
Toward Credible Capital Expenditure Estimation: Benchmarking to Risk-Based Integrated Cost and Schedule Estimation Approach

Muhammad Fadhli Zilikram*, Gatot Yudoko

Institut Teknologi Bandung, Indonesia

Email: ikram12@gmail.com

Abstract

Cost overruns and schedule delays are persistent challenges in Indonesia's downstream oil and gas projects, largely resulting from inaccurate capital expenditure (CAPEX) estimates that undermine budget reliability and investment credibility. This research aims to enhance estimation accuracy by developing a Risk-Based Integrated Cost and Schedule Estimation Model designed to strengthen the credibility of CAPEX projections during the investment proposal phase. The study applies a mixed-method approach, combining benchmarking against four international best practices—Project Management Institute (PMI), Association for the Advancement of Cost Engineering (AACE), National Aeronautics and Space Administration (NASA), and Government Accountability Office (GAO)—with qualitative validation through expert interviews and quantitative validation using Monte Carlo simulation on a test case project. The findings indicate that the existing estimation process achieves only 64% accuracy for cost and 52% for schedule performance compared to the proposed integrated model. Validation results demonstrate that the new model improves estimation accuracy within the AACE Class 3 range (−10% to −20% on the low side and +10% to +30% on the high side), with test case outcomes of +15% for cost variance and +0.6% for schedule variance. These results confirm the model's effectiveness in enhancing project budget credibility and supporting more reliable investment decision-making. Overall, the Risk-Based Integrated Cost and Schedule Estimation Model provides a structured framework for integrating risk assessment with cost and schedule planning, facilitating the adoption of international best practices in Indonesia's downstream oil and gas sector.

Keywords : *CAPEX accuracy; integrated cost-schedule; risk-based estimating*

INTRODUCTION

Cost overruns and schedule delays remain persistent phenomena in the construction industry, particularly within the oil and gas sector. These issues occur frequently and are often regarded as unavoidable (Hollmann, 2016). Moreover, the problem has become a global phenomenon (Dominteanu et al., 2023).

Found that 9 out of 10 transport infrastructure projects experienced cost escalation, based on an analysis of 258 projects across 20 countries valued at approximately US\$90 billion (Chiswa, 2024). Similarly, among 100 major global companies in the oil and gas, chemicals, metals, and mining sectors, six out of ten projects were either over budget or behind schedule (A.T. Kearney, 2017). In Asia, of 1,635 government projects in India, one in five experienced delays and one in seven encountered cost overruns. Additionally, 35% of projects experienced significant delays, contributing to 65% of total cost overruns (Shah, 2021). These findings indicate that project overruns occur across sectors, geographical regions, and time periods.

Indonesia is no exception. Of 45 oil and gas projects, 56% experienced cost overruns and delays exceeding 10%, and 36% of projects recorded overruns of up to 25% (Wisnugroho, 2020). More recently, out of 48 projects, 75% faced schedule delays exceeding 125% of the

original schedule, 31% experienced cost overruns of up to 125% of the initial budget, and 6% exceeded this threshold (Zilikram, 2023).

Previous studies have examined both the causes and impacts of project overruns. Concluded that cost escalation is systemic rather than incidental (Gómez-Cabrera, Gutierrez-Bucheli, & Muñoz, 2024). Identified contractor-related issues as a dominant cause of delays in construction projects. Argued that the primary root cause of overruns is the systematic underestimation or neglect of risk during project planning and decision-making, rather than purely technical complexity or unforeseen events (Islam, Nepal, & Skitmore, 2025; Mumtaz, Muhammad, & Abid, 2025). Wisnugroho (2020) benchmarked Indonesian oil and gas cost estimation practices against international standards and identified significant gaps in project definition maturity and risk assessment. Zilikram (2023) further confirmed ongoing weaknesses in cost and schedule estimation practices within Indonesia's downstream oil and gas sector. Despite identifying prevalent issues and underlying causes, existing research lacks a structured, risk-based integrated model that simultaneously combines cost and schedule estimation tailored specifically to Indonesia's downstream oil and gas industry (Hermawan, Isvara, & Ichsan, 2024; Swarno et al., n.d.).

Project overruns are often caused by multiple interrelated factors due to project complexity (Abdelalim, Salem, Salem, Al-Adwani, & Tantawy, 2024). Each project may have distinct root causes because of its unique characteristics. Commonly cited factors include project complexity, scope changes, technological uncertainty, demand uncertainty, unforeseen geological conditions, and regulatory dynamics. However, as emphasized, the fundamental issue lies in systematic risk underestimation during the planning and decision-making stages (Harake, 2025).

According to AACE International (2020), capital expenditure (CAPEX) estimates prepared during the investment proposal phase (Class 3 estimate) should fall within an expected accuracy range of -10% to -20% on the low side and +10% to +30% on the high side (Mohamed, 2025; Savila, 2025). Wisnugroho (2020) found that six out of ten Indonesian projects exceeded this acceptable accuracy range, contributing to cost escalation and schedule delays. These conditions undermine the credibility of CAPEX estimates, thereby weakening investment decision reliability. As a consequence, approved investment proposals may fail to adequately finance project execution or may result in unprofitable operations, ultimately disrupting business sustainability (Gatti, 2023).

This study aims to develop a Risk-Based Integrated Cost and Schedule Estimation Model that enhances the accuracy and credibility of CAPEX estimates in Indonesia's downstream oil and gas industry. The contributions of this research are threefold. Practically, it provides a structured framework for estimators and project managers to produce more reliable CAPEX estimates aligned with international best practices. Methodologically, it demonstrates the application of benchmarking and Monte Carlo simulation in constructing risk-based estimation models. Academically, it contributes to project management literature by contextualizing global best practices within a framework specifically adapted to emerging economies, particularly in the downstream oil and gas sector.

METHOD

This study employed a mixed-methods research design that integrates both qualitative and quantitative approaches in order to develop and validate the cost estimating process. The research was conducted within Indonesia's Downstream Oil & Gas Company, which manages large-scale infrastructure projects such as fuel terminals, pipelines, and distribution facilities.

The research begins with a benchmarking approach, with reference to internationally recognized frameworks. Filtering from 12 Phases & 54 Steps Benchmarking Process, this research will use 4 stages and 10 steps as follows:

1. Benchmarking Partner Selection

- Identify the external sources for collecting pre-benchmarking information
- Identify the potential benchmarking partner
- Establish the requirements for the selection of benchmarking partners
- Narrow the list to a few benchmarking partners according to the requirement

2. Pre-benchmarking activities

- Determine the benchmarking items

3. Benchmarking

- Collect data of benchmarking items
- Sort the collected data

4. Gap Analysis

- Determine the current gap
- Identification of possible causes
- Evaluating the nature of practices to determine their adaptability to the company

The process is enhanced by Non-dimensional Scaling of the Compensatory model from Multi-Attributes Decision Making (MADM) which helps to translate the qualitative data obtained to make quantitative comparisons (Sullivan et al., 2017).

The result of the benchmarking process above is the initial development of a cost estimating process that refers to external sources, which are the latest best practices, and is deemed capable of filling gaps in the previous process. However, this process may not necessarily meet internal needs; it may be too complete or insufficient. Therefore, the initial development process must be validated.

There are 2 types of validation carried out, namely qualitative and quantitative. First, the initial process is evaluated through qualitative validation with internal stakeholders who are responsible for conducting the process. It is conducted to assess the process's feasibility, acceptability, and alignment with the organizational needs. Qualitative data obtained from in-depth interviews and internal documents which are analysed using thematic coding to synthesize solutions and improvement priorities, and interpret & elaborate to get the result of actionable findings for framework development and validation. Quantitative analysis is conducted to validate the accuracy of the improved cost estimating process. This is calculated by subtracting the project budget estimate (original and recalculated using a new framework)

from the actual outcomes of completed projects, and then dividing by the project budget estimates. The acceptance criteria are the Expected Accuracy Range of AACE's Class Estimate 3.

RESULTS AND DISCUSSION

Benchmarking Process

Currently, the worldwide project management area is covered by different international standards, which are Project Management Institute (PMI), International Organization for Standardization (ISO), PRINCE2, and International Project Management Association (IPMA) (Sadeanu, 2017). Because the research focuses on the cost estimating process, there are three additional references that have been identified. Those are Association for the Advancement of Cost Engineering (AACE), the National Aeronautics and Space Administration (NASA), and the US Government Accountability Office (GAO).

From total 7 best practices, further assessment is conducted to determine whether they can all be used in this benchmarking process. Only PMI, AACE, NASA and GAO were chosen as benchmarking partners, using the following requirements:

- Must be used or internationally recognized in the construction, oil & gas, or large infrastructure industries.

- Focus on project management standards covering cost estimating and schedule development.

- Explains cost estimating and schedule development methods.

- Includes guidelines covering steps or best practices in creating cost and schedule estimates.

According to PMI (2019), estimating techniques used may differ based on the amount of time allocated, the amount of information available, the industry, the application area, the complexity and identified risks. One of the considerations in making estimates is the cost-schedule interrelationship. Refer to AACE (2020), it divides the project phases into five levels according the degree of project definition, outlining the cost and schedule estimation methodology and the documents required to achieve the expected accuracy. AACE International (2023) also conveyed that for supporting investment or tender decision making (AACE Class Estimate 3 or 2), the cost estimate calculation is carried out using integrated cost and schedule risk analysis with contingency determination using estimate ranging and expected value with Monte Carlo simulation. Similarly, National Aeronautics and Space Administration (2015) requires the application of Joint Cost and Schedule Confidence Level (JCL) to provide probabilistic ranges rather than deterministic point estimates. U.S. Government Accountability Office (2015) explains something similar, yaitu salah satu best practice untuk project schedule adalah assigning resources to all activities. A resource-loaded schedule therefore implies that all required labor and significant materials, equipment, and other costs are assigned to appropriate activities. U.S. Government Accountability Office (2020) add that risk analysis should be conducted in the estimation process.

Latest practices of project management emphasize that credible estimates must integrate cost, schedule, and risk factors. Recent studies highlight that organizations adopting risk-based estimation approaches achieve higher estimation accuracy and reduce deviations from actual project performance (Hollmann, 2024). These findings suggest that deterministic approaches and separate cost and schedule estimation calculations are increasingly insufficient in managing project complexity and uncertainty.

Therefore, the benchmarking process was carried out on the cost and schedule estimating processes of the four benchmarking partners. From all the steps in the processes, it becomes benchmarking items. After collecting, sorting and comparing, the following are the completed of cost and schedule estimating processes.

Table 1. Completed of Schedule Estimating Processes

No	Process	Explanation
1	Define schedule estimate purpose	Identify the objective of preparing the schedule (e.g., feasibility, baseline, tender submission) and how it will be used for planning and control.
2	Choose schedule estimate classification and fulfil the maturity	Determine the estimate class (Class 5–1) based on the level of project definition and ensure required maturity of deliverables and data is met.
3	Collect work breakdown structure and technical deliverables	Gather the WBS, design deliverables, and technical documentation that form the basis of schedule development.
4	Select time unit	Determine the smallest time measurement unit (e.g., hours, days, weeks) to be used consistently throughout the schedule.
5	Determine schedule outline (level of detail of WBS)	Define the level of detail for schedule activities in alignment with the WBS and project requirements.
6	Establish schedule coding structure	Create a coding system for activities (e.g., by discipline, location, phase) to enable filtering, sorting, and reporting.
7	Capturing all milestones and activities	Identify and list all major milestones and detailed tasks required to deliver the project scope.
8	Sequencing all activities	Arrange activities in a logical order, showing dependencies (FS, SS, FF, SF) to reflect the work flow.
9	Assigning resources and cost to all activities	Allocate labor, equipment, and materials to each task, along with associated costs if applicable.
10	Establishing duration for all activities	Estimate realistic durations for each task based on productivity, resource availability, and complexity.
11	Resource Leveling to align with the availability of funding	Adjust the schedule so that resource use and cash flow requirements match available resources and budget.
12	Schedule assessment	Review the schedule for completeness, correctness, and compliance with requirements.
12. a	Verifying that the schedule is traceable horizontally and vertically	Ensure that schedule logic is consistent across all levels and that dependencies are clearly linked.
12. b	Confirming that the critical paths and activities are valid	Check that the identified critical path is accurate and truly represents the longest path to completion.

12. c	Ensuring reasonable total float	Verify that total float values are realistic and not artificially constrained.
13	Conducting integrated cost schedule risk analysis (ICSRA) to determine schedule reserve and contingency	Perform a quantitative analysis to establish schedule contingency based on integrated cost-schedule risk modeling.
14	Approve the schedule	Obtain formal approval from project stakeholders for the schedule as the official plan.
15	Baseline the schedule model	Set the approved schedule as the baseline against which performance will be measured.
16	Schedule documentation and communication	Fully document the schedule, including assumptions and constraints, and communicate it to stakeholders.

Source: Compiled by researcher from benchmarking synthesis of PMI (2019), AACE International (2020, 2023), NASA (2015), and GAO (2015, 2020)

Table 2. Completed of Cost Estimating Processes

No	Process	Explanation
1	Define cost estimate purpose	Identify why the estimate is being prepared (e.g., feasibility study, budget approval, bid submission) and how it will be used for decision-making.
2	Choose cost estimate classification and fulfil the maturity	Determine the estimate class (Class 5–1) based on the level of project definition and ensure required maturity of deliverables and data is met.
3	Determine work breakdown structure, technical deliverable, execution strategy, schedule duration and quantity of resources as technical baseline	Establish the project's scope structure, technical specifications, execution plan, schedule parameters, and resource quantities as the foundation for the estimate.
4	Quantify scope content (take-off)	Measure and list all quantities of work items (materials, labor, equipment) needed to execute the project.
5	Identify ground rules and assumptions	Define key assumptions, constraints, and conditions under which the estimate is prepared, including exclusions and special conditions.
6	Obtain, validating, normalizing and analyzing the data	Gather historical cost data, vendor quotes, and productivity rates, check accuracy, normalize to current conditions, and analyze for applicability.
7	Develop the point estimate	Produce the base cost estimate without contingency, incorporating measured quantities and selected cost data.
7. a	Cost the scope content using the selected methodology	Apply chosen estimating methods (analogous, parametric, unit-rate, detailed take-off) to convert quantities into costs.
7. b	Price the cost estimate (add overhead, profit, mark up to improve cash flow)	Include mark-ups for contractor overhead, profit margins, and other commercial adjustments.
8	Conduct sensitivity analysis	Test the impact of changes in key variables (e.g., material prices, productivity rates) on total cost to identify major cost drivers.

9	Conduct risk and uncertainty analysis through integrated cost-schedule risk analysis (ICSRA) / joint confidence level (JCL)	Perform quantitative risk analysis to determine the probability distribution of the cost outcome, considering both cost and schedule risks together.
10	Budget costs	Convert the approved cost estimate into a time-phased budget for cost control and cash flow management.
11	Analyze the cash flow	Assess the project's expenditure pattern over time to ensure funding availability aligns with planned work.
12	Review and document the estimate	Conduct internal or external peer reviews for quality assurance and fully document assumptions, methodology, and results.
13	Present the Cost Estimate Results	Communicate the estimate to stakeholders and decision-makers, including cost range, risks, and recommendations.

Source: Compiled by researcher from benchmarking synthesis of PMI (2019), AACE International (2020, 2023), NASA (2015), and GAO (2015, 2020)

Referring to the current internal flow processes in the Company, an assessment of compliance with benchmarking items is conducted. The evaluation uses the Non-dimensional Scaling of the Compensatory model from Multi-Attributes Decision Making (MADM), where compliance will use a range of rating values of 1 to 5 (1: very unsatisfactory; 2: unsatisfactory; 3: neutral; 4: satisfactory; 5: very satisfactory).

Table 3. Rating of Company's Schedule Estimating Processes

No	Process	Max Rating	Company's Rating
1	Define schedule estimate purpose	5	1
2	Choose schedule estimate classification and fulfil the maturity	5	1
3	Collect work breakdown structure and technical deliverables	5	3
4	Select time unit	5	5
5	Determine schedule outline (level of detail of WBS)	5	3
6	Establish schedule coding structure	5	1
7	Capturing all milestones and activities	5	3
8	Sequencing all activities	5	2
9	Assigning resources and cost to all activities	5	1
10	Establishing duration for all activities	5	3
11	Resource Leveling to align with the availability of funding	5	1
12	Schedule assessment		
12. a	Verifying that the schedule is traceable horizontally and vertically	5	1
12. b	Confirming that the critical paths and activities are valid	5	5
12. c	Ensuring reasonable total float	5	1
13	Conducting integrated cost schedule risk analysis (ICSRA) to determine schedule reserve and contingency	5	1

14	Review & Approve the schedule estimate	5	5
15	Baseline the schedule model	5	5
16	Schedule documentation and communication	5	5
Total Score		90	47

Source: Researcher's assessment based on Non-dimensional Scaling of Compensatory model from Multi-Attributes Decision Making (MADM), using benchmarking results from Table 1, 2025

Table 4. Rating of Company's Cost Estimating Processes

No	Process	Max Rating	Company's Rating
1	Define cost estimate purpose	5	1
2	Choose cost estimate classification and fulfil the maturity	5	1
3	Determine work breakdown structure, technical deliverable, execution strategy, schedule duration and quantity of resources as technical baseline	5	3
4	Quantify scope content (take-off)	5	4
5	Identify ground rules and assumptions	5	1
6	Obtain, validating, normalizing and analyzing the data	5	3
7	Develop the point estimate		
7. a	Cost the scope content using the selected methodology	5	5
7. b	Price the cost estimate (add overhead, profit, mark up to improve cash flow)	5	5
8	Conduct sensitivity analysis	5	1
9	Conduct risk and uncertainty analysis through integrated cost-schedule risk analysis (ICSRA) / joint confidence level (JCL)	5	1
10	Budget costs	5	5
11	Analyze the cash flow	5	5
12	Review & Approve the Cost Estimate	5	5
13	Cost Estimate documentation and communication	5	5
Total Score		70	45

Source: Researcher's assessment based on Non-dimensional Scaling of Compensatory model from Multi-Attributes Decision Making (MADM), using benchmarking results from Table 2, 2025

From the combined assessment of the company's cost estimate and schedule estimate processes, several recurring gaps were identified. Most notably the absence of a standardized Work Breakdown Structure (WBS) and comprehensive technical baseline. Critical inputs, such as the Basis of Estimate for cost and standard milestone guidelines for schedule, are not formally documented, reducing traceability and consistency. Quantitative methods like sensitivity analysis and integrated cost-schedule risk analysis (ICSRA) are applied only partially or not at all, limiting the understanding of uncertainty impacts. In addition, resource assignment, productivity data, and standardized take-off procedures are either missing or

inconsistently applied, resulting in reliance on individual judgment rather than structured, repeatable processes.

From Completed of Cost and Schedule Estimating Processes above, the initial process development can be described as follows:

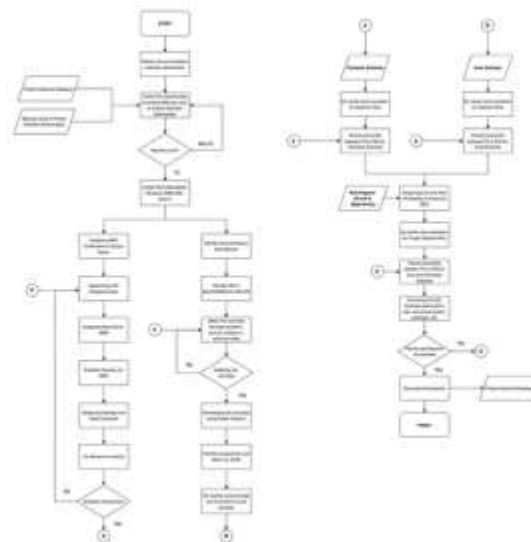


Figure 1. Initial Risk-Based Integrated Cost-Schedule Estimation Flow Process

Source: Developed by researcher based on benchmarking synthesis from PMI, AACE, NASA, and GAO best practices, 2025

Qualitative Validation

Primary data were collected through semi-structured interviews with six experts selected using purposive sampling. The respondents included senior project managers, cost engineers, and scheduling specialists, each with more than ten years of professional experience in managing capital projects. Their insights provided a comprehensive understanding of current estimation practices, the causes of inaccuracies, and their perspectives on the adoption of risk-based integrated approaches.

Table 5. Resume of Interview Coding

Theme	Stakeholder Insights	Interpretation
Current Estimating Practice	Practices have improved compared to previous years, mainly due to adoption of standard templates and clearer approval flow. However, estimation remains deterministic and data quality varies among projects.	Estimation procedures are standardized administratively but not yet technically robust.
Causes of Inaccuracy	Inaccurate estimates often stem from weak project scope definition, limited historical data, and optimistic assumptions.	Root causes not align with AACE's definition of low maturity and poor input quality.
Risk-Based Estimation	All respondents agreed on the importance of incorporating risk, particularly for price escalation,	Organizational awareness of risk-based estimation exists

	productivity, and schedule delay. However, implementation is partial and not yet systematic.	but lacks supporting tools and training.
Integrated Cost–Schedule Estimation	Respondents supported integration of cost and schedule, especially to improve time–cost correlation and more realistic contingency.	Confirms the relevance of adopting Integrated Cost & Schedule approach.
Implementation Challenges	Barriers include lack of probabilistic analysis capability, limited historical data, and management’s preference for deterministic budget figures.	The new process must be accompanied by training, data system enhancement, and policy endorsement.

Source: Thematic coding analysis of semi-structured interviews with six senior experts (project managers, cost engineers, and scheduling specialists), conducted by researcher, 2025

Overall, the respondents perceived the new process as feasible and beneficial, provided that supporting infrastructure (software, database, and competency development) is strengthened. The qualitative validation confirmed that the process aligns with the company’s needs and strategic direction toward improving project governance and investment credibility. The qualitative findings served as the basis for refining the framework before quantitative validation, ensuring that the process is both technically sound and operationally applicable within the company’s environment.

However, regarding the implementation of the new estimation process, all speakers highlighted several challenges. These challenges include resistance to change due to old habits, limited human resource capacity, lack of technical understanding of probabilistic methods such as Monte Carlo, limitations in historical databases, and a weak culture of risk-based planning within the organization. To overcome these obstacles, top management support is seen as a crucial factor. This support includes formal policies supporting the adoption of new methods, strengthening the risk and historical data database, developing more detailed standard work procedures (SOP), and programs to enhance the competency of estimators and planners at all levels of the organization.

Quantitative Validation

As a quantitative validation step, here is a simulation of example project with high capital, high complexity, and integration with other ongoing projects. This project was planned to run for "X" months with a value of "Y." However, during the project's progress, several adjustments were made, resulting in the final duration of the project being 163% of X and the value of the project being 126% of Y.

To see the readiness of the underlying document used to compile the estimate, it is necessary to carry out an assessment of the project definition's maturity level checklist. In accordance with the investment proposal estimation document which is required with AACE estimate class 3, the results indicate that the project meets 85.6% of the checklist.

Using the previous deterministic cost and schedule estimate, it is conducted Monte Carlo simulation based on cost and schedule risk analysis separately for systemic risk. The simulation are using lognormal distribution for cost risk analysis due to its right-skewed nature

(National Aeronautics and Space Administration, 2015) and 3-point estimate with PERT distribution for schedule risk analysis (U.S. Government Accountability Office, 2015).

Table 6. Project Cost & Schedule Risk Analysis - Systemic Risk

Percentile	Cost			Schedule Duration
	Time Independent	Time Dependent (Ls)	Total	
P5	48,69%	41,46%	90,15%	89,66%
P10	53,33%	43,15%	96,48%	92,15%
P20	59,78%	45,48%	105,27%	96,17%
P30	65,09%	47,40%	112,49%	99,81%
P40	70,12%	49,22%	119,34%	105,36%
P50	75,29%	51,09%	126,38%	113,03%
P60	80,98%	53,13%	134,11%	121,46%
P70	87,70%	55,55%	143,25%	131,23%
P80	96,52%	58,71%	155,23%	143,10%
P90	110,76%	63,78%	174,54%	160,34%
P95	124,64%	68,69%	193,33%	177,59%

Source: Monte Carlo simulation results using lognormal distribution for cost risk analysis and PERT distribution for schedule risk analysis, based on project test case data, processed by researcher, 2025

According to AACE, good estimate is one that has a 50/50 chance that the actual value will be below or above that value. However, for the budgeting process, AACE and GAO recommend using P70 to determine the contingency reserve needed to cover unforeseen design complexity, incomplete requirements, technology uncertainty, and other related uncertainties. Even P70 can be considered to include management reserve.

Using risk register that consist of threats and opportunities, it were assigned in to selected percentile of schedule as well as selected percentile of cost (time dependent and time independent) as integrated approach. The monte carlo simulation is conducted for second time to Integrated Cost & Schedule Risk Analysis (ICSRA) by selecting the P70 as the initial simulation reference for Project Specific Risk using the same types of distribution. The bottom left quadrant is selected with a total population of 50% of the iterations performed in the Monte Carlo simulation, which can represent P50 for Project Specific Risk or around P70 for each axis, namely cost and schedule.

When compared to the actual condition of 126% of Y in the cost estimate, the estimation results using the new process can produce 146% of Y or 115% of the actual. This means that the excess 46% of the base estimate is contingency to accommodate from systemic and project-specific risks (known-known, unknown-known, and known-unknown). Meanwhile, for the schedule, the actual condition is 163% of X, and the new estimate is 164% of X or 100.6% of the actual. The 63% is also the contingency for schedule to accommodate the risks.

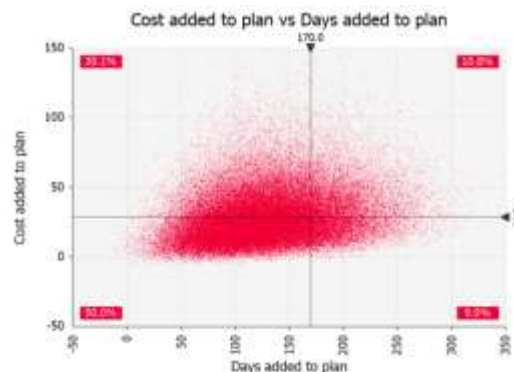


Figure 2. Integrated Cost & Schedule Risk Analysis (ICSRA) – Project Spesific Risk

Source: Monte Carlo simulation results from Integrated Cost & Schedule Risk Analysis on test case project, processed by researcher, 2025

The results of the new estimation process demonstrate that the Monte Carlo simulation-based cost and schedule integration approach is capable of meeting budget planning needs early in the project, as mentioned in the expected accuracy by AACE Class 3. As demonstrated in the simulation results, the resulting distribution provides more realistic picture of potential deviations compared to the baseline. This process also explicitly considers both project-specific and systemic risks affecting cost and schedule. So, the estimation results are not merely nominal figures but also contain information regarding the level of confidence in achieving the project's cost and schedule. The implication is the availability of a more credible budget planning basis early in the project, as it includes the probability of actual realization.

CONCLUSION

This study examined the persistent issue of cost overruns and schedule delays in Indonesia's downstream oil and gas projects, with a particular focus on the credibility of capital expenditure (CAPEX) estimation during the investment proposal phase. Through benchmarking against international best practices from the Project Management Institute (PMI), Association for the Advancement of Cost Engineering (AACE), National Aeronautics and Space Administration (NASA), and Government Accountability Office (GAO), the research identified significant gaps in the company's existing estimating process. These gaps were primarily related to insufficient scope definition maturity, limited use of probabilistic analysis, and the absence of clear separation between base estimates and contingency allowances.

To address these issues, a risk-based integrated cost and schedule estimation model was developed and validated through expert interviews and Monte Carlo simulation. A comparative assessment revealed that the company's existing cost estimation process achieved only 64% compliance with international best practices, while the schedule estimation process reached 52% compliance. Validation results demonstrated substantial improvement, with estimation accuracy increasing from -26% (cost) and -63% (schedule) to within the AACE Class 3 tolerance range. The test case results showed deviations of +15% for cost and +0.6% for schedule relative to actual outcomes. These findings indicate that the proposed integrated

model generates more credible and realistic CAPEX estimates by presenting results in probabilistic ranges rather than relying solely on deterministic projections.

The implications of this research are both managerial and academic. From a managerial perspective, the model offers a structured and practical framework to reduce budget deviations, enhance investment decision-making, and promote a risk-informed culture within project planning processes. From an academic standpoint, the study contributes to project management literature by adapting international best practices into a contextualized framework suitable for emerging economies. In conclusion, adopting a risk-based integrated cost and schedule estimation approach represents a significant advancement toward credible and data-driven CAPEX planning in Indonesia's downstream oil and gas sector, strengthening both organizational performance and theoretical development in project management.

REFERENCE

- AACE International. (2020). 18R-97: Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries. AACE International.
- AACE International. (2023). 123R-22 Integrated Cost And Schedule Risk Analysis And Contingency Determination Using Estimate Ranging And Expected Value With Monte Carlo Simulation.
- Abdelalim, Ahmed Mohammed, Salem, Maram, Salem, Mohamed, Al-Adwani, Manal, & Tantawy, Mohamed. (2024). An analysis of factors contributing to cost overruns in the global construction industry. *Buildings*, 15(1), 18.
- A.T. Kearney. (n.d.). Excellence in Capital Projects: A Goal Yet to Be Achieved. Retrieved April 18, 2025, from <https://www.atkearney.com>
- Chiswa, Natasha. (2024). Unlocking Africa's economic potential: The role of PPPs in fuelling infrastructure development and investment–South Africa's perspective. *Jindal Global Law Review*, 15(1), 157–185.
- Dominteanu, Teodora, Smîdu, Neluța, Voinea, Andreea, Dinciu, Corina Claudia, Porfireanu, Maria Cristiana, & Iacobini, Adrian. (2023). What are esports? Introduction to the global phenomenon of esports. *Proceedings of the International Conference on Business Excellence*, 17(1), 1421–1430. Sciendo.
- Gatti, Stefano. (2023). *Project finance in theory and practice: designing, structuring, and financing private and public projects*. Elsevier.
- Gómez-Cabrera, Adriana, Gutierrez-Bucheli, Laura, & Muñoz, Santiago. (2024). Causes of time and cost overruns in construction projects: a scoping review. *International Journal of Construction Management*, 24(10), 1107–1125.
- Harake, M. F. (2025). *Evaluating Project Scope in Unstable Environments: Adaptive Frameworks for Uncertainty and Change*.
- Hermawan, Dedi, Isvara, Wisnu, & Ichsan, Mohammad. (2024). Critical risk factors associated with schedule delays in gas processing facility projects: Case study in Indonesia. *Global Business & Finance Review (GBFR)*, 29(6), 60–73.
- Hollmann, J. K. (2016). Project risk quantification: A practitioner's guide to realistic cost and schedule risk management. Validation Estimating LLC.
- Islam, Muhammad Saiful, Nepal, Madhav, & Skitmore, Martin. (2025). Structuring risks for a comprehensive understanding of cost overruns in power plant projects. *Construction Innovation*, 25(3), 1014–1032.
- Mohamed, Habiba Mahdy. (2025). *Study of Capital and Operation Costs for Reverse Osmosis*

- Desalination Plants*. The American University in Cairo (Egypt).
- Mumtaz, Farhad, Muhammad, Tahir, & Abid, Hafiz Muhammad Sarmad. (2025). Budget Overruns in Large-Scale Projects: Root Causes and Preventive Project Management Practice. *Advance Journal of Econometrics and Finance*, 3(3), 21–33.
- National Aeronautics and Space Administration. (2015). NASA cost estimating handbook (CEH). National Aeronautics and Space Administration (NASA).
- Project Management Institute. (2019). Practice Standard for Project Estimating. www.PMI.org
- Sadeanu, M. (2017). ISO 21500:2012 vs Other Project Management Standards. <https://www.researchgate.net/publication/349054238>
- Savila, Santtu. (2025). *Optimizing Investment Project Cost Control*.
- Shah, V. A. (2021). Cost and Time Overrun in Various Construction Projects: A Review (Vol. 58, Issue 5). Article Accepted. www.psychologyandeducation.net
- Sullivan, W. G., Wicks, E. M., & Koelling, C. P. (2017). *Engineering Economy* (17th ed.). Pearson.
- Swarno, Husna Aini, Ali, Rabiatul Adawiyah, Rahman, Mazlinda Abdul, Hussein, Siti Nurliyana Che, Habib, Nor Saiful Hafiz Abd, Zaini, Mohd Saufi Mohd, Othman, Nurnida Elmira, & Ahmad, Nurul Huda. (n.d.). Integrated Climate Risk Management for Enhancing Resilience and Sustainability of Petroleum Exploration in Southeast Asia in the Context of Future Climate Scenarios. *Available at SSRN 5509246*.
- U.S. Government Accountability Office. (2015). Schedule assessment guide: Best practices for project schedules. U.S. Government Printing Office.
- U.S. Government Accountability Office. (2020). Cost Estimating and Assessment Guide: Best practices for developing and managing program costs. U.S. Government Printing Office.
- Wisnugroho, J. (2020). Indonesia Oil & Gas Cost Estimating vs International “Best-Tested and Proven” Practices – A Benchmarking Study. *PM World Journal*, IX.
- Zilikram, M. (2023). Benchmarking Indonesia’s Downstream Oil & Gas Construction: Evaluating Project Scheduling and Cost Estimating Processes Against Global “Best-Tested and Proven” Practices. *PM World Journal*, 12(10).