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RESEARCH ARTICLE

INTEGRATING STAGE-GATE GOVERNANCE, DIGITAL PROJECT CONTROLS AND RISK MANAGEMENT TO IMPROVE EXECUTION READINESS IN SAUDI MINING PROJECTS UNDER VISION 2030

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Abstract

Execution readiness requires mature engineering, credible delivery plans and accepted residual risks. This integrative review proposes a framework connecting stage-gate governance, digital controls and risk management for Saudi mining projects under Vision 2030. Targeted scholarly searches and official reporting inform the analysis. A gate evidence register links requirements to controlled documents, schedules, costs, risk owners and approval conditions. Mandatory constraints remain separate from general maturity assessments. Digital reporting supports traceability, while independent review challenges investment assumptions. Three tables specify evidence, readiness domains and pilot measures; a conceptual diagram explains the proposed relationships. Published Ma'aden revenue figures provide context rather than evidence of effectiveness. The paper proposes longitudinal validation using authorized project records. Its contribution is an operational account of how project information can support defensible investment decisions. The framework remains untested; improved delivery outcomes cannot yet be claimed.

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Introduction:-

Saudi mining investment requires evidence that technical scope, infrastructure, contracts and operating assumptions can be delivered together. Vision 2030 identifies mining as a diversification priority (Saudi Vision 2030, 2024), but strategic relevance alone does not establish execution readiness. Investment gates must translate policy objectives into specific, testable delivery commitments. Readiness depends on interacting uncertainties. Geological interpretation affects resources, metallurgical testing affects process selection, and infrastructure constrains construction and operations. Advanced drawings cannot compensate for an unresolved water supply agreement. The assessment must therefore examine dependencies across the project rather than count completed engineering documents.

Governance oversees investment choices; management organizes delivery. Musawir et al. (2020) identify a need for context-specific governance, while Samset and Volden (2016) distinguish strategic investment success from tactical performance. Execution gates should test both investment validity and deliverability, retaining the ability to revisit earlier authorization. Scheduling, enterprise, document and reporting systems can connect governance to delivery evidence. Their coexistence does not guarantee consistency. Chen et al. (2025) emphasize sociotechnical integration

in digital transformation. Readiness assurance must establish how information is produced, checked and interpreted before relying on dashboard summaries. The paper addresses a practical research gap between broad governance principles and operational readiness assessment. It asks how stage-gate authority, digital controls, and risk analysis can function as one decision process without imposing excessive administration. The proposed contribution is a traceable evidence architecture, a constrained readiness assessment, and an explicit validation strategy.

Aim and Research Questions:-

The study develops a literature-informed execution-readiness framework. Its objectives are to identify integration mechanisms, define observable evidence, preserve critical constraints, allocate responsibilities and propose empirical validation. The contribution is conceptual; it does not measure achieved improvement in Saudi mining projects. Four questions guide the synthesis: what makes a gate substantively effective; how can digital controls supply credible readiness evidence; how should unresolved risks affect authorization; and what evaluation design could test integration? Each question connects a management practice to a decision mechanism rather than assuming checklist completion demonstrates viability.

Review Methodology:-

An integrative review addresses the topic's overlap between governance, investment definition, digital transformation and mining risk. Snyder (2019) emphasizes transparent review purposes and methods. This study develops a testable framework; it does not claim exhaustive systematic coverage, bibliometric representativeness or a statistical meta-analysis. Targeted web searches on 11 October 2026 combined mining projects, stage-gate governance, front-end definition, digital controls, earned value and risk management. Publisher records and official sources were prioritized. Authenticated Scopus and Web of Science searches were not conducted, and subscription restrictions limited some full-text appraisal.

Sources were retained for relevance to authorization, planning maturity, information integrity, mining uncertainty or sector context. Scholarly publications informed mechanisms; official reports supplied descriptive context. Promotional claims were excluded. Foundational sources were retained alongside recent studies because publication date alone does not establish conceptual or methodological quality. Evidence was organized into authorization, front-end definition, information integrity, uncertainty and handover. Reported findings were separated from proposed applications. Restricted sources supported only claims visible in accessible material. No screening counts, interviews or performance estimates were invented. These access limitations constrain the review's methodological depth. The synthesis connects governance authority, digital evidence and mining risk through proposed readiness rules. Table 1 summarizes central evidence streams and limitations. The framework is an original analytical proposition, rather than an established company procedure or an integration model already tested by the reviewed studies.

Table 1 Evidence sources and their analytical limits

Source	Role in synthesis	Limit
Musawir et al. (Musawir et al., 2020)	Governance and strategic alignment	Broad project contexts
Samset and Volden (Samset and Volden, 2016); Babaei et al. (Babaei et al., 2021)	Front-end definition and interconnected issues	Transfer to mining requires testing
Cooper (Cooper, 2008)	Staged commitment and scalable gates	Originally product development
Chen et al. (Chen et al., 2025)	Sociotechnical digital integration	Not Saudi mining outcome evidence
Aramali et al. (Aramali et al., 2022)	Earned value system practice	Does not validate readiness model
Faúndez and Guzmán (Faúndez and Guzmán, 2025)	Mining cost and delay drivers	Not a Saudi-specific estimate
Official reports (Saudi Vision 2030, 2024; Ma'aden, 2025)	Policy and corporate context	Descriptive rather than causal

Saudi mining context and investment discipline:-

Potential mining-project benefits include capacity, downstream integration, supplier development and technical employment. Each requires an owner, baseline and realization period. A business case should explain the mechanism generating these benefits and how unresolved constraints affect their credibility; merely mentioning Vision 2030 is insufficient. Ma'aden reported consolidated revenue of SAR 40,277 million in 2022, SAR 29,272 million in 2023 and SAR 32,546 million in 2024 (Ma'aden, 2025). Figure 1 reproduces these values. Revenue reflects markets, volumes and portfolio composition, so it cannot establish project readiness or governance effectiveness.

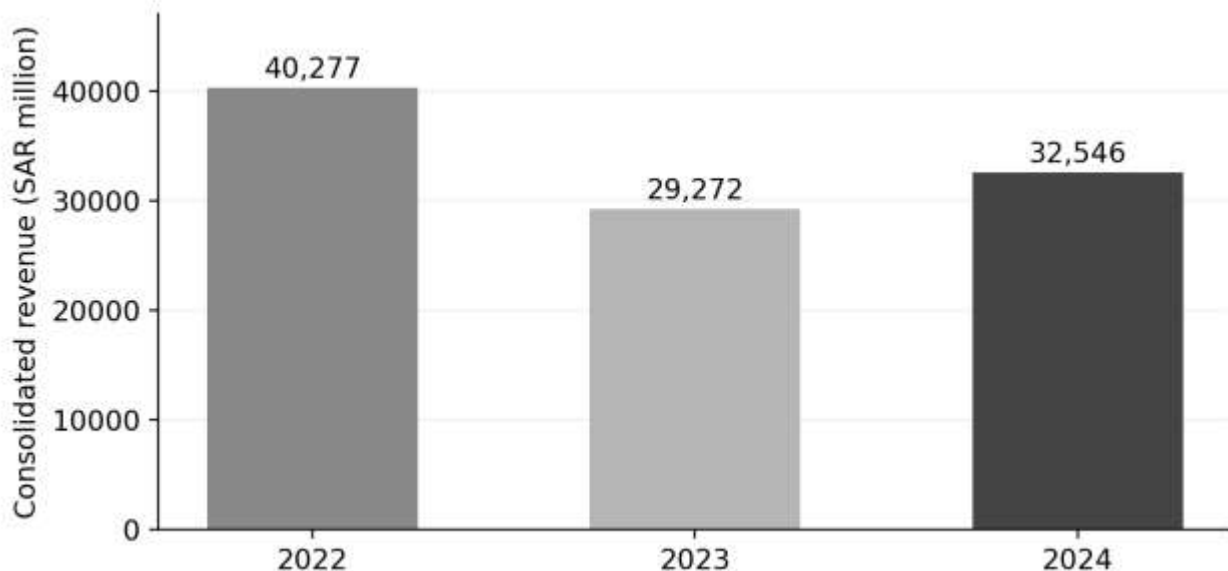


Figure 1 Published Ma'aden consolidated revenue in 2022–2024, in SAR million (Ma'aden, 2025). Contextual financial data only; not evidence of governance effectiveness.

Investment justification and execution assurance require connected evidence. Commercial sensitivity tests value under changing assumptions; delivery assurance tests scope, schedule, contracts and resources. A project can satisfy one assessment while failing the other. The gate record should preserve both conclusions rather than equating policy relevance with executable investment.

Literature Synthesis:-**Stage-gate governance and front-end definition:-**

Stage-gate governance structures commitment around maturity assessments. Cooper (2008) emphasizes meaningful gate decisions, scalability and avoidance of bureaucracy in product development. Mining application requires adaptation to resources, process performance, infrastructure and procurement. The transferable principle is evidence-informed commitment, not a universal deliverable list. Front-end maturity concerns whether technical assumptions, estimates, schedules and benefits describe the same project. Samset and Volden (2016) distinguish strategic and tactical success; Babaei et al. (2021) identify interconnected infrastructure front-end issues. These perspectives motivate consistency checks but do not establish Saudi mining effect sizes. A gate weakens when approval is assumed before review. Each unresolved condition needs an owner, due date, affected commitment and closure consequence. Reviewers must distinguish manageable execution conditions from gaps undermining authorization. The distinction is a proposed safeguard, not a measured company characteristic.

Digital controls and information credibility:-

Common identifiers should connect scope, schedule, cost, procurement, documents and risks. This enables reviewers to trace an indicator to its evidence and detect inconsistent representations. Without reconciliation, digital consolidation can conceal mismatches. Ownership and revision control should therefore precede automated scoring or predictive analytics. Aramali et al. (2022) review the relationship between earned value research and industrial practice. Readiness assessment should verify budgets, progress rules and cost collection before relying on performance indices. Favorable ratios cannot compensate for unresolved technical constraints or inconsistent

contractor measurement practices. Cost performance index equals earned value divided by actual cost; schedule performance index equals earned value divided by planned value. Neither directly establishes completion-date confidence or investment viability. Gate reviewers should verify measurement rules, cost recognition and change treatment before approving the baseline. Dashboards should expose overdue conditions, obsolete revisions, unsupported progress and incompatible procurement dates. Missing information must remain visible. An absent approval differs from approval of an obsolete document: both require attention, but different responses. Reviewers need access to source explanations rather than colors alone.

Risk Integration and Mining Uncertainty:-

Faúndez and Guzmán (2025) distinguish price, quantity and time drivers of mining cost deviation. Readiness assessment should similarly separate scope maturity, market exposure and duration-related costs. Contingency can appear sufficient while omitting engineering quantity growth or procurement exposure, so its underlying assumptions require review. Schedule risk analysis should test logic, duration ranges and correlated dependencies using evidence on equipment, methods, access and commissioning. A delayed utility may affect several systems simultaneously. Model assumptions require challenge; acceptable completion confidence should reflect economics and risk appetite rather than a universal threshold.

Each material risk needs a cause, affected deliverable, consequence, response, owner and residual exposure. Mitigation requires evidence: identifying a supplier is weaker than obtaining a qualified offer with credible delivery capacity. Reviewers should assess response maturity rather than count risks labelled mitigated. Some uncertainty can be accepted through contingency and accountable response plans. Critical technical, legal, environmental or safety gaps may require resolution before commitment. Mandatory constraints must remain separate from maturity scores, preventing strong financial or schedule results from compensating for an unresolved authorization requirement. 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.

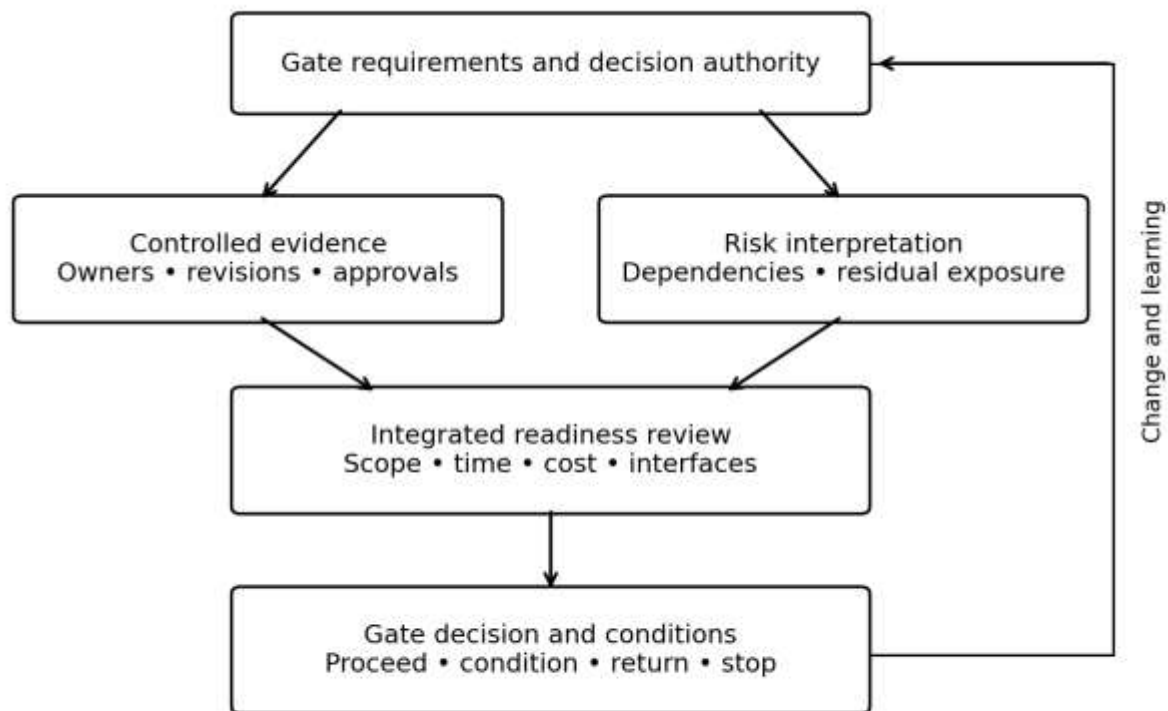
Stakeholder relationships also shape evidence acceptance. Derakhshan et al. (2019) identify limitations in the treatment of external stakeholders; Müller et al. (2014) examine organizational enablers and flexibility. Together, these perspectives support involving responsible suppliers and specialist 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. Forecast methods also require evaluation before gate reviewers rely on automated predictions. Ottaviani et al. (2024) investigate progress-based forecast factors, and Yalçın et al. (2024) evaluate earned-value-based machine learning. Bahnas et al. (2024) examine blockchain-enabled buffer monitoring. These approaches inform possible extensions of the evidence architecture; none substitutes for verified scope, credible schedules or explicit acceptance of residual risks.

Proposed Integrated Execution Readiness Framework:-**Evidence Architecture:-**

The proposed architecture connects five layers: project requirements, controlled evidence, integrated controls, risk interpretation, and gate decisions. Requirements define what must be demonstrated. Controlled evidence records approved documents and accountable sign-offs. Integrated controls establish consistency across scope, cost, time, and procurement. Risk interpretation tests the resilience of those commitments under uncertainty. Gate decisions

record authorization, limitations, and follow-up obligations. Figure 2 represents the relationships and feedback paths. The diagram is a conceptual model developed here; it does not describe an implemented system or report empirical causality.



Digital evidence register connects requirements, records, controls and risks

Figure 2 Proposed integrated execution readiness framework. Original conceptual diagram; arrows represent proposed information and decision relationships, not estimated causal effects.

The evidence register records each requirement's domain, owner, controlled source, revision, approval, schedule activity, cost account, risk and open condition. It can reference existing platforms rather than replace them. A drawing change should expose linked quantity, procurement, cost and gate consequences instead of appearing as disconnected updates. Engineering certifies technical evidence; controls reconcile scope, time and cost; procurement verifies commitments; risk owners confirm responses; operations assesses handover. The PMO coordinates assurance without replacing specialist authority. Independent reviewers challenge material assumptions, and the investment authority records acceptance of remaining exposure.

Readiness Domains and Decision Rules:-

Table 2 defines seven proposed readiness domains: investment case, engineering, schedule and cost, commercial execution, infrastructure and permits, risk response, and operational handover. Domain assessment considers evidence maturity, cross-functional consistency, and unresolved dependencies. A three-state classification can support practical implementation: demonstrated, demonstrated with bounded conditions, or not demonstrated. The middle state requires explicit conditions whose effects are understood. These categories are proposed for piloting; their reliability should be evaluated through independent reviewer agreement before being adopted as organizational policy. Review mandatory constraints, investment validity and domain maturity before assessing interactions among residual conditions. Late equipment selection, incomplete foundations and restricted access may collectively threaten construction despite appearing manageable separately. The decision must explain combined exposure, not merely list individual approvals. Gate outcomes are proceed, proceed with bounded conditions, return for definition, or stop. Conditional approval specifies permitted commitments, blocking conditions and closure authority. Returned

projects need clear evidence requirements. Stopped projects should retain decision records and lessons, allowing capital to be redirected responsibly.

Change Control and Continuing Assurance:-

Execution changes can alter approved scope or accepted assumptions. Link each material change to gate evidence, costs, schedules, risks and benefits. Routine changes follow delegated authority; changes undermining the investment basis require escalation. Earlier approval remains defensible only while its essential conditions remain sufficiently valid. Continuing assurance should respond to material resource reinterpretation, design changes, infrastructure loss or vendor failure. Targeted review can address affected domains without repeating the entire gate. Lessons from execution should update readiness requirements, including commissioning and operating preparations where repeated deficiencies emerge.

Table 2 Proposed readiness domains and gate evidence

Domain	Evidence to examine	Blocking concern
Investment case	Benefits, options, sensitivity and assumptions	Invalid value proposition
Engineering	Approved basis, tests and scope interfaces	Unresolved critical technical basis
Schedule and cost	Logic, quantities, estimate basis and risk model	Incompatible baseline assumptions
Commercial execution	Package scope, vendor capability and commitments	Unbounded supply dependency
Infrastructure and permits	Utility interfaces and approval requirements	Missing mandatory authorization
Risk response	Owners, actions, evidence and residual exposure	Unaccepted critical exposure
Operational handover	Commissioning sequence and operating requirements	Unsafe or infeasible handover

Table 2 is a proposed assessment structure. It does not reproduce an official Ma'aden procedure.

Material assumption failure should trigger reassessment before further irreversible commitments. Record the affected benefits, remaining options, committed expenditure and suspension consequences. Preserving this history distinguishes deliberate adaptation from uncontrolled drift. Pilot evaluation should examine whether reassessment occurred promptly and used current evidence. Reviewers should retain disagreement records so later evaluations can distinguish accepted uncertainty from overlooked evidence.

Implementation and practical measurement:-

Begin with a limited pilot spanning different project conditions. Confirm authorized record access and observe readiness before major outcomes occur. Map existing evidence, identifiers and certification responsibilities before procuring software. Test whether traceability improves without disproportionate administrative effort. Measurement should separate process quality from delivery results. Process indicators include the proportion of gate requirements linked to current approved evidence, unresolved condition age, reconciliation exceptions, decision turnaround time, and reviewer agreement. Delivery indicators include forecast stability, rework arising from incomplete definition, contingency consumption, and milestone deviation. Table 3 presents operational definitions and cautions. Improvements in reporting completeness should not be claimed as reductions in project risk unless the additional evidence changes uncertainty, response effectiveness, or the quality of the authorization decision.

Forecast stability deserves particular attention because a repeatedly revised baseline can hide weak definition. Researchers should distinguish changes caused by approved scope growth from deviations caused by omitted work or inaccurate assumptions. The same distinction applies to cost. A final cost increase may reflect a value-creating expansion rather than poor readiness. Outcome assessment should therefore retain original and revised baselines, change classifications, and the date when the information became available. These records support a more defensible evaluation than comparing final expenditure with the latest approved budget. Training should address cross-functional evidence, uncertainty interpretation and decision responsibility. Dashboard operation alone cannot resolve governance weaknesses. Establish access controls and confidentiality arrangements for owner and contractor records. Research use requires separate authorization; operational access does not establish permission to publish sensitive project information.

Table 3 Proposed pilot indicators

Indicator	Operational definition	Interpretation caution
Evidence coverage	Requirements with current approved evidence ÷ applicable requirements	Completion is not adequacy
Condition age	Elapsed days since condition creation; report median and maximum	Complexity affects closure time
Reconciliation exceptions	Open inconsistencies across linked scope, cost and schedule records	Detection may initially increase counts
Review agreement	Independent classifications agreeing ÷ classifications compared	Agreement is not correctness
Decision time	Days from complete submission to recorded gate decision	Track review effort separately
Forecast stability	Successive forecast changes classified by cause	Scope growth differs from error
Definition-related rework	Verified rework attributed to incomplete pre-execution definition	Requires consistent attribution

Discussion and Research Propositions:-

The framework's central proposition is complementarity. Governance determines whether commitments may be made, digital controls determine whether relevant evidence is connected and inspectable, and risk management determines how uncertain commitments should be interpreted. Each function can be present without the others being effective. Their integration is expected to matter when an approval decision depends on relationships spanning organizational boundaries. This expectation is conceptually grounded in the reviewed themes, but its strength and boundary conditions remain empirical questions rather than established Saudi mining findings. Proposition one states that evidence traceability is associated with more consistent readiness judgments when reviewers have access to comparable source records. Proposition two states that integrated schedule, cost, and risk reconciliation is associated with earlier identification of contradictory delivery assumptions. Proposition three states that mandatory constraints reduce the incidence of authorization despite unresolved critical conditions. Proposition four states that benefits depend on decision authority and specialist participation, rather than software availability alone. These propositions identify observable mechanisms and can be rejected or refined through project-level evidence.

Potential counterarguments deserve consideration. Additional review can delay procurement, increase transaction costs, or duplicate existing assurance. Strict evidence requirements may also disadvantage early projects whose uncertainty is legitimate and unavoidable. The proposed answer is proportionality: evidence maturity should match the commitment being authorized. A study-stage gate need not demand construction-level detail, but it should identify which uncertainties require resolution before later commitments. Evaluation must measure the administrative burden as well as decision quality. A framework that identifies more issues but delays every decision unnecessarily may have limited practical value.

Another concern is measurement behavior. Teams can optimize indicators by redefining requirements, closing conditions prematurely, or moving uncertain work outside the assessed boundary. Independent sampling and preserved decision records help detect these responses. Researchers should examine whether indicators change underlying behavior or merely reporting presentation. Qualitative interviews can explain why formally compliant projects still experience avoidable failures. Such evidence is especially important when organizational incentives encourage optimistic forecasts or when authority to challenge a gate is weaker than the documented governance structure suggests.

Empirical validation and future research:-

A longitudinal comparative design would provide a stronger evaluation than a retrospective satisfaction survey. Projects assessed with the integrated framework could be compared with similar projects using existing assurance arrangements. Matching should consider investment scale, commodity, location, delivery model, technical novelty, and baseline engineering maturity. Where adoption is phased, researchers may examine before-and-after differences while controlling for market and portfolio changes. The analysis should retain unsuccessful, delayed, and cancelled projects to avoid selecting only investments that survived the governance process. The unit of analysis should include both the project and the gate decision. Project outcomes reveal delivery consequences; gate records reveal what decision makers knew and accepted at the time. Combining them allows researchers to distinguish unforeseeable events from information that was available but ignored. Data should include dated evidence registers,

independent review comments, risk-model versions, approved baselines, condition closure records, and categorized changes. Interviews can contextualize these records but should not replace contemporaneous evidence when evaluating the quality of authorization.

A mixed-method approach could test reviewer agreement, model associations between readiness domains and outcomes, and examine decision episodes qualitatively. Quantitative analysis must report uncertainty and avoid claiming causality from small observational samples. Interview analysis should disclose sampling and coding procedures. Access agreements should protect commercially sensitive technical data and ensure that researchers can report unfavorable findings without identifying confidential projects. These arrangements are prerequisites for credible research, particularly where the participant also holds a professional role within the project organization. Future studies should investigate differences between greenfield development, brownfield expansion, and infrastructure-dependent processing investments. They should also examine whether digital integration increases decision speed after initial adoption costs are absorbed. Another priority is calibration of readiness thresholds using outcomes rather than expert preference alone. Cross-country comparison could establish which mechanisms transfer across mining jurisdictions and which depend on regulatory or organizational context. The Saudi setting offers a relevant application, but the framework should be tested for specificity rather than assuming universal applicability from national strategic ambition.

Managerial and policy implications:-

For project owners, the practical implication is to make readiness evidence inspectable before commitments become difficult to reverse. PMOs can coordinate the register, standardize definitions, and monitor exceptions while specialist functions retain certification responsibility. Investment committees can require explicit treatment of material uncertainty and documented boundaries for conditional approval. Contractors can improve interface clarity by linking commitments to controlled technical records and realistic required dates. These practices should be introduced through proportionate pilots, with administrative effort and decision turnaround included in the assessment.

For policymakers and sector institutions, the framework suggests a capability agenda rather than a mandatory national software platform. Shared training in front-end assurance, risk interpretation, and evidence governance could improve professional consistency while allowing different owners to retain appropriate systems. Research partnerships could develop anonymized benchmarks without disclosing proprietary resource or process information. Policy relevance lies in strengthening the credibility of investment delivery and benefit realization. The paper does not recommend replacing legal approvals or claiming that an internal readiness assessment satisfies regulatory requirements.

Limitations:-

The review is targeted and integrative rather than exhaustive. Search results and publicly accessible material cannot substitute for a complete database search or detailed appraisal of every full text. Several foundational sources originate outside Saudi mining, so transfer depends on context. Official corporate reporting supplies descriptive evidence only. No project dataset, interviews, causal estimates, or validated readiness thresholds are presented. Accordingly, statements about potential improvements describe mechanisms and hypotheses, not demonstrated reductions in cost, time, or risk. Journal submission should retain these distinctions and expand the evidence base where required.

The proposed architecture also assumes that organizations can maintain reliable identifiers and specialist accountability across systems. Projects with fragmented contracts, weak data ownership, or limited review capacity may struggle to implement it. Organizational culture and incentives could undermine formal procedures even when technical integration succeeds. These factors should be treated as variables in validation rather than implementation details outside the research model. The framework's practical value will depend on whether it improves decisions under real resource constraints, not simply whether its register can be populated.

Conclusion:-

Execution readiness in Saudi mining projects requires a defensible relationship between investment purpose, delivery evidence, and accepted uncertainty. This paper proposes an integrated framework in which stage-gate governance establishes decision authority, digital controls connect evidence, and risk management tests the reliability of planned commitments. Mandatory constraints, traceable conditions, and continuing assurance preserve

the meaning of authorization. The framework provides a structured basis for piloting and longitudinal research under Vision 2030. Its effectiveness remains to be tested with authorized project records before improved delivery performance or investment outcomes can be asserted.

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