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(Research Article)

A comparative analysis of project performance: Public–Private Partnership (P3) Highway Projects vs. Design-Build (DB) and Design-Bid-Build (DBB) Highway Projects

Ruchit Parekh [1, *] and Wil V Srubar [2]

[1] *Department of Engineering Management, Hofstra University, New York, USA.*

[2] *Department of Civil Engineering and Sustainability, Cornell University, Ithaca, USA.*

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Abstract

Public–private partnerships (P3) have become increasingly significant in both advanced and emerging economies in recent years. In the United States, P3 contracts have been utilized across a wide range of infrastructure sectors. However, it is crucial to evaluate how P3 projects perform in terms of cost and schedule compared to traditional project delivery methods to make informed decisions. This study focuses on comparing the performance of P3 highway projects with those delivered through design-build (DB) and design-bid-build (DBB) methods, particularly in terms of cost and schedule growth. Statistical analyses revealed that P3 highway projects showed a mean cost growth of 2.12%, whereas DB projects recorded 8.95% and DBB projects 7.27%. In terms of schedule growth, P3 projects had a mean growth of 0.59%, while DB projects experienced 37.94% and DBB projects 31.39%. These findings provide valuable insights to support decision-making for future projects, benefiting government agencies, private companies, and other stakeholders in infrastructure development. The results can assist in choosing the appropriate project delivery method, potentially minimizing disputes and project failures.

Keywords: Public–private partnerships; Highways; Project performance; Cost escalation; Schedule overrun

1. Introduction

Public–private partnerships (P3s) have gained substantial traction over the past few decades in both developed and developing countries. This growing popularity is largely attributed to the advantages P3s offer in delivering public infrastructure projects. The appeal of P3s lies in their ability to tap into new funding sources and transfer certain project risks to private entities. Governments around the world are increasingly adopting P3 models to harness the expertise and resources of the private sector, thereby addressing significant shortfalls in public infrastructure and services. In the United States, investment in P3 projects saw a dramatic rise, with the total reaching USD 83.3 billion in 2019, a notable increase from USD 19.5 billion in 2018 and USD 19.7 billion in 2017.

Key factors determining the success of construction projects are cost control and adherence to schedules, with time and budget management being critical. In the public highway construction sector, challenges like cost overruns and schedule delays have persisted over the past decade. These issues are often exacerbated by frequent change orders and poor construction management. As a result, completing projects on time and within budget while maintaining the original scope has become essential for effective project management by state departments of transportation (DOTs) across the United States. Various project delivery methods have been explored by state agencies to mitigate these risks. In this context, public–private partnerships (P3s) have emerged as a promising approach, offering potential solutions to enhance efficiency, reduce costs, and ensure timely delivery of public infrastructure projects.

* Corresponding author: Ruchit Parekh

The rise of P3s in the United States is largely a response to the increasing demands placed on the transportation system and the limitations of public funding. This method of project delivery has the potential to significantly influence the performance of P3 projects when compared to design-build and traditional delivery methods. Despite its growing popularity, the literature presents mixed outcomes regarding its success. Although P3s have been promoted as a more efficient solution for managing the cost and timeline of public infrastructure projects compared to traditional delivery methods, empirical evidence supporting this claim remains limited. Furthermore, while numerous studies have compared project performances between design-build (DB) and design-bid-build (DBB) methods in the U.S., there is a lack of research specifically comparing the cost and schedule outcomes of P3 projects with those of traditional methods in the U.S. infrastructure marke

This study sets out to evaluate the cost and schedule performance of P3 highway projects in comparison to DB and DBB projects. The research involves benchmarking P3 highway projects against DB and DBB projects by examining cost growth and schedule growth, using statistical analysis. The findings provide critical insights that can guide decision-making for future projects, which will be particularly valuable to state departments of transportation, transportation agencies, and other stakeholders involved in infrastructure development. These results will enable stakeholders to make better-informed decisions when choosing a project delivery method, ultimately helping to minimize disputes and project failures.

2. Literature Review

Public–private partnership (P3) project delivery has been applied across various sectors, including urban development, public infrastructure, transportation, healthcare, and education, by harnessing the combined expertise and resources of both public and private sectors. In urban development, P3 initiatives have resulted in the creation of sustainable communities, while in the realm of public infrastructure, they have facilitated the construction and maintenance of essential facilities such as roads and utilities. Transportation systems have also benefitted from P3s, particularly through large-scale projects like highways and public transit systems, as demonstrated by Weng et al. (2024) in their risk assessment research. Healthcare and education sectors have similarly seen improvements in service access and facility quality, as evidenced by studies like Castelblanco et al. (2023), which explored the effectiveness of P3s in healthcare settings. The study underscores the importance of strategic planning and risk management to balance stakeholder interests and ensure financial sustainability, particularly in healthcare-related P3s. Furthermore, comparative studies by Aljaber et al. (2024) on briefing frameworks and success factors for water and power P3s in developing countries provide valuable insights into effective strategies for P3 implementation globally.

Several studies have identified key factors that influence the performance of P3 projects. Arce et al. (2023) highlights the importance of conducting technical evaluations to ensure the long-term condition and performance of P3 infrastructure. Additionally, to maximize project impact and performance, integrating sustainability measures in alignment with the United Nations' Sustainable Development Goals (SDGs) is crucial. Akomea-Frimpong et al. (2022) emphasizes the necessity of incorporating such measures to ensure that P3 projects contribute positively to broader social, environmental, and economic goals. Moreover, Mazher et al. (2022) stresses the significance of risk management and effective collaboration among stakeholders as essential elements for the successful implementation of P3 projects.

Previous studies have explored the cost and schedule performance of highway projects delivered through various project methods, including P3s. For example, the Federal Highway Administration (FHWA) conducted a review of highway projects between 1990 and 2006, revealing a substantial rise in both construction and maintenance costs, which tripled between 2003 and 2006 compared to the 1990-2003 period. Fathi et al. (2020) compared the performance of highway and wastewater projects using design-build (DB) delivery in terms of change orders and schedule outcomes. While DB wastewater projects experienced fewer change orders than highway projects, DB highway projects were completed more quickly, despite having more change orders.

Research comparing P3 projects to traditional delivery methods has been conducted in mature P3 markets such as Europe and Canada, but such studies are limited in the North American context. A study by Brude et al. (2006) analyzed 200 European Investment Bank (EIB)-funded road projects and found that road construction costs to the public sector were 24% higher with P3 delivery compared to traditional methods. The study attributed these higher costs to the transfer of construction risk, which led to cost growth in projects using traditional procurement methods.

A Canadian study comparing 39 traditional projects with 27 P3 projects revealed that traditional projects had a cost growth of 28.8%, whereas P3 projects only experienced 1.22% cost growth. Similar trends were observed in terms of schedule performance, with traditional projects facing an average delay of four months, while P3 projects were completed on time. Additionally, Chasey et al. (2012) reviewed 12 completed P3 highway projects in North America and found that cost growth for P3 projects averaged 0.81%, compared to 1.49% for DB projects and 12.71% for DBB projects. In terms of schedule growth, P3 projects showed a reduction of -0.30%, whereas DB projects had a growth of 11.04% and DBB projects 4.34%.

Ramsey and El Asmar (2015) examined 25 completed mixed-type P3 projects in the U.S. to assess their cost and schedule performance against traditional project delivery methods. The study found that P3 projects had an average cost growth of 3.22% and a schedule growth of -2.97%, while DBB projects exhibited cost growth ranging from 3.6% to 25% and schedule growth from 4.34% to 33.5%. Moreover, P3 projects were completed 3.4% ahead of schedule, whereas traditional projects were finished 23.5% behind schedule, highlighting the superior performance of P3 methods compared to traditional approaches, as also demonstrated in Australia.

3. Methodology

The overall methodology utilized in this research is outlined in Figure 1. To achieve the research objectives, the study was conducted through three key steps: data collection, empirical analysis, and statistical testing. Each of these steps is further detailed in the sections below.

3.1. Data Collection

The study gathered construction cost and schedule data from highway projects delivered through three different project delivery methods: Public–Private Partnerships (P3), Design-Build (DB), and Design-Bid-Build (DBB). This data was essential for assessing project performance, particularly in terms of whether projects were completed within their expected timelines and budgets. Since the project data covered a wide range of timeframes, a normalization process was implemented to account for cost changes over time. The cost normalization utilized indices from the National Highway Construction Cost Index (NHCCI), as outlined in Table 1, ensuring that all costs were adjusted to reflect equivalent values as of December 2022.

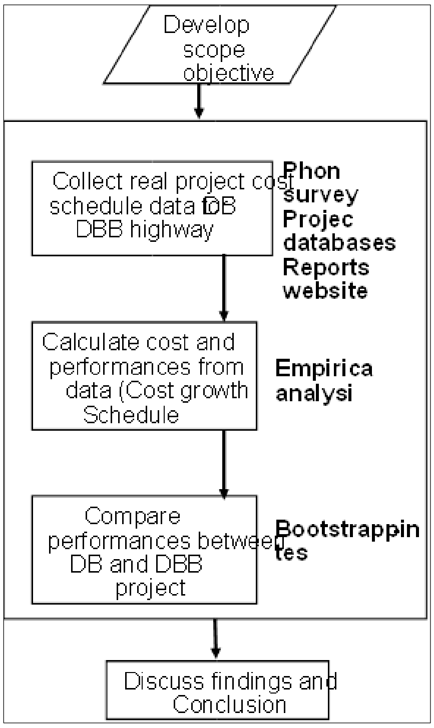

Figure 1 Study methodology

Table 2 provides an overview of the number of projects, their locations, project sizes, and completion years for the highway projects included in this study. Data related to project location (state), type of contract, construction completion year, estimated and final project costs, as well as estimated and final project durations, were gathered from various state departments of transportation (DOTs), published reports, and online databases. The study focused on projects with a budget exceeding USD 25 million. Most of the projects were located in Texas, California, Florida, and Virginia, and the data were sourced from their respective state DOTs. During the data collection process, specific details such as elevation, ground type, number of lanes, and road dimensions (length and width) were not collected, as the study's primary goal was to analyze relative performance metrics like cost growth and schedule growth. While these additional factors can influence the absolute cost per lane mile, they do not affect the percentage growth in cost and schedule, which was the key focus of this study. Therefore, only the relevant data for cost and schedule growth were collected.

Table 1 Data collection

Year Quarters		**NHCCI Index**	
2022Q1		2.28	
2022Q2		2.56	
2022Q3		2.79	
2022Q4		2.76	
Number of Project Delivery Projects	State	Project Size	Completion Year
Public–Private Partnerships	Texas, California, Florida	Greater than 100 million	2007–2020
Design-Build	Florida, Arizona, Maryland, Texas	Greater than 25 million	2009–2020
Design-BidBuild	Texas, Florida	Greater than 25 million	Texas: 2016–2020 Florida: 2018–2021

This study conducted an empirical analysis to evaluate and compare the performance of highway projects delivered through Public-Private Partnerships (P3), Design-Build (DB), and Design-Bid-Build (DBB) methods. The objective was to assess the differences in cost and schedule growth associated with each delivery method. Project cost and schedule metrics were developed to evaluate the performance across these delivery methods.

To establish project cost metrics for P3 and DBB projects, data on both the estimated and actual costs were collected. For assessing schedule growth, data on estimated and actual construction durations were gathered. Metrics were calculated using equations (1) and (2).

3.2. Research Hypotheses

The hypotheses proposed for this research are as follows:

- Hypothesis 1: Highway projects employing the Public-Private Partnership (P3) delivery method are expected to show superior performance in both cost and schedule compared to those using the Design-Build (DB) approach.
- Hypothesis 2: Highway projects utilizing the P3 delivery method are projected to experience lower cost increases and fewer schedule delays compared to projects using the Design-Bid-Build (DBB) method.
- Hypothesis 3: Highway projects that use the Design-Build (DB) delivery method are anticipated to perform better in terms of cost and schedule compared to those following the Design-Bid-Build (DBB) method.

These hypotheses were formulated into a null hypothesis to assess if there are statistically significant differences in cost and schedule performance among highway projects using P3, DB, and DBB delivery methods. The null hypothesis posits that there are no significant differences in performance metrics between P3, DB, and DBB projects.

3.3. Statistical Testing

To assess the null hypothesis established for this research, statistical tests were required to determine if there were significant differences in project performance. These tests rely on certain assumptions to ensure accuracy and reliability. The study aimed to compare the performance of projects delivered through the Public-Private Partnership (P3) method with those using the Design-Build (DB) and Design-Bid-Build (DBB) methods, focusing on whether notable differences existed between the groups by analyzing their means.

The t-test is commonly used for comparing the means of two groups, and its effectiveness depends on several key assumptions:

- the independence of datasets,
- normality of data, and
- homogeneity of variances among groups [23].

Data were collected from various state agencies and were independent, meaning the observations were not related. To verify the normality of data, Kolmogorov-Smirnov tests were performed to assess if the cost and schedule growth data for the P3, DB, and DBB projects followed a normal distribution. Results, as detailed in the Results section, showed that both cost growth and schedule growth data deviated from a normal distribution, indicating non-normality. Levene's test was used to evaluate the equality of variances for cost and schedule growth among the three delivery methods. The results indicated unequal variances in schedule growth among these groups.

Given the non-normal distribution of the data and unequal variances, coupled with relatively small sample sizes, a bootstrapping t-test was selected as the preferred statistical method. This approach is suitable for comparing group performances while accommodating non-normal distributions. Although non-parametric tests like the Mann-Whitney U test are typically used for comparing central tendencies between two independent groups, the bootstrapping t-test was deemed more appropriate for this study. Unlike traditional t-tests, which assume equal variances, the bootstrapping test does not require this assumption and does not need to check for statistical similarity of variances among project groups [25]. Thus, the bootstrapping t-test was employed to evaluate cost and schedule performance differences across different delivery methods despite the data's non-normality and the small sample sizes.

In this study, a bootstrapping t-test was utilized to determine whether there were significant differences in cost and schedule growth among projects using the P3, DB, and DBB delivery methods. This resampling technique is particularly effective when traditional parametric test assumptions are not satisfied, such as with non-normally distributed data [26]. When data do not meet the normality assumption, a bootstrapping t-test is suitable for identifying significant differences between data groups.

The core of bootstrapping involves generating a distribution of t-statistics by repeatedly resampling the dataset with replacement. According to recent research by Zhao et al. (2021), the bootstrap t-test has been shown to offer superior accuracy compared to traditional t-tests in various testing scenarios [27]. This method allows for the computation of the t-test statistic's sampling distribution, even when data do not conform to normal distribution [27,28]. Figure 2 illustrates the specific bootstrapping methodology used in this research.

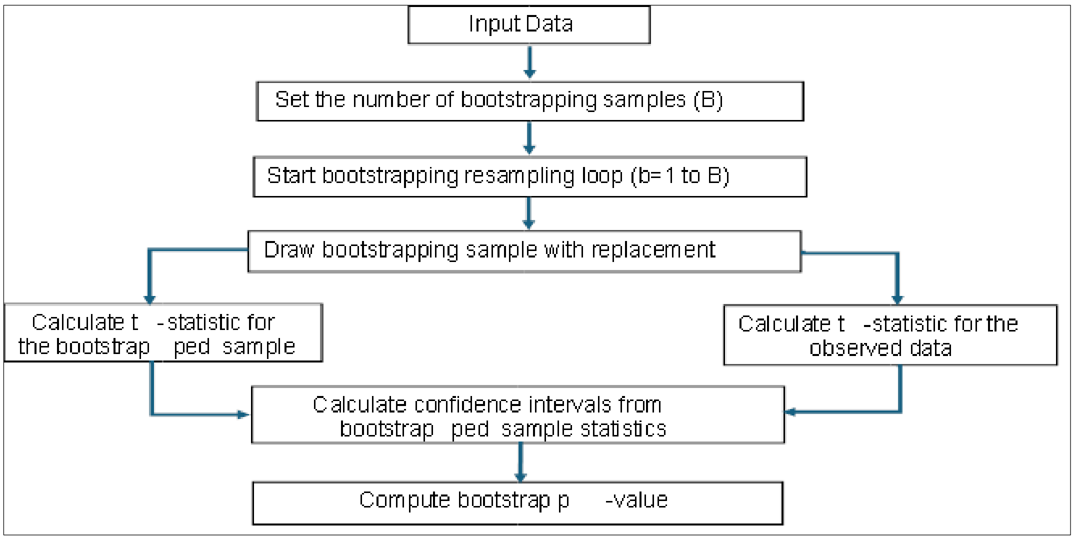

Figure 2 Bootstrapping methodology

4. Results

This section is divided into two sub-sections. The first provides an overview of descriptive statistics related to the cost and schedule performance for P3, DB, and DBB projects. The second sub-section details the results of a bootstrapping t-test used to assess significant differences in cost and schedule growth among these project delivery methods.

4.1. Descriptive Statistics

Descriptive statistics were calculated for cost growth and schedule growth in highway projects delivered through P3, DB, and DBB methods. Figures 3 and 4 display the average cost growth and schedule growth across the dataset for these delivery methods. For highway projects using the P3 delivery method, the average cost growth was 2.12%. In comparison, DB and DBB projects showed higher cost increases of 8.95% and 7.27%, respectively, relative to their initial estimates. Regarding schedule growth, P3 projects saw a 0.59% increase in their timelines, while DB and DBB projects experienced much greater schedule expansions of 37.94% and 31.39%, respectively.

4.2. Results for t-Test Assumptions

Kolmogorov-Smirnov normality tests revealed that the p-value for cost growth data across all highway project groups was less than 0.001, indicating that the data did not conform to a normal distribution and deviated from the standard normal curve. The results of the normality tests for cost growth in P3, DB, and DBB highway projects are summarized in Table 3, with Q-Q plots for these tests shown in Figure 5.

Table 2 Normality Test Statistics for Cost Growth

Cost Growth	Statistic	Degree of Freedom	Significance
Public–Private Partnerships	0.280	31	<0.001
Design-Build	0.221	40	<0.001
Design-Bid-Build	0.151	50	<0.001

Table 4 presents the results of the normality tests for schedule growth data across highway projects using the P3, DB, and DBB delivery methods. Figure 6 depicts the corresponding Q-Q plots for these tests. The Kolmogorov-Smirnov normality tests indicate that the p-value for schedule growth data in P3 and DB projects was less than 0.001, while for DBB projects, it was 0.033 (both values are below the significance level of 0.05). These results strongly suggest that the schedule growth data do not follow a normal distribution and deviate from the standard normal distribution curve.

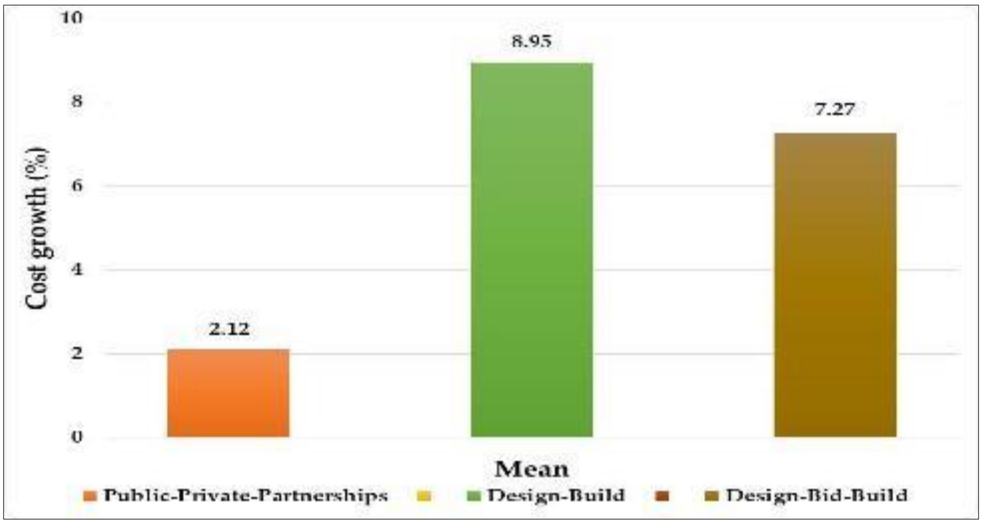

Figure 3 Mean cost growth for highway projects under three project delivery methods

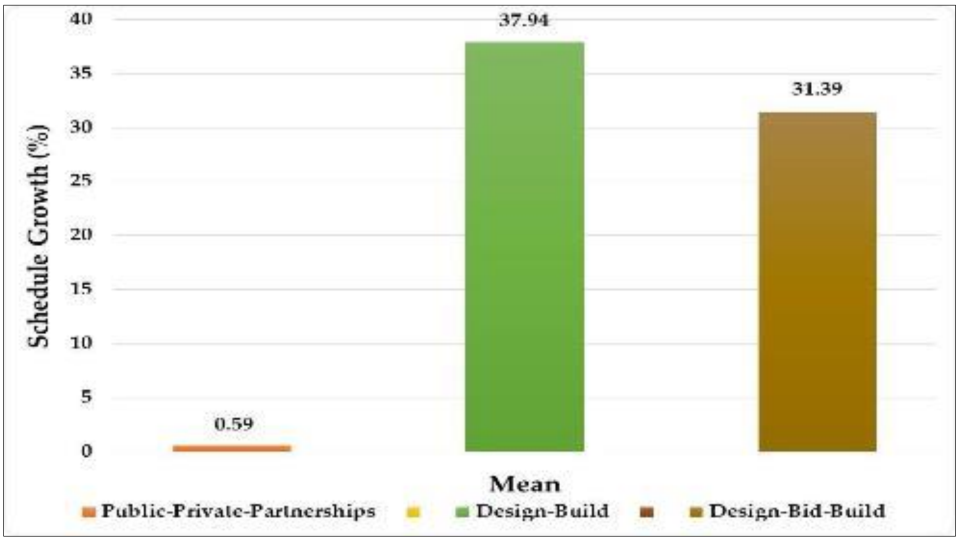

Figure 4 Mean schedule growth for highway projects under three project delivery methods

To assess the equality of variances among the groups for cost growth and schedule growth in P3, DB, and DBB projects, Levene's test was conducted. The results are summarized in Table 5. For cost growth, Levene's test indicated that the variances were equal across the P3, DB, and DBB projects, as the p-values exceeded the significance threshold of 0.05, confirming that the assumption of equal variances was met [23]. In contrast, for schedule growth, the test results revealed unequal variances among the three project delivery methods, as the p-values were below the significance threshold of 0.05, indicating a violation of the equal variances assumption.

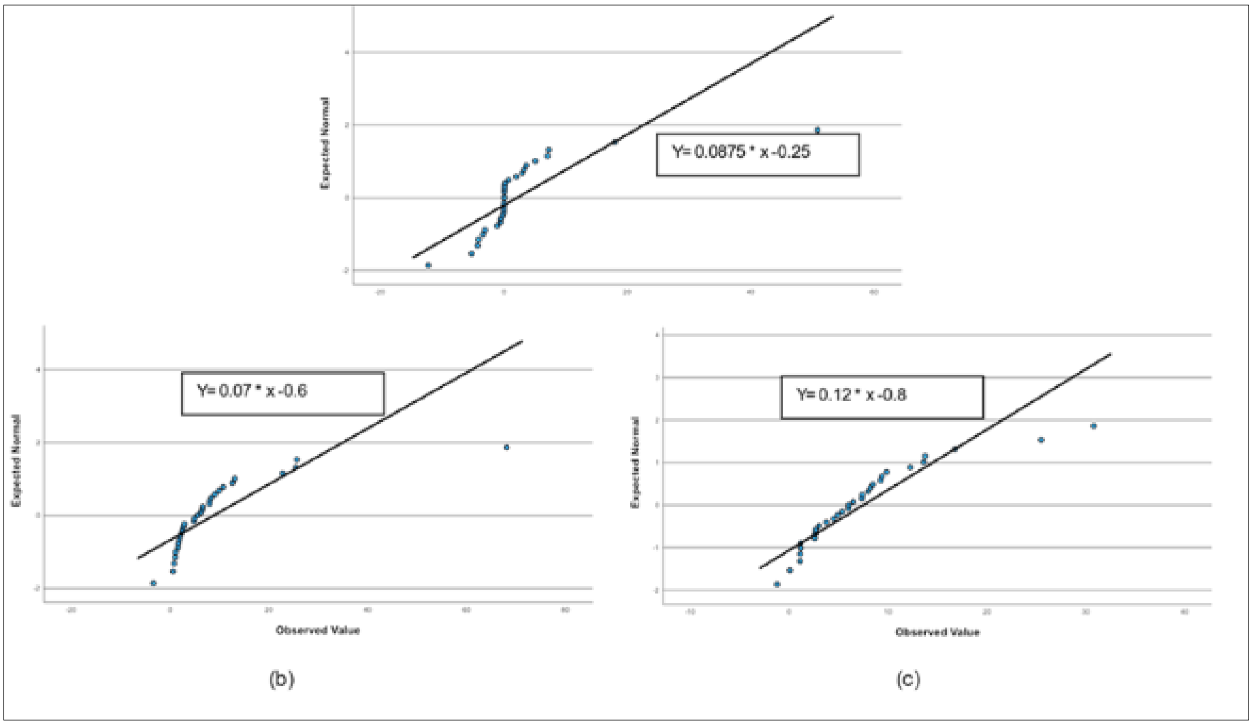

Figure 6 Q-Q plots for schedule growth. (a) Public–private partnership projects. (b) Design-build projects. (c) Design-bid-build projects

Table 3 Project Delivery Stats

Project Delivery	Performance Metrics	Levene's Statistic	Significance
Public–Private Partnerships vs. Design-Build	Cost Growth	1.6	0.21
	Schedule Growth	27.18	<0.001
Public–Private Partnerships vs. Design-Bid-Build	Cost Growth	0.035	0.853
	Schedule Growth	8.709	0.004
Design-Build vs. Design-Bid-Build	Cost Growth	2.805	0.098
	Schedule Growth	11.186	0.001

Table 4 Bootstrapping- test statistics

Performance Metrics	Project Delivery	t-Statistic	Significance
Cost Growth	Public–Private Partnerships	2.12	0.017*
	Design-Build	8.95	
	Public–Private Partnerships	2.12	0.023
	Design-Bid-Build	7.27	
	Design-Build	8.95	0.502
	Design-Bid-Build	7.27	
Cost Growth	Public–Private Partnerships	0.59	<0.001 *
	Design-Build	37.94	
	Public–Private Partnerships	0.59	<0.001 *
	Design-Bid-Build	31.39	
	Design-Build	37.94	0.241
	Design-Bid-Build	31.39	

Statistically significant at alpha level 0.05.

4.3. Cost Performance Comparison

This section discusses the cost performance results for the P3, DB, and DBB project delivery methods.

4.3.1. Cost Growth of Public-Private Partnerships vs. Design-Build Projects

The bootstrapping results show that DB highway projects had a mean cost growth of 8.95%, compared to 2.12% for P3 highway projects. The t-test produced a p-value of 0.017, which is below the significance level of 0.05, indicating that the difference between the mean cost growth of P3 and DB projects is statistically significant [23]. This suggests that P3 projects performed significantly better in terms of cost growth compared to DB projects.

4.3.2. Cost Growth of Public-Private Partnerships vs. Design-Bid-Build Projects

For DBB highway projects, the mean cost growth was 7.27%, whereas P3 projects had a mean cost growth of 2.12%. The t-test yielded a p-value of 0.023, which is also below the significance threshold of 0.05, indicating a statistically significant difference between the cost growth of P3 and DBB projects [23]. This implies a notable difference in cost performance between the two groups, with P3 projects demonstrating better cost control than DBB projects.

4.3.3. Cost Growth of Design-Build vs. Design-Bid-Build Projects

The analysis shows that DB highway projects had a mean cost growth of 8.95%, whereas DBB highway projects had a mean cost growth of 7.27%. The t-test results yielded a p-value of 0.502, which is greater than the significance level of 0.05, indicating that the difference between the mean cost growth of DB and DBB projects is not statistically significant [23]. This suggests that there is no meaningful distinction in cost performance between DB and DBB projects.

4.4. Schedule Performance Comparison

This section presents the results regarding the schedule performance of P3, DB, and DBB project delivery methods.

4.4.1. Schedule Growth of Public-Private Partnerships vs. Design-Build Projects

The bootstrapping t-test results show that DB highway projects had a mean schedule growth of 37.94%, while P3 highway projects had a mean schedule growth of 0.59%. The p-value of <0.001, which is below the significance level of 0.05, indicates that the difference in schedule growth between P3 and DB projects is statistically significant [23]. This suggests a significant difference in schedule performance, with P3 projects demonstrating better schedule control compared to DB projects.

4.4.2. Schedule Growth of Public-Private Partnerships vs. Design-Bid-Build Projects

The results indicate that DBB highway projects had a mean schedule growth of 31.39%, while P3 highway projects had a mean schedule growth of 0.59%. The p-value of <0.001, significantly less than 0.05, strongly suggests a statistically significant difference between the two groups [23]. This highlights a meaningful difference in schedule performance, with P3 projects showing better performance in terms of schedule control compared to DBB projects.

4.4.3. Schedule Growth of Design-Build vs. Design-Bid-Build Projects

The bootstrapping t-test results show that DB highway projects had a mean schedule growth of 37.94%, whereas DBB highway projects had a mean schedule growth of 31.39%. The t-test produced a p-value of 0.008, which is significantly less than 0.05, indicating a statistically significant difference in mean schedule growth between these two groups [23]. This suggests a meaningful distinction in schedule performance, with DB projects exhibiting higher schedule growth compared to DBB projects.

The study found statistically significant differences in cost performance between P3 and DB projects. Specifically, the cost and schedule growth for P3 and DB projects were slightly higher than those reported by Fathi and Shrestha (2022) [6]. This suggests that while P3 and DB projects generally performed well, recent trends or specific factors may have led to higher-than-expected growth in cost and schedule for these project types. However, the cost performance findings are consistent with earlier research by Zhang et al. (2020) and Ramsey and El Asmar (2015) [19,20]. Zhang et al. (2020) reported that P3 projects in Canada had an average cost growth of just 1.22%, compared to 28.8% for traditional projects. Similarly, Ramsey and El Asmar (2015) found that P3 projects had a cost growth average of 3.22%, significantly lower than the 3.6% to 25% range observed for DBB projects. Factors contributing to cost growth in highway projects include changes in scope, design errors, material price increases, and ineffective project management. However, in P3 and DB projects, the likelihood of design errors is reduced because the design-builders handle both design and construction, which may explain why these projects had lower cost growth compared to DBB projects.

Furthermore, the examination of highway project schedule performance corroborates the findings of Ramsey and El Asmar (2015) and Chasey et al. (2012), suggesting that P3 projects generally demonstrate superior schedule performance compared to traditionally managed projects [1,20]. This can be attributed to the integrated approach of P3 projects, where a single entity oversees design, construction, and often maintenance, leading to more streamlined processes and fewer delays. Although there were statistically significant differences in schedule performance between P3 and DBB projects, no significant differences were observed between DB and DBB projects. This indicates that while P3 projects exhibit a notable advantage in schedule performance over both DB and DBB projects, the difference between DB and DBB projects is less significant. Factors contributing to schedule delays in highway projects include scope creep, design errors, and ineffective project management. In P3 projects, the likelihood of scope creep and design errors is reduced since the design-builder and owner collaborate closely on the project scope and design. As a result, the study found that P3 projects experienced less schedule growth compared to both DB and DBB projects

5. Conclusion

The adoption of the Public-Private Partnership (P3) delivery method for highway projects in the United States has seen significant growth over the past decade. This study aimed to evaluate whether P3 highway projects offer cost and schedule advantages over those delivered through Design-Build (DB) and Design-Bid-Build (DBB) methods. To address this, cost and schedule data were collected from DB, DBB, and P3 highway projects completed in the U.S. since 2007. Projects were selected from similar geographical regions and had comparable costs to minimize variability.

The analysis of performance metrics revealed that P3 highway projects had a mean cost growth of 2.12%, significantly lower than the 8.95% growth for DB projects and 7.27% for DBB projects. In terms of schedule growth, P3 projects experienced an average increase of 0.59%, compared to 37.94% for DB projects and 31.39% for DBB projects. These results indicate that P3 projects generally demonstrate superior cost and schedule performance compared to DB and DBB projects.

The findings highlight the effectiveness of the P3 approach in managing project costs and schedules more efficiently. The collaborative nature of P3 projects, involving both public and private sectors, appears to offer substantial advantages in highway construction. This suggests that P3s could be a viable option for government agencies, such as state departments of transportation, seeking to deliver large-scale highway projects more cost-effectively and with better adherence to schedules.

Nevertheless, while the study's conclusions are supported by empirical data, further research is needed to explore the specific factors contributing to the cost and schedule advantages observed in P3 projects. Future studies should investigate additional variables that may impact performance and validate these findings across diverse project settings and geographical regions.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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