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An Integrated Cost–Quality–Time Project Control Framework for Saudi Infrastructure Projects

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Abstract-* *The increased development of infrastructure in connection with Saudi Arabia's Vision 2030 initiative makes it necessary to utilize advanced project control systems that could assist in reducing cost risks, guaranteeing quality, and minimizing schedule risks amid very complicated construction settings. Despite this, many projects still face numerous problems connected with disintegrated reporting, reactive decision-making, the absence of data integration, and insufficient deviation management. This review paper covers the latest literature from 2020 to 2025 about advanced project control systems for Saudi Arabia infrastructure projects with a special emphasis on earned value analysis, 4D/5D BIM, common data environments, digital twins, forecasting with artificial intelligence, lean production control, integrated quality management, and governance structures that promote alignment between field performance and top management decisions. The literature review is conducted through a systematic review process involving problem identification, study selection, coding, and comparison instead of a meta-analysis because the source material consists of theoretical papers, empirical research, case studies, and technology adoption studies. As a result of the review, it becomes evident that advanced project controls have to be used in an integrated managerial framework rather than as standalone software solutions. In terms of cost performance, there will be benefits when quantity, productivity, procurement, and change management information become consistently integrated into forecasting models and earned value analysis. As far as quality performance goes, the advantages will be achieved if inspection, non-conformance management, design coordination, and supplier management processes become automated and integrated into work planning. Concerning schedule performance, the improvements will come with the integration of look-ahead planning, progress sensing, predictive delay analysis, and fast decision-making procedures. It should be noted that the Saudi Arabian infrastructure projects face certain difficulties, such as being giga-projects, multi-stakeholder governance, dynamic scope development, localization, and different organizational maturity levels. This paper offers a model where advanced project controls function at five levels of integration: baseline determination, data gathering, analytics, decision-making, and corrective learning. . This model is referred to as the Integrated Cost–Quality–Time Control Framework for Saudi Infrastructure Projects (ICQTCF-SIP). It concludes that Saudi infrastructure clients and contractors should prioritize interoperable data environments, control-led governance, role clarity, and phased capability building to convert digital tools into measurable project outcomes.

Keywords: Project Control Systems, Saudi Infrastructure, Cost Performance, Quality Performance, Schedule Performance, BIM, Digital Twins, Earned Value, Construction Analytics, Vision 2030

I. INTRODUCTION

The traditional project management process in the construction industry included routine reporting, manual generation of reports, different methods of handling costs and schedules, and lag indicators that could only highlight problems after serious degradation had taken place. The above method has proven insufficient in dealing with projects where there is continuous design development, global procurement systems, interface problems, manufacture of modules, environmental issues, and politically critical milestones.

The advanced project management process has come about as a result of this change and incorporates baseline management, automatic data gathering, forecasting, and decision making. The importance of the advanced project control process is not just the speed of reporting but the ability to detect problems early, assess their impact, and act before the problem becomes a lost cause.

This review examines how advanced project control systems can optimize cost, quality, and time performance in Saudi infrastructure projects. The paper proposes the Integrated Cost–Quality–Time Control Framework for Saudi Infrastructure Projects (ICQTCF-SIP) as an integrated managerial architecture linking baseline governance, live operational data, predictive analytics, escalation workflows, and organizational learning. Unlike narrow tool-based studies, the paper treats project controls as an enterprise capability linking planning, execution, governance, and learning.

The study has three objectives. First, it identifies the main control technologies and managerial practices that support the simultaneous management of cost, quality, and time. Second, it evaluates how these systems operate in the particular institutional and delivery conditions associated with Saudi infrastructure. Third, it proposes an integrated synthesis framework that can guide clients, consultants, and contractors in improving practical implementation.

The paper is designed as a review article to align with contemporary journal expectations for conceptual consolidation, strategic interpretation, and actionable research synthesis. Within this context, the ICQTCF-SIP framework is introduced as a structured implementation model tailored to the governance and delivery conditions of Saudi infrastructure programs.

II. REVIEW METHODOLOGY

A four-stage process was adopted for conducting this review. In the first stage, the problem area was formulated as pertaining to advanced project control systems and the three dimensions of performance being cost, quality, and time associated with infrastructure delivery projects. Stage two involved identifying relevant literature from the period 2020 to 2025 using combinations of keywords including project controls, cost control, quality management, schedule control, BIM, digital twins, earned value, construction analytics, Saudi construction, and infrastructure project performance.

Stage three involved screening articles for topical relevance, timeliness, and conceptual contribution, prioritizing peer-reviewed journal articles and studies with explicit research methodology. Finally, stage four involved coding the articles into thematic categories, which included control system effectiveness, cost forecasting and budget control, quality assurance and inspection integration, schedule control and delay prediction, enabling digital transformation, governance constraints, and Saudi delivery environment.

This review adopts an interpretive rather than statistical approach. The aim here is not to calculate pooled effect sizes, as there is considerable heterogeneity between studies in terms of unit of analysis, data source, and intervention design. Instead, what this review aims to do is compare levels of agreement among the studies regarding conditions under which advanced project control systems contribute to visibility, responsiveness, and coordination.

This is an appropriate approach in this case since project control performance is contingent upon organizational processes and implementation discipline as much as software technology. Furthermore, it will help establish a stronger link between the findings of the literature and Saudi project environments.

III. THEORETICAL FOUNDATIONS OF ADVANCED PROJECT CONTROL SYSTEMS

Increasingly, many works published both in Saudi Arabia and worldwide prove the high importance of organizational clarity, baseline quality, communication infrastructure, and managerial commitment for the successful implementation of project controls. For instance, according to Jawad et al. (2022), effective implementation of project control systems in Saudi engineering and construction projects cannot be accomplished with just the appropriate application of tools but should include a consistent approach to procedures, roles, interfaces, and reviews.

Extending this line of thought, Alotaibi et al. (2025) construct a model of project control effectiveness in Saudi construction project delivery and emphasize the necessity to take into account interactions between project control inputs, organizational factors, and project outputs. This approach is significant because it shifts the focus from technology fascination to system design. No matter how sophisticated the dashboards you have, nothing can save you from an unstable baseline, incoherent coding, or analysis that ignores warnings.

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Moreover, a trend can be observed towards the convergence of several different schools of project management. Earned value management offers cost and schedule measures and forecasting principles.

BIM and digital twin technologies offer modeling, visualization, and asset information integration. Lean construction offers workflow reliability and look-ahead planning. Quality management offers process discipline and non-conformances learning. AI and machine learning offer pattern recognition and scenario forecasting. What we need now is to integrate all these into one system of project control.

The proposed system architecture is provided in this paper as part of its Integrated Cost-Quality-Time Control Framework for Saudi Infrastructure Projects (ICQTCF-SIP). Projects tend to fail not because methods are unknown but because they are performed separately by separate groups of people with inconsistent reports.

Table 1 summarizes the principal advanced project control mechanisms identified in the literature and their expected contributions to cost, quality, and time optimization within Saudi infrastructure delivery environments

Control mechanism	Primary function	Cost/quality/time contribution	Typical Saudi application
Earned value and earned schedule	Integrates physical progress with budget and time baselines	Early warning on cost and schedule variance; supports forecast at completion	Major infrastructure packages and milestone governance
4D/5D BIM	Links design, quantities, sequencing, and cost plans	Reduces design-change disruption; improves quantity confidence and scenario testing	Transit stations, utilities corridors, public buildings
Digital quality capture	Records inspections, nonconformances, and closeout evidence in real time	Cuts rework and accelerates issue closure with traceable accountability	High-volume civil and MEP inspection environments
AI and predictive analytics	Identifies anomaly patterns and likely future deviation	Improves delay prediction, cost forecasting, and resource prioritization	Giga-project reporting and portfolio dashboards
Lean production control	Stabilizes workflow through look-ahead planning and constraint removal	Improves schedule reliability while reducing productivity loss and hidden cost	Interface-heavy infrastructure and repetitive workfronts

IV. COST PERFORMANCE OPTIMIZATION THROUGH ADVANCED CONTROL

Whereas the importance of 5D BIM and digital quantity environments lies in helping construction companies deal with uncertainties caused by fast-track procurement and scope complexity, this issue becomes even more relevant within Saudi Arabia. By establishing the connections between quantities in the model, packaging schemes, and schedule logic for control accounts, project managers would be able to assess the impact of design changes quickly and reduce friction associated with manual forecasting.

Research in this area reveals that combining model information and machine learning can assist in predicting the impact of any design changes on cost and schedule much earlier (Abdulfattah et al., 2023; Torres et al., 2025). Such information would become critical when it comes to infrastructure projects, where any changes to interfaces could affect multiple work packages.

In addition to uncovering the hidden cost drivers that would normally remain undetected with monthly reporting, advanced cost control systems provide companies with an opportunity to identify the reasons behind variances and take necessary corrective actions. In order to further improve the efficiency of advanced cost control, companies can use anomaly detection and predictive forecasting using artificial intelligence.

With such advanced technologies, companies would be able to detect unusual spending patterns, cost exposures associated with delays, or supply chain risks much faster compared to traditional analysis methods. Recent research shows that predictive cost control is most effective when it is trained with real-time data from projects (Zhang et al., 2024; Tanim & Ahmad, 2025).

Besides the need to detect and analyze cost variances within infrastructure projects in Saudi Arabia, companies face the challenge of implementing advanced cost controls capable of handling owner-driven changes and milestone commitments related to Vision 2030. The problem is that, in such circumstances, cost optimization requires an efficient change control system.

Therefore, the cost management system should include design approval, scope instructions, estimates, and contingency drawdowns in one governed environment. Otherwise, there is a risk that project teams would have several different versions of the financial truth. Although value engineering may offer additional benefits, its effectiveness appears to depend on practitioners' skills and capabilities (Alhumaid et al., 2024).

Figure 1 illustrates the proposed Integrated Cost–Quality–Time Project Control Framework for Saudi Infrastructure Projects (ICQTCF-SIP). The framework conceptualizes advanced project controls as an integrated managerial architecture linking baseline governance, live operational visibility, predictive analytics, escalation protocols, and corrective learning into a continuous performance optimization cycle across cost, quality, and time dimensions.

Figure 1. Integrated Cost–Quality–Time Control Framework for Saudi Infrastructure Projects (ICQTCF-SIP)

V. QUALITY PERFORMANCE OPTIMIZATION THROUGH ADVANCED CONTROLS

The trend towards digital quality controls is caused by the capability of converting field observations into patterns. Mobile inspection tools based on model checklists, sensor verification, and data sharing decrease the gap between observation and management decision-making.

Recent studies, which concentrate on the inspection planning using ontologies, workmanship benchmarking, and design-behaviour analytics in BIM, prove that digital environments can enhance the accuracy of defect detection and root cause analysis in cases of repetitive processes and high package volume (Lünig et al., 2025; Ni et al., 2024).

Such an assumption is highly applicable to the Saudi mega-programs using replicating assets, interface conditions, and packages in various geographies.

The design stage is crucial for quality control, since its failure in constructability, information completeness, and change management will lead to the downstream inspection systems working only with the results of poor quality. Consequently, BIM coordination, clash detection, methodological analysis, and submittal control are parts of the quality control process, and not just design facilitators. Literature on the challenges of BIM in the Saudi construction management supports the idea and shows that collaboration and quality benefits are limited by the lack of standards, competencies, and discipline (Alshibani et al., 2024; Nassereddine et al., 2021).

In real life, quality performance increases when a single model environment is used for design coordination, package releases, field activities, and closeout.

Another implication, derived from the literature review, is that quality performance can be optimized using short feedback loops and responsibility for problems. In the best quality management systems, quality deviations should show up in daily and weekly control meetings together with production and safety metrics.

Managers will be able to decide if the issue relates to an individual case or to the whole process. Supplier quality management is yet another component that should be considered in the Saudi context, where mega-projects use international and local suppliers with different maturity levels. Submittals control; supplier inspection records, logistics visibility, and installation readiness are instruments that help avoid latent defects before the delivery takes place.

VI. TIME PERFORMANCE OPTIMIZATION WITH ADVANCED CONTROLS

The combination of schedule controls with lean and digital solutions has already been proven by numerous researchers. Earned schedule and earned value indicators are both important because they assess the efficiency of scheduled production. The use of those metrics becomes much more efficient when combined with look-ahead planning, constraint elimination, and location or flow scheduling in projects with a repetitive, interface-intensive nature.

With dynamic controls, probabilistic forecasting, and line-of-balance analysis, it can be stated that time performance increases if the schedule is managed as a living production system rather than a static contract (Kammouh et al., 2022; Jacobsen & Teizer, 2024). It is particularly applicable to the situation in Saudi Arabia because of the instability of critical paths that can appear due to simultaneous workfronts, logistical difficulties, and the environment.

Predictive delay analytics can be regarded as one of the most crucial inventions in schedule management. Machine learning algorithms capable of predicting delay risks based on historical and project-specific data are highly promising. According to a case study related to delay prediction in construction in Saudi Arabia, advanced algorithms have proved their capability to classify delays with great precision (Alsulamy et al., 2025).

However, one has to keep in mind that no predictive model should ever be seen as an alternative to managerial intuition. Predictions will prove useful only if there is enough high-quality data, relevant and sufficient, and a willingness on the part of the managers to be ready. Face management is essential for schedule optimization as well.

Almost all infrastructure projects in Saudi Arabia involve various design consultants, package contractors, utility authorities, and stakeholders at the client side. Time overruns will probably not result from ineffective performance of separate activities but from complex dependencies between packages, approvals, and access conditions.

Advanced project controls are supposed to detect such dependencies, relate them to milestones, and monitor them with the same diligence as construction progress. It is possible to achieve it with model-based coordination within a common data environment, which will increase visibility of inter-boundary dependencies. In combination with weekly reviews and escalation protocols, it will shorten the delay between an issue and its resolution.

VII. INTEGRATED COST-QUALITY-TIME CONTROL FRAMEWORK FOR SAUDI INFRASTRUCTURE PROJECTS (ICQTCF-SIP)

The suggested ICQTCF-SIP will operate within five interacting managerial layers meant to integrate baseline governance, live data visibility, integrated analytics and forecasting, decision-making escalation, and organizational learning into Saudi infrastructure project delivery.

7.1 Baseline Governance Layer

Baseline definition will mean creating a consistent work breakdown structure, alignment of coding between cost and schedule management, definition of quality criteria, pack-level accountability, and contingency logic.

7.2 Live Operational Data Layer

Live data collection will include gathering standardized input data regarding project progress measurement, inspections, submittals, procurement, productivity, and changes.

7.3 Integrated Analytics and Forecasting Layer

Integrated analytics will be achieved by merging the data streams above through dashboards and reviews instead of analyzing them separately.

7.4 Escalation and Response Governance Layer

Decision escalation will mean establishing thresholds for decision escalation and forums for dealing with escalated decisions.

7.5 Corrective Learning and Organizational Maturity Layer

Corrective learning will mean gaining feedback from estimating processes, design standards, procurement policies, and project planning to enhance the project control system.

Alongside controls, Saudi projects will face the problem of implementation maturity. The digital transformation maturity, BIM adoption, and AI-driven digital twin technology require maturity in roles, data governance, and process governance for companies to reap the benefits of such platforms (Zhu et al., 2023; Alnaser et al., 2025).

Practically, many projects will probably benefit from progressive adoption rather than complete digitalization. An appropriate strategy may consist of coding integration, robust earned value and change management, and digital quality documentation. Afterward, such controls can be followed by 4D/5D BIM integration, forecasting, and live data visualization via digital twins. Such a gradual strategy will be much more realistic than waiting for advanced controls after purchasing digital licenses.

Another challenge that Saudi projects will encounter is related to owner capability. Organizations usually create milestones, define scope, and manage consultants. Therefore, immature owner-side controls will prevent project stabilization regardless of the sophistication of the contractor's controls.

In other words, advanced controls should be understood as shared governance frameworks that involve owner, consultant, and contractor parties. Such an approach will ensure transparency in reporting definitions, agreed variance thresholds, common data standards, and fast issue resolution processes.

Table 2 presents a phased implementation roadmap for deploying the proposed ICQTCF-SIP framework across Saudi infrastructure organizations, beginning with baseline discipline and progressing toward predictive control and portfolio-level learning capability.

Phase	Core actions	Key data requirements	Expected outcome
Phase 1: Baseline discipline	Align WBS, cost codes, progress rules, and change logs	Approved budget, master schedule, package structure	Single source of baseline truth
Phase 2: Digital field capture	Mobilize daily progress, inspection, and procurement reporting	Mobile forms, inspection templates, material status data	Faster and more reliable variance visibility
Phase 3: Integrated analytics	Combine cost, quality, and time dashboards with threshold alerts	Linked cost, schedule, quality, and change datasets	Actionable forecasting and priority focus
Phase 4:	Use	Historical	Earlier

Predictive control	machine learning and scenario testing for delay and overrun risk	project data plus live operational feeds	intervention and better contingency use
Phase 5: Portfolio learning	Feed lessons into estimating, standards, and supplier strategies	Structured lessons learned and benchmark libraries	Cumulative organizational maturity

VIII. CHALLENGES, RISKS, AND GOVERNANCE REQUIREMENTS

Technology-specific risks also need to be identified. For instance, artificial intelligence forecasting can engender false confidence if based on flawed data and/or used without proper context. Digital twins can prove to be just another costly visualization tool and not a means for control if not linked to governed decision-making. The BIM environment may not result in better outcomes if the models' completeness, updating discipline, and intended uses are poor.

It is thus recommended that the governance-first principle be adhered to. In the ICQTCF-SIP model, governance is the integrating element that ensures the connection between cost, quality, and time controls is achieved as part of a managerial system. Control technologies should be chosen in accordance with managerial purposes, available data, and organizational maturity, not popularity.

Governance requirements are fairly straightforward from the literature. Firstly, control ownership needs to be defined with the right powers to question variance and trigger corrective action. Secondly, data standards and coding need to be developed early and strictly enforced. Thirdly, the review process must be tiered, with daily operational, weekly package coordination, and monthly executive reviews.

Fourthly, if feasible, quality, cost, and scheduling information should be reviewed simultaneously in order to identify trade-offs and causality. Finally, lessons learned should be embedded at the portfolio level so that future Saudi infrastructure programs learn from previous control experiences rather than starting from scratch.

8.1. Implementing the ICQTCF-SIP Framework in Saudi Organizations

In order to maximize the benefit of advanced controls, the ICQTCF-SIP framework requires tight integration of data capture, escalation authority, and corrective actions across all project levels.

Secondly, it is necessary to digitalize workflows at the point of execution. Engineers, site inspectors, planners, and package managers must have disciplined methods to record actual production, results of inspections, availability of materials, and interface issues. The power of mobile inspection reports, model-linked progress updates, and daily reporting is enormous because they enable the creation of an accurate picture of current operations instead of retrospective reporting.

In Saudi Arabia, such visibility will help projects with dispersed sites and extreme weather conditions in terms of faster decision-making, reduced duplication of efforts, and separation of local disruptions from systemic problems by management. The key message here is that control data must be captured on-site, rather than recreated in corporate offices.

Thirdly, it is important to develop escalation discipline. Even the most technically advanced control system will not work without proper project knowledge of the moments when variance becomes critical, responsibility for recovery planning, and forums that are entitled to reassign resources, change the sequence of tasks, and authorize mitigation costs. Projects should be provided with thresholds of indicators that trigger certain actions.

For instance, quality failures in one package may require joint quality-production reviews; slippages in procurement of long-lead items may demand executive interventions; and decreased schedule

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efficiency on near-critical paths may necessitate revision of plans. Such action rules are crucial for making project controls efficient.

Lastly, organizations must institutionalize learning. The implementation of Saudi infrastructure programs generates enormous amounts of delivery data, including those related to transport, urban development, utilities, marine, logistics, and public buildings. However, many companies continue to underutilize post-project data.

The value of advanced controls will be created if data is used to update estimation databases, supplier qualification, risk libraries, benchmark productivity ranges, quality checklists, and digital twins in future projects. Such portfolio feedback is vital for building cumulative national delivery capacity through projects associated with Vision 2030.

8.2. Research and Policy Implications
In relation to policy and major public clients, it is important to note that while mandates on digitization can be useful, they are not sufficient in and of themselves. Using BIM, common data environments, or digital reporting may have an impact on project performance, yet this depends on data standards, capability development, alignment through contractual mechanisms, and review governance.

Thus, public sector guidelines should go beyond mandating tools and define minimum controls required for coding integration, measurement of progress, quality traceability, and issue escalation. In doing so, comparable standards would be developed, and the current fragmentation of performance learning across the market would be alleviated.

The second implication relates to the workforce needed to operate advanced project controls. The complex nature of these systems requires individuals capable of understanding relationships between costs, quality, time, digital models, and reality on the ground. In light of this, the ICQTCF-SIP framework suggests that there is a need for interdisciplinary capability development combining technical, commercial, operational, and governance aspects. Thus, in Saudi organizations, capability development rather than software training should take place. Planners need to understand commercial dynamics, quantity surveyors need to understand production dynamics, quality engineers need to understand scheduling implications, and project managers need to use predictive analytics for decision-making.

Finally, the implication concerning resilience needs to be highlighted. Given that infrastructure delivery in Saudi Arabia is taking place in conditions of growing uncertainty (market volatility, supply chain disruption, completion event pressure, rapid urban transformation), it is not enough for advanced project control systems to be capable of tracking project performance under stable conditions. It is also necessary that these systems allow absorbing shocks, reforecasting credibly, and recovering with minimal losses.

Figure 2 illustrates the capability maturity pathway associated with the ICQTCF-SIP framework, showing how Saudi infrastructure organizations can progressively scale from fragmented reporting environments toward integrated predictive and portfolio-level control systems.

Figure 2. ICQTCF-SIP Capability Maturity Pathway for Saudi Infrastructure Portfolios

CONCLUSION

From a strategy point of view, this means that project controls must be viewed as a fundamental part of the project delivery process. The ICQTCF-SIP proposed framework brings to bear a Saudi-specific governance structure where baseline control, live monitoring, predictive analysis, escalation management, and organizational learning combine to provide a holistic project delivery system.

First, organizations need to establish solid foundations through coding integration, baseline quality, change management, and rigorous reviews. After that, the journey can move toward more advanced forms of controls, such as model-based controls, predictive analysis, and digital twin visualization capabilities.

Research needs to focus on longitudinal case studies of Saudi giga-projects and public infrastructure programs in order to analyze the impact of integrated controls on outcome effectiveness. In terms of practice, the most critical insight is that advanced project control systems work when all three components of technology, process, and accountability are integrated into the system.

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