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Critical Success Factors, Risk Allocation, and Schedule Planning in Major Infrastructure Projects: A Structural Equation Modeling Analysis

1Dr. Pratap Kumar Sahu, 2Dr. Amrita Singh, 3Dr. Charu Goyal, 4Dr. Shveta Shah, 5Dr.Ajit Kimar, 6Swadhin Kumar Rout, 7Dr. Dhruv Bajpai

[1]Assistant Professor, Department of Bachelor of Business Administration, Parul Institute of Business Administration, Faculty of Management Studies, Parul University, Vadodara, Gujarat, India. Email: pks26061983@gmail.com, ORCID: 0009-0001-4198-7898 Corresponding Author
[2]Assistant Professor, Department of Bachelor of Business Administration Parul Institute of Business Administration, Faculty of Management Studies, Parul University, Vadodara, Gujarat, India. Email: amrita4288@gmail.com , ORCID: 0000-0002-5464-1343
3Assistant Professor, Department of Bachelor of Business Administration, Parul Institute of Business Administration, Faculty of Management Studies, Parul University, Vadodara, Gujarat, India. Email: charms30.87@gmail.com, ORCID: 0000-0003-3065-4104
4Assistant Professor, Department of Bachelor of Business Administration, Parul Institute of Business Administration, Faculty of Management Studies, Parul University, Vadodara, Gujarat, India. Email: shveta.shah2512@gmail.com, ORCID: 0009-0003-3506-483X
5Assistant Professor, Department of Bachelor of Business Administration, Parul Institute of Business Administration, Faculty of Management Studies, Parul University, Vadodara, Gujarat, India.Email id: ajit.finit@gmail.com
[6]Research Scholar, Department of Business Management and Commerce, Arni University, Kangra, Himachal Pradesh, India. Email: routswadhinkumar@gmail.com, ORCID iD: 0009-0003-4123-0072
[7]Assistant Professor, Department of Bachelor of Business Administration, Parul Institute of Business Administration, Faculty of Management Studies, Parul University, Vadodara, Gujarat, India. Email: dhruvbajpai7@gmail.com, ORCID: 0009-0006-7918-7032

ABSTRACT: There are usually cost and time issues, and problems with quality, with big infrastructure projects. This paper analyses the impact of governance and leadership capacity, technical and organizational capability, stakeholder alignment, quality of risk management, and maturity of schedule management on operational project performance, using the structural equation modeling technique. The analysis was performed on an anonymized dataset with 400 project observations across six regions, six infrastructure sectors, five delivery models and eight professional roles. Reflective measurement blocks were studied based on standardized loadings, Cronbach's alpha, composite reliability, average variance extracted and the heterotrait-monotrait ratios. Operational project performance combined several perceptual measures and objective measures including schedule and cost performance indices, delays, cost overruns, change orders, safety incidents, and variance in critical path. The analysis showed that governance and leadership capacity positively predicted the quality of risk allocation (β = .485), and that technical and organizational capability positively predicted the maturity of schedule planning (β = .433). The quality of risk allocation (β = .319), and the maturity of schedule planning (β = .275), positively predicted operational performance, with the model explaining 68.1% of the variance. Stakeholder alignment did not have a significant direct effect on operational performance (β = .028, p = .456); however, an indirect effect through the quality of risk allocation was observed, along with governance, leadership and technical capacity, with partial mediation. The size, duration and complexity proxy did not have a significant moderating effect on the relationship between quality of risk allocation and performance, or maturity of schedule planning and performance. The evidenced pathways support the development of a practice-based risk allocation and schedule management framework based on the following concepts: an edge in management and control, absorption and use of relevant information, clarity with respect to the value of contingencies, and governance of P50/P80 milestones.

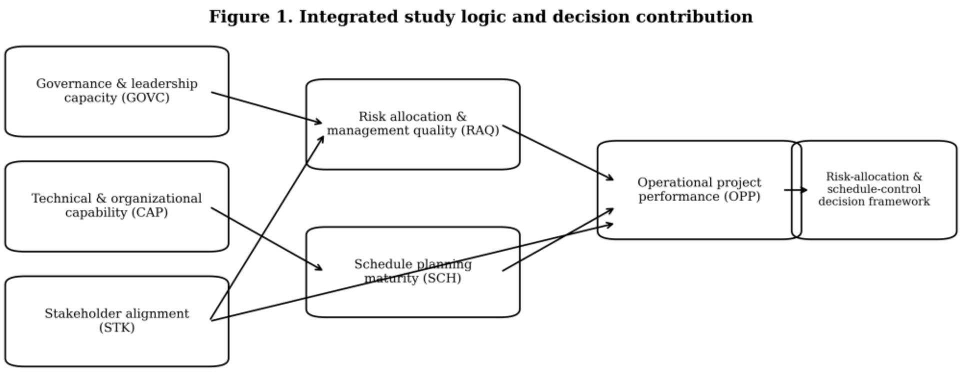

Figure 1. Integrated study logic and decision contribution

Explanation. The graphical abstract shows the structural logic analyzed in the study: upstream governance, capability, and stakeholder conditions connect to risk-allocation and schedule-control mechanisms, which influence operational project performance and form the managerial decision-making framework.

1. INTRODUCTION

Large scale infrastructure projects represent the integration of public policy, private finance, and engineering capabilities with construction and service commitments spanning decades. They shape public mobility and access to utility services such as energy and water. They contribute to expanding industrial activity and urban development. The delivery challenges experienced by these projects do not diminish their strategic importance. There is an operational challenge beyond the scope of individual delays or budget discrepancies. A project can come to a completion date while incurring multiple change orders and claims. Delays can be compensated by an unplanned operating handover. A project can create a substantial public benefit even if costs are not contained. Project success should be the result of a portfolio approach that captures the reliability of schedule and budget, rework and safety in operations, service availability, customer satisfaction, and positive outcomes. Public-private partnerships and infrastructure delivery research show that successful projects achieve more than one of the defined outcomes. The governance approach tended to fragment that success across multiple performance silos (Cui et al., 2018; Esperilla-Niño-de-Guzmán et al., 2024; Mazher, 2025).

Project controls are typically structured in the same way that the majority of institutions are, in silos. Governance teams set the terms of contracts and control approvals; the commercial team manages the risk transfer; the planners own the baseline schedule and delivery teams report the earned value and milestones. When the boundaries between these functions are weak, risk is often transferred to an unknowing party. This risk is often transferred without control over the information, the capacity to absorb it, or the ability to reasonably price it. The schedule will be a reflection of a lot of assumptions; incomplete design is assumed to be complete, risks are omitted and placed in the activity logic, and resources are assumed to be available with no feasible calendar. This goes hand in hand with defensive pricing, claims behavior, float consumption, stalling decisions, and unpredictable completion. Integration of risk ownership in construction and stakeholder management shows that the separation of stakeholder and risk ownership registers should not be maintained, but should be integrated instead (Rasheed et al., 2022; Xia et al., 2018).

The literature on critical success factors is useful because it identifies recurring conditions attached to the delivery of infrastructure. The delivery of infrastructure in developed and developing economies has focused on stable institutions, transparent procurement, capable public agencies and private partners, clear goals, supportive stakeholders, adequate financing, leadership, and project management capability (Aljaber et al., 2024; Osei-Kyei & Chan, 2017; Yang et al., 2024). However, the ranking of factors does not explain how performance is generated. A factor that is ranked high may function directly, via a contract, through more mature planning, or only in a specific lifecycle phase. The differences seen in various sectors and lifecycle phases show that a standard checklist conceals the causal chain that links the upstream abilities to the everyday operational outcomes (Ojiako et al., 2025; Özcan, 2025).

Risk allocation is one possible transmission mechanism. The best allocation does not necessarily mean the highest percentage transferred to the private party. It refers to matching the risk with the party that can control the occurrence of the risk, obtain the necessary information, absorb the impact, determine the exposure, and respond, without incurring excessive transaction costs. Research on PPP risk preferences and allocation practices shows that inappropriate transfer can reduce bid realism, increase renegotiation, and focus more on the recovery of contractual obligations than on preventing them (Buzzetto & Carvalho, 2022; Fathi & Shrestha, 2023; Mazher, 2025). The second mechanism is schedule planning maturity. A schedule that is planning control mature has a valid work breakdown structure, clear precedence logic, feasible resource levels, risk - adjusted schedules, integrity of progress data, discipline in forecasting, and explicit contingency planning. These attributes transform an organization's capability into a reliable overall schedule and early warning signals, rather than baseline dates that remain fixed.

Structural equation modeling (SEM) is appropriate for this research problem because the core concepts are not directly observable and must be represented by multiple indicators. SEM also allows the researcher to estimate direct and indirect pathways, assess measurement quality, and evaluate the explanatory and predictive power of the model. Ahmad et al. (2021) and Fathi (2024) provide examples of infrastructure studies that also utilized SEM, but both studies rely heavily on perceptual success scores or one sector-specific setting. A final methodological gap is the incomplete integration of latent organizational constructs and operational definitions of the schedule performance index (SPI), cost performance index (CPI), percentages of delay and overrun, change orders, safety events, and critical path variance.

This study fills this gap by utilizing a project-level model with 400 anonymized observations from large-scale infrastructure projects. The model positions governance and leadership capacity, technical capacity, and stakeholder alignment as critical success factors. Risk allocation and management quality, and schedule planning maturity, are modeled as intervening constructs and operational project performance is measured from both survey responses and measurable project outputs. Project size and planned duration form only a size-duration proxy for project complexity. The study aims to answer the following questions: Which of the critical success factors contribute most strongly to the explanation of project performance? Do constructs of risk allocation and schedule maturity mediate their effects on performance? Does this proxy change the strength of those mechanisms? How can the statistically important pathways inform a conceptual allocation and schedule-control framework?

The contribution is threefold. The study moves from ranking factors to a mechanism model connecting governance, capability, and scheduling with stakeholder alignment indirectly through RAQ; complexity moderation has not been supported. In terms of methodology, the study presents a hierarchical composite SEM that integrates both perceptual and operational data and provides evidence of measurement validity, bootstrap mediation, moderation assessments, predictive testing, and subgroup robustness. From a management perspective, it positions the supported pathways as a conceptual implementation framework to articulate risk exposure, establish contingency ownership, include P50/P80 milestones, and oversee rebalancing triggers. The rest of the paper builds the hypotheses, explains the data and analytical method, provides the empirical findings, explains their importance, and gives the resulting framework.

2. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

2.1 Defining success in large-scale infrastructure projects

Success for a project has many dimensions. Success for a project-management system involves achieving the agreed time, cost, quality and safety goals for the project delivery. The success of a product or asset is achieved if the facility performs reliably after it is handed over. Success in partnership is achieved when there is long-lasting cooperation between organizations, as well as peace and equitable value for the participants. Success in the public realm is measured by accessibility, legitimacy, social and environmental impacts, and lasting service outcomes. More than one dimension of success exists, but a narrow perspective, like the iron triangle, can reward local success and time, cost, and quality goals, while overlooking claims, operational availability, and positive performance value.

A workable and measurable solution to the many dimensions of success for an operational project (OPP) has been developed for empirical study. The present study has developed a five-element perceived performance block and a normalized objective index. The objective index rewards high schedule and cost performance and imposes a penalty for schedule and cost overruns, change orders, safety incidents, and critical path deviations. Because an absolute schedule delay has a different meaning for an 18-month telecommunication project than for an 82-month transport project, it is necessary to normalize. The hybrid approach and combined perceptual and objective assessment elements also reduce the influence of a single overall success judgment by a respondent. Evidence from studies on operational management success and PPP success supports the use of multiple criteria, rather than a single measure of final cost or completion time (Osei-Kyei et al., 2017a; Phong et al., 2020; Surachman et al., 2020).

2.2 Critical success factors as higher-order capabilities

Stable credible rules that are enforceable depend on the governance and institutional capacity of the actors involved in projects. The necessary capacities are, for instance, well-defined decision-making powers, orderly policies, transparent procurement, timely approvals, coordinated regulations, public sponsorship that is sufficient and competent, and accessible mechanisms to resolve disputes. Relevant studies from the transitional and emerging market contexts have found that one of the key conditions for the private participation in projects and for ensuring the continuity of the projects is the quality of institutions (Agyapong et al., 2025; Amović et al., 2020; Berisha et al., 2022; Hai et al., 2022). Comparative studies also show that the importance and the way these factors are expressed vary with the national context and the maturity of the market for public-private partnerships (Deinde-Adedeji et al., 2024; Osei-Kyei & Chan, 2017; Yang et al., 2024).

Governance is the implementation of policies and strategies, and leadership is the yang to that yin. Formal approval matrices cannot replace the discipline required from leaders to make decisions and coordinate actions across the organization. The provided dataset distinguishes four governance indicators and four leadership indicators. Therefore, we model governance and leadership capacity (GOVC) as a higher-order composite built from two validated lower-order blocks. This specification is supported by evidence that contract governance can strengthen or weaken the effect of partnership success factors on performance, and that institutional actors shape the implementation of PPP (Abdul Latif et al., 2023; Biygautane et al., 2019). It also avoids isolating leadership as a personality trait when its role is to convert institutional arrangements to decisions and actions.

The area of concern expecting the ability to manage complex work (CAP) incorporates maturity of design, assembled teams, integration of systems, governed changes, the quality of data, and availability of adequate resources. Characteristics of clients, public agencies, and the private sector have been observed as success factors in several South African, Indonesian and Vietnamese as well as other developing countries (Nuseeb et al., 2021; Phong et al., 2020; Surachman et al., 2020). The quality of the schedule is expected to influence performance because the use of specialist skills is required to construct activity logic; estimate effort and duration; assess and load resources to define the allocated work; model uncertainty; and determine the state of the work.

Alignment of stakeholders (STK) is discussed as shared vision and goals, solidarity and partnership, informed and involved communication, clear support of the community, coordination of interfaces, and timely decisions. Infrastructure projects involve a wide range of actors with different legal rights, resources, and knowledge, as well as exposure to the result. Community support could determine the social license for the project; and finance and operation influence the scope of work and the requirements of maintainability and approvals, respectively. Research on affordable housing, community sustainability, and infrastructure partnerships shows that early participation and credible communication reduce resistance and improve implementation legitimacy (Kavishe & Chileshe, 2019; Toriola-Coker et al., 2023).

More recent data suggests that critical success factors depend on the lifecycle stage and industry sector. Certain types of projects, like availability-payment projects, smart-city infrastructure, transport PPPs, and water and power partnerships, need specific combinations of institutional support, technical capability, and risk management (Al-Saadi et al., 2024; Almarri & Boussabaine, 2025; Shodiqi et al., 2024; Özcan, 2025). This doesn't mean that standard frameworks are pointless, but that they should be treated as flexible capabilities, rather than being defined once and for all. A more advanced level of governance and leadership is therefore appropriate for assessing the overall process, while the robustness analysis can be reserved for the differences among sectors and delivery models.

2.3 Risk allocation quality

Risk allocation quality (RAQ) refers to the appropriateness of allocating a risk to a party that will control the risk event and its consequences. An acceptable allocation should answer at least five questions. Who has control over the underlying cause? Who is in the best position to provide the needed information? Who is financially and technically capable of responding to the risk? Who is in a better position to price or insure the exposure at the overall cost? Which option does not create excessive liability and risk while also retaining the desired incentives? Such principles distinguish an allocation from an indiscriminate transfer. A high percentage of risk transferred in a contract may not necessarily mean that the risk is under better control. It may in fact mean that the contract is very aggressive and the parties involved may be likely to renegotiate the terms of the contract. The PPP risk research reviewed in recent publications has noted that allocation should be analyzed as a part of an overall package that includes risk-sharing mechanisms along with guarantees, retained obligations, and the overall stage and maturity of the risks (Ampratwum et al., 2023; Mazher, 2025; Rasheed et al., 2022).

The dataset includes dimensions for risk allocation and risk-management maturity. In this study, the two are conceptualized and treated as lower-order components of a higher-order RAQ composite as contractual allocation and the integrative response are mutually dependent. The allocation determines who will have the incentives to address the risk, and the management maturity will determine the owner's willingness and ability to identify, monitor, and manage the risk. The owner will decide the exposure level and whether it will be accepted or avoided (Buzzetto & Carvalho, 2022). Research on allocations at the transfer phase also suggests that the allocated risk should not cease to exist at financial closure. It should be maintained during the management period and should be in an acceptable state at the time of its return (Bao et al., 2023).

The anticipated performance mechanisms are incentive alignment, moral hazard reduction, realistic pricing, efficient contingency, faster decisions, and fewer disputes. For RAQ, governance should mean clarifying authority, ensuring transparency, and enforcing allocation rules. Stakeholder alignment should mean decreasing information asymmetry and increasing acceptance of shared or contingent arrangements. RAQ should be in the same way that the party that is best positioned to act is incentivized and authorized to do so. These arguments are in line with what we see in highway projects, together with contract-governance studies and structural models of risk and success (Abdul Latif et al., 2023; Fathi, 2024; Fathi & Shrestha, 2023).

H1: There is a positive influence of governance and leadership capacity on risk allocation and management quality.

2.4 Schedule planning maturity and algorithmic control

There is more to schedule planning maturity (SCH) than the establishment of a baseline. To achieve an acceptable level of maturity, work in this domain requires consideration of the work breakdown structure, precedence logic, resource calendars, duration estimates, risk integration, progress measurement, forecast routines, and the governance of corrective actions. While deterministic estimations of critical path scheduling will always be necessary, a single duration estimate for an activity can be a significant oversimplification and can conceal uncertainty and correlation. Therefore, a schedule planning control system maturity requires the baseline be supplemented by schedule risk analysis, criticality indices, sensitivity analysis, and limited rules for the protection and/or consumption of contingency, in addition to resource-constrained rescheduling. Maturity in planning, monitoring, and communicating as well as resource allocation has been identified as recurring success factors in different types of operational management and infrastructure partnerships (Osei-Kyei et al., 2017a; Osei-Kyei & Chan, 2018).

Technical and organizational capability should improve SCH as design knowledge, construction techniques, resource productivity data, interface mindfulness, as well as controlled and disciplined change management, should also be considered. Moreover, effective planning should enhance OPP by revealing infeasible logic and unstable resource peaks and by identifying milestone risk to the extent that action is feasible. The mechanism is essential when contractual allocation and scheduling are done concurrently. If a party has the land access risk, the baseline should contain access milestones and decision date and access-related contingency. If a party has the contractual risk of the controls on design and construction productivity, the baseline should contain design release logic and resource criticality. This integrated approach responds to the most common issue in project management today, that is maintaining the risk register and schedule in silos.

Algorithm 1 details the order of operations. The procedure verifies the logic of the schedule, links risk events to activities, assigns distributions, performs a Monte Carlo simulation, identifies criticality and sensitivity, resolves resource conflicts by a serial scheduling scheme or metaheuristic search, and then feedbacks high-criticality risks into allocation and contract governance. The current dataset lacks activity-level network data, so the algorithm is presented as an implementation framework rather than as an empirically executed optimization. Its purpose is to convert the SEM pathways into a manageable routine. The associated hypotheses are:

Algorithm 1. Risk-adjusted resource-constrained schedule procedure

1. Input the work breakdown structure, precedence network, baseline durations, resource calendars, risk register, contractual owner, and progress cut-off data.
2. Validate schedule logic by removing open ends, excessive constraints, negative lags, and infeasible calendars.
3. Assign duration distributions and risk-event impacts; document dependencies, correlations, and response assumptions.
4. Run Monte Carlo analysis to estimate P50/P80 finish dates, activity criticality indices, and schedule-sensitivity rankings.
5. Where resource conflicts are material, apply a serial schedule-generation scheme and optimize priority rules or a genetic search objective.
6. Reallocate or mitigate high-criticality risks when the current owner lacks control, information, or absorptive capacity.
7. Re-simulate and compare baseline and revised dates, expected delay, float consumption, and resource peaks.
8. Output risk-adjusted milestones, contingency thresholds, responsible owners, and early-warning indicators.

Methodological note. Algorithm 1 is a conceptual/practice-oriented implementation framework developed from empirical SEM findings. The survey data set lacks an activity-level precedence network, activity-level durations or their distributions, resource calendars, or the link of risk to activities needed to perform empirical Monte Carlo schedule simulation or resource-limited schedule optimization. Therefore, Algorithm 1 was not empirically performed, tested, or validated with the provided survey data set; it is provided simply as a practice-oriented translation of the supported SEM pathways.

2.5 Stakeholder alignment and project complexity

Alignment of stakeholders influences performance in both visible and invisible ways. Visibly, stakeholder alignment leads to swifter communication, coordination, and decision-making. Invisible alignment leads to better perceived distribution of risk. The impacted stakeholders understand the reasoning behind risk-sharing, retention, or transfer. In urban waste and water management contexts, diverging stakeholder groups impact which initiatives and projects are prioritized to be undertaken (Muñoz-Jofré et al., 2023; Ngullie et al., 2021). Once governance, RAQ, and schedule maturity are modeled simultaneously, the size and significance of any remaining direct STK → OPP effect are treated as empirical questions rather than assumed in advance. Accordingly, the study tests the originally specified H6: Stakeholder alignment positively affects operational project performance.

Project magnitude can include factors such as length, size, and level of Novelty, interdependence, and regulatory/stakeholder interfaces. The annex does not contain a psychometric complexity estimate. As a substitute, this study utilizes a measurable proxy of the standardized log of project size and duration. Even if complexity requires more advanced controls, project planning may become more flexible when the environment and stakeholders change rapidly relative to contract and project baseline flexibility. Such flexibility will be reached based on the PPP literature which describes how the scope of a project can change (Ojiako et al., 2025). H9 therefore tests whether the observed size-duration proxy conditions the RAQ → OPP and SCH → OPP relationships; the direction, magnitude, and statistical significance of both interaction effects are assessed empirically.

2.6 Conceptual model and research gap

The studies in the review point to established critical success factors, risk tiers, and project success criteria. However, not many studies model the causal order of the upstream capabilities, the quality of the allocation, the degree of schedule maturity, and the operational metrics. The existing SEM applications have focused on the all-in PPP success rate, sustainability, the securitization of municipal assets, and the planning of municipal waste (Ahmad et al., 2021; Deng et al., 2021; Liu et al., 2021; Ngullie et al., 2022). The current model moves this body of work forward by including two higher-order managerial mechanisms and a hybrid performance outcome. The estimated model is reported in Figure 2, and the construct architecture and the associated hypotheses are summarized in Tables 1 and 2.

Table 1. Construct definitions, measurement blocks, and model roles

Construct	Definition	Indicators / metrics	Specification	Model role
GOVC	Institutional governance and leadership capacity for stable rules, transparent decisions, timely approvals, escalation, and accountable coordination.	GOV1-GOV4; LEAD1-LEAD4	Higher-order composite	Exogenous CSF
CAP	Technical and organizational ability to design, integrate, resource, execute, and control complex work.	CAP1-CAP4	Reflective composite	Exogenous CSF
STK	Shared objectives, trust, communication, participation, community support, and interface coordination.	STK1-STK4	Reflective composite	Exogenous CSF / predictor
RAQ	Fit of risk ownership with control, information, capacity, incentive, pricing, and active risk-management maturity.	RA1-RA5; RM1-RM4; transferred-risk percentage used descriptively	Higher-order composite	Mediator
SCH	Quality of schedule logic, resources, uncertainty treatment, baseline integrity, and progress/forecast routines.	SCH1-SCH5	Reflective composite	Mediator
PCX	Observed proxy capturing only project scale and temporal burden; not a comprehensive latent complexity measure.	z[ln(project value)] and z[planned duration], combined with equal weight	Observed size-duration composite	Moderator / control
OPP	Predictable delivery and operational outcomes across cost, time, change, safety, critical path, and perceived success.	PP1-PP5 plus CPI, SPI, delay, overrun, change orders, safety incidents, critical-path variance	Hybrid higher-order outcome	Endogenous outcome

Note. The anonymized dataset includes item codes, but not complete wording for the questionnaire, exact verbal anchors for the five-point scale, or citations for the original source at the item level. Therefore, these elements will not be reconstructed and must be added by the authors before submission. PCX is an estimated size-duration proxy that is based on standardized log project value and standardized planned duration and is not a complete measure of latent project complexity.

Explanation. The construct architecture separates upstream critical-success-factor capabilities from the mediating mechanisms and the operational-performance outcome. It also makes clear that PCX is an observed size-duration proxy rather than a comprehensive latent complexity construct.

Table 2. Hypotheses and theoretical mechanisms

Hypothesis	Path	Expected relationship	Mechanism
H1	GOVC → RAQ	Positive	Clear authority, transparency, and decision capacity improve ownership fit and enforceability.
H2	STK → RAQ	Positive	Aligned stakeholders improve information quality, legitimacy, and acceptance of shared treatment.
H3	CAP → SCH	Positive	Technical capability improves logic, resource feasibility, uncertainty treatment, and forecasting.
H4	RAQ → OPP	Positive	Fit-for-purpose ownership aligns incentives, reduces disputes, and improves contingency efficiency.
H5	SCH → OPP	Positive	Mature schedules improve early warning, resource stability, and milestone reliability.
H6	STK → OPP	Positive	Possible direct pathway through access, decision speed, and interface resolution; tested empirically alongside the modeled indirect pathway.
H7	GOVC → RAQ → OPP	Positive indirect	RAQ transmits part of governance capacity into operational performance.
H8	CAP → SCH → OPP	Positive indirect	SCH transmits part of technical capability into operational performance.
H9	PCX × RAQ → OPP; PCX × SCH → OPP	Conditional	The observed size-duration proxy is tested as a possible boundary condition; interaction direction and significance are assessed empirically.

Explanation. *The hypotheses specify the proposed direct, indirect, and conditional pathways tested in the structural model. H1-H8 define the principal capability, mediation, and performance relationships, while H9 tests moderation by the observed size-duration proxy.*

3. MATERIALS AND METHODS

3.1 Research design and data setting

The study employed an explanatory, cross-sectional, project-level design. Data were analyzed from the anonymized workbook provided for the study which contained 400 complete observations, 52 variables, and one observation per knowledgeable project respondent. The worksheet captured the project respondent's professional role, project type, delivery model, project value, project duration, completion percentage, 35 Likert-scale statements, and eight operational or allocation metrics. There were no missing values at the Item level or project level. The data lacked respondent identifiers, organization names, collection dates, counts of surveys sent, and project identifiers that may have indicated if more than one respondent was captured for the same project. Therefore, the analysis does not report a response rate or intraclass aggregation statistics, and this metadata should be confirmed before the journal submission.

Metadata for data collection. Fieldwork dates: [AUTHOR TO PROVIDE: fieldwork dates]; target sampling frame/population: [AUTHOR TO PROVIDE: target sampling frame/population]; number invited/contacted: [AUTHOR TO PROVIDE: number invited/contacted]; usable responses: 400; response rate: [AUTHOR TO PROVIDE: response rate]; recruitment/data-collection method: [AUTHOR TO PROVIDE: recruitment/data-collection method]; pilot-testing procedure and pilot sample: [AUTHOR TO PROVIDE: pilot-testing procedure and pilot sample].

The project portfolio had a wide geographical and sectoral scope. Observations spanned Asia-Pacific, the Middle East, Europe, Africa, North America, and Latin America. Project types encompassed transport, energy, industrial, urban development, water/wastewater, and telecommunications. Delivery models included engineering-procurement-construction (EPC), design-bid-build, PPP/concession, design-build, and construction management. Project values varied from USD 50 million to USD 6 billion, planned durations extended from 18 to 82 months, and completion levels ranged from 10% to 98%. The size and timeframe spanned a large interpretation of infrastructure projects and warranted specific controls for both.

3.2 Sample profile and power considerations

The sample included 81 project managers, 68 construction managers, 54 project-controls engineers, 51 site engineers, 50 planning/scheduling engineers, 34 contract managers, 34 risk managers, and 28 consultants. The mean professional experience was 12.26 years (SD = 5.72; range = 2-31 years). Respondents had direct project experience. About 30.3% of respondents worked in the transport sector, while about 23.5% of respondents worked in the energy sector. EPC (28.0%) and design-bid-build (27.3%) were the dominant delivery models, while PPP/concessions were 20.3% of the observations. While these samples were helpful, they do not comprise a probability sample of the global infrastructure population.

The model consisted of eight lower-order measurement blocks, two higher-order composites, three endogenous equations, direct effects, two mediation pathways, and two interaction terms. A sample of 400 is considered sufficient for stable composite estimation, while 5,000-resample bootstrapping was executed based on the observed effect size. A more thorough approach to assessing confidence-interval precision included consideration of how well the model explained the variance, the out-of-sample prediction, and the size of the subgroup samples. Since the PPP subgroup comprised 81 observations, path estimates were interpreted with caution and more in terms of direction than to justify strong claims of path invariance.

3.3 Instrument architecture and construct operationalization

All psychometric indicators were on a five-point scale, with higher values indicating stronger levels of governance, leadership, stakeholder alignment, technical capability, schedule maturity, quality of risk allocation, maturity of risk management, and project performance. The measurement architecture included GOV1-GOV4, LEAD1-LEAD4, STK1-STK4, CAP1-CAP4, SCH1-SCH5, RA1-RA5, RM1-RM4, and PP1-PP5. Since the available workbook didn't have item wording or source citations at the item level, no item wording was constructed. The analysis kept item codes and connected them to the construct definitions in the approved outline. Before publishing, the writers should add the last questionnaire and item-source matrix as supplemental files. The supplied authoritative materials also do not provide the exact verbal labels for the five-point response anchors; the placeholder matrix below identifies the item wording, anchors, and original citations that must be supplied without reverse-engineering them from variable codes.

Table 3. Item-source matrix (author completion required)

Construct block	Item codes	Exact questionnaire wording / five-point anchors	Original source citation
GOV	GOV1-GOV4	[AUTHOR TO PROVIDE: exact wording for each GOV1-GOV4 item and the exact verbal anchors used for response values 1-5]	[AUTHOR TO PROVIDE: original source citation(s) for GOV1-GOV4]
LEAD	LEAD1-LEAD4	[AUTHOR TO PROVIDE: exact wording for each LEAD1-LEAD4 item and the exact verbal anchors used for response values 1-5]	[AUTHOR TO PROVIDE: original source citation(s) for LEAD1-LEAD4]

Construct block	Item codes	Exact questionnaire wording / five-point anchors	Original source citation
CAP	CAP1-CAP4	[AUTHOR TO PROVIDE: exact wording for each CAP1-CAP4 item and the exact verbal anchors used for response values 1-5]	[AUTHOR TO PROVIDE: original source citation(s) for CAP1-CAP4]
STK	STK1-STK4	[AUTHOR TO PROVIDE: exact wording for each STK1-STK4 item and the exact verbal anchors used for response values 1-5]	[AUTHOR TO PROVIDE: original source citation(s) for STK1-STK4]
SCH	SCH1-SCH5	[AUTHOR TO PROVIDE: exact wording for each SCH1-SCH5 item and the exact verbal anchors used for response values 1-5]	[AUTHOR TO PROVIDE: original source citation(s) for SCH1-SCH5]
RA	RA1-RA5	[AUTHOR TO PROVIDE: exact wording for each RA1-RA5 item and the exact verbal anchors used for response values 1-5]	[AUTHOR TO PROVIDE: original source citation(s) for RA1-RA5]
RM	RM1-RM4	[AUTHOR TO PROVIDE: exact wording for each RM1-RM4 item and the exact verbal anchors used for response values 1-5]	[AUTHOR TO PROVIDE: original source citation(s) for RM1-RM4]
PP	PP1-PP5	[AUTHOR TO PROVIDE: exact wording for each PP1-PP5 item and the exact verbal anchors used for response values 1-5]	[AUTHOR TO PROVIDE: original source citation(s) for PP1-PP5]

Explanation. *This matrix identifies the questionnaire blocks that require author-supplied item wording, response anchors, and original source citations. These missing details are intentionally left as placeholders and should not be reconstructed from the variable codes.*

The capacity for governance and leadership (GOVC) was estimated as a higher-order composite of standardized governance and leadership components. Governance and leadership components were combined as a higher-order composite to present the joint determination of decision-making capacity as an overall governance component. Standardized risk allocation and risk management components were combined as the Risk Allocation and Management Quality (RAQ) component. Active risk control and contractual risk-bearing components were combined as a risk management component. Schedule planning maturity, technical capability, and stakeholder alignment were represented by their validated lower-order composites.

Operational project performance was a combination of subjective and objective performance data. The objective performance index was standardized and included seven components. SPI and CPI were included in the index in a positive fashion. Schedule delays, cost overruns, change order percentage, Safety Incident Rate (SIR), and Critical-Path Variance (CPV) were all included in the index in a negative fashion. A high index value was indicative of better performance. The objective index exhibited a high level of internal consistency ($\alpha = .906$) and a correlation of .837 with the PP composite. The OPP index was the standardized equal-weight average of the two dimensions to avoid survey responses or operational metrics from dominating the index. The risk that was transferred to the private party was included in an indicator fashion, and was not included as a performance component, as a high level of transferred risk is not indicative of efficient performance.

Project complexity (PCX) only measures size and duration as an observed proxy. It's made up of an equal-weight combination of the standardized logarithm of project value and standardized planned duration. It only quantifies size and duration of a project. It doesn't capture technological novelty, interface density, diverse stakeholders, regulatory complexity, technological interdependence, or other forms of project complexity. For this reason, when PCX is moderated, it is only seen as a size-duration proxy test, not as a test for a complete latent complexity construct.

3.4 Operational metrics

The schedule performance index was calculated as earned value divided by planned value. Values under 1 indicated earned value schedule slippage. The cost performance index was calculated as earned value divided by actual cost, and values under 1 indicated schedule cost inefficiency. Schedule and cost overrun percentages indicated deviations from approved baselines. The change-order percentage represented scope/design instability and governance friction. The safety incident rate incorporated exposure-adjusted safety performance provided in the dataset. Critical-path variance represented deviations

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from the planned critical path. These metrics were reviewed at the project cut-off date and not as final project outcomes as completion ranged from 10% to 98%.

To reduce ambiguity, it was decided that positive schedule or cost underruns would be reported and not truncated at zero. Continuous metrics were evaluated for range, center, and outliers. The dataset contained no undefined indices or missing cells. Project value was log-transformed only for the observed size-duration proxy because of its right-skewed range; the descriptive table reports values in original USD millions. The primary outcome index included standardized components which made it possible to express different units metrics on a single scale.

3.5 Composite-based SEM protocol

The research adopted a two-phase approach to composite-based SEM combining prediction and hierarchical components. Initially, reflective blocks were standardized, and the first principal component was used to represent each. Loadings were oriented so that all outer loadings were positive. The quality of the measurement was assessed using standardized loadings, Cronbach's alpha, composite reliability, average variance, and heterotrait-monotrait ratios. Alpha and composite reliability of .70 and greater, average variance of .50 and greater, and HTMT less than .85 were considered evidence and were not mechanically, arbitrarily viewed as cutoffs. This reporting logic is in line with the suggestions of composite SEM and PLS-SEM (Hair et al., 2019).

Next, structural equations were estimated after the construction of higher-order composites and standardizing the scores. RAQ was predicted by GOVC and STK. SCH was predicted by CAP. OPP was predicted by RAQ, SCH, STK, GOVC, CAP, PCX, RAQ × PCX, and SCH × PCX. The direct GOVC and CAP paths allowed the evaluation of partial versus full mediation. Indirect effects were calculated by the product of the constituent paths. Standardized interaction terms were determined by centered product scores. Here, PCX denotes only the observed size-duration proxy based on standardized log project value and planned duration; the interaction terms therefore test moderation by scale and duration only, not a comprehensive latent complexity construct.

We evaluated uncertainty using 5,000 nonparametric bootstrap resamples. Each resample allowed us to re-estimate the standardized structural equations, and we reported percentile 95% confidence intervals along with two-sided bootstrap probabilities. For the OPP predictors, effect sizes were set at $f^2 = (R^2 \text{ included} - R^2 \text{ excluded})/(1 - R^2 \text{ included})$. To estimate predictive performance, we used shuffled 10-fold cross-validation, calculated Q^2predict, RMSE, MAE, and the correlation between observed and predicted OPP. We also calculated the composite-model standardized root mean square residual from the difference between observed and main-effects-implied latent correlation matrices. As a measure of approximate fit, we excluded interactions from the hypothesis model (which we keep), but did not exclude them from this covariance-implied fit diagnostic.

To test the robustness of the model, we re-estimated the OPP equation using the objective index and the perceptual PP composite as outcomes, respectively. A multi-group comparison was used to estimate the selected paths for the PPP/concession projects and all other delivery models. For directional stability, we used group-specific bootstrap intervals. Formal path-difference assertions were avoided because the dataset did not permit a complete measurement-invariance sequence with item wording and signaling identifiers. The SEM estimation and robustness workflow did not execute Algorithm 1; the supplied dataset contains no activity-level precedence network, activity-duration distributions, resource calendars, or risk-to-activity links needed for that practice-oriented schedule procedure.

3.6 Bias controls, ethics, and reproducibility

Some design constraints mean that some limitations cannot be reversed for the anonymized secondary workbook. Typical method bias was reduced through a combination of objective measures along with the PP block, differentiating predictors from outcomes, and testing discriminant validity. The high agreement between the objective-only and subjective-only robustness models implies that the main conclusions were not driven by any single outcome source. Multicollinearity was assessed through construct correlations and effect stability; HTMT values stayed below .70. No cases were removed solely to improve fit.

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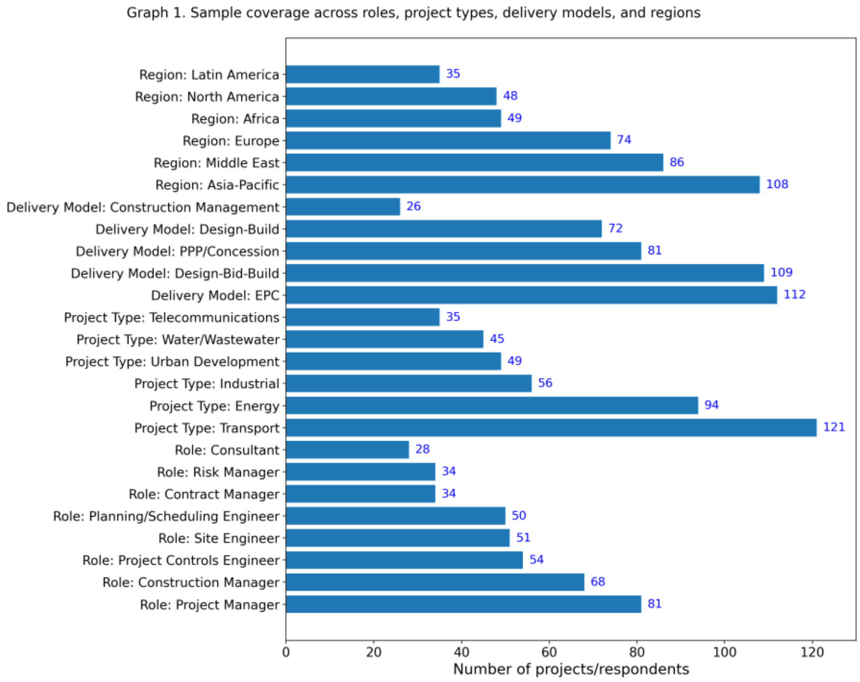
The statistical process documented in the available workbook allows for easy replication of the analysis. This is due to the set random seed, construct mapping, and bootstrap data as input. These things (which are required for a complete submission-ready empirical report) were not present in the uploaded dataset.

Ethics status. [AUTHOR TO PROVIDE: ethics approval/exemption details]. No verified ethics/IRB approval or exemption reference was supplied in the materials reviewed, so no approval or exemption is asserted in this manuscript.

4. RESULTS

4.1 Sample and project profile

100% of the rows were kept. The Asia-Pacific region provided 108 observations (27.0%), followed by the Middle East at 86 observations (21.5%), Europe at 74 observations (18.5%), Africa at 49 observations (12.3%), North America at 48 observations (12.0%), and Latin America at 35 observations (8.8%). The sample was dominated by transport and energy at 53.8%. The average project value was USD 615.77 million (SD = 640.46; median = 423.50), and the average projected duration was 45.37 months (SD = 12.89). The mean completion was 55.66%, indicating a portfolio of both developing and late-stage projects. Graph 1 and Table 4 provide details on the coverage and imbalance across the categories.



Graph 1. Sample coverage across roles, project types, delivery models, and regions

Explanation. The sample was broad, though not evenly distributed. Transport, energy, EPC, design-bid-build, Asia-Pacific, and project-management roles were most highly represented. Therefore, the findings should be interpreted with awareness of this uneven representation across project categories.

Table 4. Respondent and project characteristics

Characteristic	Category / statistic	n or mean (SD)	% or range
Professional role	Project manager	81	20.3%
	Construction manager	68	17.0%
	Project controls engineer	54	13.5%
	Site engineer	51	12.8%

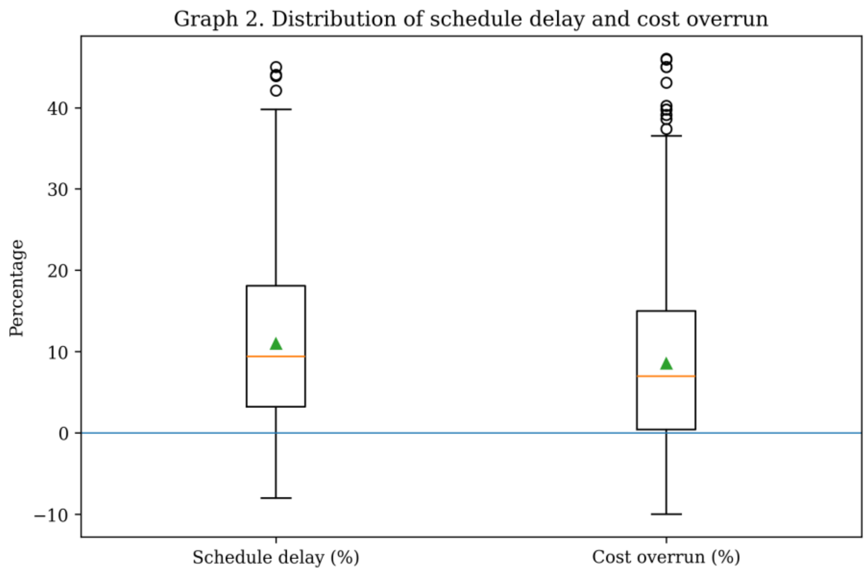
Characteristic	Category / statistic	n or mean (SD)	% or range
	Planning/scheduling engineer	50	12.5%
	Contract manager	34	8.5%
	Risk manager	34	8.5%
	Consultant	28	7.0%
Region	Asia-Pacific	108	27.0%
	Middle East	86	21.5%
	Europe	74	18.5%
	Africa	49	12.3%
	North America	48	12.0%
	Latin America	35	8.8%
Project type	Transport	121	30.3%
	Energy	94	23.5%
	Industrial	56	14.0%
	Urban development	49	12.3%
	Water/wastewater	45	11.3%
	Telecommunications	35	8.8%
Delivery model	EPC	112	28.0%
	Design-bid-build	109	27.3%
	PPP/concession	81	20.3%
	Design-build	72	18.0%
	Construction management	26	6.5%
Continuous variables	Experience (years)	12.26 (5.72)	2-31
	Project value (USD million)	615.77 (640.46)	50-6,000
	Planned duration (months)	45.37 (12.89)	18-82
	Project completion (%)	55.66 (22.71)	10-98

Explanation. *The sample covers multiple professional roles, sectors, delivery models, and regions, but the distribution is not uniform. The profile should therefore be considered when interpreting the generalizability of the structural-model results.*

4.2 Descriptive operational performance

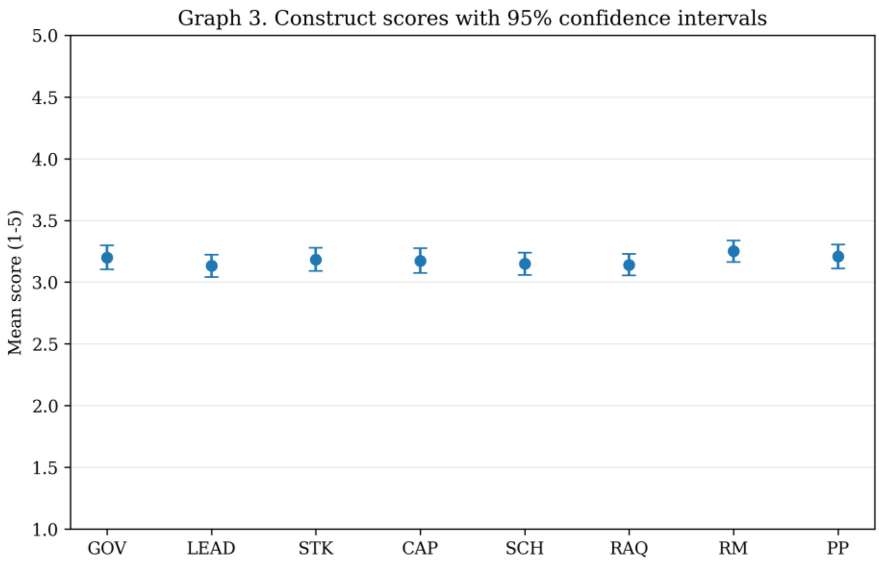
The average scheduled and cost performance indices were .922 (SD = .085) and .938 (SD = .089) respectively. Such values indicate that the average project completed less than the scheduled and cost work targets. The average schedule delay was 10.97% (SD = 10.81; median = 9.43%) with the average cost target overrun at 8.53% (SD = 11.31; median = 6.96%). The changes to the portfolio mean that the average change order was 9.53% with an average safety incident at 1.76 per 100 worker days and an average critical path variance at 12.15 days. The average risk transferred to the private party was at 52.13% (SD = 14.02) with a range of 20% to 85%. The differing levels of risk transferred indicates that some degree of risk was transferred, but not all.

Graph 2 indicates that the completion and cost overrun/underrun metrics had a long positive tail and could take on negative values (i.e., completion in advance or cost savings). The most extreme values were a 45.0% schedule delay and a cost overrun of 46.03%. The multi-metric outcome provides a better estimate for the performance of the portfolio than determining if the performance was a success or failure.



Graph 2. *Distribution of schedule delay and cost overrun*

Explanation. Both outcomes are asymmetric and include substantial positive tails. The median project experienced lower delay and overrun than the mean, showing that a smaller set of poorly performing projects raises the portfolio average.



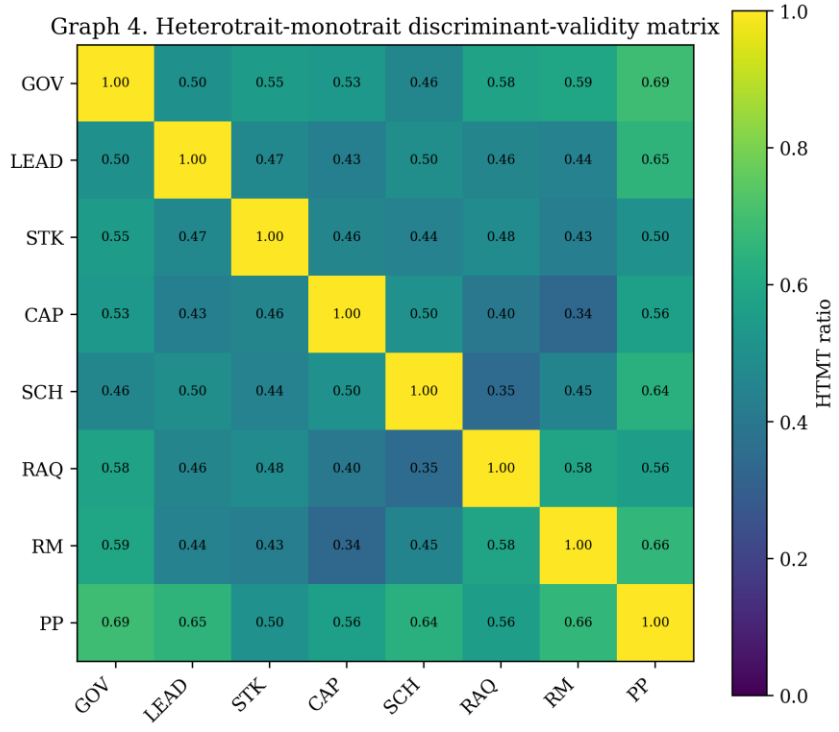
Graph 3. *Construct scores with 95% confidence intervals*

Explanation. The original five-point scale scores group around the middle. The close confidence intervals reflect the sample size, but the statistical precision shouldn't be confused for evenly high managerial maturity.

4.3 Measurement model

All standardized outer loadings were above .718, with the highest being .869. Cronbach's alpha ranged from .753 for risk-management maturity to .870 for technical capability. Composite reliability was in the range of .844 to .912, while AVE was in the range of .562 to .721. These values point towards indicator reliability, internal consistency, and convergent validity. The lowest reliability block remained above the conventional .70 standard, and no item was removed based on the statistics performed.

Discriminant validity was also good. The highest HTMT ratio was .691, which falls well below .85. From Graph 4, the largest cross-construct ratios were performance and governance/leadership, schedule maturity, and risk management, which was as expected as these constructs are direct predictors or constituent mechanisms. The approximate composite SRMR, was .097, which is close to the more relaxed .10 benchmark. Therefore, it is interpreted that the results from the assessment of the structural and predictive validity are to be combined, as relying on a single fit statistic is not sufficient.



Graph 4. Heterotrait-monotrait discriminant-validity matrix

Explanation. All off-diagonal HTMT values remain below .70, meaning that the eight lower-order constructs are empirically separate despite significant theoretical linkages.

Table 5. Measurement-model reliability and convergent validity

Construct	**Items**	**Loading range**	**Cronbach α**	**Composite reliability**	**AVE**	**Assessment**
GOV	4 (GOV1, GOV2, GOV3, GOV4)	0.791-0.844	0.834	0.890	0.668	Acceptable
LEAD	4 (LEAD1, LEAD2, LEAD3, LEAD4)	0.762-0.812	0.789	0.863	0.613	Acceptable
STK	4 (STK1, STK2, STK3, STK4)	0.757-0.815	0.790	0.864	0.614	Acceptable
CAP	4 (CAP1, CAP2, CAP3, CAP4)	0.829-0.869	0.870	0.912	0.721	Acceptable

Construct	Items	Loading range	Cronbach α	Composite reliability	AVE	Assessment
SCH	5 (SCH1, SCH2, SCH3, SCH4, SCH5)	0.737-0.821	0.840	0.887	0.612	Acceptable
RAQ	5 (RA1, RA2, RA3, RA4, RA5)	0.718-0.787	0.805	0.865	0.562	Acceptable
RM	4 (RM1, RM2, RM3, RM4)	0.728-0.779	0.753	0.844	0.575	Acceptable
PP	5 (PP1, PP2, PP3, PP4, PP5)	0.774-0.821	0.853	0.895	0.629	Acceptable

Note: Maximum HTMT = 0.691; composite-model SRMR = 0.097. AVE means average variance extracted.

Explanation. *All reported measurement blocks meet the stated reliability and convergent-validity criteria. The accompanying HTMT evidence also supports discriminant validity among the lower-order constructs.*

4.4 Structural model and hypothesis tests

The main mediated mechanism was shown to be supported by the structural results. GOVC highly predicted RAQ (β = .485, 95% bootstrap CI [.402, .566], p < .001), therefore supporting H1. STK also predicted RAQ (β = .184, CI [.094, .272], p < .001), supporting H2. The two factors together accounted for 35.6% of the variance in RAQ. CAP predicted SCH (β = .433, CI [.349, .513], p < .001), therefore supporting H3 and accounting for 18.7% of the variance in schedule-maturity.

Positive predictions of RAQ on OPP (β = .319, CI [.246, .391], p < .001) as well as SCH (β = .275, CI [.200, .348], p < .001), supported H4 and H5. The direct STK → OPP path was small and nonsignificant (β = .028, 95% CI [-.043, .094], p = .456); H6 was not supported. STK nevertheless retained a significant indirect effect through RAQ (β = .059, 95% CI [.028, .093]), reported in Section 4.5 and Table 7, rather than a significant remaining direct performance effect. GOVC directly influenced OPP in a positive manner (β = .316, CI [.239, .393], p < .001), as did CAP (β = .116, CI [.054, .181], p < .001), showing partial mediation.

Table 6. Structural paths, uncertainty, effect sizes, and hypothesis decisions

Hypothesis / path	β	95% CI	Bootstrap p	f^2 on outcome	R^2 endogenous	Decision	Interpretation
H1 GOVC → RAQ	0.485	[0.402, 0.566]	<.001	—	0.356	Supported	Strong governance-to-allocation pathway
H2 STK → RAQ	0.184	[0.094, 0.272]	<.001	—	—	Supported	Alignment improves allocation quality
H3 CAP → SCH	0.433	[0.349, 0.513]	<.001	—	0.187	Supported	Capability improves planning maturity

Hypothesis / path	β	95% CI	Bootstrap p	f^2 on outcome	R^2 endogenous	Decision	Interpretation
H4 RAQ → OPP	0.319	[0.246, 0.391]	<.001	0.201	0.681	Supported	Largest mediator effect
H5 SCH → OPP	0.275	[0.200, 0.348]	<.001	0.167	—	Supported	Strong schedule-control effect
H6 STK → OPP	0.028	[-0.043, 0.094]	.456	0.002	—	Not supported	No significant remaining direct effect; significant indirect STK → RAQ → OPP effect is reported in Table 7
Direct GOVC → OPP	0.316	[0.239, 0.393]	<.001	0.162	—	Significant	Partial mediation
Direct CAP → OPP	0.116	[0.054, 0.181]	<.001	0.029	—	Significant	Partial mediation
PCX → OPP	0.075	[0.013, 0.136]	.016	0.017	—	Significant	Small positive control effect
H9a RAQ × PCX → OPP	-0.003	[-0.070, 0.065]	.932	0.000	—	Not supported	No evidence of RAQ moderation by the observed size-duration proxy
H9b SCH × PCX → OPP	0.007	[-0.059, 0.073]	.860	0.000	—	Not supported	No evidence of SCH moderation by the observed size-duration proxy

Note. β values are standardized. Confidence intervals are percentile intervals from 5,000 bootstrap resamples. f^2 is reported for predictors in the OPP equation.

Explanation. *The structural-path results support H1-H5 and show significant positive effects for governance/leadership, technical capability, risk-allocation quality, and schedule maturity. The direct stakeholder-to-performance path and the two size-duration moderation effects are not supported, while the full model explains 68.1% of OPP variance.*

The observed size-duration proxy (PCX) had a small positive main effect (β = .075, 95% CI [.013, .136], p = .016). H9a was not supported: RAQ × PCX → OPP β = -.003, 95% CI [-.070, .065], p = .932. H9b was not supported: SCH × PCX → OPP β = .007, 95% CI [-.059, .073], p = .860. These nonsignificant interactions do not provide evidence of moderation by the size-duration proxy. The full model explained 68.1% of the variance in OPP (95% bootstrap CI [.629, .739]). RA

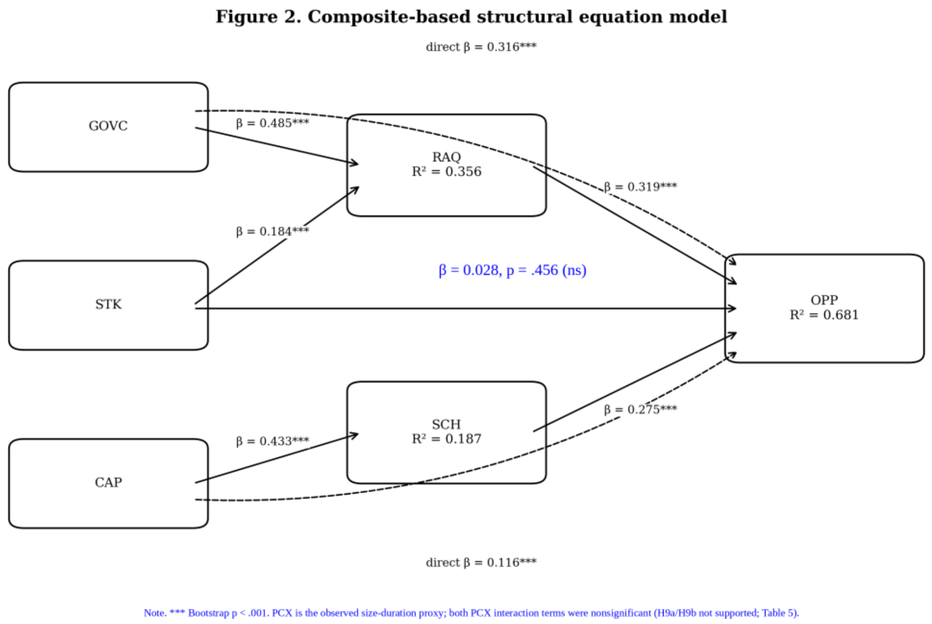


Figure 2. Composite-based structural equation model

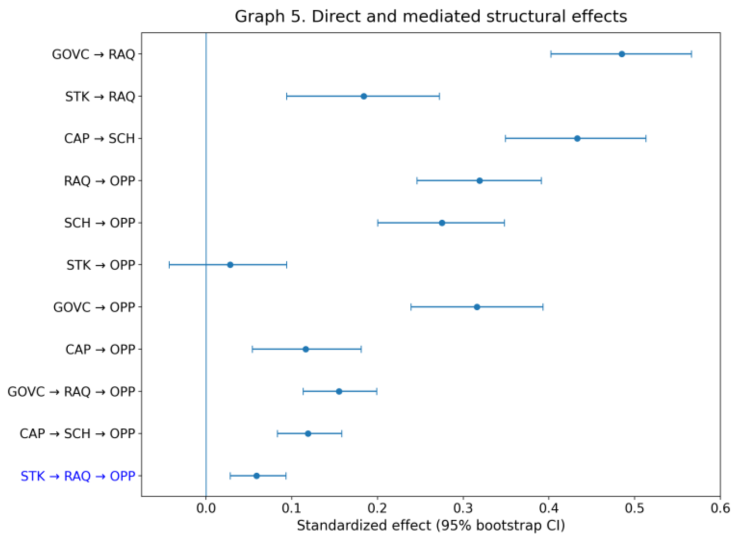
Explanation. *The model indicates that governance and leadership capacity and technical capacity both impact performance by the quality of risk allocation and the maturity of schedules, respectively, in addition to the direct impacts. Stakeholder alignment retains a significant indirect pathway through RAQ, while its remaining direct STK → OPP path is nonsignificant (H6 not supported); the two interactions with the observed size-duration proxy are also nonsignificant (H9a and H9b not supported).*

4.5 Mediation, prediction, robustness, and multi-group results

The indirect effect of GOVC on RAQ on OPP was .155 (CI [.113, .199], $p < .001$). This effect supports H7. Since the direct effect of GOVC on OPP remained significant, we can claim that RAQ offered partially complementary mediation. The indirect effect of CAP on SCH on OPP was .119 (CI [.083, .158], $p < .001$), which also supports H8 and partially complementary mediation. The indirect effect of STK on RAQ on OPP was .059 (CI [.018, .093]), and the remaining direct effect was not significant, which shows that STK also offered partially complementary mediation. The total effects of GOVC were .471, CAP were .235, and STK were .086. Thus, the capacity for governance and leadership was the highest-order construct.

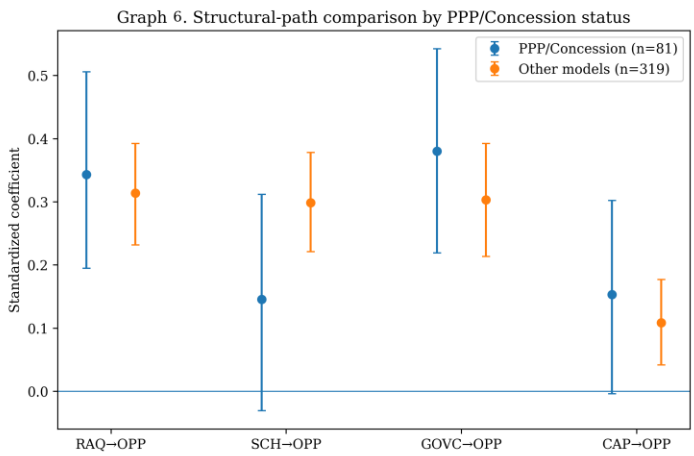
Predictive assessment reasonably strong. The 10 cross-validated folds resulted in a Q^2predict value of .666, RMSE of .577, and MAE of .456; the observed-predicted correlation was .816 on the standardized scale for OPP. The objective-only model explained 69.4% of the variance, with the perceptual-only model explaining 57.1%. RAQ, SCH, GOVC, and CAP remained positive and significant in both specifications; the direct STK path remained nonsignificant. These findings relieve concerns that the primary model was a result of integrating objective and subjective outcome components.

The multi-group comparison was substantially the same. For non-PPP projects, GOVC → OPP was .380 and RAQ → OPP was .343. For other models, the corresponding effects were .303 and .314. The SCH → OPP effect was more precise and larger in other models (.298, CI [.221, .378]), compared to a less precise value in the PPP subgroup (.145, CI [-.031, .312]). Because the intervals overlap and the sample size for PPP projects is small, this effect will not be attributed to a difference in delivery models, but is noted



Graph 5. Direct and mediated structural effects

Explanation. *Bootstrap intervals show that the governance-allocation, capability-schedule, and both mediator-to-performance paths are confidently positive. The direct STK → OPP interval crosses zero, whereas the STK → RAQ → OPP indirect effect is positive (β = .059, 95% CI [.028, .093]), consistent with stakeholder influence through RAQ rather than a significant remaining direct effect.*



Graph 6. Structural-path comparison by PPP/concession status

Explanation. Quality of risk allocation continues to be a good performance driver in both delivery-model groups. Schedule maturity is harder to measure precisely in the smaller PPP/concession subgroup, so the difference seen here should be checked with bigger invariant samples.

Table 7. Mediation, prediction, robustness, and subgroup evidence

Analysis	**Effect / statistic**	**Estimate**	**95% CI or error**	**Decision**	**Meaning**
Mediation	GOVC → RAQ → OPP	0.155	[0.113, 0.199]	H7 supported	Complementary partial mediation

Analysis	Effect / statistic	Estimate	95% CI or error	Decision	Meaning
Mediation	CAP → SCH → OPP	0.119	[0.083, 0.158]	H8 supported	Complementary partial mediation
Mediation	STK → RAQ → OPP	0.059	[0.028, 0.093]	Significant	Significant indirect effect via RAQ; no significant remaining direct STK → OPP effect
Prediction	10-fold Q^2predict	0.666	RMSE=0.577; MAE=0.456	Strong	Substantial out-of-sample relevance
Robustness	Objective-only OPP R^2	0.694	—	Stable	Key paths remain significant
Robustness	Perceptual-only PP R^2	0.571	—	Stable	Key paths remain significant
PPP subgroup	RAQ → OPP	0.343	[0.195, 0.505]	Positive	n=81
Other models	RAQ → OPP	0.314	[0.232, 0.392]	Positive	n=319
PPP subgroup	SCH → OPP	0.145	[-0.031, 0.312]	Imprecise	Interval includes zero
Other models	SCH → OPP	0.298	[0.221, 0.378]	Positive	Stable non-PPP estimate

Explanation. *The mediation and robustness evidence supports complementary partial mediation through RAQ and SCH, while predictive and subgroup results indicate broadly stable model behavior. The smaller PPP/concession subgroup should nevertheless be interpreted cautiously.*

5. DISCUSSION

5.1 Interpretation of the main pathways

The results show large-scale infrastructure performance is not a result of any major checklist element. Performance is a result of capacity, control mechanisms, and the direct effect, which combined, form a chain. Governance and leadership capacity had the largest upstream total effect on OPP (.471) and the strongest predictor effect on RAQ (.485). This indicates an institutional and leadership environment in which authority is clearly established and assumed, responsibilities are determined, and decisions are made on a timely basis. The result is consistent with studies that position institutional quality, transparent governance, and public sector competence as central conditions for effective PPP implementation (Agyapong et al., 2025; Berisha et al., 2022; Deinde-Adedeji et al., 2024).

RAQ had the largest mediating effect on OPP. The result corroborates the view that the allocation of risks is important, in that it affects the manner in which people are motivated to act, and not because the unwanted transfer of the risks is considered desirable. The average transferred risk in the data set was 52%. Transferred risks ranged from 20% to 85%, which indicates that a high degree of transferred risk does not necessarily mean that the recipient has control over the risk and the unaffected party has the ability to absorb the risk. The importance of the RAQ pathway means that clarity, fit and active control are most important. This view supports the "risk arm wrestling" theory on the preferred allocation of risks and studies on the consequences of the misallocation of risks, where risks are allocated to parties that are likely to increase claims and/or lead to a change in contract terms (Buzzetto & Carvalho, 2022; Mazher, 2025; Rasheed et al., 2022).

OOPEL Technical capability influenced OPP both directly and indirectly via SCH. The indirect effect (.119) indicates that only part of capability matters when an effort is made to specify a feasible, risk-adjusted, and data-disciplined schedule. The other direct effect means that technical capability also improves design, integration, productivity, and change control outside the schedule. This kind of partial mediation is quite plausible: a good planner cannot entirely make up for poor engineering, and a good technical team cannot reliably control delivery without a real schedule. The result adds to the research on operational critical success factors that links management capability, planning, monitoring, and coordination (Osei-Kyei et al., 2017a; Osei-Kyei & Chan, 2018).

We found a substantial influence of stakeholder alignment on RAQ and a substantial indirect influence on OPP (indirect effect = .059, 95% CI [.028, .093]). The remaining direct STK → OPP path was not significant ($\beta = .028$, $p = .456$). Hence, H6 could not be supported. In the current model, stakeholder alignment is predicting OPP primarily through RAQ, with the remaining effects assumed to be controlled, rather than through a direct effect. This means value is realized through the institutionalization of stakeholder alignment for risk ownership, for information, and for the definition of rules. This supports the findings of host-community and stakeholder studies, which indicate that support is a prerequisite for participation, and the delegation of responsibilities and implementation (Toriola-Coker et al., 2023; Xia et al., 2018).

Project Complexity did not moderate the RAQ → OPP or SCH → OPP paths. RAQ × PCX → OPP = $\beta = -.003$, $p = .932$, and SCH × PCX → OPP = $\beta = .007$, $p = .860$. Therefore, H9 is not supported. The null moderation of PCX is specific to the size-duration proxy/*. This does not indicate that PCX does not exist, or that TNC (technological novelty), ID (interface density), RC (regulatory complexity), SD (stakeholder divergence), and other PCX dimensions do not exist. In the data available, the size-duration proxy did not indicate a boundary condition for the RAQ or SCH effects.

5.2 Comparison with prior evidence

This governance-allocation pathway complements numerous cross-country and sector analyses. They all reference the need for institutional resources, capable competent authorities, stable policies, and transparent procurement practices (Al-Saadi et al., 2024; Aljaber et al., 2024; Yang et al., 2024). This pathway provides an additional element. Governance impacts performance through the quality and enforceability of risk ownership. The direct effect complements the allocations framework and suggests governance influences approvals and financing, as well as the resolution of disputes and changes, regardless of allocation.

The results line up with structural models that show positive associations between the success factors and outcomes of a given project (Ahmad et al., 2021; Fathi, 2024; Shah et al., 2024). This model introduces two advances. First, it pulls risk allocation and schedule planning apart and considers them as mediating factors, as opposed to combining them with all other project management practices. Second, it verifies the result against operational metrics. The pure modeling approach outperformed the hybrid modeling approach and the key relationships were stable, suggesting they are not primarily based on the respondents' global success opinions.

Contextual studies help explain why the exact size of effects may differ. In some situations, institutional entrepreneurship can complement or find ways to work around formal structures (Biygautane et al., 2019). Housing, water, waste, transport, and smart-city projects may have different types of demand, handback, community and technology risks (Almarri & Boussabaine, 2025; Bao et al., 2023; Ngullie et al., 2021; Özcan, 2025). The availability-payment design modifies the exposure to revenue risk and alters the government's obligations (Shodiqi et al., 2024). For this sample, we attempted to integrate both sectors and regions to identify the main pathways, and therefore, sector-specific models should be viewed as complementing, and more refined, theories.

The results from the PPP subgroup provide a useful example. For RAQ, there were no major changes from previous delivery models, even though SCH became less precise. Compared to other models of delivery, PPP projects may require a greater reliance on contract governance, lifecycle allocation, and special-purpose-vehicle coordination. It is possible that other models of delivery may create schedule-control effects more directly. The finding is also consistent with research that focuses on the lifecycle of a project and highlights how the effects of the different factors change throughout the stages of procurement, construction, operations and transfer (Ojiako et al., 2025).

5.3 Theoretical contributions

The first original idea here is moving from lists to mechanisms. Critical success factors are typically ranked but sorting them in a list doesn't help identify what is a cause, mediator, result, or a contextual factor. In the validated model, the upstream GOVC, CAP, and STK are separated from RAQ and SCH and then from OPP. The mechanism unpacks what is the importance of governance and why is capability necessary and how stakeholders' alignment is operational. The mechanism also shows where mediation is partial so it cannot be said that one mechanism fully represents the organization's capability.

The second original idea here is the hierarchy of governance and risk. Governance and leadership combine a joint capacity and decision-making construct. The risk allocation and the maturity of risk management combine a joint ownership and action construct. This specification is closer to the reality of a project than dealing with contracts, leadership, and risk registers as unrelated constructs. It also helps to reconcile studies that stress the importance of the quality of institutions, contract governance, and managerial capability (Abdul Latif et al., 2023; Agyapong et al., 2025; Fathi & Shrestha, 2023).

The third original idea here is the integration of measurement. The OPP construct links the perceptual success of the CPI, SPI, delay, overrun, change orders, safety, and variance of the critical path. The strong correlation of PP with the objectives allows convergence. The robustness results show that the key path survives even with different end-result definitions. This idea addresses the deficiency in most SEM studies that model only success that is self-reported and provides a sustainable interface between the theories of the organization and the project control.

The fourth contribution is the boundary-condition result. Instead of telling a major moderation story, the study shows that the size-duration proxy did not affect the RAQ or SCH effectiveness. This null result narrows the claim: the two mechanisms seem to be generally useful across the observed project scale, but a more sophisticated complexity instrument is needed before concluding that institutional or technical complexity has no moderating role.

5.4 Managerial and policy implications

Total effects in Graph 7 translate to priorities in the importance-performance map. Of the total effects, governance and leadership capacity top the list, so public clients and sponsors should prioritize addressing decision rights, approval service levels, procurement transparency, escalation paths, and dispute-resolution capacity. These interventions impact OPP and also impact RAQ. A contract cannot substitute for unclear authority. Risk ownership should be approved after the responsible party, decision clock, data source, funding route, and escalation trigger are defined.

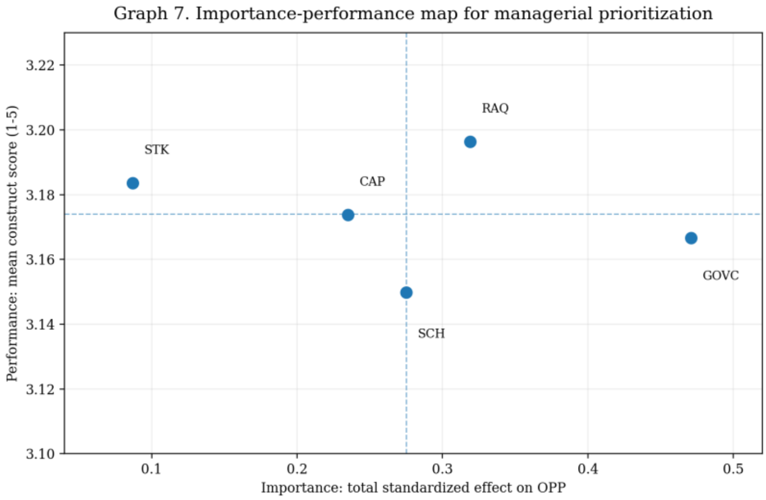
RAQ should be strategically managed as a fit test rather than a transfer target. The project should document control, information advantage, technical capacity, financial absorption, insurability, pricing clarity, and lifecycle stage for each major risk. Public or sovereign risks such as land acquisition, statutory approvals, and policy changes should usually not be transferred and should be supported by the authority in charge. Design, construction, productivity, and operating risks can be transferred if the private party is in charge of the decisions and is able to price the exposure. Demand, force-majeure, interface, and highly interdependent risks may require shared bands, contingent mechanisms, guarantees, or reopening clauses. Figure 3 outlines the strategy.

Schedule maturity is the second of three operational priorities. Risk allocation must be aligned to schedule contingency and logic. Authority-retained risks require the reserving of milestones and decision dates. Conversely, the contractor-owned risks require the contractor logic, resource loading, and recovery thresholds. The P50/P80 dates must be aligned to the commercial contingency and governance gates. The criticality indices and sensitivity drivers will determine the risks that will be elevated to the executive level. When the current owner is either unable or unwilling, the most likely appropriate solution is reallocation, joint mitigation, or changed contingency, rather than just scheduling more float time.

The immediate GOVC and CAP impacts indicate management should not cease operations after the two intermediary issues have been addressed. Governance and capability affect funding, approvals, claims, and organizational coordination. Capability also affects the quality of design, assurance of system safety, and productivity integration. The most appropriate course of action is a combination of improvements to the institutions, discipline and rigor of scheduling, and design capability.

The model allows policy makers to structure the risk-assurance 'gates' of a project. At the stage of the business case, the authority should assess the governance capacity and alignment of stakeholders. The risk allocation matrix should be assessed prior to tendering against the control and pricing criteria. Prior to baseline approval, the schedule should have logical, resource, and risk integration checks. During the delivery phase, it is essential there be monthly reviews that incorporate allocation exceptions, critical path changes, SPI/CPIs, change orders, safety and risk indicators. Control, information and absorptive capacity should be reallocated based on evidence the capacity has changed.

Algorithm 1 should be treated as a theoretical approach to translating the SEM pathways it supports into a schedule-control flow. As it hasn't been carried out, tested, or confirmed with the present dataset, the data lack basics like activity-level precedence networks, activity-duration distributions, resource assignments, and connections to activity risk. As such, the P50/P80 and resource-limited steps should be seen as implementation advice for future use with appropriate schedule-network data, rather than as empirical findings from this study.



Graph 7. Importance-performance map for managerial prioritization

Explanation. *Governance/leadership, RAQ, and SCH fall in the high-importance area. The map shows where attention to capability-building and governance are likely to bring the biggest improvement in operational project performance.*

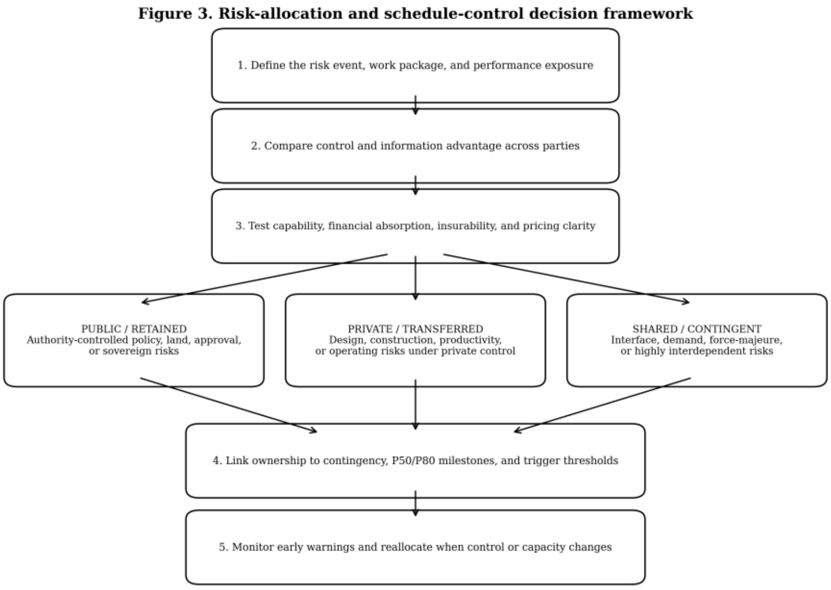


Figure 3. Risk-allocation and schedule-control decision framework

Explanation. *The framework turns the SEM evidence into a five-stage decision process. Allocation is selected only after control, information, capacity, and pricing tests, and each decision is connected to schedule contingency and monitored for changes that justify reallocation.*

6. Conclusions

This study examined how critical success factors, risk allocation, and schedule planning jointly relate to operational performance in large-scale infrastructure projects. H1–H5 were supported: GOVC predicted RAQ (β = .485), STK predicted RAQ (β = .184), CAP predicted SCH (β = .433), RAQ predicted OPP (β = .319), and SCH predicted OPP (β = .275). Governance and leadership capacity had the strongest upstream total effect on OPP, followed by technical and organizational capability. By contrast, the remaining direct STK → OPP effect was not significant (β = .028, p = .456), so H6 was not supported; stakeholder alignment's demonstrated performance contribution was primarily/indirectly through RAQ.

Both proposed mediation mechanisms were supported. RAQ partially mediated GOVC → OPP (H7 indirect effect = .155, 95% CI [.113, .199]), and SCH partially mediated CAP → OPP (H8 indirect effect = .119, 95% CI [.083, .158]); the significant direct GOVC and CAP effects indicate complementary partial mediation. Project Complexity did not moderate either mechanism: RAQ × PCX → OPP (β = -.003, p = .932) and SCH × PCX → OPP (β = .007, p = .860) were both non-significant, so H9 was not supported. Because PCX is only a size-duration proxy based on standardized log project value and planned duration, this null result must not be generalized to all dimensions of project complexity.

The implementation contribution is deliberately more limited than an empirical validation claim. The supported SEM pathways inform a practice-oriented conceptual decision framework in which each risk is assessed for controllability, information advantage, technical and financial capacity, insurability, pricing clarity, and lifecycle relevance, and then linked to schedule contingency and early-warning governance. Algorithm 1 is a conceptual/practice-oriented translation of those findings; it was not empirically executed, tested, or validated with activity-level schedule-network data in this study. Its P50/P80 milestone, Monte Carlo, and resource-constrained scheduling steps therefore require future application to suitable network-level project data.

The study has limitations. The data are cross-sectional and anonymized; collection dates, response rate, sampling procedure, ethics metadata, item wording, and project identifiers were not supplied. Project heterogeneity may introduce unobserved sector or country effects. The complexity proxy captures only value and duration. Projects at different completion stages may have different forecast reliability, and endogeneity cannot be eliminated without longitudinal or instrumental designs. Although objective metrics strengthen the outcome, some operational definitions may vary across organizations.

Future studies ought to use longitudinal panels, final-account and digital schedule logs, contract-text analytics, and activity-level risk networks. Bayesian SEM and causal designs could allow for modelling reciprocal relationships and unobserved heterogeneity. Cross-country measurement invariance and sector-specific models should examine if the same pathways hold for transport, energy, water, urban, industrial, and telecommunications projects. More delivery-model samples could show if schedule maturity works differently in PPP/concession frameworks. In the constraint of the cross-sectional style, the current data is consistent with better operational results when governance, risk assignment, and schedule design form an integrated control system instead of being treated as separate administrative tasks.

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Appendix A. Objective Metric Definitions

Table A1. *Objective metric definitions and interpretation rules*

Metric	Operational rule	Interpretation	Caution
CPI	EV / AC	Values below 1 indicate cost inefficiency at the cut-off.	Requires credible earned-value rules and stable scope.
SPI	EV / PV	Values below 1 indicate earned-value schedule slippage.	Can converge toward 1 near completion; pair with duration metrics.
Cost overrun (%)	(Actual/final cost - approved baseline) / baseline × 100	Positive values indicate overrun.	Document legitimate scope and price-base revisions.
Schedule delay (%)	(Actual/forecast duration - approved baseline) /	Positive values indicate delay.	Use comparable milestone definitions.

Metric	Operational rule	Interpretation	Caution
	baseline × 100		
Change-order (%)	Approved change value / contract value × 100	Scope/design stability and governance friction.	Distinguish owner, unforeseen, and contractor causes.
Safety incident rate	Exposure-adjusted rate supplied in the dataset	Workforce safety outcome.	Definitions may vary across organizations.
Critical-path variance	Observed/forecast deviation in critical path, days	Schedule stability and forecast discipline.	Dependent on baseline quality and update practices.

Explanation. *The appendix table documents how each objective metric is operationalized, how higher or lower values are interpreted, and the principal cautions relevant to cross-project comparison.*

Supplementary-material note. The supplied materials do not contain the full questionnaire wording, exact five-point verbal anchors, item-level original source citations, fieldwork dates, sampling/recruitment details, invitation/contact count, response rate, or a verified institutional ethics approval/exemption reference. These elements must be supplied by the authors before submission and should not be reconstructed from variable codes or inferred from the dataset.