Toward More Reliable Maintenance Cost Estimates for Oil Storage Tanks: A Gold Price Index Approach [1, 2]

Kamal Fu'ad

ABSTRACT

This paper aims to identify the most reliable approach for forecasting oil storage tank maintenance project costs under economic uncertainty and to evaluate how such forecasts support planning, budgeting, procurement, and cost control in projectized operations. The research addresses three questions: which economic adjustment method provides the most reliable forecast, how economic volatility can be incorporated into maintenance cost estimates, and how improved estimation supports project and program management decisions. A combined methodology is applied, integrating non-compensatory and compensatory decision-making models with probabilistic analysis across multiple confidence levels. The findings demonstrate that the Gold Price Index is the most consistent and reliable escalation factor across both decision frameworks. Furthermore, the P75 confidence level is identified as the most defensible balance between cost efficiency and risk protection. The study concludes that integrating structured decision models with probabilistic methods improves forecasting reliability, supports more defensible Owner's Estimates, strengthens contractor evaluation, and enhances cost control during project execution.

Keywords: *Cost Estimation, Gold Price, Maintenance Projects, Projectized Operations, Storage Tanks.*

INTRODUCTION

A. National Oil Company Tank Storage Management

Indonesia's oil and gas operates within one of the most geographically complex supply chains in the world. In line with that concern, the Global Gas Security Review states that "storage tanks function as critical buffering assets across the national energy system."[3]

[1] How to cite this paper: Fu'ad, K. (2026). Toward more reliable maintenance cost estimates for oil storage tanks: A gold price index approach.; *PM World Journal*, Vol. XV, Issue VI, June.
[2] This paper was originally prepared during a 6-month long Graduate-Level Competency Development/Capacity Building Program developed by PT Mitrata Citragraha and led by Dr. Paul D. Giammalvo to prepare candidates for AACE CCP or other Certifications. https://build-project-management-competency.com/our-faqs/.
[3] Global Gas Security Review. https://www.iea.org/reports/global-gas-security-review-2023

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Figure 1. Oil Supply Chain in Indonesia [4]

Oil consumption in Indonesia remains consistently high, where Gasoline and Gasoil dominate the consumption profile. Indonesian Government states that "Under such conditions, storage tanks are not passive assets but essential operational components that ensure continuity between supply and demand across regions".[5]

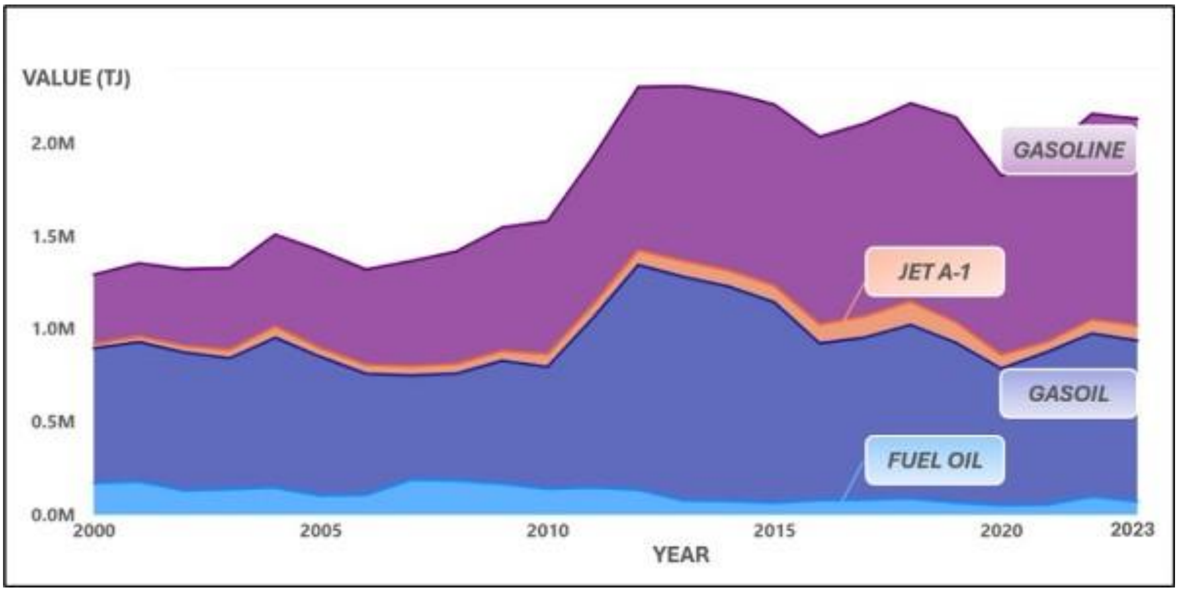

Figure 2. Indonesia's Oil Consumption by 2000 - 2023 [6]

[4] By Author
[5] Ministry of Energy and Mineral Resources. (2021). *Regulation of the Minister of Energy and Mineral Resources No. 32 of 2021 on Technical Inspection and Safety of Oil and Gas Installations*.
[6] Oil final consumption by product, Indonesia 2000-2023. (2024). Indonesia - Countries & Regions - IEA. IEA. https://www.iea.org/countries/indonesia/oil

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The American Petroleum Institute emphasizes that "storage tanks must be properly maintained to ensure safe and reliable operation throughout their service life, particularly through periodic inspection and integrity management practices."[7] When asset integrity declines, the consequences extend beyond individual facilities and may disrupt broader supply chain performance.[8]

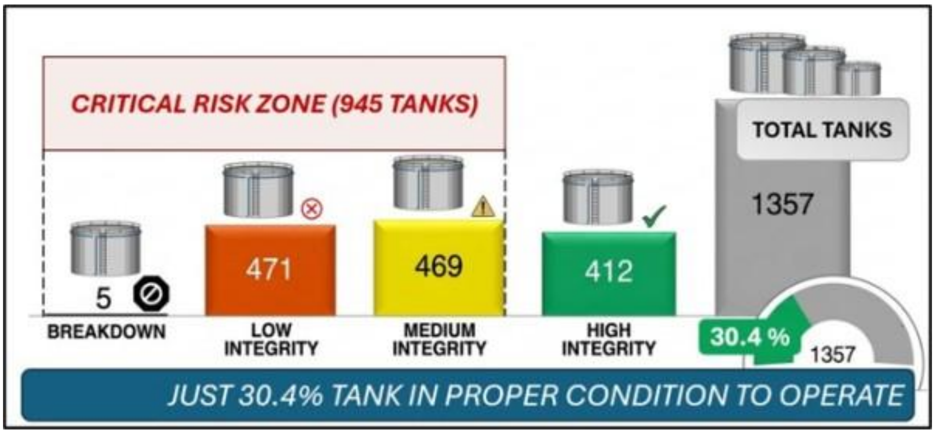

Figure 3. Oil Tank Condition in National Oil Company[9]

ISO states that "asset management is coordinated activities of an organization to realize value from assets."[10] In this context, maintenance becomes a strategic requirement, requiring structured planning and reliable cost estimation to support decision-making under operational constraints.

Figure 4. Oil Tank Before and After Maintenance[11]

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[7] American Petroleum Institute. (2014). Tank inspection, repair, alteration, and reconstruction (API Standard 653, 5th ed.). American Petroleum Institute.
[8] GFMAM. (2016). The value of asset management to an organization. Global Forum on Maintenance and Asset Management.
[9] By Author
[10] International Organization for Standardization. (2024). ISO 55000:2024 Asset management — Vocabulary, overview and principles. International Organization for Standardization.
[11] By Author

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B. Cost Estimation Challenges of Projectized Operation

The 1987 PMBOK recognizes that "projects exist within broader corporate, facility, and product life cycles."[12] In the context of oil storage tanks, maintenance activities occur during the operation phase of the facility life cycle but are executed through project life cycle processes such as concept, development, implementation, and termination.

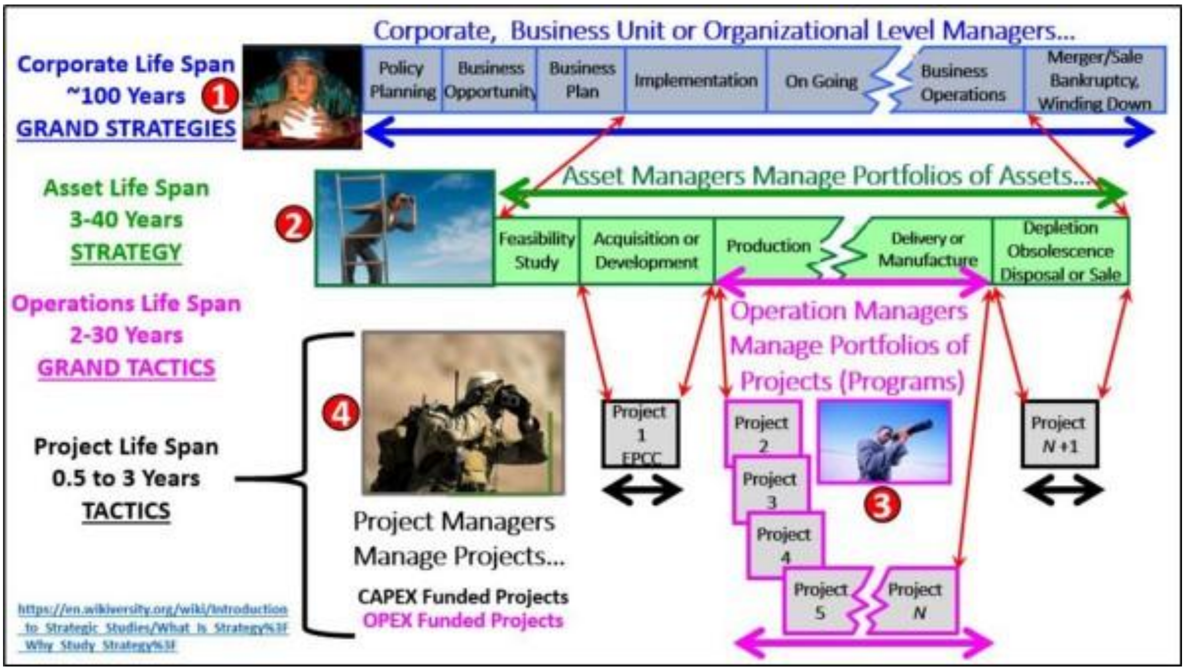

Figure 5. Integrated Asset, Portfolio, Program, and Project Management[13]

Similarly, Giammalvo explains that "even repeated activities may still be considered projectized operations when each activity has a defined scope, budget, schedule, contractor involvement, and control requirements."[14] Supporting that connection, GAPPS states that "program management is the coordinated management of related projects to achieve benefits that could not be obtained if the projects were managed separately."[15] Therefore, reliable tank maintenance cost estimation supports not only individual project planning, but also program-level budgeting, prioritization, procurement, and cost control.

[12] Project Management Institute. (1987). The project management body of knowledge. Project Management Institute.
[13] Project Management Institute. (1987). The project management body of knowledge. Project Management Institute.
[14] PTMC, & Giammalvo, P. D. (2021). 1.4.1.1 unit 1 – Governance and Integration
[15] Global Alliance for Project Performance Standards. (2011). A framework for performance-based competency standards for program managers. Global Alliance for Project Performance Standards.

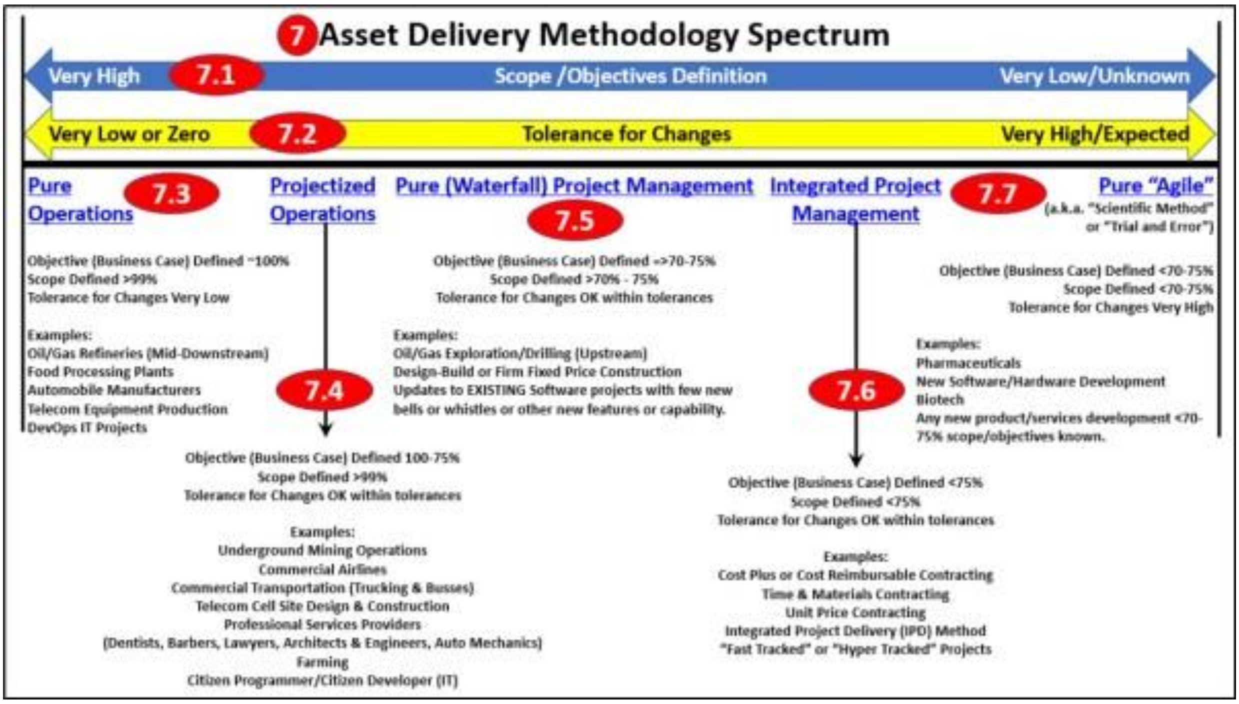

Figure 6. Asset Delivery Option Spectrum of Choice[16]

Because tank maintenance is delivered through projects and programs, the quality of early-stage cost estimation becomes critical. The importance of early-stage decision-making is captured in the concept of Front-End Loading (FEL), where the ability to influence outcomes is highest while the cost of change is lowest. The U.S. Government Accountability Office states that "cost estimates are critical to supporting informed decisions,"[17] particularly during early project phases.

[16] PTMC, & Giammalvo, P. D. (2021). 1.4.1.1 unit 1 – Governance and Integration
[17] U.S. Government Accountability Office (GAO). (2020). *Cost estimating and assessment guide: Best practices for developing and managing capital program costs*. GAO.

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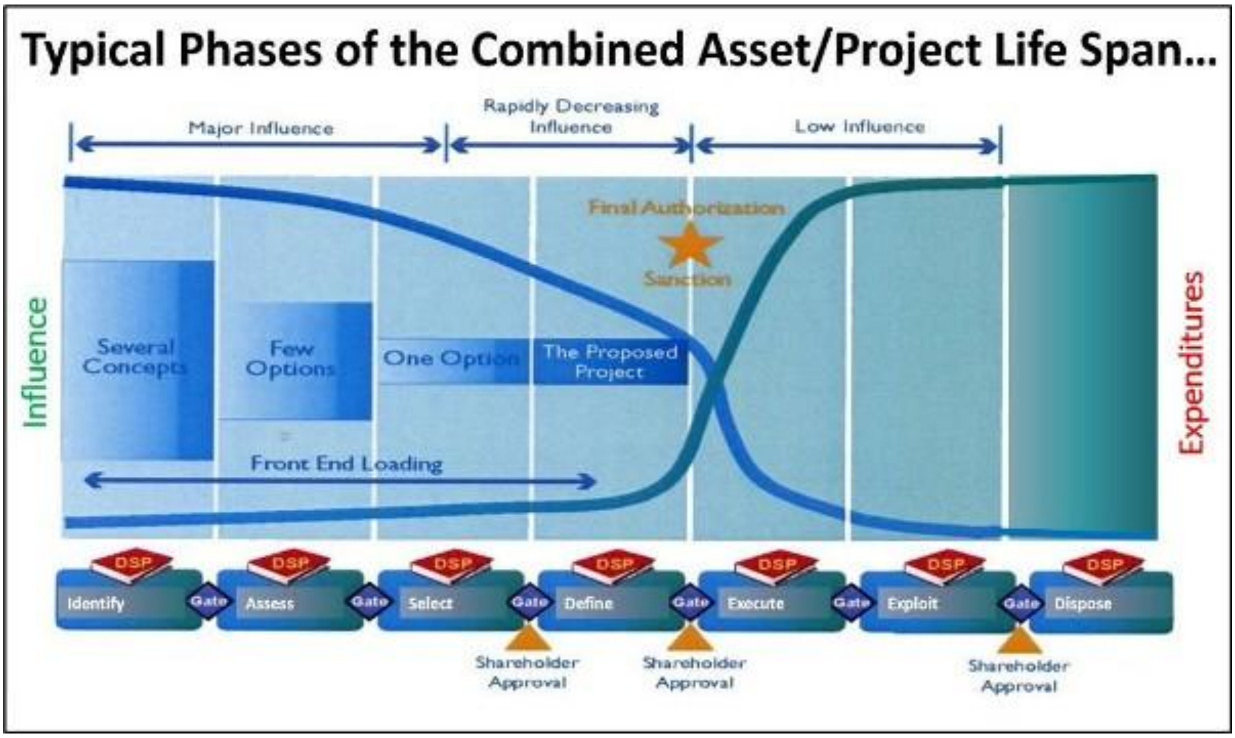

Figure 7. The Asset Life Span Decision Influence (MacLeamy Curve)[18]

This condition can be described as a "broken FEL system," where structured evaluation of alternatives and rigorous cost estimation are not consistently applied. Giammalvo notes that "poor decision outcomes are often not due to a lack of tools, but due to failure in applying them effectively."[19]

NASA highlights that "inaccurate cost estimates are a leading cause of program cost growth."[20] Align with NASA Montang states that "improving estimation reliability is not only a technical challenge but a strategic requirement for effective asset management."[21]

Recent research has attempted to improve estimation practices through statistically grounded approaches. A data-driven study on oil storage tank maintenance shows that "early-stage estimates often rely on engineering judgment or regional historical figures," which are "subjective, inconsistent, and lack statistical grounding".[22] To address this limitation, the study introduced a regression-based Cost Estimating Relationships (CER) using historical data.

[18] PTMC, & Giammalvo, P. D. (2021). 1.4.1.1 unit 1 – Governance and Integration
[19] U.S. Government Accountability Office (GAO). (2020). *Cost estimating and assessment guide: Best practices for developing and managing capital program costs*. GAO.
[20] Giammalvo, P. D. (2023). Practical cost engineering and risk management in project controls. *PM World Journal*.
[21] Montang, S. Y. (2023). Revolutionizing feasibility studies: A proprietary complex model for atmospheric API 650 storage tank cost estimation in national oil company. PM World Journal, 12(10).
[22] Ardiansyah, M., Sutawijaya, M. D., & Prasetio, R. (2025). Integrating statistical analysis into maintenance cost benchmarking for oil storage tanks. Proceedings of the Fourth Australian International Conference on Industrial Engineering and Operations Management, Melbourne, Australia.

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Ardiansyah et al. indicate that "capacity is the only consistent and significant driver of maintenance cost, while other variables such as tank age have minimal influence."[23] This result provides an important shift from subjective estimation toward measurable engineering relationships, enabling more consistent early-stage cost estimation.

$$Y = 123.687.641 + 1.360.981,69X - 97,647X^2 + 0,002276X^3$$

Where
X : *Tank Capacity*
Y : *Project Budget Estimation*

Figure 8. Cost Estimating Relationships (CER) of Tank Maintenance Cost[18]

However, despite its strengths, this approach remains limited by its reliance on nominal cost data. The model may produce inconsistent results when applied across different economic periods.

C. Economic Distortion and the Need for Improved Estimation Frameworks

Sullivan emphasizes that "money has a time value,"[24] indicating that cost data from different periods cannot be directly compared without adjustment. Inflation, exchange rate volatility, and commodity price fluctuations are well-documented sources of uncertainty in engineering cost estimation, particularly in capital-intensive industries such as oil and gas.[25] [26]

Inflation-based adjustment, using indices such as IDR inflation, provides a straightforward way to update historical costs. However, the Bureau of Labor Statistics states that "inflation reflects general price levels and may not capture sector-specific cost drivers relevant to oil and gas maintenance."[27]

Currency-based approaches, particularly using USD, introduce global comparability but are subject to exchange rate volatility. International Monetary Fund explains that "These fluctuations may reflect financial market dynamics rather than actual changes in engineering cost structures."[28]

[23] Ardiansyah, M., Sutawijaya, M. D., & Prasetio, R. (2025). Integrating statistical analysis into maintenance cost benchmarking for oil storage tanks. Proceedings of the Fourth Australian International Conference on Industrial Engineering and Operations Management, Melbourne, Australia.
[24] Sullivan, W. G., Wicks, E. M., & Koelling, C. P. (2023). Engineering economy (17th ed.). Pearson.
[25] Mishkin, F. S. (2019). The economics of money, banking, and financial markets (12th ed.). Pearson.
[26] Damodaran, A. (2012). Investment valuation (3rd ed.). Wiley.
[27] Bureau of Labor Statistics. (2023). Consumer Price Index: Overview. U.S. Department of Labor.
[28] International Monetary Fund. (2022). Exchange rates and international finance. IMF.

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From a theoretical perspective, Purchasing Power Parity (PPP), often illustrated through the Big Mac Index, The Economist suggests that "exchange rates should equalize the price of identical goods between countries."[29] While this concept provides insight into economic comparability, its direct application to engineering cost estimation remains limited.

An alternative perspective is the use of gold as a macroeconomic reference. Erb and Harvey describe gold as "a long-term store of value,"[30] reflecting its ability to preserve purchasing power amid inflation and currency instability. Baur & McDermott state that "Gold has historically been used as a hedge against inflation and currency devaluation".[31] making it a potential reference point for long-term cost normalization in volatile economic environments.

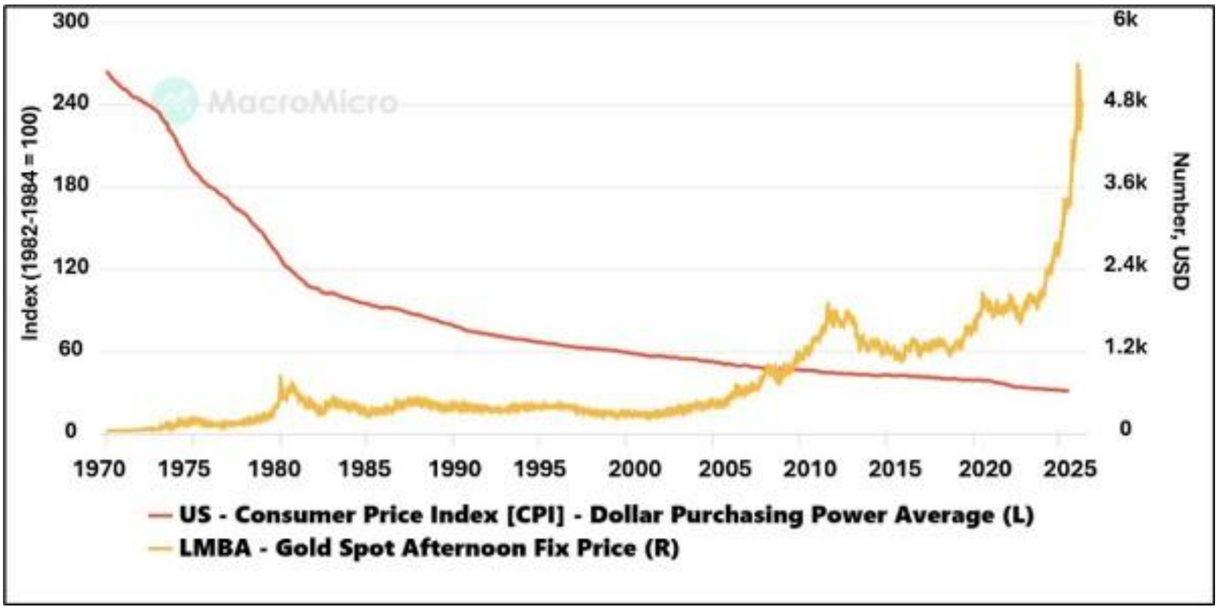

Figure 9. Gold versus USD Purchasing Power[32]

Accordingly, the goal of this paper is to evaluate how different economic adjustment approaches can improve the estimation of Tank Maintenance costs and to determine whether a more robust framework can enhance decision-making in maintenance planning and asset management.

Specifically, this study would answer the following research questions:

[29] The Economist. (2023). *The Big Mac index*. https://www.economist.com/big-mac-index
[30] Erb, C. B., & Harvey, C. R. (2013). The golden dilemma. *Financial Analysts Journal*, 69(4), 10–42.
[31] Baur, D. G., & McDermott, T. K. (2010). Is gold a safe haven? Journal of Banking & Finance, 34(8), 1886–1898.
[32] MacroMicro. (2025). Gold vs USD Purchasing Power https://en.macromicro.me/charts/141084/us-purchasing-power-of-the-us-dollar-vs-gold

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1. Which economic adjustment approach provides the most reliable basis for forecasting oil storage tank maintenance project costs under varying economic conditions?
2. How can economic volatility be incorporated into maintenance project cost estimates to support more defensible budgeting, contingency planning, and Owner's Estimate preparation?
3. How can improved maintenance cost estimation support better decision-making in projectized operations, particularly in project planning, procurement, contractor evaluation, and program-level asset management?

METHODOLOGY

This paper will use the structured procedure analysis of Engineering Economics as its methodology. The methodology being developed is shown in Figure 10.

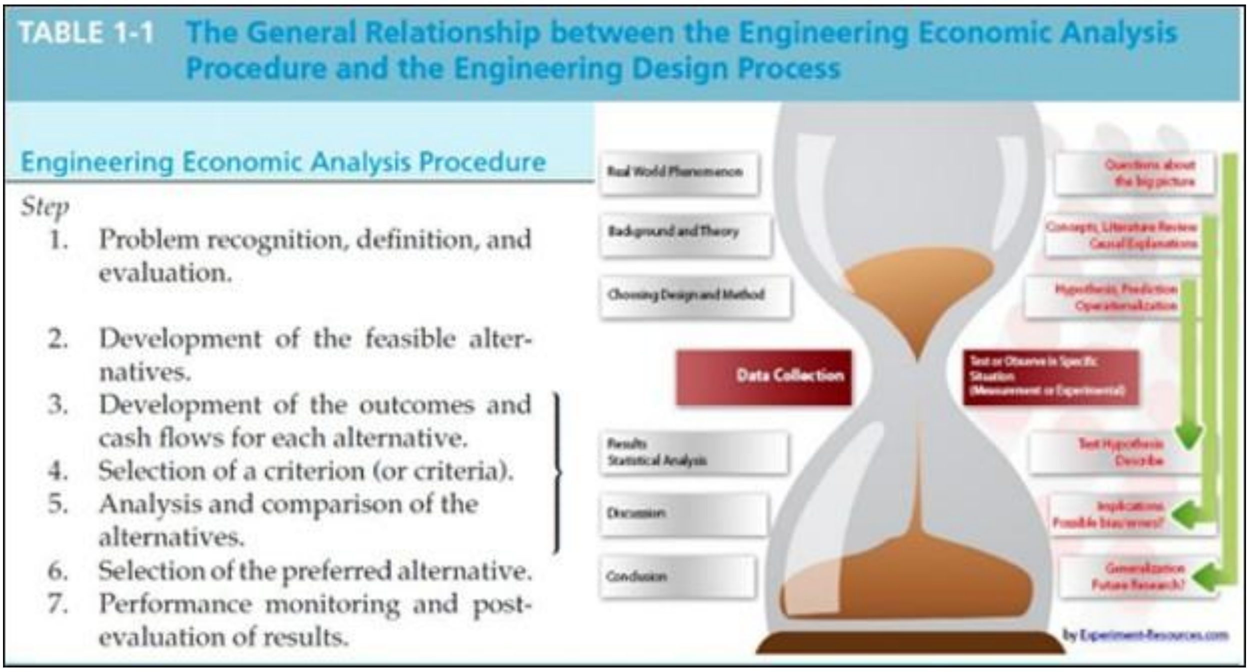

Figure 10. Engineering Economic Analysis Procedure[33]

Step 1 - Problem Definition

The developed Cost Estimation Relationships (CER) for estimating Tank maintenance represent the relationship between tank capacity and maintenance cost. However, applying the same model directly to projects executed in other years may produce estimation inaccuracies.

[33] Sullivan, W. G., Wicks, E. M., & Koelling, C. P. (2023). Engineering economy (17th ed.). Pearson.

Gold primarily reflects financial market behaviors but does not fully represent real economic purchasing power. In other hand, the Big Mac Index, based on Purchasing Power Parity (PPP), Investopedia reports that "this is a consumer-based economic indicator that provides a more representative escalation factor."[34,35] However, cost escalation in storage tank maintenance projects is influenced by other economic dimensions. Such as the US Dollar (USD), as the currency that is globally used, and the Indonesian Rupiah (IDR), as the Indonesian currency.

Therefore, Ramadhan states that "the selection of an escalation factor is not merely an analytical task, but a decision-making problem involving multiple alternatives and evaluation criteria."[36]

Based on the research gap and research question, this study aims to achieve the following objectives:

1. To identify the most reliable economic adjustment approach for forecasting oil storage tank maintenance project costs under varying economic conditions.
2. To develop a method for incorporating economic volatility into maintenance project cost estimates to support more defensible budgeting, contingency planning, and Owner's Estimate preparation.
3. To evaluate how improved maintenance cost estimation supports projectized operations, particularly in project planning, procurement, contractor evaluation, and program-level asset management.

Step 2 - Identify The Feasible Alternative

2.1 Value Drivers Structures & Attributes

To address the decision problem, this study considers four economic indicators as potential escalation drivers: Gold, Big Mac Index, US Dollar (USD), and Indonesian Rupiah (IDR). Each indicator represents a different economic condition that may affect storage tank maintenance costs.

The Big Mac Index and Gold Price Index are both related to purchasing power, but they represent different economic perspectives. The Big Mac Index reflects consumer purchasing power through the price of a standardized product, while the Gold Price Index

[34] Investopedia. (n.d.-a). What is purchasing power parity (PPP), and how is it calculated?
[35] Investopedia. (n.d.-b). Understanding purchasing power and the consumer price index.
[36] Ramadhan, G. C. D. (2023). Bridging the time gap: Exploring escalation method for accurate, precise, reliable and valid project budgeting. PM World Journal, XII(10). https://pmworldlibrary.net/wp-content/uploads/2023/10/pmwj134-Oct2023-Ramadhan-bridging-the-time-gap-exploring-escalation-method.pdf

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reflects broader macroeconomic uncertainty, inflation expectations, and currency instability.[37]

Gold tends to move inversely to both the US dollar and interest rates: when the dollar strengthens or yields rise, gold becomes less attractive because it does not generate interest, leading to weaker performance. Conversely, during periods of declining yields or a weakening dollar, gold prices increase as investors seek a store of value and hedge against uncertainty.

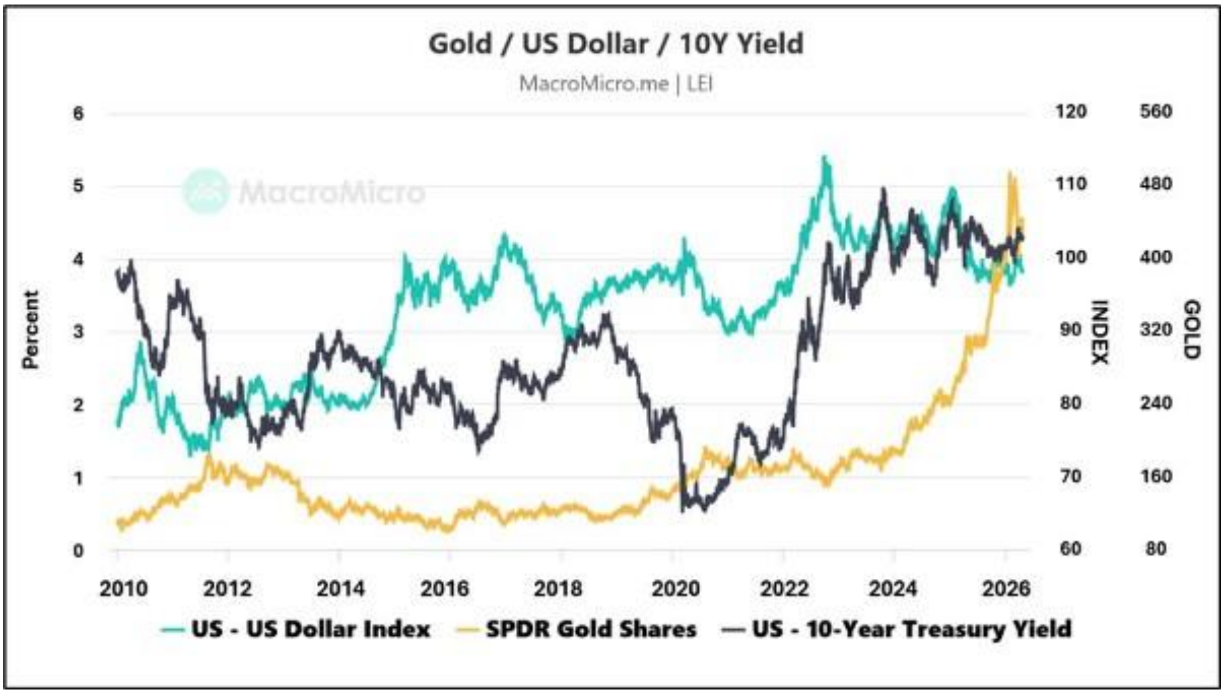

Figure 11. Gold versus USD Index[38]

Meanwhile, inflation gradually reduces the purchasing power of the US dollar, while gold has historically demonstrated stronger value preservation during periods of economic uncertainty and inflationary pressure. This makes gold relevant as a potential reference for long-term cost escalation and purchasing power adjustment. Sellappan states that "the sharp rise in gold in recent years further reflects heightened concerns over inflation, monetary expansion, and global instability, reinforcing gold's role as a hedge against the erosion of purchasing power."[39]

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[37] Fu'ad, K. (2026, March 23). W4.0_KFU_ Applying Big Mac Index escalation for storage tank maintenance cost estimation: A comparison with the Gold Price Index approach. 14 Clovers. https://14cloversaace.wordpress.com/2026/03/23/w4-0_kfu_-applying-big-mac-index-escalation-for-storage-tank-maintenance-cost-estimation-a-comparison-with-the-gold-price-index-approach/

[38] MacroMicro. (n.d.). Gold price vs. U.S. 5-year real yield. https://en.macromicro.me/charts/81733/Gold-Price-vs-US5-Year-Real-Yield

[39] Sellappan, H. K. (2012). Exploring gold as alternative currency for cost estimation in telecommunication projects. PM World Journal,.

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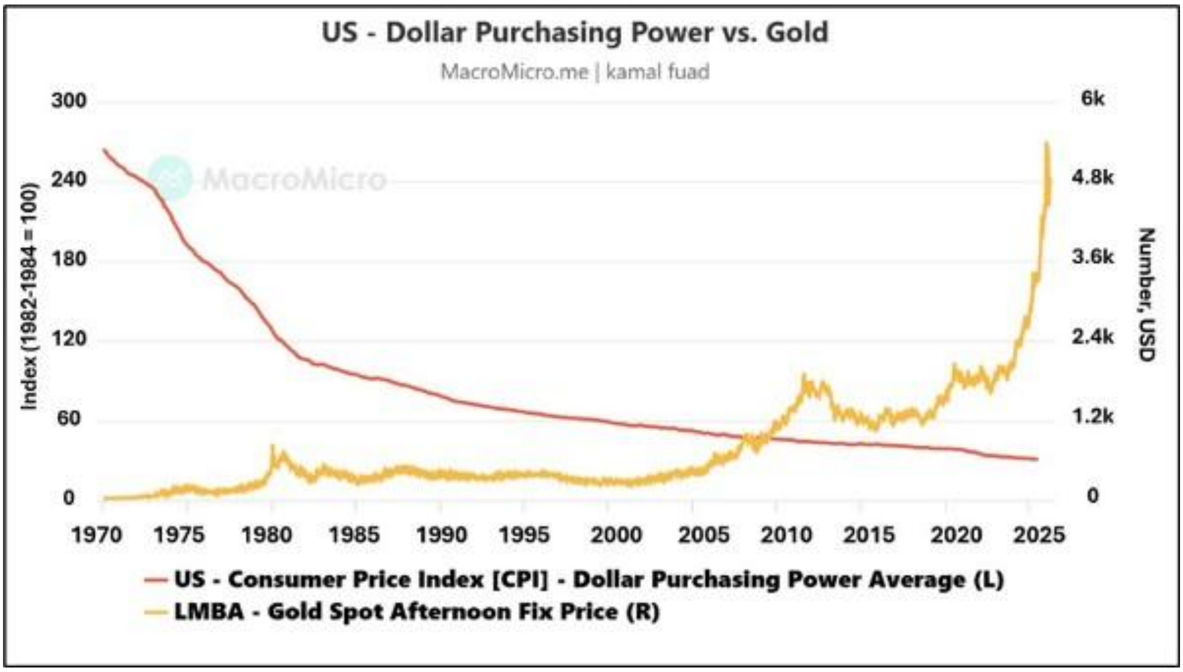

***Figure 12. Gold versus USD Purchasing Power*[40]**

In recent years, the upward trend of the USD/IDR exchange rate indicates persistent pressure on the Rupiah. This movement is important for oil and gas maintenance projects because exchange rate changes can directly affect the cost of imported materials, equipment, and foreign services. Krugman and Obstfeld state that "exchange rate movements influence international purchasing power and the relative cost of traded goods, which is especially relevant for capital-intensive industries that depend on global supply chains."[41]

[40] MacroMicro. (2025). Gold vs USD Purchasing Power https://en.macromicro.me/charts/141084/us-purchasing-power-of-the-us-dollar-vs-gold
[41] Krugman, P., & Obstfeld, M. (2018). International economics (11th ed.). Pearson.

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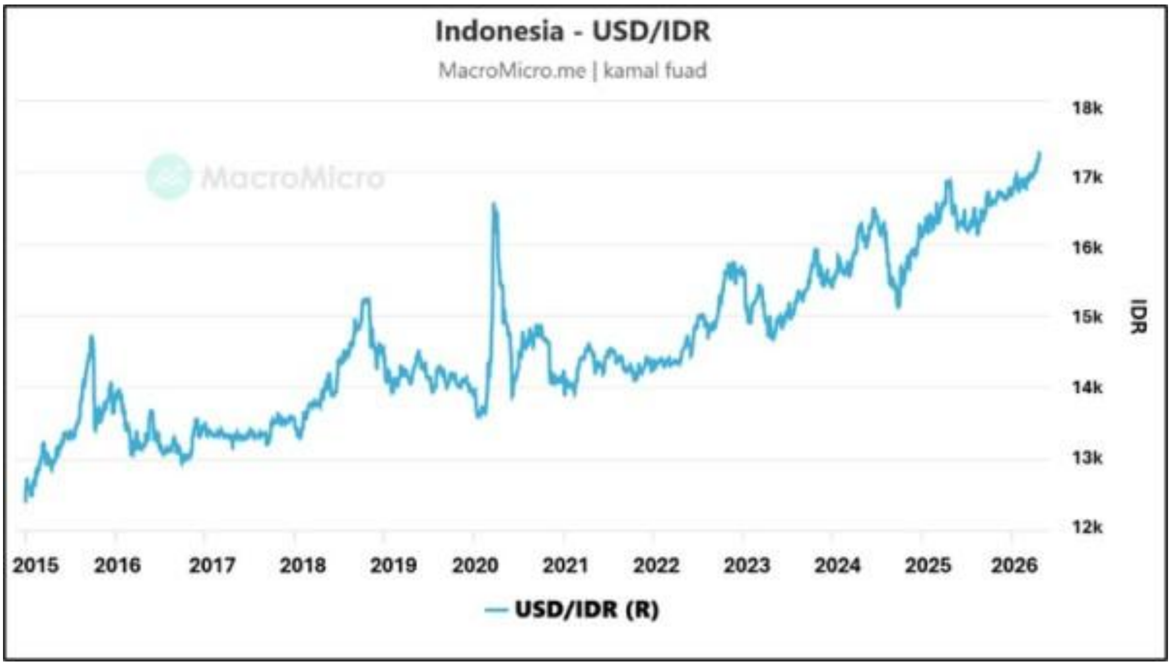

Figure 13. USD Exchange Rate to IDR[42]

Overall, the four indicators provide different views of economic escalation. These escalation driver profiles are summarized in Table 1.

Table 1. Escalation Driver Profiles[43]

Indicator	Index Trend	Purchasing Power Trend	Coverage	Key Cost Linkage to Tank Maintenance
Gold	Inclining	Stable / preserves value	Global	Reflects material cost, commodity trend, capital-intensive projects
Big Mac	Inclining (slow)	Declining	Global (PPP-based)	Represents consumer price level (General)
USD	Inclining vs IDR	Declining	Global	Affects imported materials, equipment, and foreign services
IDR	Declining vs USD	Declining	Domestic	Affects labour, local services, and domestic materials

5 criteria were defined through a structured review of the escalation drivers. Table 2 presents the complete criterion definition matrix.

[42] MacroMicro. (2025). IDR vs USD data. https://en.macromicro.me/series/742/fx-usd-idr
[43] By Author

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Table 2. Evaluation Criteria Definition Matrix[44]

Code	Criteria	Description
C1	Industry Relevance	Alignment with capital-intensive oil & gas maintenance projects
C2	Sensitivity to Cost Escalation	Ability to reflect cost changes based on index trend
C3	Stability	Consistency based on purchasing power behaviours
C4	Data & Usability	Availability and ease of application
C5	Cost Driver Representation	Ability to represent cost drivers based on coverage (global vs domestic)

Each alternative represents a different economic mechanism influencing project costs, including global macroeconomic conditions, purchasing power behaviors, currency dynamics, and domestic economic conditions.

2.2 The Framework Methods Overview

Multi-Attribute Decision-Making (MADM) techniques are widely applied in engineering and project management to support structured evaluation of alternatives under multiple criteria, particularly when trade-offs between technical and economic factors are required.[45,46]

Non-compensatory Multi-Attribute Decision-Making (MADM)

In addition to defining the feasible alternatives, this study adopts a non-compensatory Multi-Attribute Decision-Making (MADM) framework to support the selection process. The bases for selection on each of the MADM Non-Compensatory Model:[47]

Dominance
Applying the definition of Sullivan,[24] an alternative is dominated — and therefore eligible for elimination — if a second alternative performs at least as well on every criterion in Table 3 and strictly better on at least one.

Satisficing
Following Sullivan,[24] Satisficing tests each alternative against a pre-defined minimum (for Minimize criteria) or maximum acceptable value (for Maximize criteria), referred to as the standard for every attribute in Table 3.

[44] By Author
[45] Triantaphyllou, E. (2000). Multi-criteria decision making methods. Springer.
[46] Saaty, T. L. (2008). Decision making with the analytic hierarchy process. International Journal of Services Sciences.
[47] Sullivan, W. G., Wicks, E. M., & Koelling, C. P. (2023). Engineering economy (17th ed.). Pearson.

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Disjunctive Resolution
"The disjunctive method is similar to satisficing in that it relies on comparing the attributes of each alternative to the standard. The difference is that the disjunctive method evaluates each alternative on the best value achieved for any attribute.
.
Lexicography
The Lexicographic method requires the decision maker to rank the evaluation criteria in order of importance before any analysis begins. All alternatives are compared to the most important criterion; the alternative performing best on that criterion advances.

Compensatory Multi-Attribute Decision-Making (MADM)

The Compensatory Model allows attributes of an alternative to compensate for each other. That is, good performance in one attribute may compensate for poor performance in another.[23] This property distinguishes compensatory models from the non-compensatory methods, where failure on any single criterion, regardless of performance elsewhere, was sufficient for elimination. Following Sullivan, this research exercises two compensatory techniques:

Non-Dimensional Scaling

A popular way to standardize attribute values is to convert them to nondimensional form. There are two important points to consider when doing this. First, the nondimensional values should all have a common range, such as 0 to 1 or 0 to 100. Second, all of the dimensionless attributes should follow the same trend with respect to desirability; the most preferred values should be either all small or all large.

Additive Weighting Technique

Additive weighting is probably the most popular single-dimensional method because it includes both the performance ratings and the importance weights of each attribute when evaluating alternatives. Furthermore, Sullivan states that "it produces recommendations that tend to agree with the intuitive feel of the decision maker concerning the best alternative.[48]

$$Score\ S\ (Ai) = W\_C5 * r\_C5 + W\_C4 * r\_C4 + W\_C3 * r\_C3 + W\_C2 * r\_C2 + W\_C1 * r\_C1$$

Figure 14. Equation for Additive Weighting Technique[49]

[48] Sullivan, W. G., Wicks, E. M., & Koelling, C. P. (2023). Engineering economy (17th ed.). Pearson.
[49] By Author

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Step 3 - Development of The Feasible Alternative

3.1 Non-compensatory Multi-Attribute Decision-Making (MADM)

At this step, Table 1 and Table 2 are used to build Table 3, presenting the consolidated decision matrix from all four escalation drivers, as shown below:

Table 3. Decision Matrix – Raw Performance Data[50]

Criteria	Gold	Big Mac	USD	IDR
C1 – Industry Relevance	High – capital-intensive alignment	Low – consumer-based	High – import-driven cost	High – domestic cost driver
C2 – Sensitivity (Index Trend)	High – strong upward trend	Moderate – slow increase	High – responsive to exchange rate	High – inflation-driven
C3 – Stability (Purchasing Power)	High – preserves value	Moderate – declining	Moderate – declining	Moderate – declining
C4 – Data & Usability	High	High	High	High
C5 – Cost Driver Representation	High – global (preferred)	Low – consumer-based	High – global (preferred)	Moderate – domestic

Dominance Modeling

The Dominance Modeling confirms that Big Mac is consistently dominated and therefore eliminated. Gold shows the strongest dominance characteristics among the remaining alternatives.

Table 4. Dominance Modeling Results[51]

Pair	Criteria Comparison	Dominance Verdict
Gold vs Big Mac	Gold superior in C1, C2, C3, C5	Gold dominates Big Mac
Gold vs USD	Gold superior in C1, C3; USD stronger in C2	No dominance
Gold vs IDR	Gold superior in C1, C3, C5	Gold dominates IDR
USD vs IDR	USD superior in C5; IDR similar in C2	No dominance
USD vs Big Mac	USD superior in C1, C2, C5	USD dominates Big Mac
IDR vs Big Mac	IDR superior in C1, C2, C5	IDR dominates Big Mac

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[51] By Author

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Satisficing Modeling

Refer to Table 3 Decision Matrix – Raw Performance Data, these are the Thresholds for this section:

Table 5: The Thresholds for Satisficing Modeling[52]

C1	C2	C3	C4	C5
High	High	High	High	High

The Satisficing Modeling confirms that Only Gold satisfies all minimum criteria, others fail due to lack of stability and/or global representation.

Table 6: Satisficing Modeling Results[53]

Criteria	Gold	Big Mac	USD	IDR
C1	PASS	FAIL	PASS	PASS
C2	PASS	FAIL	PASS	PASS
C3	PASS	FAIL	FAIL	FAIL
C4	PASS	PASS	PASS	PASS
C5	PASS	FAIL	PASS	FAIL

Table 7: Satisficing Modeling Conclusion[54]

Indicator	Strong Criteria	Verdict
Gold	C1, C2, C3, C4, C5	Strong
USD	C1, C2, C4, C5	Moderate
IDR	C1, C2, C4	Weak
Big Mac	C4	Eliminated

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[53] By Author
[54] By Author

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Disjunctive Resolution Modeling

The priority order applied in this analysis reflects the economic importance of cost drivers in storage tank maintenance projects as follows:

Table 8: Disjunctive Resolution Modeling Conclusion[55]

Rank	Criteria
1	**C1 - Industry Relevance** Primary filter; must align with capital-intensive oil & gas characteristics
2	**C5 - Cost Driver Representation** Global economic coverage preferred over domestic
3	**C2 - Sensitivity to Cost Escalation** Ability to capture cost changes through index movement
4	**C3 - Stability** Consistency of purchasing power over time
5	**C4 - Data & Usability** Supporting criterion for practical implementation

Table 9. Pairwise Comparison for Criteria Priority[56]

No	Results of Paired Comparison	Description
1	C1 > C5	Industry relevance is more important than cost coverage
2	C1 > C2	Industry relevance is more important than sensitivity
3	C1 > C3	Industry relevance is more important than stability
4	C1 > C4	Industry relevance is more important than usability
5	C5 > C2	Global coverage is more important than sensitivity
6	C5 > C3	Global coverage is more important than stability
7	C5 > C4	Global coverage is more important than usability
8	C2 > C3	Sensitivity is more important than stability
9	C2 > C4	Sensitivity is more important than usability
10	C3 > C4	Stability is more important than usability

[55] By Author
[56] By Author

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Table 10. Pairwise Comparison for Criteria Priority[57]

Rank	Criteria	Code	Number of Times Preferred
1	Industry Relevance	C1	4
2	Cost Driver Representation	C5	3
3	Sensitivity to Cost Escalation	C2	2
4	Stability	C3	1
5	Data & Usability	C4	0

The disjunctive resolution modeling confirms that:

- Industry relevance (C1) is the most critical criterion, acting as the first filter.
- Global cost representation (C5) is prioritized over domestic factors, reinforcing the importance of external economic drivers.
- Sensitivity (C2) and stability (C3) serve as secondary differentiators.
- Data usability (C4) is supportive but not decisive.

This priority structure ensures that the selected escalation indicator is primarily aligned with the economic nature of oil & gas projects, rather than general or consumer-based indicators.[58]

Lexicographic Modeling

Lexicographic Modeling confirms that Gold demonstrates the strongest performance across critical criteria.

Table 11. Lexicographic Modeling Results[59]

Step	Criteria	Remaining	Eliminated	Reason
1	C1	Gold, USD, IDR	Big Mac	Not industry-relevant
2	C5	Gold, USD	IDR	Domestic only
3	C2	Gold, USD	—	Both satisfy
4	C3	Gold	USD	Better purchasing power stability

[57] By Author
[58] Giammalvo, P. D. (2021). Unit 10- Managing Cost Estimating and Budgeting.
[59] By Author

3.2 Compensatory Multi-Attribute Decision-Making (MADM)

Using the Rank Order Centroid (ROC) method, the criteria weights are derived based on their ordinal ranking. Barron and Barrett demonstrated that "ROC weighting performs better than equal weighting, rank-sum, and rank-reciprocal methods when ordinal rank information is available."[60] The resulting weights are presented as follows:

```
n = 5 criteria
(Rank 1) = ( 1/5) x   x (1/1 + 1/2 + 1/3 + 1/4 + 1/5) = (1/5) x total_of_sum_of_reciprocals = 0.457
(Rank 2) = ( 1/5) x   x (  0 + 1/2 + 1/3 + 1/4 + 1/5) = (1/5) x total_of_sum_of_reciprocals = 0.257
(Rank 3) = ( 1/5) x   x  (0 + 0 + 0 + 1/3 + 1/4 + 1/5) = (1/5) x total_of_sum_of_reciprocals = 0.157
(Rank 4) = ( 1/5) x    x (0 + 0 + 0 + 0 + 1/4 + 1/5)   = (1/5) x total_of_sum_of_reciprocals = 0.090
(Rank 5) = ( 1/5) x    x (0 + 0 + 0 + 0 + 0 + 1/5)     = (1/5) x total_of_sum_of_reciprocals = 0.040
Total = 0.457 + 0.257 + 0.157 + 0.090 + 0.040 = 1.001 ✓
```

Figure 15. Normalized table using ROC Method[61]

From the Non-Compensatory Multi-Attribute Decision-Making result, the weights are derived as follows:

Table 12. Weighting of Rank Order Centroid (ROC)[62]

Criteria	Description	Weight (%)
C1 – Industry Relevance	Alignment with oil & gas and construction cost behavior	0,45
C5 – Cost Driver Representation	Representation of key cost components	0,25
C2 – Sensitivity to Cost Escalation	Responsiveness to cost drivers	0,15
C3 – Stability	Consistency over time	0,10
C4 – Data Availability & Usability	Accessibility and practicality	0,05
Total		1,00

[60] Barron, F. H., & Barrett, B. E. (1996). Decision quality using ranked attribute weights. Management Science, 42(11), 1515-1523. https://doi.org/10.1287/mnsc.42.11.1515
[61] By Author
[62] By Author

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Non-Dimensional Scaling

The Score for each alternative using non-dimensional scaling:

Table 13. Non-Dimensional Scaling Results[63]

Alternative	C1	C2	C3	C4	C5	Sum	Rank
Gold	5/5 = 1	5/5 = 1	4/5 = 0,8	4/5 = 0,8	5/5 = 1	4,6	1st
Big Mac	3/5 = 0,6	2/5 = 0,4	3/5 = 0,6	5/5 = 1	2/5 = 0,4	3	4th
USD	4/5 = 0,8	4/5 = 0,8	4/5 = 0,8	5/5 = 1	4/5 = 0,8	4,2	2nd
IDR	3/5 = 0,6	3/5 = 0,6	3/5 = 0,6	5/5 = 1	3/5 = 0,6	3,4	3rd

Additive Weighting Technique

The weighted score for each alternative is calculated by multiplying the score of each criterion by its corresponding weight.

Table 14. Additive Weighting Results[64]

Calculation of Weighting Factors			Calculation of Scores for Each Alternative							
			Gold		Big Mac		USD		IDR	
Atributes	Relative Rank	Normalized Weight (A)	Dimensionless Value (B)	Score (A x B)	Dimensionless Value (B)	Score (A x B)	Dimensionless Value (B)	Score (A x B)	Dimensionless Value (B)	Score (A x B)
C1 – Industry Relevance	1	0,45	1,00	0,45	0,60	0,27	0,80	0,36	0,60	0,27
C5 – Cost Driver Representation	2	0,25	1,00	0,25	0,40	0,10	0,80	0,20	0,60	0,15
C2 – Sensitivity to Cost Escalation	3	0,15	0,80	0,12	0,60	0,09	0,80	0,12	0,60	0,09
C3 – Stability	4	0,1	0,80	0,08	1,00	0,10	1,00	0,10	1,00	0,10
C4 – Data Availability & Usability	5	0,05	1,00	0,05	0,40	0,02	0,80	0,04	0,60	0,03
Total	15	1,00	1st Rank	0,95	4th Rank	0,58	2nd Rank	0,82	3rd Rank	0,64

[63] By Author
[64] By Author

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Step 4 - Selection of The Criteria

4.1 Multi-Attribute Decision-Making (MADM)

The criteria to be used for each alternative modeling are as follows:

- Dominance Modeling: every associated task dominates between a pair of alternatives.
- Satisficing Modeling: at least one task outside the limit to be rejected.
- Disjunctive Reasoning Modeling: at least one task within the limit to be able to accept.
- Lexicography: The top-ranked attribute will be chosen as the primary aspect.
- Non-Dimensional Scaling: The top Score in non-dimensional scaling will be chosen.
- Additive Weighting Technique: The top Score in the Additive Weighting Technique will be chosen.

4.2 Further Evaluation of The Chosen Escalation Factor

To evaluate the escalation model derived from the Gold Price Index, statistical criteria are required to assess both the goodness-of-fit of the regression model and the uncertainty range of the projected cost estimates.

First, the regression model representing the Gold Price Index trend is evaluated using the coefficient of determination (R^2), Montgomery states that "it indicates how well the regression equation represents the historical dataset."[65]

Second, once the escalation factor is derived from the regression model, the resulting cost estimates are evaluated using the Program Evaluation and Review Technique (PERT) and the Normal Distribution curve.[66] Vose states that "uncertainty in cost estimates can be quantified by modeling probability distributions, enabling the determination of confidence levels such as P10 to P90."[67]

[65] Montgomery, D. C., Peck, E. A., & Vining, G. G. (2012). Introduction to linear regression analysis (5th ed.). Wiley.
[66] Giammalvo, P. D. (2021). Project management contingency determination using statistical analysis. PM World Journal.
[67] Vose, D. (2008). *Risk analysis: A quantitative guide* (3rd ed.). Wiley.

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FINDING

Step 5 - Analysis of Alternative

5.1 Gold Price Index for Forecasting Tank Maintenance Cost

Employing both decision-making approaches—non-compensatory and compensatory provides a comprehensive perspective on the selection of cost escalation factors. In this analysis, the Gold Price Index emerges as the highest-value alternative across both models, confirming its robustness as a primary escalation indicator.

Table 15. Consolidated Results[68]

Alternative	Non-Compensatory Result	Compensatory Result
Gold	Selected (dominant across criteria)	1st Rank – Highest score
USD	Retained but not dominant	2nd Rank – Strong competitor
IDR	Limited performance	3rd Rank – Moderate
Big Mac	Weak / eliminated in key criteria	4th Rank – Lowest score

The comparison highlights that while both approaches confirm Gold as the preferred alternative, the compensatory model provides additional insight into the relative competitiveness of other options, particularly the USD, which demonstrates strong potential as a supporting escalation indicator.

Therefore, the selection of the Gold Price Index as the primary escalation factor remains consistent and well-supported.

5.2 Assessment of the Gold Price Index Regression Model (R^2)

The Developed Cost Estimating Relationship (CER) provides estimated storage tank maintenance costs based on tank capacity. The CER represents the cost relationship under the 2025 economic conditions, which serve as the base year of the dataset.[69]

Table 16 presents the maintenance cost estimates generated using the third-order polynomial CER for storage tank capacities ranging from 500 KL to 30,000 KL.

[68] By Author
[69] Ardiansyah, M., Sutawijaya, M. D., & Prasetio, R. (2025). Integrating statistical analysis into maintenance cost benchmarking for oil storage tanks. Proceedings of the Fourth Australian International Conference on Industrial Engineering and Operations Management, Melbourne, Australia.

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Table 16 – Dataset from Developed CER in 2025 [70]

Capacity	Orde 3 (IDR)		Orde 3 (USD)	
500	Rp	756.008.294,00	USD	45.832,57
1000	Rp	1.351.989.889,00	USD	81.963,62
1500	Rp	1.902.328.484,00	USD	115.327,58
2000	Rp	2.408.747.579,00	USD	146.028,95
2500	Rp	2.872.970.674,00	USD	174.172,21
3000	Rp	3.296.721.269,00	USD	199.861,85
3500	Rp	3.681.722.864,00	USD	223.202,36
4000	Rp	4.029.698.959,00	USD	244.298,21
4500	Rp	4.342.373.054,00	USD	263.253,90
5000	Rp	4.621.468.649,00	USD	280.173,91
10000	Rp	5.944.777.099,00	USD	360.398,73
15000	Rp	5.806.085.549,00	USD	351.990,64
20000	Rp	5.928.893.999,00	USD	359.435,83
30000	Rp	13.853.010.899,00	USD	839.830,91

The results show that maintenance cost generally increases with tank capacity, although the relationship is non-linear, confirming the suitability of the third-order polynomial CER.

To adjust these cost estimates to the economic conditions of 2026, historical Gold Price Index data are analyzed to represent the change in purchasing power.

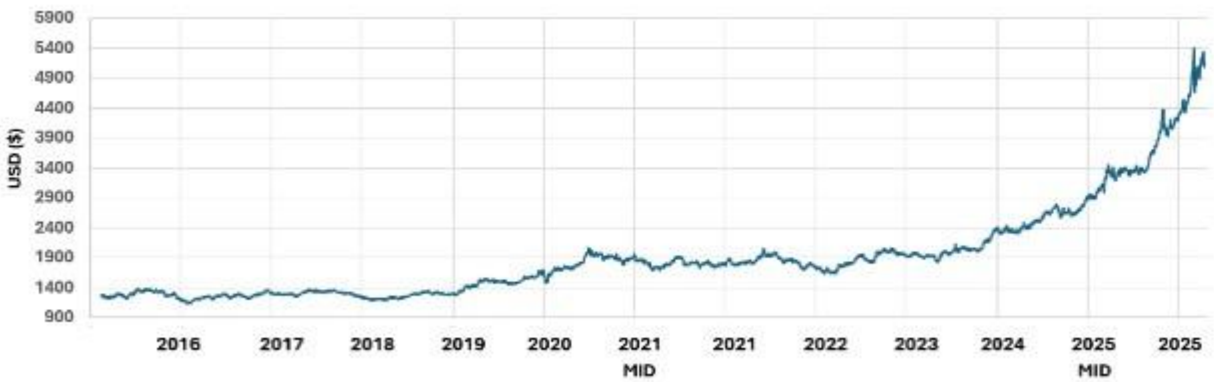

Figure 16. Plotting Historical Gold Price Index [71]

[70] By Author
[71] By Author

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Based on Figure 13, the average gold price in 2025 is calculated to be USD 3.105,01. Using this historical dataset, regression analysis was performed to model the price trend. Several regression models were evaluated, including a linear regression model and polynomial regression models of the 2nd, 3rd, 4th, 5th, and 6th orders. [72] The regression curves generated from these models are illustrated in Figure 17.

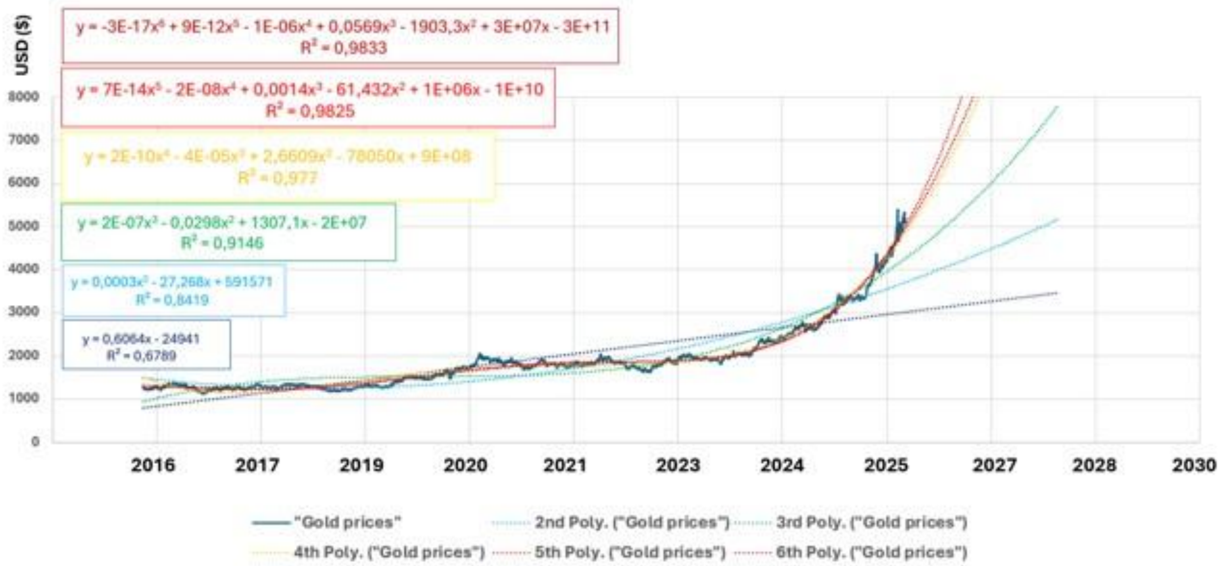

Figure 17. Gold Price Regression from 2016-2026 [73]

The regression trend curves were further extrapolated for all models, including linear regression and polynomial regressions from the 2nd to the 6th order, to project the gold price trend up to 2026. The Results from each regression model are summarized in Tables 17 & 18.

Table 17 – Comparison of Regression [74]

Regression	**R^2**
Linear	0,6789
2nd Poly	0,8419
3rd Poly	0,9146
4th Poly	0,9770
5th Poly	0,9825
6th Poly	0,9833

[72] Sugiyatno, Agung. (2026, March 9). *An index-based approach to CAPEX escalation forecasting using gold price data for HLA projects*. 14Clovers AACE Blog.
[73] By Author
[74] By Author

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Table 18 – Low, Medium, and High Scenario[75]

Regression	Y1 (Gold Price in 2025)	Y2 (Gold Price in 2026)	Remarks
Data	3.105,10		Average 2025
Linear	2.931,07	3.152,41	Low Scenario
2nd Poly	3.489,76	4.144,13	
3rd Poly	3.829,30	5.199,41	Mid Scenario
4th Poly	4.064,25	6.782,33	
5th Poly	4.099,52	7.545,27	High Scenario
6th Poly	4.101,36	7.050,93	

Based on the baseline price presented in Figure 14 and the projected gold price values obtained from the regression models, the estimated cost for Tank Maintenance in 2026 can be determined using the Gold Price Index equivalency method. The resulting projected construction costs are summarized in Table 19.

Table 19 – Estimating Maintenance Cost for 10,000 KL Tank in 2026[76]

Tank Maintenance Cost in 2026 (Cap. 10000 KL)		
Baseline (2025)	$	360.398,7300
Low	$	365.900,0185
Mid	$	603.494,6212
High	$	875.778,9651
Baseline Gold		3.105,01

5.3 Probabilistic Cost Estimation and Confidence Level Analysis Using PERT and Normal Distribution

Confidence levels ranging from P10 to P90 are applied to evaluate the uncertainty range of the estimate. This approach allows assessment of how well the projected cost aligns with the expected risk and contingency levels associated with the estimate.[77] The results of this calculation are presented in Table 20.

[75] By Author
[76] By Author
[77] AACE International. (2015). Total cost management framework: An integrated approach to portfolio, program, and project management (2nd ed.). AACE International.

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***Table 20 – Confidence Level using PERT Analysis*[78]**

Category	P-10	P-20	P-30	P-40	P-50
Baseline (2025)	$ 360.398,73	$ 360.398,73	$ 360.398,73	$ 360.398,73	$ 360.398,73
Low	$ 365.900,02	$ 365.900,02	$ 365.900,02	$ 365.900,02	$ 365.900,02
Mid	$ 603.494,62	$ 603.494,62	$ 603.494,62	$ 603.494,62	$ 603.494,62
High	$ 875.778,97	$ 875.778,97	$ 875.778,97	$ 875.778,97	$ 875.778,97
PERT Analysis					
Min	$ 365.900,02	$ 365.900,02	$ 365.900,02	$ 365.900,02	$ 365.900,02
Max	$ 875.778,97	$ 875.778,97	$ 875.778,97	$ 875.778,97	$ 875.778,97
Most Likely (average)	$ 615.057,87	$ 615.057,87	$ 615.057,87	$ 615.057,87	$ 615.057,87
Weighted Average (PERT)	$ 616.985,08	$ 616.985,08	$ 616.985,08	$ 616.985,08	$ 616.985,08
Std. Dev (δ)	$ 84.979,82	$ 84.979,82	$ 84.979,82	$ 84.979,82	$ 84.979,82
Variance	$ 7.221.570.559,46	$ 7.221.570.559,46	$ 7.221.570.559,46	$ 7.221.570.559,46	$ 7.221.570.559,46
P-number (using z-table)	-1,28	-0,84	-0,52	-0,25	0
P-value (W.A + P-number*δ)	$ 508.210,9008	$ 545.602,0236	$ 572.795,5674	$ 595.740,1200	$ 616.985,0761

Category	P-60	P-70	P-75	P-80	P-90
Baseline (2025)	$ 360.398,73	$ 360.398,73	$ 360.398,73	$ 360.398,73	$ 360.398,73
Low	$ 365.900,02	$ 365.900,02	$ 365.900,02	$ 365.900,02	$ 365.900,02
Mid	$ 603.494,62	$ 603.494,62	$ 603.494,62	$ 603.494,62	$ 603.494,62
High	$ 875.778,97	$ 875.778,97	$ 875.778,97	$ 875.778,97	$ 875.778,97
PERT Analysis					
Min	$ 365.900,02	$ 365.900,02	$ 365.900,02	$ 365.900,02	$ 365.900,02
Max	$ 875.778,97	$ 875.778,97	$ 875.778,97	$ 875.778,97	$ 875.778,97
Most Likely (average)	$ 615.057,87	$ 615.057,87	$ 615.057,87	$ 615.057,87	$ 615.057,87
Weighted Average (PERT)	$ 616.985,08	$ 616.985,08	$ 616.985,08	$ 616.985,08	$ 616.985,08
Std. Dev (δ)	$ 84.979,82	$ 84.979,82	$ 84.979,82	$ 84.979,82	$ 84.979,82
Variance	$ 7.221.570.559,46	$ 7.221.570.559,46	$ 7.221.570.559,46	$ 7.221.570.559,46	$ 7.221.570.559,46
P-number (using z-table)	0,26	0,53	0,67	0,85	1,29
P-value (W.A + P-number*δ)	$ 639.079,8305	$ 662.024,3831	$ 673.921,5585	$ 689.217,9269	$ 726.609,0496

To evaluate the reliability of the escalated maintenance cost estimates derived from the Gold Price Index regression, probabilistic analysis is performed using the Program Evaluation and Review Technique (PERT). The PERT approach allows the cost estimate to be expressed as a probability distribution, producing a range of potential outcomes across several confidence levels from P10 to P90.

***Table 21. Forecasted Tank Maintenance Cost in 2026*[79]**

Category	Tank Maintenance Cost
Baseline (2025)	$ 360.398,73
P-10	$ 508.210,90
P-20	$ 545.602,02
P-30	$ 572.795,57
P-40	$ 595.740,12
P-50	$ 616.985,08
P-60	$ 639.079,83
P-70	$ 662.024,38
P-75	$ 673.921,56
P-80	$ 689.217,93
P-90	$ 726.609,05

[78] By Author
[79] By Author

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Relying solely on a P50 estimate exposes project budgets to a significant risk of cost overrun because it does not provide adequate protection against uncertainty in cost drivers such as commodity price movements, market fluctuations, and estimation variability.[80]

At early project stages, when scope definition and market conditions are still evolving, a higher confidence level is typically recommended to provide sufficient protection against potential cost escalation. [81] [82]

Step 6 - Selection of the Preferred Alternative

The combined use of non-compensatory and compensatory decision-making approaches provides a comprehensive basis for selecting cost escalation factors. Within this framework, the Gold Price Index consistently ranks as the top alternative across both models.[83] [84]

Among the percentile outcomes produced from the probabilistic analysis, P75 is the most appropriate estimate for the project. The P75 level provides a defensible balance between cost efficiency and risk protection, making it the recommended confidence level for forecasting the storage tank maintenance cost for the planned 2026 project.[85]

The P75 forecasted maintenance cost derived from the combined CER model, Gold Price Index escalation, and probabilistic analysis serves two practical purposes. First, it provides a reliable reference for preparing the Owner's Estimate during project planning and budgeting. Second, it serves as a benchmark for evaluating contractor proposals and contract values during the procurement and contract award stages.[86]

By establishing the project cost baseline at the P75 confidence level, both budgeting and contracting decisions are supported by a time-phased, risk-informed cost estimate,

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[80] U.S. Government Accountability Office. (2020). GAO cost estimating and assessment guide: Best practices for developing and managing program costs (GAO-20-195G).

[81] AACE International. (2011). Total cost management framework: An integrated approach to portfolio, program and project management (2nd ed.). AACE International.

[82] Humphreys, G. C. (2018). Project management using earned value (4th ed.). Humphreys & Associates, Inc.

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[84] Fu'ad, K. (2026, April 12). Cost escalation factor selection for storage tank maintenance using multi-attribute decision making (MADM) compensatory model. 14Clovers AACE Blog. https://14cloversaace.wordpress.com/2026/04/12/w7-0_kfu_cost-escalation-factor-selection-for-storage-tank-maintenance-using-multi-attribute-decision-making-madm-compensatory-model/

[85] Fu'ad, Kamal (2026, March 16). Applying Gold Price Index Escalation for Storage Tank Maintenance Cost Estimation. 14Clovers AACE Blog. https://14cloversaace.wordpress.com/2026/03/16/w3-0_kfu_applying-gold-price-index-escalation-for-storage-tank-maintenance-cost-estimation/

[86] AACE International. (2016). Cost estimate classification system – As applied in engineering, procurement, and construction for the process industries (Recommended Practice No. 18R-97). AACE International.

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thereby reducing the likelihood of systematic underestimation and minimizing the risk of cost overruns during project execution. [87]

Step 7 - Performance Monitoring

Recent geopolitical developments highlight the importance of incorporating economic indicators into cost estimation models. Escalating geopolitical tensions in the Middle East, including conflicts involving Iran, have contributed to increased volatility in global commodity markets.[88]. Baur & McDermott state that "These movements demonstrate how geopolitical risks can influence the broader economic environment and ultimately affect engineering project costs."[89]

Because gold prices respond to macroeconomic and geopolitical shocks, the Gold Price Index provides a practical proxy for representing broader economic escalation effects in cost estimation.[90] However, while the analytical model provides a statistically supported estimate, the final budgeting and escalation decisions should ultimately be determined by the project's Key Stakeholders who must evaluate the probabilistic results, market conditions, and project risk tolerance before confirming the final budget baseline for the project.[91]

CONCLUSION

This study sets out to identify the most reliable approach for forecasting storage tank maintenance project costs under economic uncertainty and to determine how such forecasts can support better planning, budgeting, procurement, and asset management decisions. In the context of projectized operations, storage tank maintenance is not only an operational activity but also a project and program management concern because each maintenance intervention requires a defined scope, budget, schedule, contractor involvement, and cost control.

The findings confirm that combining non-compensatory and compensatory decision-making approaches provides a robust and logically defensible basis for selecting cost escalation factors. Across both models, the Gold Price Index consistently emerges as

[87] Fadhly Oka, Azlul. (2026, March 8). Gold price index-based CAPEX escalation forecasting for ATG unit procurement installation project. 14Clovers AACE Blog.
[88] PressReach. (2026). Key market focus points for the week: Earnings, Boeing, and economic indicators
[89] Baur, D. G., & McDermott, T. K. (2010). Is gold a safe haven? International evidence. Journal of Banking & Finance, 34(8), 1886–1898
[90] Montang, Samuel Yonathan (2023). Predicting cost using gold price index and compare with Big Mac. https://retromerci2023.wordpress.com/2023/07/10/w4-0_sy_predicting-vapor-recovery-unit-cost-for-feasibility-study-aace-class-4-in-2024-using-gold-price-index-and-compare-it-with-previous-big-mac-index/
[91] AACE International. (2020). Cost estimate classification system – As applied in engineering, procurement, and construction for the process industries (Recommended Practice No. 18R-97). AACE International.

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the most reliable escalation indicator. This confirms that the selected approach is supported by structured analysis rather than subjective judgment.

To address economic volatility, the study applied probabilistic analysis to evaluate multiple confidence levels. The results indicate that the P75 confidence level provides the most appropriate balance between cost efficiency and risk protection.

From a project and program management perspective, the P75-based forecast supports more informed decision-making by providing a credible baseline for Owner's Estimates during planning and a reliable benchmark for contractor evaluation during procurement and contract award. This alignment between estimation, budgeting, procurement, and contracting reduces the risk of systematic underestimation and strengthens cost control during execution.

The study addresses a critical gap in maintenance cost forecasting by linking analytical rigor with practical application. Future research should further explore the integration of real-time market indicators and dynamic updating mechanisms to enhance forecasting accuracy across maintenance programs under evolving economic conditions. Ultimately, integrating probabilistic analysis with structured decision models is essential for delivering reliable, defensible, and contract-ready cost forecasts in uncertain economic environments.

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Kamal Fu'ad is an engineer with over ten years of professional experience in the oil and gas sector. Currently, he works as a project inspector at the national oil company of Indonesia. Several projects have been completed in various downstream oil and gas projects, including fuel terminal, LPG terminal, and related infrastructure, with a focus on asset integrity management. He holds a bachelor's degree in physics engineering from Sepuluh Nopember Institute of Technology. He is attending a distance learning mentoring course, under the tutorage of Dr. Paul D. Giammalvo, CDT, CCE, MScPM, MRICS, GPM-m, Senior Technical Advisor at PT Mitratata Citragraha to attain Certified Cost Professional (CCP) certification from AACE International.

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