerns, the data does suggest that the likelihood and severity of unexpected events have been clearly underestimated. In their own forecasting and contingency planning, project planners and managers should increase the likelihood and magnitude of project costs and schedule delays. The current common practice of a 20 percent contingency is insufficient considering the severity of overruns and delays. We also suggest explicitly including an estimate of the likelihood of project cancellation.
- Although the pandemic imposed additional challenges on project implementation, the period of no or low traffic volumes during the pandemic also offered an opportunity to accelerate some projects. For example, no or low traffic volumes might have offered an opportunity to accelerate some infrastructure upgrades. We did not find this type of effort explicitly documented in SB1 projects. Going forward, we encourage more adaptive project management practices during disruptive events (e.g., pandemics, earthquakes, economic downturns, changes in project scope) that take advantage of the opportunities these events might offer.
- Although it is commendable that SB1 releases project performance data to the public, rather than not sharing this data at all, we believe that a more complete (fewer null values) and accurate data coding will further benefit the state's understanding of project cost overruns, delays, and cancellations. For example, we encourage the responsible agencies to list the direct and indirect reasons for cost overruns, delays, and cancellations. Moreover, when it comes to cost increases and delays, and the reasons for these negative outcomes, it is important that this information is provided in a timely manner.
- Careful mechanism design is needed to ensure that agencies and third parties have incentives to provide honest and accurate estimates of costs and durations. For example, traceable records of who did what estimates might be effective in terms of rewarding accuracy and honesty, while penalizing biased and manipulative estimations to get projects approved.

This research project provides valuable insights into the histories and the current status of cost overruns, delays, and cancellations in SB1 Projects. The findings and recommendations can be used by program and project managers to improve project outcomes and deliver successful transportation projects in California. We foresee future research on causal analysis of the overruns, delays, and cancellations when sufficient data are collected and released to the public. We also foresee potential future research on the indirect cost of low project performance that California residents must bear.

Contents

1. Introduction

In 2017, the California State Legislature passed (and the Governor signed) Senate Bill 1 (SB1), also known as the Road Repair and Accountability Act of 2017, to increase funding for maintaining and enhancing transportation infrastructure. According to the California Transportation Commission, SB1 provided the first significant, stable, and ongoing increase in state transportation funding in more than two decades. This legislative program invests $5.4 billion annually to fix roads, freeways, and bridges in communities across California and puts more dollars toward transit and safety than previously.[2] The program funds projects that address various transportation challenges, including congestion, safety, and sustainability. Table 1 lists the two types of SB1 programs, those fully funded by SB1 and those supplemented by SB1. Different programs have their specific focuses and measures of effectiveness. However, a key concern for SB1-funded projects[3] is delays in implementation and cost overruns, which can undermine the program's effectiveness. This report documents the findings from our examination of cost overruns, implementation delays, and cancellations in SB1-funded projects.

The transportation infrastructure projects chosen for funding affect the state's economy, environment, and livability in the long term. Moreover, the implementation schedule and the actual project costs are also quite important in the long term. When there are severe cost overruns, delays, and cancellations, a natural concern is that had decision-makers known the actual benefit-cost ratios and implementation schedules of these projects, they might have chosen different projects. Indeed, the cost-benefit analysis in the efficiency reports[4] that document the implementation efficiency measures with the goal of generating at least one hundred million dollars per year in savings to invest in maintenance and rehabilitation of the state highway system, are largely developed based on the assumption that the selected projects will be complete and open to the public on time and on budget. Moreover, systematically underestimating project expense, duration, and risk may form a vicious cycle by, in effect, incentivizing larger underestimates and penalizing honest and accurate estimates.

To better understand the performance of the grant programs supported by SB1 and to help prevent this potentially vicious cycle, we analyze relevant projects in terms of their cost estimates and schedule changes across different project phases. Additionally, we segment projects by type and geographic region to identify statistically significant associations between these attributes and cost overruns, delays, and cancelations. Moreover, we model aggregate project performance using statistical models to discover important patterns for informing future decision-making.

In Section 2 and 3, we explain some key technical concepts and definitions and review relevant literature. We then document how we collected and processed the data in Section 4. In Section 5 and Section 6, we present

---

[2] https://catc.ca.gov/programs/sb1

[3] https://dot.ca.gov/programs/sb1

[4] https://dot.ca.gov/programs/sb1/efficiencies-reports

the results from exploratory analysis and statistical modeling, respectively. We derive policy implications in Section 7 and conclude the report in Section 8.

Table 1. SB1 Funding Programs

Program Name	Description
Programs Fully Funded by SB1	
Solutions for Congested Corridors Program (SCCP)	The purpose of the SCCP is to provide funding to achieve a balanced set of transportation, environmental, and community access improvements to reduce congestion throughout the state. This statewide, competitive program makes $250 million available annually for projects that implement specific transportation performance improvements and are part of a comprehensive corridor plan by providing more transportation choices while preserving the character of local communities and creating opportunities for neighborhood enhancement.
Trade Corridor Enhancement Program (TCEP)	The TCEP provides an ongoing source of state funding dedicated to freight-related projects by establishing the new Trade Corridor Enhancement Account (TCEA). The TCEA will provide approximately $300 million per year in state funding for projects which more efficiently enhance the movement of goods along corridors that have a high freight volume. Subsequent legislation (SB103), combined the Trade Corridor Enhancement Program funds with existing federal freight funding.
Local Streets and Roads Program (LSRP)	The LSRP dedicates approximately $1.5 billion per year in new formula revenues apportioned by the State Controller to cities and counties for basic road maintenance, rehabilitation, and critical safety projects on the local streets and roads system.
Local Partnership Program (LPP)	The LPP provides local and regional transportation agencies that have passed sales tax measures, developer fees, or otherwise imposed transportation fees with a continuous appropriation of $200 million annually to fund road maintenance and rehabilitation, sound walls, and other transportation improvement projects.
Existing Programs Augmented by SB1	
State Highway Operation and Protection Program (SHOPP)	The additional SB1 SHOPP investment, estimated at approximately $1.5 billion annually, is designed to improve the condition of the State Highway System, and $400 million annually for bridges and culverts will also have a positive impact on the state's economy. SB1 requires the Commission to adopt and manage the SHOPP in a transparent and accountable manner.
Active Transportation Program (ATP)	The Legislature created the ATP in 2013 to encourage increased use of active modes of transportation, such as biking and walking. SB1 directs $100 million annually to the ATP, significantly augmenting the available funding for this popular program.

Source: https://catc.ca.gov/programs/sb1

2. Concepts and Definitions

A project goes through multiple phases before completion. One of the primary phases is the Project Approval/Environmental Document (PAED) phase. During this phase, the project undergoes an approval process where environmental considerations are meticulously documented. It essentially serves as a blueprint that outlines the project's environmental impact, mapping out strategies for minimizing adverse effects, and securing the necessary approvals to move forward with the project.

Following PAED, the project progresses to the Plans, Specifications, and Estimate (PSE) phase. This phase involves the development of detailed plans and specifications that guide the construction process. A comprehensive estimate of the project cost is also formulated during this phase, incorporating all necessary elements to ensure structured and systematic construction progress. It provides a clear roadmap for the contractors and stakeholders involved.

After PSE, some projects may include Right-of-Way Support (RW Sup) and Right-of-Way Capital (RW Cap) phases, where RW Sup and RW Cap can occur in parallel. The RW Sup phase encompasses negotiations, appraisals, and relocation assistance in preparation for acquiring land required for the project. The RW Cap phase involves land acquisition, including financing and purchasing.

As the project inches closer to initiation, it enters the Ready to List (RTL) phase. This phase signifies that the project is sufficiently developed, with all necessary documentation in place for contractor bidding. The projects then progress to the imminent construction phase. The construction phase of the project includes several segments, including Construction Support (Con Sup) and Construction Capital (Con Cap). While the Con Sup phase encompasses the technical and administrative support necessary during the construction process, the Con Cap phase refers to the financial investments earmarked for the actual construction work.

Subsequently, the project formally enters the Begin Construction (Begin Const) phase, where physical construction activities commence. It marks a pivotal transition from planning to action, setting the stage for tangible progress. This phase gradually evolves to the End Construction (End Const) phase, marking the completion of the construction activities and signaling the project's transition into the finalization process. Lastly, the project enters the Estimate-at-Completion (EAC) phase. This final phase involves a comprehensive analysis and compilation of the project's total costs, encapsulating all expenditures incurred throughout the project's lifecycle. It provides a detailed financial overview, serving as a critical tool for evaluating the project's financial management and effectiveness. These phases and their acronyms are summarized in Table 2.

Table 2. Project Phases Definitions and Acronyms

Acronyms	Terms
PAED	Project Approval/Environmental Document
PSE	Plans, Specifications and Estimate
RW Sup	Right of Way Support
RW Cap	Right of Way Capital
RW Cert	Right of Way Certification
RTL	Ready to List
Con Sup	Construction Support
Con Cap	Construction Capital
Begin Const	Begin Construction
End Const	End Construction
EAC	Estimate at Completion

In project management, understanding financial metrics is crucial to maintain control over the project's budget and timeline. One such metric is the Budgeted Cost of Work Scheduled (BCWS), also known as the Planned Value (PV) or Budget at Completion (BAC). This metric refers to the approved budget allocated to complete a specific task or set of tasks within a determined timeframe. Essentially, it represents the financial blueprint of the project, detailing the anticipated costs at various stages of completion. It serves as a benchmark against which actual costs can be measured, assisting in keeping the project within the stipulated budget. By monitoring the BCWS, project managers can have a clear insight into the financial trajectory of the project, enabling them to make informed decisions and adjustments, as necessary.

In tandem, the Budgeted Cost of Work Performance (BCWP) or Earned Value (EV) plays a complementary role in financial management. This metric quantifies the actual cost incurred for the work performed at a specific point in time during the project. It offers a real-time snapshot of the project's financial health, illustrating the value earned from the work completed thus far. Essentially, it enables project managers to gauge the actual performance against the planned budget (BCWS), providing a robust tool for assessing the project's financial efficiency and progress. By closely tracking the BCWP, managers can identify potential deviations from the plan early on, facilitating timely interventions and course corrections to keep the project on track. Together, BCWS and BCWP form a vital framework for effective financial management, fostering transparency.

Despite the efforts and improvement in project and program management, cost overruns, delays, and cancellations of transportation infrastructure projects are a recurring, and often severe, issue (*1*, *2*). A preliminary examination of the SB1 progress reports[5] reveals a concerning pattern of severe cost overruns, delays, and cancellations. For example, Figure 1 shows the progress of a selected project (No. T0006) for enhancing the Terminal Island railyard in the Port of Los Angeles, from the FY 2021-2022, Q2 Trade Corridor

[5] https://dot.ca.gov/programs/sb1/progress-reports

Enhancement Program (TCEP) progress report.[6] The dotted green curve illustrates the cost and time estimates used for the grant application of the project. The solid red curve illustrates the actual cost and time for the completed phases, and the dotted red curve illustrates the newly updated projection.

Some mitigation measures for project cost, duration, and risk estimates (e.g., contingency factors, multi-scenario analysis, and reference class forecasting) have been shown to be effective in recent years (Park, 2021) but have not been adopted on a large scale and have not proved to be sustainably effective.

We compared the performance of the SB1 project implementation with projects studied in the existing literature to provide useful insights for future SB1 funding decisions. To facilitate the comparison, we used standard metrics and principles (e.g., (*1–4*)). We utilized publicly available data from SB1 progress reports, required by the California Transportation Commission (CTC), to analyze the types of projects that are more likely to underestimate costs and duration, and to obtain novel insights into the global, national, and state-wide problem of project cost and duration underestimation. For example, the phase-level data available from the reports can help us answer a central question related to project delays and cost overruns: In which phase(s) of a project do cost escalations and delays tend to occur? We can also answer this question for a variety of different project types, infrastructure programs, and geographic locations (if sufficient project records are coded appropriately). The results of the analysis may also shed light on the spatial equity aspect of SB1 implementation.

This report systematically examines the difference between the initial project cost and duration estimates used for grant application and the actual project costs and duration. As we were preparing the report, most of the projects funded fully or partially by SB1 had not yet been completed, so we adopted a hybrid approach of jointly utilizing the BCWS and BCWP information updated for each report period and comparing them with the original BCWS. We consolidated the data into a standard analytics format, based on which we subsequently developed a data visualization tool. We performed basic exploratory analyses with the aid of the visualization tool and standard descriptive and inferential statistics. Informed by the findings from the exploratory analyses, we estimated stochastic models to study the cost overruns and schedule delays more closely and derived policy and practice implications.

---

[6] https://dot.ca.gov/-/media/dot-media/programs/sb1/documents/progress-reports/tcep-report-attachment1-tcep-fy-21-22-q2-combined-a11y.pdf

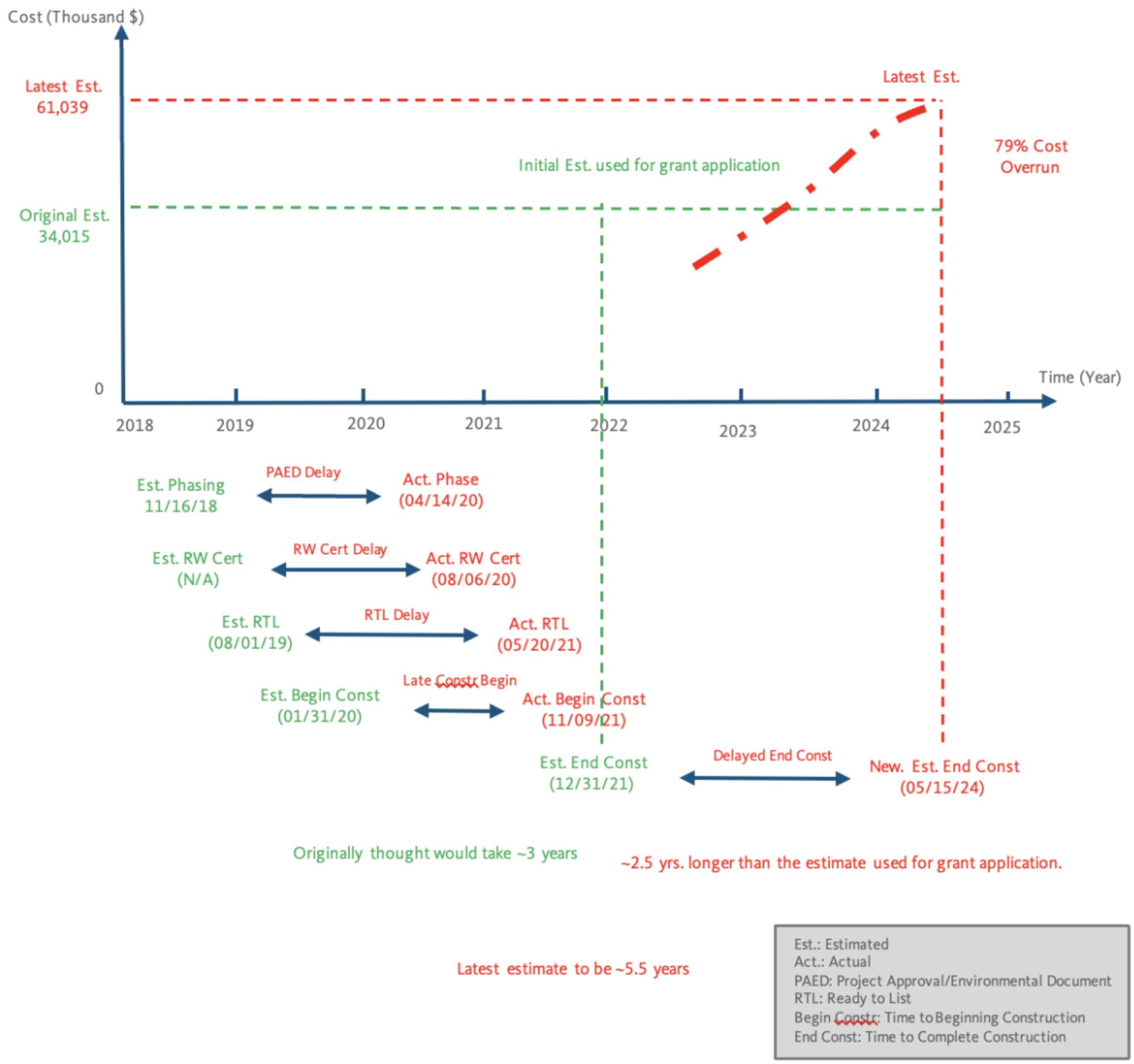


Figure 1. Illustration of the recorded progress data of Project No. T0006 LA (Alameda Corridor Southern Terminus Gap Closure)

3. Relevant Work

In the field of infrastructure development, the challenge of managing cost overruns remains a predominant theme, both in academic circles and in real-world project implementation. As Flyvbjerg et al. (*5*), Flyvbjerg and Bester (*1*), and Shafqat et al. (*6*) highlight, cost overruns are a nearly ubiquitous phenomenon, typically attributed to a host of factors, including the complexity inherent in these projects, changes in project scope, and unforeseen site conditions. Notable studies by Cantarelli et al. (*7*) and Love et al. (*4*) have sought to develop frameworks that could anticipate and mitigate these overruns, emphasizing strategies like comprehensive project planning and active stakeholder engagement as crucial in keeping costs within originally designated budgets used for project funding applications.

Project delays also represent a vital area of study in infrastructure project management and are often examined along with cost overruns (*8*, *9*). Various works have linked these delays to elements such as adverse weather conditions, contractor disputes, and unexpected site conditions (*10*, *11*). Proactive risk management strategies, which include meticulous planning and routine project reviews, have been proposed to alleviate the ramifications of these delays (*6*).

On the other hand, project cancellations, though not as prevalent as severe cost overrun and delays, have strong implications for the actual benefit-cost ratio of the investments. On one hand, some project cancellations might actually be an indicator of an effective and proactive program management; on the other hand, cancellations might indicate ineffective program planning. The literature underscores budget constraints, alterations in project scopes, and priority shifts as the main culprits behind project cancellations (*12*). To circumvent these cancellations, scholars recommend clearly articulating project objectives and fostering constant communication with stakeholders, enabling adaptation to changing circumstances without necessitating project abandonment (*13*).

Furthermore, it is pertinent to acknowledge that while overruns, delays, and cancellations are somewhat common, their incidence may vary markedly among project types, geographic locations, and funding formulas. These variations could be influenced by a range of factors including regulatory frameworks, socio-economic conditions, and region-specific environmental factors. This study endeavors to dissect these variations, to glean vital insights and lessons that could pave the way for formulating strategies that effectively counteract cost overruns, delays, and cancellations.

In recent developments, the role of data analytics in facilitating informed decision-making has drawn substantial attention. Scholars like Spalek (*14*) have accentuated the advantages that data analytics tools confer, aiding in detailed project analysis and forward planning. In line with this more data-oriented trend, our research employs a transparent data analysis approach for understanding the intricacies and "background" of the data more explicitly. We hope this effort can reveal the hidden value of the related data that is already available to the public even without using advanced statistical analytics. At the same time, we recognize that it is critical to heed the principle of "garbage in, garbage out." We believe that a refined utilization of the existing data, complemented by leveraging transparent and easy-to-use decision support tools (even without advanced data analytics), can produce a positive trajectory in future project performance, fostering an environment conducive to successful project planning and management.

4. Data Collection and Standard Data Table

Our study uses approximately 1350 SB1-funded project records completed or ongoing between 2018 and 2022, officially released by Caltrans at https://dot.ca.gov/programs/sb1/progress-reports. Despite the possibility that multiple project records correspond to one single transportation project, we treat each project segment corresponding to a project report as independent and analyze the project records as such. Nevertheless, for convenience, we still refer to each record as a project or project record. We consider this assumption reasonable as transportation projects are often segmented so that they can be performed in a relatively independent/parallel manner.

As the public records for four time periods did not provide data in .CSV or .XLSX format (and we were not able to obtain such data directly from Caltrans), and since time and budgeting did not allow us to manually convert the PDF data to CSV data (we tested various methods to automatically convert the data with the PDF format, but the results were not satisfactory due to the irregularity and lack of patterns of the data in the PDF files), we did not study every single reporting period. However, the seven periods with available .CSV or .XLSX data include valuable information about SB1 project performance thus far.

Unfortunately, the monetary costs of different projects shown in the progress reports are stated in present value, where the definition of "present" is unclear. Therefore, it would have been challenging to convert all the present values into the same year to make apples-to-apples comparisons. Hence, we used the nominal values in each project report without discounting cash flows or adjusting for inflation. We also excluded all projects with incomplete or unreliable data from our analysis to maintain the integrity of our results. We then performed a data cleaning process to address any inconsistencies, missing values, and potential outliers. We examined outliers and, if necessary, we removed them from the dataset. Specifically, after both examining the distribution of project costs, as well as the description of projects with the highest costs, we decided to remove projects with costs exceeding "$10 billion" as costs this high seemed unreasonable. We suspect staff mistakenly reported project costs in dollars instead of thousands of dollars for these projects costing over $10 billion. Table 3 lists example projects that we considered outliers.

Table 3. Selected Projects/Segments Outliers Dropped from Analysis

Time period	Program	No.	PPNO	Total Approved (1k USD)	Total Budget (1k USD)	Total Expended (1k USD)	Total EAC (1k USD)	Total Overrun (1k USD)
FY 18-19 Q4	TCEP	6	6955	50,000	25,000	8,974	5,553,474	5,503,474
FY 18-19 Q4	SHOPP	454	1339	27,130	27,130	10,190	20,740,447	20,713,317
FY 21-22 Q3-4	ATP	303	5861A	3,196	3,196	1,099,000	1,099,000	1,095,804
FY 22-23 Q1	ATP	273	5669	898	898	17	1,616,773	1,615,875
FY 22-23 Q2	SHOPP	660	3531	2,601	2,601	300	1,872,566	1,869,965
FY 22-23 Q3	ATP	77	5406	19,956	0	7,364,000	27,320,000	27,300,044
FY 22-23 Q3	ATP	78	5447	16,029	0	2,123,000	18,152,000	18,135,971

In summary, the data collection and formatting process involved the following steps:

1. Collecting data on SB1-funded projects from Caltrans.
2. Cross-verifying data across different periodical reports and efficiency reports and with other external sources for reliability and accuracy.
3. Forming a combined database for all the projects from different programs and report periods.
4. Cleaning the data by addressing inconsistencies, missing values, and outliers.
5. Forming standard data summary tables, categorizing projects based on factors such as project type, funding source, and the presence of public-private partnerships.[7]

With the data collected, formatted, and organized, we proceeded to the exploratory analysis, modeling, and forecasting stages to gain insights into the factors contributing to cost overruns, delays, and cancellations. For each project group by period, program, and geography, we have the following measures: total counts, total valid counts (records with non-missing, reasonable values), percentage of overrun or delay counts, average cost overruns or delays, and the associated standard deviations.

[7] Here is the link to the standard data summary table, which is a data informatics and visualization tool.

5. Exploratory Analysis

In this section, we utilize the standard data summary tables described in the previous section to conduct exploratory analysis. This analysis paints a comprehensive picture of the prevailing conditions and trends in SB1 projects. The subsections provide a detailed analysis considering various facets, including time periods, programs, and geographical districts.

5.1. Overall Conditions and Trends

In this initial subsection, we describe the overarching conditions of the SB1 projects thus far. Table 4 shows a summary of the standard data table by aggregating individual projects by report periods. The Total Count is the total number of records that have non-missing and reasonable values (it does not include outliers). We can see that there is significantly more missing data for the schedules than for costs. We do not know the reason for this difference.

Key cost performance measures include the number of projects that experienced cost overruns, associated percentages (ratios over the total counts), average cost severities (across all projects, not just projects with a positive cost overrun), and the standard deviation (of all projects). In addition to the concerning percentage of projects that experienced cost overruns and the average of the overruns, we also see that the distributions of the overruns have “long tails,” meaning that there are significant variations in project cost performance.

Table 4. Overall Conditions by Fiscal Quarter

Period				FY 18-19 Q4	FY 19-20 Q1-2	FY 21-22 Q3-4	FY 22-23 Q1	FY 22-23 Q2	FY 22-23 Q3
Program				(ALL)	(ALL)	(ALL)	(ALL)	(ALL)	(ALL)
District				(ALL)	(ALL)	(ALL)	(ALL)	(ALL)	(ALL)
Cost (thousand $)	Total Cost	Total Count		759	798	1377	1373	1361	1386
		Overrun	Count	233	230	525	511	530	560
			Ratio	30.7%	28.8%	38.1%	37.2%	38.9%	40.4%
		Avg.		669	285	2537	1691	1390	1843
		Std. Dev.		13161	13113	14862	13528	12958	12380
Schedule (days)	End Const	Total Count		73	83	158	160	161	183
		Delay	Count	30	53	99	101	110	130
			Ratio	41.1%	63.9%	62.7%	63.1%	68.3%	71.0%
		Avg.		122	219	337	363	401	452

Period			FY 18-19 Q4	FY 19-20 Q1-2	FY 21-22 Q3-4	FY 22-23 Q1	FY 22-23 Q2	FY 22-23 Q3
Program			(ALL)	(ALL)	(ALL)	(ALL)	(ALL)	(ALL)
District			(ALL)	(ALL)	(ALL)	(ALL)	(ALL)	(ALL)
		Std. Dev.	326	357	542	527	552	534
	Canceled	Total Count	14	240	40	43	36	0
	Completed	Total Count	0	15	31	14	19	11

Key schedule performance measures include the number of projects that experienced delays (from the original schedules), associated percentages (ratios over the total counts), average duration of delays, and standard deviation of delays. Although the percentage of delayed projects and the average postponement are concerning, we see smaller variations than those in the cost performance measures, suggesting that the delays among individual projects tend to be more evenly distributed than the cost overruns.

Most of the progress reports by period and by program do not indicate canceled projects. Instead, those projects are simply dropped from the project list in the following progress report. Some finished projects appear in the following reports, while some others do not. For the latter case, if a project is shown to be near completion and then it disappears, we considered this project finished. If a project was not near completion and it did not appear in the next progress report, we considered it canceled. Using these inferences, we find that around two to three percent of projects were canceled, perhaps due to various reasons, including the possibility of a project being split into smaller projects or multiple projects being aggregated into a major one. Furthermore, as the reports are only updated periodically rather than continuously, it is possible that the project was cancelled more than one phase after the phase it appeared in a prior report. Therefore, we did not study cancellation by phases.

5.2 Cost and Scheduling Performance: Conditions and Trends

We dissected the aggregated project performance by report periods (in chronological order) and the specific SB1 programs under which the projects were initiated. By categorizing the data in this manner, we aimed to reveal patterns that may exist between time frames and the nature of different programs. Note that some projects that are augmented (i.e., partially funded) by SB1 funding, such as those in the State Transportation Improvement Program (STIP), are not considered in the present research report due to a lack of (organized and sufficient) information. Indeed, Caltrans did not release their progress reports of those projects in their SB1 performance monitoring efforts.

Figure 2 shows the cost performance across time for five selected funding programs in this research project. Overall performance became worse over time. We can see that SCCP, TCEP, and LLP-C were generally under budget, though over time they got closer to, or exceeded (in the case of TCEP), the original budget. TCEP and ATP generally got worse over time, but SHOPP had the worst performance. LLP-C performed the best. Note that, considering the large standard deviations for most of the project categories, we divided the deviations by ten for the rest of the plots in the present Exploratory Analysis section. Although this causes the figures to under-represent the variations, the error bars still correctly indicate the relative variations when comparing different project categories. We did not use coefficients of variation for the error bars as this might penalize programs with smaller projects and create challenges in comparing variations among programs.

An interesting pattern from this figure is that, in terms of average values, only SHOPP and ATP seem to experience cost overruns, while SCCP TCEP, and LPP-C seem to either come in under budget or are not significantly different from zero on average. This pattern seems counter-intuitive when compared with Table 4. This is mainly because SHOPP and ATP have significantly more projects, as shown in Table 5. Despite the seemingly higher budgetary efficiencies in SCCP, TCEP, and LPP-C, indicated by their negative average cost overrun values, a notable increase in the magnitude of these values over time suggests a declining trend in budget savings. Additionally, it's important to note that the standard deviation is reduced by a factor of five in Figure 2, highlighting that a significant proportion of projects across all programs experience cost overruns. Note that the counts in Table 5 only consider projects that are valid, meaning there are valid values (e.g., non-null values) for the project (or project segment) records.

Figure 3 shows schedule performance. It is unclear the exact reason ATP reports projects significantly ahead of schedule in FY 19-20 Q1-2. We suspect it was due to the changing method used to measure delays or simple data reporting errors.

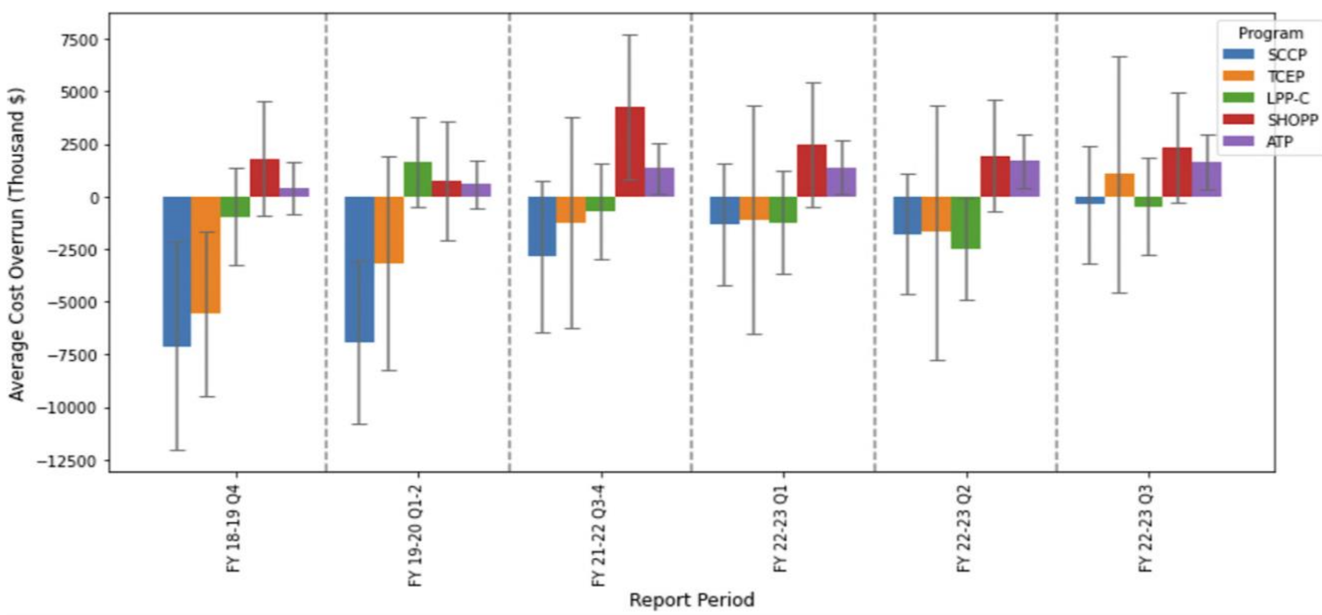


Figure 2. Mean and Variation of Cost Overruns by Report Period and Program

Table 5. Total Number of Valid Projects (or Project Segments) By Report Period and SB1 Program

	FY 18-19 Q4	FY 19-20 Q1-2	FY 21-22 Q3-4	FY 22-23 Q1	FY 22-23 Q2	FY 22-23 Q3
SCCP	28	31	60	58	55	54
TCEP	34	33	58	59	61	58
LPP-C	34	32	52	48	49	46
SHOPP	466	460	731	771	751	737
ATP	197	242	476	437	445	491
Total	759	798	1,377	1,373	1,361	1,386

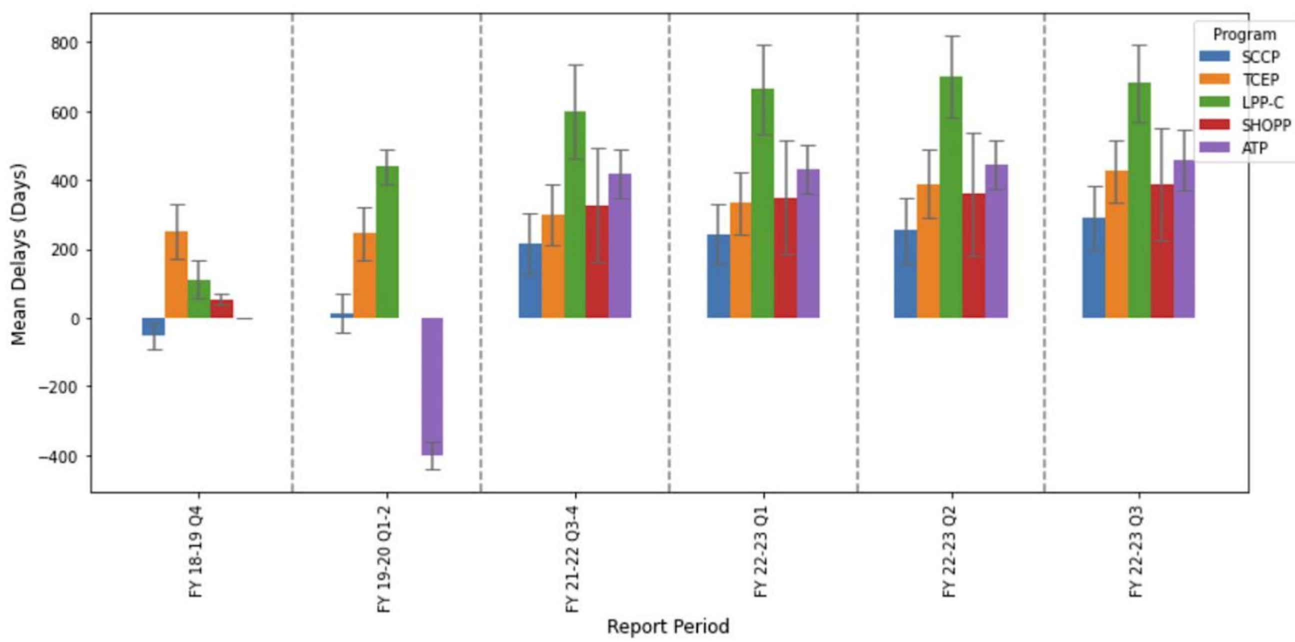


Figure 3. Mean and Variation of Delays by Report Period and Program

5.3 Overall Conditions and Trends by Geographic Area and Time Period

In this sub-section, we shift focus towards an analysis grounded in the distinct geographical districts and the periods wherein the projects were initiated. This analysis showcases potential regional discrepancies and time-bound fluctuations in project costs and timelines, offering insights into district-specific challenges or successes. In the officially released progress reports, each project record has an attribute "District." Figure 4 shows the correspondence. Districts 1-12 have regions that can be shown on the map on the right-hand side. District 53 projects are the ATP implemented by the California Conservation Corps and certified Local Community Corps. District 75 projects are railroad-related projects, which can be anywhere in California.

County Name	County Abbreviation	District	County Name	County Abbreviation	District
Alameda	ALA	4	Orange	ORA	12
Alpine	ALP	10	Placer	PLA	3
Amador	AMA	10	Plumas	PLU	2
Butte	BUT	3	Riverside	RIV	8
Calaveras	CAL	10	Sacramento	SAC	3
Contra Costa	CC	4	Santa Barbara	SB	5
Colusa	COL	3	San Bernardino	SBD	8
Del Norte	DN	1	San Benito	SBT	5
El Dorado	ED	3	Santa Clara	SCL	4
Fresno	FRE	6	Santa Cruz	SCR	5
Glenn	GLE	3	San Diego	SD	11
Humboldt	HUM	1	San Francisco	SF	4
Imperial	IMP	11	Shasta	SHA	2
Inyo	INY	9	Sierra	SIE	3
Kern	KER	6	Siskiyou	SIS	2
Kings	KIN	6	San Joaquin	SJ	10
Los Angeles	LA	7	San Luis Obispo	SLO	5
Lake	LAK	1	San Mateo	SM	4
Lassen	LAS	2	Solano	SOL	4
Madera	MAD	6	Sonoma	SON	4
Mendocino	MEN	1	Stanislaus	STA	10
Merced	MER	10	Sutter	SUT	3
Mono	MNO	9	Tehama	TEH	2
Modoc	MOD	2	Trinity	TRI	2
Monterey	MON	5	Tulare	TUL	6
Mariposa	MPA	10	Tuolumne	TUO	10
Marin	MRN	4	Ventura	VEN	7
Napa	NAP	4	Yolo	YOL	3
Nevada	NEV	3	Yuba	YUB	3

Figure 4. Left: Counties-district correspondence; Right: Map illustration of the correspondence

Overall, Figure 5 shows that, except for District 9, cost overruns either became worse or remained similar over time.

District 9 and District 75 have some records that include large overruns, which partially explains its noticeably high average cost overrun. For example, we can find that SHOPP Project (PPNO) 2633 has large cost overrun (relative to the approved budget) of $84,794,000 in FY 18-19, Q4 and $64,718,000 in FY 19-20, Q1-2, respectively. This project received a large amount of additional approved budget in the FY 21-22, Q3-4 period, leading to cost savings of $2,363,000. However, since FY 19-20, Q1-2 and FY 21-22, Q3-4 are not consecutive, we cannot determine when exactly the approved budget was increased.

Another issue is that District 53 has a very limited number of samples. The FY 18-19, Q4 progress report shows only one project (CCC01) with an overrun of $8,000,000, which is compensated for in the FY 19-20 Q1-2 report, leading to a $8,000,000 saving. Accordingly, if this information is accurate, like in the cases above in District 9, we can infer that District 53 first estimated the project cost and then got budget approval in the next period.

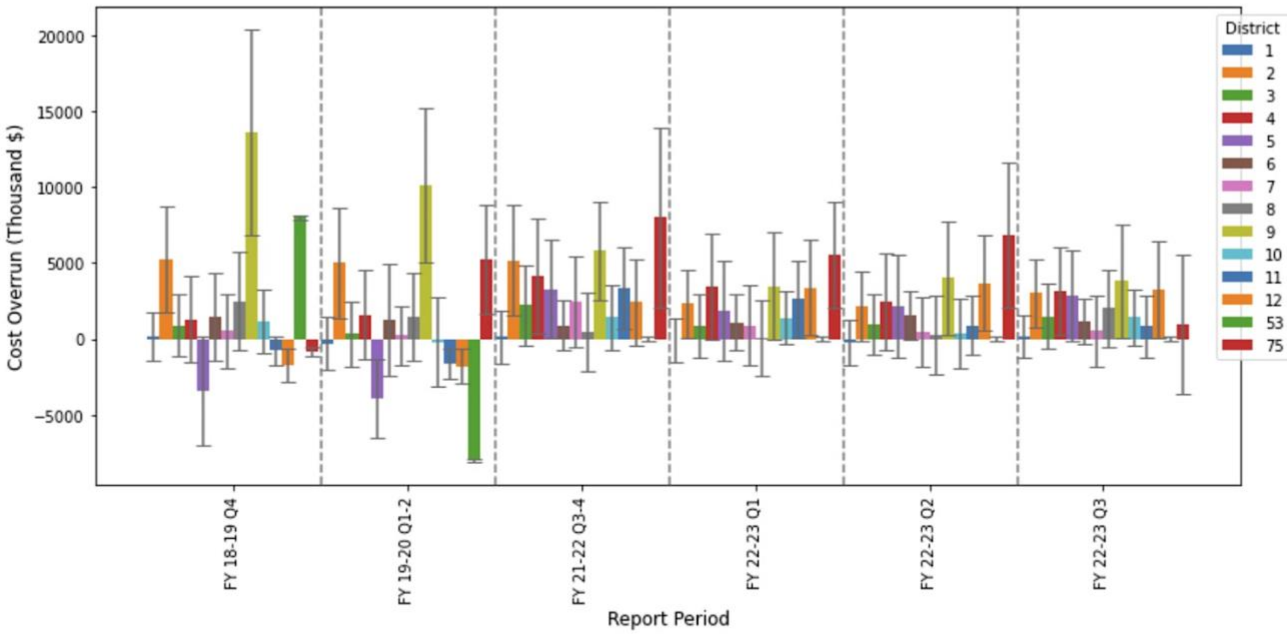


Figure 5. Mean and Variation of Cost Overruns by Report Period and Program

Figure 6 shows an overall trend of increasing average delays across districts. We also notice the large negative bar for District 1 in the second report period. Although there are many District 1 projects, very few project records include an End Const date. The first two bars (negative in FY 19-20, Q1-2 and then positive in FY 21-22, Q3-4) represent the same single project (PPNO 2391 in ATP). The approved finish date was 7/7/2022 and did not change in the second period. However, the expected finish date was 3/31/2021 in the first period and then delayed to 9/2/2024 in the second period. This expected date was slightly extended again to 10/1/2024 in the fourth period without any change in the approved finish date. This explains why the bars consistently maintain large positive values. However, we believe that this type of data coding issue/inconsistency does not influence the concerning conclusion that the overall trend is one of increasing delays across districts.

Furthermore, as we reported the cost overruns and delays using the estimates from the latest report, not the actual costs and delays when the projects finished (most projects had not yet finished when we were writing this report), it is likely that we are under-estimating the severity of the cost overruns and delays. We would need to wait until the closure of the SB1 funding efforts to have a more comprehensive summary of the SB1 project performance.

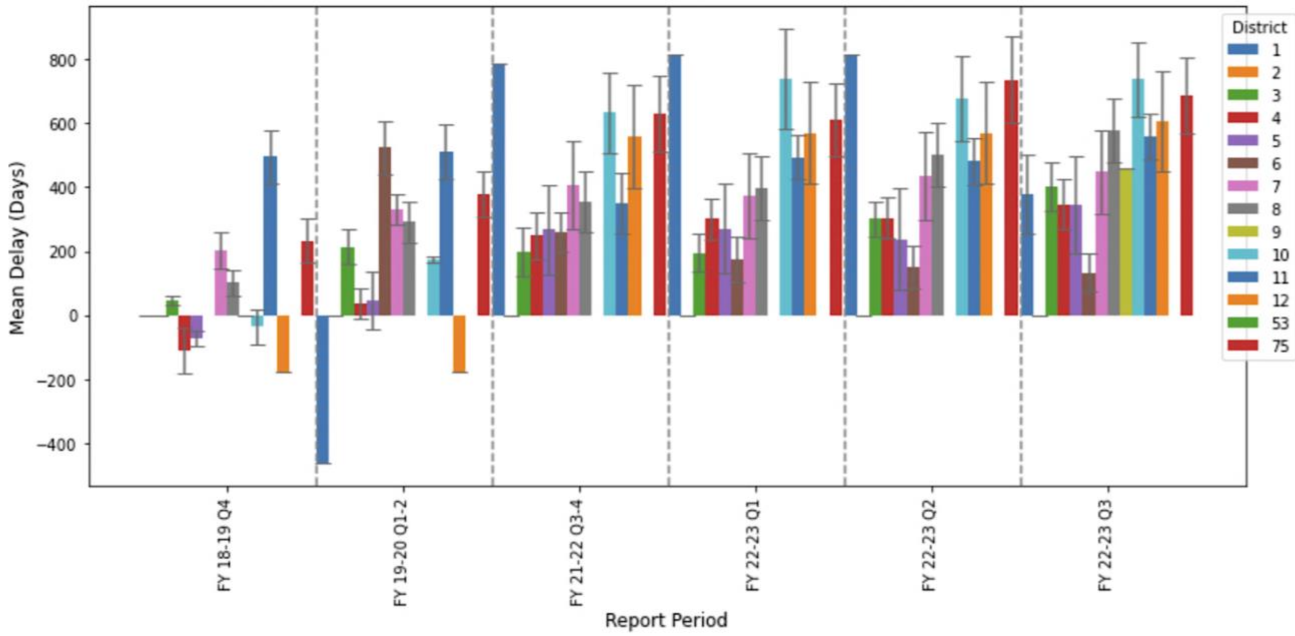


Figure 6. Mean and Variation of Delays by Report Period and Program

5.4 Cost Overruns and Delays by District and Program

Next, we explore the project performance by district and program, to ascertain if the geographic location of different programs has an impact on cost overruns and delays. This will help in mapping out program effectiveness and efficiency across different districts. In Figure 7, we see that the TCEP in District 2 (Redding area in Northern California) and District 6 (Fresno area in Central California) experienced major cost overruns. SCCP in District 8 (San Bernardino area in Southern California) and SHOPP in District 9 (Bishop area in Central California) also have major overruns. The TCEP in District 12 (Orange County in Southern California) had noticeable project savings as there were a small number of projects that performed well in terms of cost control.

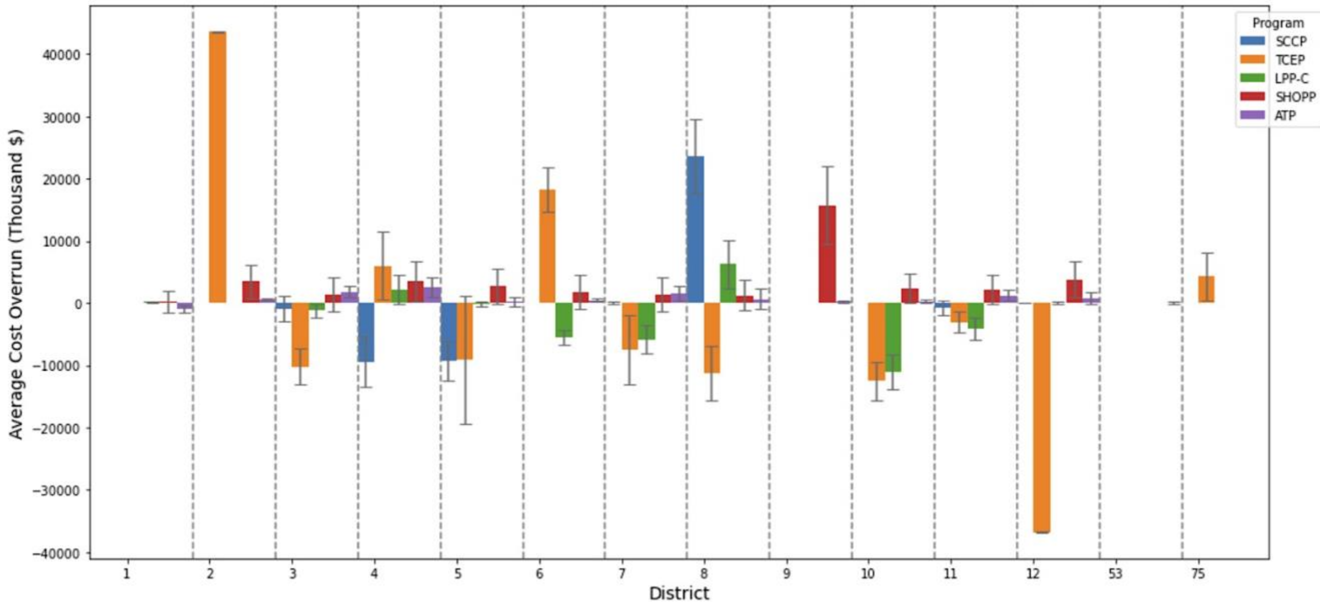


Figure 7. Mean and Variation of Cost Overruns by Report Period and Program

Figure 8 shows schedule performance by district and program. We can see that District 7 (Los Angeles and Ventura Counties), District 8 (San Bernardino and Riverside Counties), District 11 (San Diego and Imperial Counties), and District 12 experienced major delays. It is interesting to compare schedule performance jointly with cost performance as they do not necessarily exhibit similar patterns. For example, District 7 did not experience major cost overruns in terms of average project performance; however, District 7 experienced major schedule delays. It is possible that project managers in this district tend to be better at pausing a project when they realize it is not going in a desirable direction. Then, they only continue the project once they resolve the issues or cancel the project. However, we want to emphasize that although it might be a good practice to have a quick response by simply stopping the projects (and the postponement does not impose a significant cost burden on the project), the delays do impose negative impacts on society as (1) other infrastructure and land development may be dependent on the delayed project, and (2) different projects could have been implemented (i.e., opportunity cost) if the schedules were not systematically underestimated.

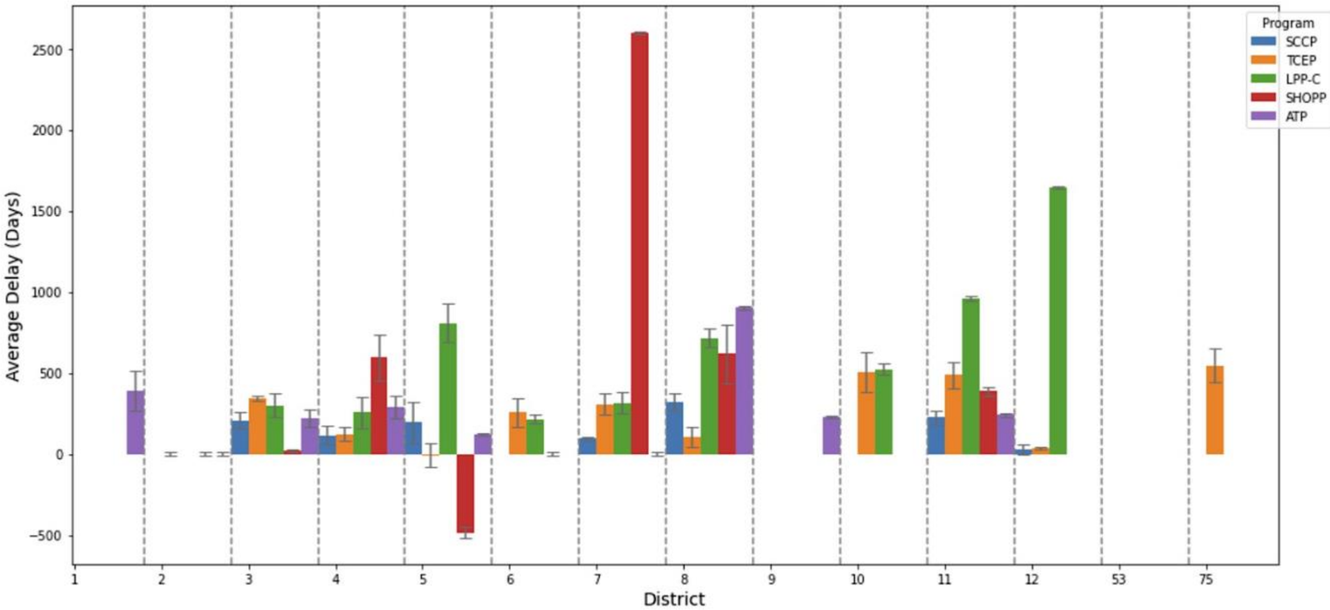


Figure 8. Mean and Variation of Delays by Report Period and Program

5.5 Cost Overruns and Delays by Program and Phase

This subsection explores the intricacies of cost overruns and delays for different programs and their respective phases. By correlating program-specific data with the various project phases, we were able to identify phase-wise discrepancies in cost management and time delays, thereby pinpointing specific areas that require focused interventions.

Figure 9 shows that in general earlier project phases tend to be under budget while later phases tend to be over budget. This phenomenon might be because the project managers tried re-balancing/re-leveraging resources individually, using resources for later phases to "cover" or "mitigate" the overrun in the initial phases so that they do not report overruns for early phases (and hope that they can delivery later project phases at lower costs, such that the final budget is not much higher than the original budget).

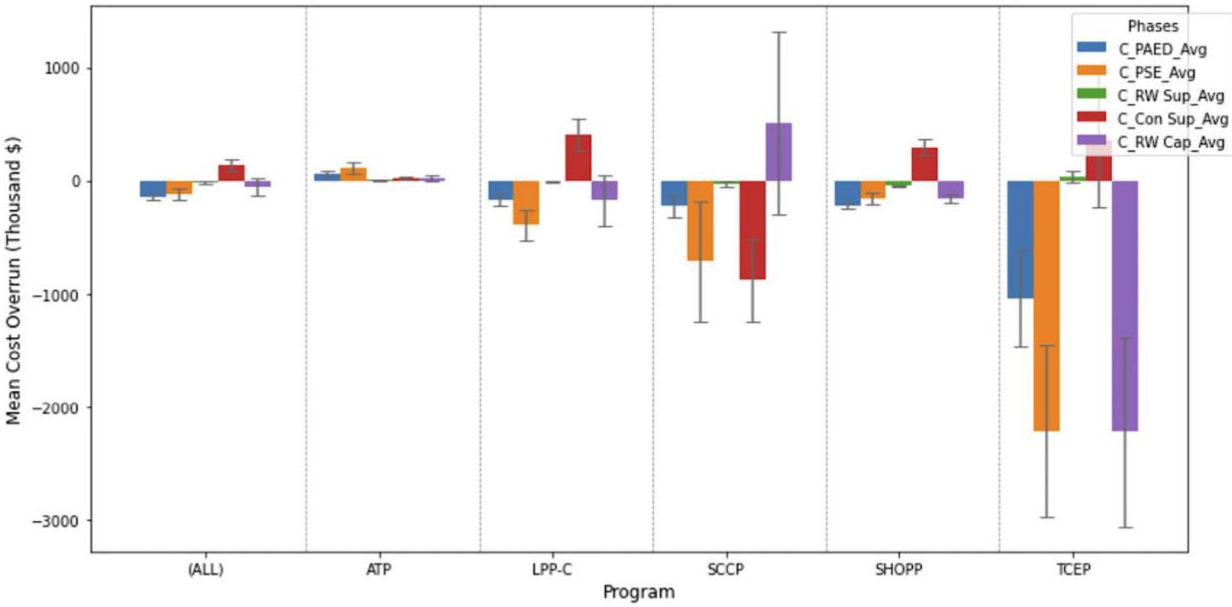


Figure 9. Mean and Variation of Cost Overruns by Report Period and Program

TCEP performed better than other programs in terms of cost control. We manually verified that the TCEP (as TCEP is a program with only a small number of project records) had fewer overruns, though these projects also experienced large delays, as shown in Figure 10. We are unsure of the deeper reason why only TCEP has this strong tendency, and we encourage future research on this phenomenon.

Unlike cost overruns, project managers cannot “reallocate” time, as they cannot “move time” from later phases to early phases, so it is harder to reallocate resources to “make the performance look good.” This might explain why Figure 10 shows schedule delays systematically increasing across project phases.

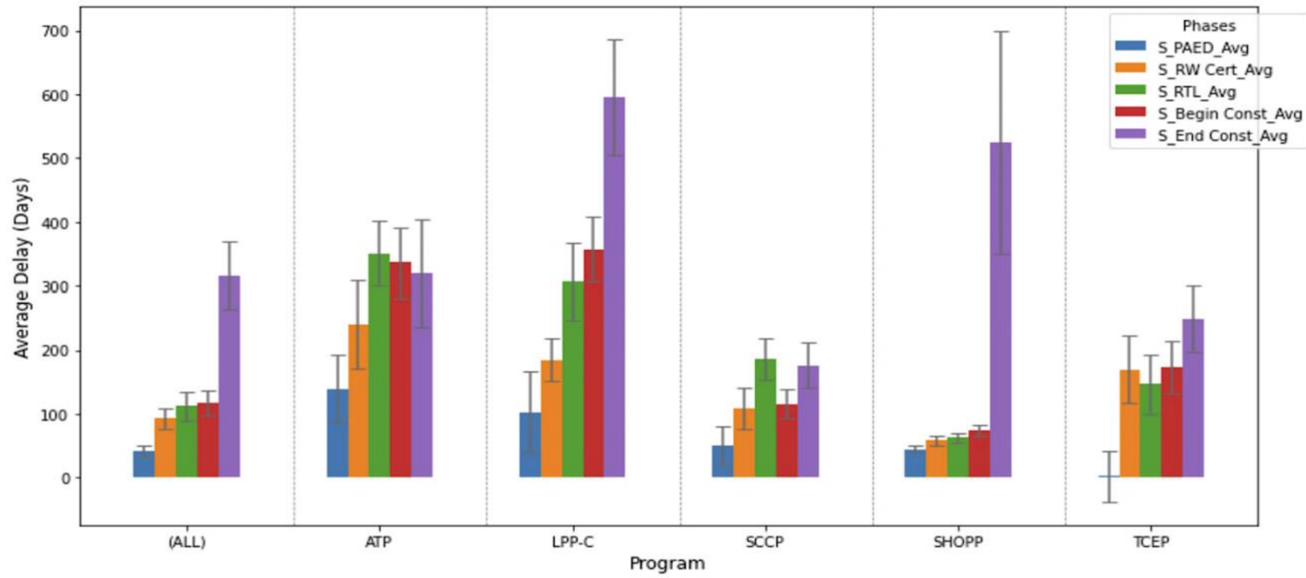


Figure 10. Mean and Variation of Delays by Report Period and Program

Overall, we see an interesting, inverse pattern between schedule delays and cost overruns when examining projects by project phases across different SB1 programs. We hypothesize this might be because the initial over runs can be temporarily resolved by relocating the budget from later phases, while the time cannot be "re-allocated." On the other hand, we did notice that, compared to the total costs and the overall schedule, there are significantly more null values for the data at the phase level. We believe that fewer null values in the data will improve our confidence in the hypothesis and allow us to derive more policy implications.

6. Statistical Modeling and Analysis

In this section, informed by the findings from our exploratory analysis, we conduct statistical modeling for more detailed analysis. In summary, we find that cost overruns have worsened over time: The TCEP and LPP-C programs performed the best in terms of cost control, relatively, while SHOPP performed the worst. SHOPP also had a more concerning delay pattern than other programs. Projects in Northern California tended to have lower delays than Southern California, though the projects in Southern California tended to have lower cost overruns.

6.1 Cost Overruns and Delays by Program and Phase

We investigated whether it was possible to use report period, program, and district information in an additive linear formulation to predict cost overruns and delays. Specifically, we adopted a basic linear regression approach for analysis to predict total cost overruns (or the latest estimate for ongoing projects that have not been finished or canceled) and to predict the schedule timing.

For cost overruns, we have:

$$C_i = \sum_{prd} \beta^{prd} \delta_i^{prd} + \sum_{prg} \beta^{prg} \delta_i^{prg} + \sum_{dist} \beta^{dist} \delta_i^{dist} + \varepsilon_i$$

where δ_i^{prd}, δ_i^{prg}, δ_i^{dist} are the dummy variables for report periods, programs, and districts, respectively. For example, for the records of District 9, we have $\delta_i^{dist} = 1$ when $dist = 9$ and 0 otherwise. β^{prd}, β^{prg}, and β^{dist} are the corresponding coefficients. ε_i is the error term for project i. C_i is the cost overrun for the project i. When $C_i < 0$, it means that the project i is under budget (thus far). As having many districts would lead to a large number of dummy variables, we aggregate districts into three mega-districts: Northern California (NC), Southern California (SC), and Other (Districts 53 and 75).

The regression analysis results using the Excel Solver are shown in Tables 6-8. We can see in Table 6 that the regression results are not satisfactory, as the multiple R score is only 0.18. The adjusted R-square is as low as 0.01 when considering the use of coefficients. However, we can still see from Table 7 that the coefficients generally agree with our findings in the exploratory analysis. For example, the later the report, the higher the corresponding coefficients, indicating that the cost overrun is becoming worse over time. Program TCEP and LPP-C performed the best, relatively, while SHOPP performed the worst. Southern California (especially Los Angeles and Ventura Counties) tends to have lower cost overruns.

Table 6. Regression Statistics for Cost Overruns Using Linear Regression

Regression Statistics	
Multiple R	0.18
R Square	0.03
Adjusted R Square	0.01
Standard Error	10685
Observations	540

Table 7. Analysis of Variance (ANOVA) Summary

	df	*SS*	*MS*	*F*	*Significance F*
Regression	13	2125497533	163499810	1.43	0.14
Residual	526	60052664952	114168565		
Total	539	62178162485			

Table 8. Summary of Estimates for Cost Overruns

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-93	2299	-0.04	0.97	-4610	4423	-4610	4423
District_New ID_NC	1728	1904	0.91	0.36	-2012	5468	-2012	5468
District_New ID_SC	-672	1951	-0.34	0.73	-4505	3160	-4505	3160
District_New ID_Other	1285	2181	0.59	0.56	-3000	5569	-3000	5569
Period_FY 19-20 Q1-2	440	1593	0.28	0.78	-2689	3569	-2689	3569
Period_FY 21-22 Q3-4	1626	1593	1.02	0.31	-1503	4755	-1503	4755
Period_FY 22-23 Q1	1554	1593	0.98	0.33	-1575	4683	-1575	4683
Period_FY 22-23 Q2	1132	1593	0.71	0.48	-1998	4261	-1998	4261
Period_FY 22-23 Q3	2161	1593	1.36	0.18	-968	5290	-968	5290
Program_ATP	-1066	1593	-0.67	0.50	-4195	2063	-4195	2063
Program_LPP-C	-2977	1593	-1.87	0.06	-6106	152	-6106	152
Program_SCCP	-1557	1593	-0.98	0.33	-4686	1572	-4686	1572
Program_SHOPP	1075	1593	0.68	0.50	-2054	4205	-2054	4205
Program_TCEP	-3016	1593	-1.89	0.06	-6145	113	-6145	113

Similarly, delays are modeled as:

$$S_i = \sum_{prd} \gamma^{prd} \delta_i^{prd} + \sum_{prg} \gamma^{prg} \delta_i^{prg} + \sum_{dist} \gamma^{dist} \delta_i^{dist} + \zeta_i$$

where δ_i^{prd}, δ_i^{prg}, δ_i^{dist} are the dummy variables for report periods, programs, and districts, respectively. β^{prd}, β^{prg}, and β^{dist} are the corresponding coefficients. ζ_i is the error term for project i. S_i is the schedule delay for the project i. When $S_i > 0$, it means that the project i was delayed (according to the original schedule). When $S_i < 0$, it means that the project was ahead of the originally approved schedule (thus far).

The regression analysis results are shown in Tables 9-11. We can see in Table 9 that the regression results are not satisfactory as the multiple R score is only 0.4, though it performs better than the results from the cost overrun prediction. The adjusted R-square is as low as 0.14 when considering the use of coefficients. However, we can still see from Table 11 that the directionally of the coefficients generally agree with our findings in the exploratory analysis. For example, the later the report, the higher the corresponding coefficients, indicating that the cost overrun worsened over time. The projects in Northern California tended to have lower delays than Southern California, though the projects in Southern California tended to have lower cost overruns.

Table 9. Regression Statistics for Schedule Delays Using Linear Regression

Regression Statistics	
Multiple R	0.40
R Square	0.16
Adjusted R Square	0.14
Standard Error	306.32
Observations	540

Table 10. Analysis of Variance (ANOVA) Summary

	df	*SS*	*MS*	*F*	*Significance F*
Regression	13	9622974	740229	7.89	1.7862E-14
Residual	526	49355169	93831		
Total	539	58978143			

Table 11. Summary of Estimates for Schedule Delays

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	130	66	1.98	0.05	0.70	259.65	0.70	259.65
District_NewID_NC	-9	55	-0.17	0.86	-116.57	97.87	-116.57	97.87
District_NewID_SC	107	56	1.91	0.06	-3.14	216.60	-3.14	216.60
District_NewID_Other	73	63	1.17	0.24	-49.58	196.08	-49.58	196.08
Period_FY 19-20 Q1-2	50	46	1.10	0.27	-39.68	139.73	-39.68	139.73
Period_FY 21-22 Q3-4	188	46	4.13	0.00	98.69	278.10	98.69	278.10
Period_FY 22-23 Q1	204	46	4.46	0.00	114.15	293.56	114.15	293.56
Period_FY 22-23 Q2	221	46	4.85	0.00	131.76	311.17	131.76	311.17
Period_FY 22-23 Q3	231	46	5.07	0.00	141.60	321.01	141.60	321.01
Program_ATP	18	46	0.40	0.69	-71.58	107.83	-71.58	107.83
Program_LPP-C	181	46	3.95	0.00	90.88	270.29	90.88	270.29
Program_SCCP	-56	46	-1.23	0.22	-145.91	33.50	-145.91	33.50
Program_SHOPP	93	46	2.04	0.04	3.44	182.85	3.44	182.85
Program_TCEP	-47	46	-1.04	0.30	-136.97	42.44	-136.97	42.44

6.2 Decision Tree Analysis for Nonlinearity

Although the signage of the coefficients in the linear regression analysis seems reasonable, the goodness-of-fit measures are not satisfactory. It is likely that there are nonlinear relationships among sequential report periods, which might render the inefficient (though unbiased) use of data for estimation, which caused low goodness-of-fits in the linear regression models. It is also possible that there are correlations among programs and districts as some projects might be co-funded by more than one program and near the border with another district.

The basic idea behind decision tree regression is similar to that of decision tree classification. At each node, we split the data based on a feature and a threshold such that the resulting subsets have the lowest possible variance (or some other specified criterion). The process is recursive and continues until a predefined stopping criterion is met, such as maximum depth of the tree or a minimum number of samples per leaf. Mathematically, the algorithm aims to minimize the following objective for a given split:

$$J(D, f, t) = \frac{1}{n}\left(n_L Var(x_L) + n_R Var(x_R)\right)$$

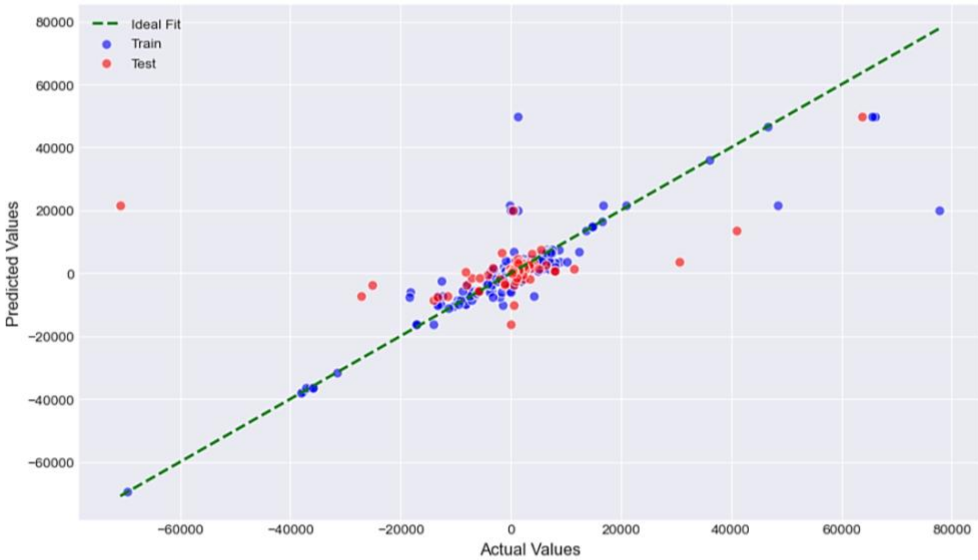
where $J(D, f, t)$ is the objective (or cost) for a potential split on feature f with a threshold t, D is the data at the current node, n_L and n_R are the number of samples in the left and right child nodes resulting from the split, n is the number of samples at the current node, $Var(x_L)$ and $Var(x_R)$ are the variance of the target variable x in the left and right child nodes, respectively.

Table 12 shows the goodness-of-fit statistics from using a decision tree model for cost overruns by randomly splitting data into the training (80%) and test (20%) datasets. We conducted a comprehensive grid search to find the superior hyperparameter set. We see that the goodness-of-fits are significantly better than using linear regressions, though the scores for the test set are still low.

Table 12. Goodness-of-Fit Summary of Cost Overrun Prediction Using Decision Tree Regression Model

	Training	Test
Mean Squared Error (MSE)	2.41e+7	1.16e+8
Mean Absolute Error (MAE)	1.56e+3	3.77e+3
R-Squared	0.782	0.130

Table 13 shows the comparison between observed and predicted cost overruns. We can see that the dummy variable for the TCEP is the most important factor for prediction. Combined with the findings from the exploratory analysis, we can conclude that TCEP indeed performed better than other programs in terms of cost control. The second important (but much less significant) factor is the reporting period FY 19-20 Q1-2 (which is for 2020 January to June), which is highly likely due to the influence of the pandemic.



Feature	Importance
Program_TCEP	0.504099
Period_FY 19-20 Q1-2	0.108681
Program_SCCP	0.076035
District_2	0.050897
District_5	0.047374
District_12	0.035926
Program_LPP-C	0.024042
Period_FY 18-19 Q4	0.022576
District_8	0.020199
District_4	0.014902
District_6	0.013359
Period_FY 22-23 Q2	0.013099
District_7	0.012517
District_10	0.012195
District_3	0.009487
District_11	0.007632
Period_FY 22-23 Q3	0.005371
Period_FY 21-22 Q3-4	0.004538
Program_SHOPP	0.003809
Program_ATP	0.003204
District_9	0.002458
District_(ALL)	0.002090
District_53	0.001714
District_75	0.001447
District_1	0.001382
Program_(ALL)	0.000856
Period_FY 22-23 Q1	0.000111

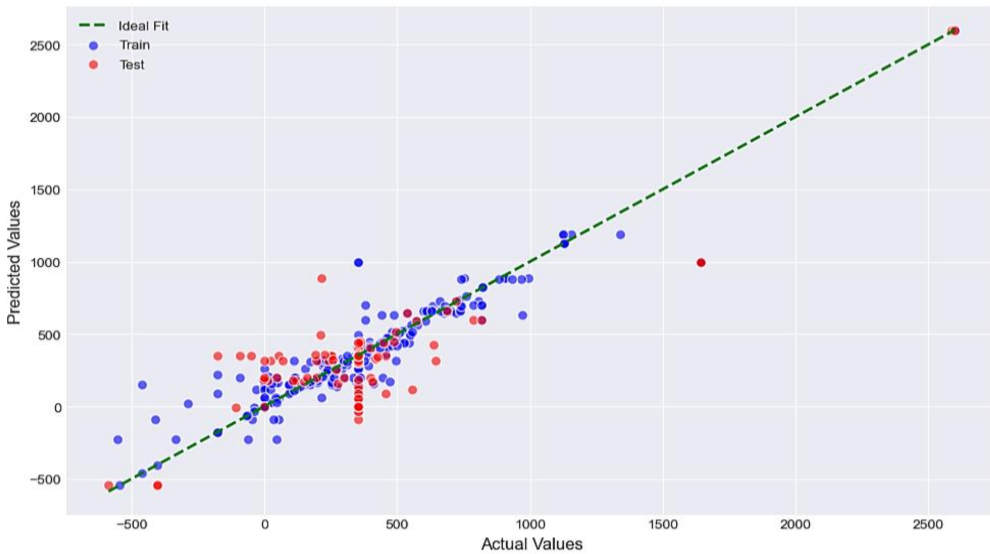
Figure 11. Cost overrun comparison (observed vs. modeled) using decision tree regression model

Table 13 shows the summary of using a decision tree model for regression analysis of schedule delays by splitting data into the training (80%) and test (20%) datasets. We conducted a comprehensive grid search to find the superior hyperparameter set. We can see that the goodness-of-fits are significantly better than using linear regressions in terms of both the training set and the test set.

Table 13. Goodness-of-Fit Summary of Schedule Delay Prediction Using Decision Tree Regression Model

	Training	Test
Mean Squared Error (MSE)	1.17e+4	4.41e+4
Mean Absolute Error (MAE)	51.45	135.17
R-Squared	0.87	0.74

Figure 12 shows the comparison between observed and predicted schedule delays. We can see that the dummy variable for the SHOPP is the most important attribute. Combined with the findings from the exploratory analysis, we conclude that SHOPP had a more concerning delay pattern than other programs. The second and third important (but much less significant) factors are the reporting period FY 18-19 Q3 (which is for 2019 January to March) and the ATP dummy. We leave the investigation of underlying reasons to future research.



Feature	Importance
Program_SHOPP	0.284191
Period_FY 18-19 Q4	0.070429
Program_ATP	0.066225
Program_LPP-C	0.061650
District_12	0.057368
Period_FY 19-20 Q1-2	0.056150
District_11	0.049924
District_8	0.045084
District_5	0.042002
Program_(ALL)	0.037632
Program_TCEP	0.037501
District_7	0.033114
District_4	0.025819
District_1	0.020847
District_10	0.020722
District_75	0.015317
District_6	0.014924
District_3	0.014715
District_(ALL)	0.013647
District_2	0.009724
Period_FY 22-23 Q3	0.007409
Program_SCCP	0.007087
District_53	0.004090
Period_FY 21-22 Q3-4	0.003929
Period_FY 22-23 Q2	0.000499
Period_FY 22-23 Q1	0.000000
District_9	0.000000

Figure 12. Schedule delay comparison (observed vs. modeled) using decision tree model

7. Discussion and Policy Suggestions

The findings of this study reveal a concerning trend of cost overruns, delays, and cancellations in transportation projects within the SB1 program. These issues, while prevalent to varying degrees, have significant implications for project management and the successful delivery of transportation infrastructure in California.

The study highlights that approximately 37 percent of the transportation projects analyzed experienced cost overruns. These overruns not only result in budgetary strain but also disrupt project timelines. The severity of overruns varies by fiscal period, program, and spatial location. Notably, the COVID-19 pandemic had a major impact on cost overruns in the fiscal year 2021-2022. These findings emphasize the need for proactive budget management and risk assessment throughout the project lifecycle.

Over 60 percent of the projects analyzed faced delays, with an average delay of around 1.5 years. The causes of delays range from weather conditions to issues with right-of-way acquisition. The upward trajectory in delays since 2018 raises concerns about project scheduling and management. Addressing these delays is critical to ensuring projects are completed on time and within budget. Approximately two percent of projects were canceled, with the major reasons being budget constraints, changes in project scope, and priority shifts. Canceling projects not only wastes resources but also hinders infrastructure development. This calls for a robust evaluation process before initiating projects to prevent unnecessary cancellations. While we could not identify the specific reasons for delays or cost overruns, the results suggest that scope changes resulting from unexpected issues, such as utility relocation and administrative coordination among agencies, are common culprits.[8] These findings underscore the importance of thorough risk assessment and contingency planning in project management.

The analysis highlights significant performance differences among programs and districts. The Trade Corridor Enhancement Program (TCEP) stands out as an example of effective budget control. This suggests the need for knowledge sharing and collaboration among programs and districts to improve project outcomes. To address the disparities in project performance, program managers, districts, and implementation phases should actively communicate and share best practices. Establishing forums for knowledge exchange can help identify effective strategies for cost and schedule management.

---

[8] Only a small portion of the project records in the corrective action plans describe the causes of delays and overruns, and these descriptions are very brief and sometimes unclear. For example, in the FY 22-23, Q3-Q4 SCCP Corrective Action Plan, Project 05-2897 was delayed because "SBCAG [Santa Barbara County Association of Governments] noted that they will request a 12-month extension for the Construction Award date to finalize design and coordination with other agencies before construction administration." But the report does not mention the reason SBCAG will need to request a 12-month extension for the Construction Award. This project aside, and based on limited data, it seems that scope changes caused by "unexpected" issues (e.g., extensive utility relocation, administrative coordination among agencies, and right-of-way acquisition) are common.

Project planners and managers should reevaluate risk assessment practices. A 20 percent contingency may not be sufficient given the severity of overruns and delays. Moreover, project cancellation likelihood should be explicitly estimated in project planning to prevent unexpected terminations. This study suggests that the COVID-19 pandemic created both challenges and opportunities for project implementation. Embracing flexible and resilient project planning and management practices can help respond to unforeseen disruptive events like pandemics, earthquakes, and economic downturns.

While SB1 releases project performance data to the public, data quality concerns remain. Agencies that are responsible for project data reporting should provide more complete and accurate information about the reasons for overruns, delays, and cancellations. This can aid policymakers and researchers in gaining a deeper understanding of underlying issues. Implementing mechanisms to reward accuracy and honesty while penalizing biased estimations can encourage agencies and third parties to provide honest and accurate information. Trackable records of estimates and actions can contribute to this effort.

8. Concluding Remarks

As we conclude this study, it is clear that the Senate Bill 1 (SB1) projects are grappling with significant challenges, chiefly characterized by cost overruns, delays, and project cancellations. Our analysis indicates that approximately 37 percent of transportation projects have experienced cost overruns, with an average overrun of $1.8 million. Delays are also prevalent, affecting over 60 percent of projects, with an average duration of around 1.5 years. Cancellations, though less frequent, affect around two percent of projects.

Program managers should acknowledge and investigate performance disparities among various programs and districts. Moreover, given the project delays and cost overruns associated with SB1 projects, program managers should also put serious effort into contingency planning. Flexible and resilient project planning is essential, particularly in response to unforeseen events like pandemics or natural disasters. Also, Improvements in data quality and transparency from SB1 are crucial for a better understanding of project challenges.

It is important to note the limitations of our study, particularly the lack of comprehensive data on the causes of cost overruns and delays. Consequently, our conclusions are based on the available data, which may not capture the full complexity of the issues at hand.

Future research should focus on a more detailed causal analysis of these overruns, delays, and cancellations, provided that sufficient and detailed data become available. Additionally, exploring the indirect costs borne by California residents due to these project inefficiencies is another important research area.

This research contributes to a clearer understanding of SB1-funded transportation projects' current status, by quantifying cost overruns, delays, and cancellations, and doing so across funding programs and geographic regions.

References

1. Flyvbjerg, B., and D. W. Bester. How (In)Accurate Is Cost-Benefit Analysis? Data, Explanations, and Suggestions for Reform. *Infrastructure Economics and Policy: International Perspectives*, 2022.

2. Flyvbjerg, B. *Over Budget, Over Time, Over and Over Again*. Oxford: Oxford University Press, 2011.

3. Flyvbjerg, B. Cost Overruns and Demand Shortfalls in Urban Rail and Other Infrastructure. *Transportation Planning and Technology*, Vol. 30, No. 1, 2007, pp. 9–30. https://doi.org/10.1080/03081060701207938.

4. Love, P. E. D., Z. Irani, J. Smith, M. Regan, and J. Liu. Cost Performance of Public Infrastructure Projects: The Nemesis and Nirvana of Change-Orders. *Production Planning & Control*, Vol. 28, No. 13, 2017, pp. 1081–1092. https://doi.org/10.1080/09537287.2017.1333647.

5. Flyvbjerg, B., M. K. Skamris Holm, and Sø. L. Buhl. What Causes Cost Overrun in Transport Infrastructure Projects? *Transport Reviews*, Vol. 24, No. 1, 2004, pp. 3–18. https://doi.org/10.1080/0144164032000080494a.

6. Shafqat, A., J. Oehmen, and T. Welo. Planning Unplanned Design Iterations Using Risk Management and Learning Strategies. *Journal of Engineering Design*, Vol. 33, No. 2, 2022, pp. 120–143. https://doi.org/10.1080/09544828.2021.1994531.

7. Cantarelli, C. C., B. Flyvbjerg, E. J. Molin, and B. Van Wee. Cost Overruns in Large-Scale Transportation Infrastructure Projects: Explanations and Their Theoretical Embeddedness. arXiv preprint arXiv:1307.2176, 2013.

8. Paraskevopoulou, C., M. Dallavalle, S. Konstantis, P. Spyridis, and A. Benardos. Assessing the Failure Potential of Tunnels and the Impacts on Cost Overruns and Project Delays. *Tunnelling and Underground Space Technology*, Vol. 123, 2022, p. 104443. https://doi.org/10.1016/j.tust.2022.104443.

9. Honnappa, D., and S. P. S. Padala. BIM-Based Framework to Quantify Delays and Cost Overruns Due to Changes in Construction Projects. *Asian Journal of Civil Engineering*, Vol. 23, No. 5, 2022, pp. 707–725. https://doi.org/10.1007/s42107-022-00451-x.

10. Aibinu, A. A., and G. O. Jagboro. The Effects of Construction Delays on Project Delivery in Nigerian Construction Industry. *International Journal of Project Management*, Vol. 20, No. 8, 2002, pp. 593–599. https://doi.org/10.1016/S0263-7863(02)00028-5.

11. Assaf, S. A., and S. Al-Hejji. Causes of Delay in Large Construction Projects. *International Journal of Project Management*, Vol. 24, No. 4, 2006, pp. 349–357. https://doi.org/10.1016/j.ijproman.2005.11.010.

12. Morris, P. W. G., and G. H. Hough. *The Anatomy of Major Projects: A Study of the Reality of Project Management*. Chichester, UK: John Wiley and Sons, 1987.

13. Williams, T., and K. Samset. Issues in Front-End Decision Making on Projects. *Project Management Journal*, Vol. 41, No. 2, 2010, pp. 38–49. https://doi.org/10.1002/pmj.20160.

14. Spalek, S. *Data Analytics in Project Management*. Boca Raton, FL: CRC Press, 2019.