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Original Research Article

Digital Project Controls for Improving Cost and Schedule Performance in Saudi Mining and Industrial Projects under Vision 2030

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Abstract: Digital project controls can strengthen capital-project decisions when reliable field evidence, commercial records, schedules, and risk assessments are connected through consistent definitions. Software adoption alone does not establish better cost or schedule performance. This integrative review develops a decision-oriented framework for Saudi mining and industrial projects under Vision 2030. Targeted searches of publicly accessible scholarly material inform an analysis of earned value management, forecasting, information governance, and organizational adoption. The proposed framework links data capture, validation, integrated analysis, managerial intervention, and verification of outcomes. It distinguishes reporting speed from forecast accuracy and separates approved scope growth from uncontrolled deviation. An explicitly hypothetical cost-forecast sensitivity exercise demonstrates how assumptions about remaining productivity affect estimated final cost; it is not presented as a Saudi project dataset. Three tables summarize evidence, control measures, and implementation responsibilities, while a conceptual diagram explains the feedback process. The paper proposes a phased pilot and longitudinal evaluation using dated forecasts, baseline histories, and categorized changes. Its contribution is a practical explanation of the conditions under which digital information may improve control decisions. The framework requires empirical validation and cannot establish achieved savings, reduced delays, or sector-wide performance effects.

Keywords: Digital Project Controls, Earned Value, Forecasting, Cost Performance, Schedule Management, Saudi Vision 2030.

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1. INTRODUCTION

Cost and schedule performance influence whether mining and industrial investments deliver their intended benefits. A delayed processing plant can postpone production while increasing financing and indirect costs. Incomplete engineering can alter quantities after contracts are awarded, and equipment delivery problems can disrupt construction sequences. These exposures are interconnected. Project controls therefore need to explain how scope, expenditure, physical progress, and completion forecasts relate. Digital systems offer ways to assemble this information, but effective control depends on the quality of the decisions that follow, not the number of dashboards produced.

Saudi Vision 2030 identifies mining and industrial development as elements of economic diversification (Saudi Vision 2030, 2024). Capital projects supporting these sectors involve technical interfaces, infrastructure dependencies, international procurement, and operational handover. Their relevance to national policy does not remove the need for disciplined commercial and

engineering decisions. This paper examines digital project controls as a capability for managing those decisions. Vision 2030 provides the application context; the analysis does not assume that every digital initiative produces measurable economic benefits or that policy alignment demonstrates an individual investment's success.

The central problem is fragmentation. Planning teams may update activities while finance closes accounts on a different timetable. Engineering changes may be approved without their schedule consequences being recorded. Procurement reports can show an order placed without indicating whether its delivery supports the current construction sequence. Each system can be internally correct while the combined picture remains misleading. The research question is consequently how digital controls can create a coherent and accountable representation of project performance across functions, contractors, and decision levels.

2. AIM OBJECTIVES AND RESEARCH QUESTIONS

The aim is to explain how digital project controls may improve cost and schedule decisions in Saudi mining and industrial capital projects. Four objectives guide the review: identify mechanisms linking digital integration to control quality; define credible performance and forecasting measures; develop an implementation framework with clear responsibilities; and specify a validation strategy. These objectives distinguish the proposed contribution from a technology inventory. The concern is whether information changes decisions and whether those decisions improve outcomes after accounting for project context.

Three research questions organize the paper. Which data and governance conditions make digital control indicators credible? How should integrated controls identify cost and schedule problems without confusing scope change, accounting timing, and productivity deviation? What evidence would establish that implementation improves forecasting and corrective action? The questions connect technical design to management practice and evaluation. They also require explicit treatment of unsuccessful interventions, because a system can improve transparency while revealing deterioration that existed before its adoption.

3. REVIEW METHODOLOGY

An integrative review is appropriate for a question spanning governance, earned value systems, forecasting, digital transformation, and mining investment risk. Snyder emphasizes the importance of purpose and transparency in literature-review design (Snyder, 2019). The present review uses targeted scholarly searches and conceptual synthesis. It does not claim an exhaustive systematic review, a database census, or a statistical meta-analysis. Its contribution rests on identifying compatible mechanisms and defining an original framework whose propositions can subsequently be tested with project records.

Targeted web searches were conducted on 11 October 2026. Search combinations included digital project controls, cost forecasting, earned value management, schedule performance, project governance, mining cost overrun, and industrial project monitoring. Publisher-hosted material was prioritized, alongside an official Vision 2030 report for context. Authenticated Scopus and Web of Science searches were not conducted. Where subscription restrictions prevented full-text access, interpretation was limited to accessible abstracts and publisher descriptions. No inaccessible results were reconstructed, and no screening totals were invented.

Sources were retained when they addressed a control mechanism, an implementation condition, or a relevant limitation. Academic studies informed the review; policy reporting supplied contextual statements. Marketing claims, unsupported savings percentages, and promotional software comparisons were excluded. Foundational methodology and governance sources were retained alongside recent research. Table 1 identifies the principal evidence streams and their limitations. The evidence was coded conceptually into data credibility, baseline consistency, forecast assumptions, decision accountability, and organizational adoption rather than counted as a representative sample of the literature.

Table 1: Evidence and transfer limits

Source	Contribution	Limit
Governance (Musawir *et al*., 2020)	Decision authority	Not mining-specific
Digital transformation (Chen *et al*., 2025)	Organizational integration	No Saudi effect estimate
Earned value (Aramali *et al*., 2022)	Measurement discipline	Implementation varies
Mining risk (Faúndez and Guzmán, 2025)	Price, quantity and delay	Context-dependent
Forecasting (Ottaviani *et al*., 2024; Yalçın *et al*., 2024)	Performance assumptions	Transfer needs testing
Buffer monitoring (Bahnas *et al*., 2024)	Traceable records	Technology-specific

4. LITERATURE REVIEW AND CRITICAL ANALYSIS

4.1 Governance and Organizational Conditions

Musawir and colleagues connect project governance to strategic implementation while identifying a need for context-specific guidance (Musawir *et al*., 2020). This suggests that digital controls should support defined decisions and authorities. A variance report needs an accountable recipient who can change resources, approve scope, challenge assumptions, or escalate an issue. Without these connections, improved visibility may produce repeated warnings without intervention. The proposed framework therefore treats ownership and decision rights as part of the control architecture, alongside data structures and analytical methods.

Chen and colleagues frame digital transformation in project management through sociotechnical integration and governance (Chen *et al*., 2025). Their review supports examining the interaction between digital tools and working practices. A field engineer may record progress consistently only when measurement rules are clear and reporting effort is proportionate. A contractor may share useful procurement information only when contractual expectations define the required evidence. These examples are applications proposed here, not findings tested in Saudi mining. They explain why implementation should address incentives, competence, and accountability alongside software configuration.

4.2 Earned Value and Credible Measurement

Earned value management connects planned value, earned value, and actual cost within a defined measurement baseline. Aramali and colleagues review the relationship between academic development and industrial earned value practice (Aramali *et al*., 2022). The relevant implication is that analytical sophistication must be matched by operational discipline. Work packages require measurable completion rules, budgets, responsible owners, and compatible cost records. Digital integration can make this discipline easier to maintain, but it cannot establish whether a progress percentage reflects completed physical work unless the underlying evidence supports it.

The cost performance index is CPI = EV/AC, where EV denotes earned value and AC actual cost. The schedule performance index is SPI = EV/PV, where PV denotes planned value. Values below one indicate unfavorable performance against the defined baseline, subject to measurement quality. However, SPI is not a direct measure of calendar delay or confidence in a completion date. Progress measured in budget units may conceal a late critical package while noncritical activities earn value. Network analysis remains necessary when decisions depend on completion milestones.

Actual costs also require interpretation. Invoice timing may lag physical progress, and commitments may not yet appear as expenditure. An apparently favorable CPI can result from incomplete accruals rather than efficient production. The proposed approach reconciles actuals, accruals, commitments, and forecast remaining costs. It preserves their different meanings instead of combining them into an unexplained total. Table 2 defines indicators and cautions that can help managers distinguish commercial exposure from recorded expenditure and physical progress from accounting completion.

4.3 Forecasting and Analytical Assumptions

Ottaviani and colleagues investigate progress-based performance factors for cost and duration forecasting (Ottaviani *et al.*, 2024). Their work illustrates that forecasts depend on assumptions about how performance evolves during remaining work. The present paper applies that insight by requiring each forecast to state whether it assumes persistent current efficiency, recovery, or package-specific productivity. The reviewed study's results should not be generalized automatically to Saudi mining. Instead, it motivates testing forecasting alternatives against local records and reporting performance across different stages of completion.

Yalçın and colleagues evaluate machine-learning approaches using earned-value-based cost estimation inputs from a construction setting (Yalçın *et al*., 2024). Their study demonstrates a research route for combining established control variables with predictive methods. Transfer requires caution because project structure, data generation, and sample independence affect model validity. In mining, one project can produce many correlated reporting observations without providing many independent projects. Evaluation must therefore separate training and testing by project where possible. Randomly splitting periodic records can exaggerate accuracy when the same project appears in both datasets.

4.4 Mining Cost Drivers and Schedule Interfaces

Faúndez and Guzmán analyze mining cost deviation through price, quantity, and delay relationships (Faúndez and Guzmán, 2025). Their decomposition supports examining the causes behind an aggregate overrun. A digital control system should distinguish additional quantities, changing unit rates, and duration-related indirect costs. These drivers may require different responses. Improving field productivity cannot eliminate a commodity-driven equipment price increase, while renegotiating

rates cannot correct omitted scope. The proposed framework connects variance classification to the responsible specialist and the management decision needed.

Schedule interfaces connect those cost drivers to delivery logic. Late technical approval can postpone procurement, which can delay installation and increase site overheads. A dashboard that reports each function separately may miss this chain. Integrated analysis should map package dates to predecessor evidence, required delivery dates, and commissioning dependencies. Where uncertainty is material, schedule risk analysis can examine duration ranges and correlated events. Its assumptions should be visible; the paper does not prescribe a universal confidence level for every project or milestone.

Bahnas and colleagues investigate blockchain-enabled critical-chain monitoring (Bahnas *et al*., 2024). This represents a technology-specific approach to recording and monitoring buffers, but it does not establish that blockchain is necessary for project control. Owners should compare the proposed capability with conventional controlled databases and existing audit arrangements. Technology choice depends on shared-record needs, trust boundaries, integration effort, and operational cost. The paper retains the broader lesson of traceable monitoring while rejecting an automatic progression from conventional systems to increasingly complex platforms.

Table 2: Control indicators and interpretation

Measure	Definition	Caution
CPI	EV divided by AC	Check accrual completeness
SPI	EV divided by PV	Not calendar delay
Forecast error	Forecast minus final outcome	Compare common scope
Reporting lag	Days from data date to report	Speed is not accuracy
Open interfaces	Unresolved cross-package dependencies	Assess criticality
Change exposure	Approved and pending changes separately	Retain original baseline

Governance research locates investment oversight at several organizational levels. Too and Weaver (2014) connect portfolio choice, sponsorship, PMO oversight and project management, while Biesenthal and Wilden (2014) emphasize the multilevel character of governance. Applied here, this requires escalation rules that distinguish package decisions from investment decisions.

Stakeholder relationships also shape evidence acceptance. Derakhshan *et al*., (2019) identify limitations in the treatment of external stakeholders; Müller *et al*., (2014) examine organizational enablers and flexibility. Together, these perspectives support involving responsible suppliers and specialist reviewers while retaining clear approval authority.

Benefits should remain connected to investment decisions throughout delivery. Musawir *et al*., (2017) examine governance, benefit management and project success. A digital control record should therefore connect material changes to the investment thesis. Vial (2019) further emphasizes organizational changes surrounding digital transformation, supporting attention to incentives and working practices.

Digital twins require precise definition. Kritzinger *et al*., (2018) distinguish digital models, shadows and twins by integration, while Jiang *et al*., (2021) distinguish twins from BIM and cyber-physical systems. A periodically refreshed dashboard should consequently be described by its actual capabilities rather than automatically labelled a digital twin.

Boje *et al*., (2020) outline semantic construction digital-twin research, and Opoku *et al*., (2021) review construction applications across lifecycle phases. These sources support investigating connected representations of scope and progress. They do not establish that a twin reduces Saudi mining overruns or that every capital project requires one.

Manufacturing literature offers additional transfer considerations. Tao *et al*., (2018) connect data lifecycles to smart manufacturing, while Soori *et al*., (2023) review digital-twin applications and challenges. Project-to-operations handover can benefit conceptually from compatible asset identities, but capital-project control and production optimization require different measurement boundaries.

Execution control inherits earlier investment decisions. Cooper (2008) emphasizes scalable gate discipline, Samset and Volden (2016) discuss front-end investment choices, and Babaei *et al*., (2021) identify interconnected front-end issues. A digital-control baseline should therefore preserve assumptions authorized before execution. Ma'aden's

annual report (Ma'aden, 2025) provides commercial context, but corporate financial results cannot establish project-control effectiveness.

5. Proposed Digital Control Framework

5.1 Information Architecture

Figure 1 presents a proposed feedback architecture linking operational evidence to management action. Its first layer captures field quantities, timesheets, approved documents, purchase commitments, and schedule updates. The second validates identifiers, reporting dates, revisions, and completeness. Integrated analysis then connects cost, schedule, scope, and risk. Management selects an intervention, and subsequent observations test whether it achieved the intended result. The return path matters: reporting without outcome verification cannot establish that a corrective action improved performance.

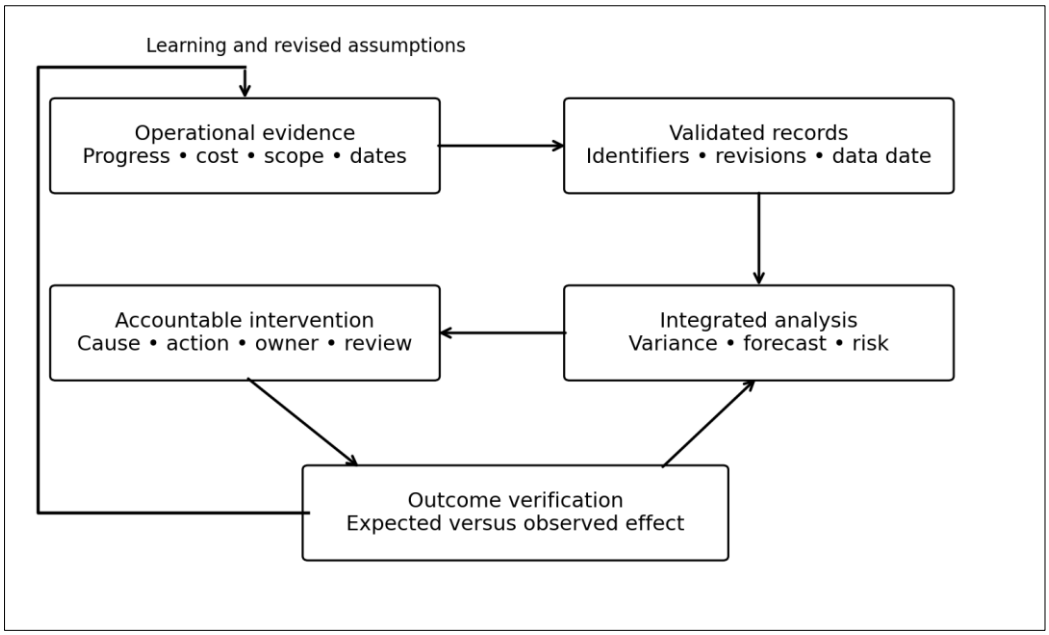


Figure 1: Proposed digital control feedback framework. Original conceptual diagram; relationships require empirical testing

Common identifiers provide the architecture's foundation. Scope elements should map to work packages, activities, cost accounts, procurement packages, and relevant changes. One relationship may be many-to-many, so integration should preserve the mapping rather than forcing artificial one-to-one matches. The owner needs a controlled dictionary defining terms, units, responsibilities, and approved transformations. For example, installed quantity and accepted quantity may differ where testing remains incomplete. Combining them without explanation can inflate progress and weaken forecast credibility.

5.2 Control Cycle and Decision Accountability

The reporting cycle should establish a common data date, submission timetable, validation period, and decision forum. Engineering, construction, procurement, finance, and operations need compatible reporting responsibilities. Project controls can reconcile their records but should not certify specialist facts outside its competence. Decisions should identify the issue, considered alternatives, expected impact, owner, and review date. Table 3 proposes responsibilities that can be adapted to different contracting arrangements while preserving accountability for the source evidence.

A variance should trigger interpretation before escalation. Reviewers should ask whether it results from timing, approved scope, measurement error, or actual performance deterioration. Material issues then require a response matched to the cause. Options may include resequencing, additional resources, engineering clarification, supplier intervention, or formal scope revision. The intervention record should state expected cost and schedule effects, including possible trade-offs. Accelerating one activity may raise expenditure or increase congestion elsewhere, so local improvement should be evaluated within the project network.

Change control preserves the meaning of the baseline. Approved changes should update budgets and schedules through a documented process while retaining earlier versions. Reports should show performance against the current authorized baseline and explain movement from the original commitment. Otherwise, repeated rebaselining can make every report appear acceptable while

concealing cumulative deterioration. The proposed system retains change categories and approval dates so researchers and decision makers can distinguish legitimate investment evolution from errors in initial definition or execution.

6. Analytical Cost Forecast Sensitivity

Figure 2 illustrates how remaining productivity assumptions affect an estimate at completion. The scenario uses normalized cost units rather than Saudi project observations. Budget at completion is 100, earned value is 40, and actual cost is 50. The remaining budgeted work is therefore 60. The forecast formula is EAC = AC + (BAC − EV)/f, where f represents assumed future cost efficiency. The exercise varies f while holding scope and recorded actual cost constant.

For assumed efficiencies of 0.8, 0.9, 1.0, 1.1, and 1.2, forecast costs are respectively 125.00, 116.67, 110.00, 104.55, and 100.00 units. These are calculated values, not empirical findings or measured savings. Current CPI is 0.8, so maintaining current efficiency gives 125 units. Achieving the original budget requires future efficiency of 1.2 under the scenario assumptions. This explains why a forecast of recovery needs credible operational evidence rather than a managerial preference for meeting the original target.

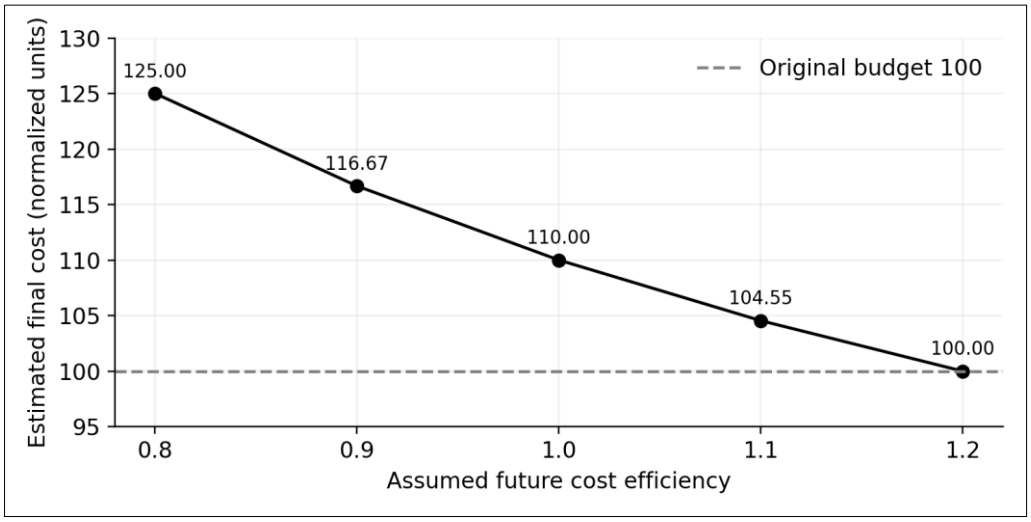


Figure 2: Hypothetical forecast sensitivity. EAC = 50 + 60/f. Calculated normalized units; not Saudi project observations or measured savings.

The calculation is deliberately limited. It excludes additional scope, changing prices, risk events, and schedule-dependent overheads. It does not estimate the probability of achieving a particular efficiency. A package-based forecast could produce a different result because remaining work may differ from completed work. The scenario's purpose is to make assumptions inspectable and support discussion of required recovery. In practice, managers should document the resources, methods, and constraints supporting improved productivity before accepting a recovery forecast.

Cost sensitivity should also be connected to the schedule. Adding resources may improve production rates but increase cost, while resequencing can alter access or commissioning dependencies. A useful control system evaluates alternatives rather than treating cost and time as independent targets. Analysts should retain the original forecast and the revised forecast after an intervention. Subsequent evidence can then indicate whether the expected improvement occurred, whether new risks emerged, and whether the decision produced value after its additional costs were included.

Table 3: Proposed responsibilities

Function	Evidence responsibility	Control role
Engineering	Approved scope and revisions	Explain quantity changes
Construction	Verified installed quantities	Identify constraints
Procurement	Commitments and delivery evidence	Monitor vendor exposure
Finance	Actuals and accruals	Reconcile expenditure
Project controls	Integrated baseline and forecasts	Explain discrepancies
Project leadership	Intervention decisions	Verify outcomes

7. Saudi Application and Implementation Roadmap

Implementation should begin with a diagnosis of current records and decisions. The owner should identify reporting delays, inconsistent definitions, recurrent forecast errors, and unresolved interfaces. Procuring software before understanding these problems risks automating existing weaknesses. A pilot should use a limited number of projects or packages with authorized access to records. The pilot's objective is to test information reliability and decision usefulness, not to announce sector-wide benefits from a single successful demonstration.

The first phase establishes common structures and reconciles a baseline. The second integrates periodic data and exception reporting. The third introduces forecast comparisons and intervention tracking. Predictive analytics should follow only when historical records are sufficiently consistent for meaningful testing. Each phase needs acceptance criteria and an assessment of reporting effort. A simpler system that reliably supports decisions may be preferable to a sophisticated platform requiring extensive manual corrections, specialist coding, or duplicate contractor submissions.

Saudi mining and industrial applications require attention to differences between greenfield developments, brownfield expansions, and operating-site modifications. Brownfield projects may face access restrictions and shutdown dependencies, while greenfield facilities may depend heavily on infrastructure completion. These are analytical distinctions rather than measured comparisons in this paper. Pilots should document such conditions and adjust control definitions accordingly. The aim is comparable evidence without forcing different project types into identical schedules, progress rules, or organizational structures.

8. EVALUATION DISCUSSION AND FUTURE RESEARCH

Evaluation should distinguish data quality, decision quality, and delivery performance. Data measures include completeness, reporting lag, reconciliation exceptions, and revision accuracy. Decision measures include issue-resolution time, forecast explanations, and intervention follow-through. Delivery measures include categorized cost deviation, milestone delay, and verified rework. A project can improve reporting while remaining over budget because its underlying problems were already substantial. Researchers should therefore assess changes relative to a documented starting condition rather than equating unfavorable outcomes with failed digital adoption.

A longitudinal study should compare dated forecasts with subsequent outcomes. Forecast accuracy can be measured at comparable stages of completion, while bias indicates systematic optimism or pessimism. Researchers should preserve cancelled and delayed projects where access permits, because excluding them creates survivorship bias. Approved scope growth should be separated from uncontrolled deviation. Project size, commodity, delivery model, complexity, engineering maturity, and market conditions may confound results and should be considered in comparisons between digital-control adopters and other projects.

Future research should investigate whether predictive models transfer between industrial construction and mining facilities. It should also examine how contractual incentives influence reporting accuracy and whether increased transparency changes decision behavior. Mixed methods can combine forecast-error analysis with interviews explaining why warnings were acted upon or ignored. Any study using company records needs explicit permission, confidentiality arrangements, and reporting independence. Operational access to a dashboard should not be assumed to authorize research use of commercially sensitive data.

9. Limitations

The review uses targeted publicly accessible literature rather than exhaustive authenticated database retrieval. Some evidence originates in construction or general project management, limiting direct transfer to Saudi mining and industrial projects. The proposed architecture has not been implemented or empirically tested here. The numerical exercise is hypothetical and cannot demonstrate project savings or performance improvement. No software ranking, validated effect size, or universal implementation threshold is provided. These boundaries should remain explicit when the manuscript is adapted to a selected journal.

10. CONCLUSION

Digital project controls may improve cost and schedule decisions when they connect reliable evidence, consistent baselines, explicit forecasting assumptions, and accountable interventions. The proposed framework places data validation and outcome verification around integrated analysis, preventing reporting speed from becoming a substitute for decision quality. For Saudi mining and industrial projects under Vision 2030, a phased pilot offers a practical route to testing these mechanisms. Demonstrated benefits require longitudinal project

evidence; adoption alone does not establish improved investment performance.

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