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Evaluating Skilled Labor Shortage Impacts on Construction Cost and Schedule: A Case Study of the California High-Speed Rail Project

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The U.S. construction industry continues to face a critical shortage of skilled workers due to rising infrastructure demand alongside an aging workforce. This research examines the California High-Speed Rail (CAHSR) project to assess the impact of skilled labor shortages on cost and schedule performance, as well as effective responses. A qualitatively driven mixed-methods design was adopted, with a combination of a targeted literature review, analysis of California High-Speed Rail Authority (CHSRA) business plans and labor data (2021-2024), and semi-structured interviews with CAHSR project stakeholders. The findings reveal that labor shortages are linked to higher costs associated with wage inflation, overtime premiums, and extended project durations; while schedule risks stem from delays on critical-path activities, task resequencing, reliance on overtime, and reduced flexibility. The study also highlights the limitations of short-term solutions and the importance of scalable, long-term workforce planning strategies such as internal workforce development, targeted recruitment, early planning, and selective technology adoption. These insights can inform comparable megaprojects seeking greater performance control and delivery resilience.

Keywords: Workforce Shortage, Skilled Labor, California High-Speed Rail, Infrastructure

Introduction

The construction industry in the United States is experiencing sustained workforce pressures, with an estimated 649,300 annual openings projected from 2024 to 2034 (U.S. Bureau of Labor Statistics, 2024). Skilled labor shortages have been identified as a major challenge affecting project performance, particularly in labor-intensive construction trades such as electrical, plumbing, and ironworking (Elbashbishy & El-Adaway, 2024). These challenges are especially consequential in infrastructure megaprojects, where the coordination of specialized crafts are essential to project success. In this study, labor shortage is defined as constraints in the timely availability of skilled construction labor required to meet planned staffing levels during specific project phases. The California High-Speed Rail (CAHSR) project, the nation's first high-speed rail project (California High-Speed Rail Authority, n.d.), provides an excellent case study for examining the systemic effects of labor shortages on cost, schedule, and delivery performance.

The root causes of the labor challenge are diverse. Declining participation in vocational programs, an aging population, and stricter immigration policies have contributed to a decline in the skilled labor industry (Karimi et al., 2018; Ceric & Ivic, 2020). These difficulties are exacerbated by competition from simultaneous infrastructure projects such as renewable energy plants and road expansions, which further constrain worker availability in California (CAISO, 2024). The impacts are significant, including delays in foundational work, increased reliance on overtime, and cost overruns of up to 19% (Hanna et al., 2005; Adam et al., 2017).

In response, CAHSR stakeholders have established mitigation measures, including local training centers, prefabrication, drone-based surveillance, and recruitment from outside the region. While these initiatives have offered assistance, they frequently fall short of addressing the underlying causes of labor shortages. The use of technology, such as Building Information Modeling (BIM) and modular construction, has shown promise; however, it requires a tech-ready workforce that is still being developed (Mai et al., 2025; Linares-Garcia & Roofigari-Esfahan, 2024).

This study employs a qualitatively driven mixed-methods approach, including a structured, targeted review of academic literature and California High-Speed Rail Authority (CHSRA) labor and business reports (2021–2024), and semi-structured interviews with industry professionals involved in the CAHSR project. The purpose is to examine the multidimensional effects of labor shortages and the effectiveness of mitigation solutions. The central research questions (RQs) guiding this study are:

- RQ1. How do labor shortages contribute to delays and cost overruns in the CAHSR project?
- RQ2. Which strategies have been effective in mitigating labor-shortage impacts on the CAHSR project, and what lessons can inform future infrastructure projects?

By addressing these questions, the study aims to provide actionable insights for workforce planning and resilience in future U.S. infrastructure megaprojects.

Literature Review

The construction sector is facing a significant shortage of skilled workers, particularly for large-scale infrastructure projects. This literature analysis combines findings from academic research and industry reports to investigate the origins, consequences, and mitigation solutions for labor shortages in construction megaprojects, with a focus on the CAHSR project.

Academic Research Review

Causes of Skilled Labor Shortages

Labor shortages in the construction industry are caused by a combination of demographic, educational, and policy factors. Riccardi (2016) discusses the aging workforce and the decreased interest of younger generations in traditional occupations. Specialized projects, such as CAHSR, require specialized skills in electrification and precision track installation, which are not widely available in the general labor market (Karimi et al., 2018). Immigration restrictions have also limited the availability of migrant labor, a critical component of the construction industry that was previously a significant source of labor (Ceric & Ivic, 2020). According to Johari and Jha (2019), negative perceptions about construction labor continue to depress enrollment in vocational programs, thereby limiting the supply of certified, trade-qualified workers. The recent COVID-19 epidemic further intensified existing labor shortages and delayed workforce development.

Cost Implications

Labor shortages have been strongly connected to rising project costs. Karimi et al. (2018) indicate cost overruns of up to 19% due to wage inflation, delayed procurement schedules, and decreased productivity. Contractors often pay wage incentives and provide relocation incentives, which increase both direct and indirect expenses (Johari & Jha, 2019; Hanna et al., 2005). However, these solutions do not create new skilled labor; rather, they relocate current labor from one place to another, disrupting project budgets (Mai et al., 2025). Overtime is frequently used to compensate for staffing gaps, but productivity declines by 15–20% when workers exceed 50 hours per week (Hanna et al., 2005, 2008). This results in diminished cost-efficiency and increased fatigue-related risks.

Schedule Delays

Labor shortages also cause substantial schedule delays. Adam et al. (2017) observe that delays in foundational tasks, such as electrification and system integration, have a knock-on effect on dependent operations, including track laying and signaling. According to Karimi et al. (2018), in labor-constrained situations, even slight delays in vital path tasks can deplete available float and extend total project timelines. Overtime and constrained schedules reduce flexibility, increasing the likelihood of accidents and interruptions (Hanna et al., 2008). Seasonal labor shortages, particularly during the summer months, exacerbate scheduling difficulties, especially in megaprojects with intricate interdependencies.

Mitigation Strategies

To overcome labor shortages, several mitigating methods have been proposed and implemented. *Training initiatives and public-private partnerships* aim to expand the local labor pool by targeting underserved communities and unemployed individuals (Won et al., 2021). *Apprenticeships and vocational training* are considered the most durable and long-term alternatives (Aiyetan & Dilip, 2018). *Flexible procurement techniques*, such as design-build delivery, enable contractors to better mobilize labor (Nasirian et al., 2019). *Prefabrication and modular construction* reduce on-site labor demands, with studies indicating labor reductions of up to 30% in certain components (Azhar, 2011; Mai et al., 2025). However, successful adoption requires a technologically savvy workforce, which remains a hurdle (Linares-Garcia & Roofigari-Esfahan, 2024). *Recruitment incentives*, including bonuses and wage increases, have had limited success. While they temporarily attract workers, they do not address structural labor shortages and often increase overall project costs (Hanna et al., 2008; Elbashbishy & El-adaway, 2024).

Review of CHSRA Reports (2021–2024)

In addition to scholarly sources, this study reviewed publicly available reports from the CHSRA, including its biennial business plans and monthly labor data published between 2021 and 2024. These documents provide an applied context for understanding the dynamics of skilled labor availability, cost escalation, and scheduling complexity discussed in the academic literature. This review establishes an empirical foundation for subsequent analysis, linking theoretical perspectives on labor shortages and mitigation strategies to documented practices within the CAHSR project. The detailed findings from this document review are presented in Results and Findings section.

Research Design

This study adopts a qualitatively driven mixed-methods research design to investigate the impacts of skilled labor shortages on cost and schedule performance in the CAHSR project. The methodology comprises two core components: (1) a structured, targeted review of academic literature and CHSRA

labor and business reports (2021–2024), and (2) semi-structured interviews with industry professionals involved in the CAHSR project. This triangulated approach ensures a comprehensive understanding of the issue by combining theoretical insights, empirical data, and practitioner perspectives.

Literature and Document Review Approach

A targeted review of scholarly publications between 2000 and 2025 on skilled labor shortages in construction megaprojects was conducted using Scopus, Web of Science, Engineering Village, and Google Scholar. The search initially generated approximately 980 records, which were then screened for relevance, yielding 140 abstracts and ultimately, 32 full-text empirical studies that addressed cost, schedule, or mitigation dimensions for inclusion. In parallel, CHSRA documents (2021–2024), including biennial business plans (issued in even years, CHSRA, 2021–2024) and monthly labor updates (recorded in board meeting minutes, CHSRA, 2021–2024), were examined for evidence on workforce availability, schedule risk, and mitigation initiatives. Findings from both sources informed the interview protocol and provided a baseline for triangulation.

Interview Instrument Design and Alignment

To gain practical insights, semi-structured interviews were conducted with professionals directly involved in the CAHSR project. Participants included general contractors, project managers, engineers, and union representatives overseeing trades such as welding, concrete, steelwork, and electrical systems. The 14-item interview instrument was developed from preliminary insights identified in the literature review and aligned with the two research questions. Interview questions covered staffing levels, root causes of shortages, schedule and cost impacts, mitigation strategies, recruitment efforts, and the use of technology. The complete protocol is available upon request.

Interview Data Collection and Handling

The research protocol was approved by California State University, Fresno's Institutional Review Board (IRB Protocol #2860), and informed consent was obtained from all participants. Eight interviews were conducted between March and April 2025 using a purposive sampling strategy, supplemented by snowball recruitment. Interview participants were individual professionals with more than two years of experience serving in project management and construction oversight roles within general contractor (GC) or project and construction management (PCM) organizations on the CAHSR project. PCM firms provide owner-side oversight on behalf of the CHSRA, while GCs execute construction work. Each interview lasted between 30 and 60 minutes and was conducted via Zoom or Google Meet. With participant consent, all sessions were audio-recorded, transcribed verbatim, and de-identified for analysis. Transcripts were manually coded and analyzed using thematic clustering, with codes structured around the impacts of cost and schedule, as well as mitigation strategies. **Table 1** summarizes the interview participants by employer type (i.e., GC or PCM), job role, their CAHSR construction package # (CP #), and the trades they oversee.

Table 1. Profiles of Interview Participants on the CAHSR Project

Interviewee #	Employer Type	Job Role	CP #	Trade workers
1	GC	Project Manager	CP 2-3	Heavy equipment, Iron, Carpenter, Concrete workers

# 2	GC	Project Handover Specialist	CP 1	Heavy equipment, Iron, Carpenter, Concrete workers, Welding, Track laying
# 3	GC	Earthwork /Structures Manager	CP 2-3	Heavy equipment, Iron, Carpenter, Concrete workers
# 4	PCM	Quality Control Manager	CP 1	Heavy equipment, Iron, Carpenter, Concrete workers
# 5	GC	Utilities Engineer	CP 2-3	Heavy equipment, Iron, Carpenter, Concrete workers
# 6	GC	Project Engineer	CP 2-3	Heavy equipment, Iron, Carpenter, Concrete workers
# 7	GC	Design Manager	CP 2-3	Heavy equipment, Iron, Carpenter, Concrete workers, Electrification
# 8	GC	Field Engineer	CP 2-3	Heavy equipment, Iron, Carpenter, Concrete workers

Data Analysis Strategy

A hybrid deductive-inductive thematic analysis was applied. An a priori framework, informed by the literature, guided the initial coding into three core thematic categories: *Cost Impacts*, *Schedule Impacts*, and *Mitigation Strategies*, while inductive coding allowed subthemes to emerge from the interview transcripts and CHSRA documents. Subthemes were consolidated within each category, and their frequency across participants was recorded to indicate relative prevalence. To strengthen reliability, findings were triangulated across interviews, CHSRA documents, and academic literature. The following section presents these results, accompanied by supporting quotes and literary evidence.

Results and Findings

This section presents the key findings derived from three primary sources: (1) document analysis of CHSRA labor and business reports from 2021 to 2024, (2) thematic analysis of eight semi-structured interviews with professionals involved in the project, and (3) synthesis of literature on labor shortages in construction megaprojects.

Findings from CHSRA Reports (2021-2024)

A longitudinal document review was conducted using monthly labor data and biennial business plans published by the CHSRA between January 2021 and July 2024. The review focused on three key areas: *Workforce Availability Challenges, Project Staging and Delays*, and *Training and Hiring Initiatives.*

A descriptive quantitative analysis of CHSRA workforce data (2021–2024), as recorded in monthly board meeting minutes (CHSRA, 2021–2024), was conducted to contextualize the study's qualitative findings. **Figure 1** presents labor trends by construction package (CP1: initial section; CP2-3: central corridor; CP4: peripheral systems) from January 2021 to July 2024. CP2-3 remained the most labor-intensive segment, driving the overall increase in the workforce; CP1 showed moderate and consistent growth; and CP4 displayed volatility, with a sharp decline after mid-2023, reflecting the project phase-out. The early disruption phase (2021–2022) coincided with heightened workforce management

challenges associated with extended heavy-rain periods and COVID-19 quarantines, whereas peaks in 2023–2024 align with intensified labor-intensive activities, such as track laying and electrical integration. It is worth noting that labor shortages on CAHSR are not characterized by falling total headcount but by mismatches between labor demand and labor availability at specific times, locations, and construction packages. These trends provide context for the interview-based analysis of cost and schedule impacts.

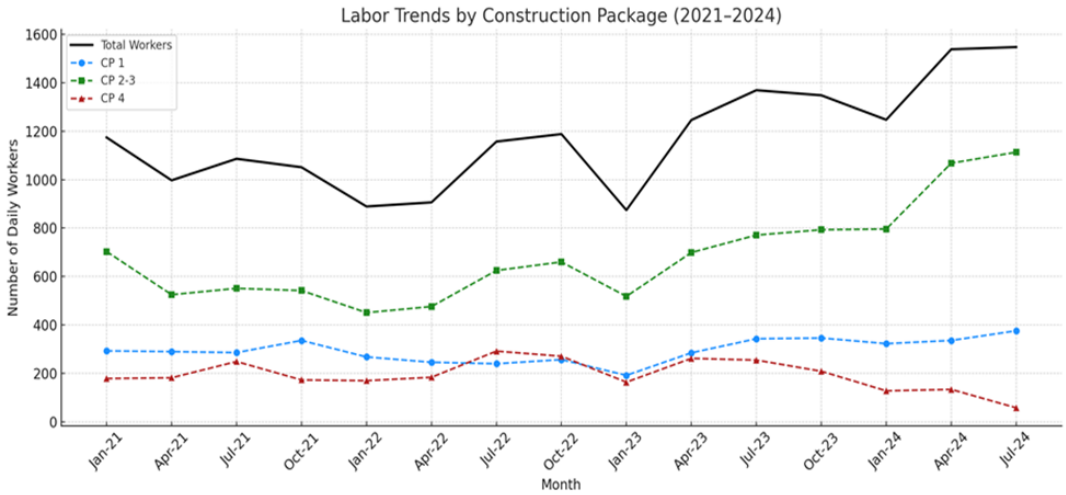

Figure 1. Labor trends by construction package on CAHSR (2021–2024)

Interview Findings and Thematic Integration

Findings from the interviews were triangulated with insights from the academic literature and CHSRA documents. Three core thematic categories aligned with research questions **RQ1** and **RQ2** were identified, with subthemes illustrating specific mechanisms within each category. Reported frequencies indicate the number of interviewees referencing each subtheme. They reflect prevalence rather than independent thematic dominance.

Cost Impacts of Skilled Labor Shortages

Table 2 addresses **RQ1** by showing how skilled labor shortages contribute to cost overruns on the CAHSR project through wage inflation, overtime reliance, and extended project durations - mechanisms that go beyond general market inflation. Interviewee 4 noted, "*We've had to raise wages to attract qualified trades.*" Overtime was frequently used to backfill gaps to maintain progress, but it strained the budget, as Interviewee 6 stated, "*Overtime pay surged due to working six-day weeks*." Overall, these findings align with the literature, which suggests that labor shortfalls contribute to cost overruns in infrastructure projects.

Table 2. Thematic summary: cost impacts of skilled labor shortages

Subtheme	Key Insights	Frequency (out of 8)	Research Question
Wage Inflation for Scarce Skills	Rising wages are needed to retain limited skilled labor in competitive markets	7	RQ1

Daily Overhead from Delays	Delays increase indirect costs such as equipment rental, security, and project management	6	RQ1
Overtime and Acceleration Costs	Extra work hours and weekends inflate labor costs and reduce cost-efficiency due to fatigue	6	RQ1
Extended Project Duration	Prolonged timelines result in sustained costs for staffing, oversight, and overhead	5	RQ1
Training and Turnover Costs	Turnover requires repeated onboarding and training, adding to resource strain	4	RQ1

Schedule Disruptions Due to Labor Shortages

Table 3 further addresses **RQ1** by illustrating how skilled labor shortages have caused widespread scheduling disruptions on the CAHSR project, resulting in delays on critical-path activities, task resequencing, and reduced flexibility to address unforeseen events. Interviewee 3 noted, "*We had to resequence work due to hiring delays*," while Interviewee 7 reported that "*Lack of carpenters delayed bridge work and track laying*." Seasonal spikes in regional demand further intensified shortfalls. While targeted regional hiring helped mitigate delays, it was not always sufficient to prevent schedule slippage (Interviewee 4). Overtime was often used to maintain progress, but it eroded productivity (Interviewee 6), consistent with prior studies (Hanna et al., 2005, 2008). Overall, disruptions were most pronounced in labor-intensive phases, such as concrete pouring, steelwork, and system integration, where specialized skills and sequencing constraints leave little room for flexibility. These findings indicate that construction schedule delays can stem from trade-specific and phase-related labor gaps rather than uniform workforce shortages.

Table 3. Thematic summary: schedule impacts of skilled labor shortages

Subtheme	Key Insights	Frequency (out of 8)	Research Question
Delays in Key Work Activities	Shortage in critical trades like carpenters and rebar crew's stalls progress on foundational tasks	7	RQ1
Frequent Re-Scheduling	Schedules require ongoing adjustment due to unpredictable workforce availability	6	RQ1
Reliance on Overtime	Overtime is commonly used to compensate for gaps but strains crew and reduces flexibility	6	RQ1
Extended Task Durations	Smaller crew sizes lead to longer durations for planned activities	5	RQ1
Seasonal Workforce Shortfalls	Labor becomes scarce in summer months due to regional competition	4	RQ1

Mitigation Strategies and Optimization

Table 4 addresses **RQ2** by identifying mitigation strategies that were effective in reducing the impacts of skilled labor shortage on the CAHSR project. The list closely mirrored approaches recommended in the literature. The findings indicate that long-term strategies, such as internal workforce development, local training, partnerships, and early hiring, were more effective than short-term fixes, such as wage increases. Union-led training and internal upskilling/promotions reduced skill gaps and turnover. "*Our union training programs ensured we had enough skilled workers*," noted Interviewee 1. Prefabrication and modular construction reduced on-site labor demands for repetitive components (Interviewee 7). Digital tools supported scheduling precision and resource efficiency ("*Drones help us track progress and optimize labor deployment*," Interviewee 2), though prior research suggested that the effectiveness of these tools depends on having a tech-ready workforce (Linares-Garcia & Roofigari-Esfahan, 2024). Overall, planning-driven approaches helped improve workforce stability and reduce reliance on overtime during peak demand periods.

Table 4. Thematic summary: mitigation strategies for skilled labor shortages

Subtheme	Key Insights	Frequency (out of 8)	Research Question
Internal Workforce Development	On-the-job upskilling reduces need for high-wage external hires over time	7	RQ2
Local Training & Apprenticeships	Training centers established to supply skilled labor to the project consistently	6	RQ2
Out-of-Region Recruitment	Recruited labor from other regions and visa-supported hiring expanded the labor pool	5	RQ2
Advanced Planning & Hiring	Early hiring and seasonal forecasting helped stabilize manpower before peak demand	5	RQ2
Retention & Workforce Stability	Sustained job security and positive culture reduced turnover and boosted morale	5	RQ2
Competitive Incentives	Raised wages and highlighted project benefits to attract new workers	4	RQ2
Prefabrication & Off-site Work	Reduced need for skilled on-site labor and increased speed via modular construction	4	RQ2
Collaboration & Communication	Meetings and transparency ensured coordination among unions, contractors, and CHSRA	4	RQ2
Use of Technology	Suggested use of AI, robotics, drones, and innovative software tools to optimize workflows	3	RQ2

Conclusions

This study examined the implications of skilled labor shortages for cost, schedule, and project management in large-scale infrastructure projects, using the CAHSR project as a case study. Drawing on academic literature, CHSRA labor data, and semi-structured interviews with industry professionals, the findings reveal that higher costs are often driven by wage inflation, overtime premiums, and extended project durations; schedule risks include delays on critical-path activities, task resequencing, reliance on overtime, and reduced flexibility. While the study does not establish definitive statistical causality, triangulated evidence suggests that these outcomes were plausibly associated with trade-specic and timing-related labor constraints. Effective long-term mitigation strategies emphasize internal workforce development, targeted recruitment, early planning, and selective technology adoption.

The study has several limitations, including restricted access to CHSRA officials, reliance on publicly available data, and a small interview sample (n=8) with limited industry diversity. The study also has a geographic focus on California, which limits generalizability. However, it provides in-depth insights applicable to similar infrastructure megaprojects facing skilled labor shortages.

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