The Missing Link in Repair–Replace Decisions: A Quantitative Threshold for Oil and Gas Assets[1, 2]

Andika Jaka Saputra

ABSTRACT

Repair–replacement decisions in aging oil and gas assets often lack a defensible quantitative threshold, as economic, technical, risk, and opportunity factors are typically evaluated in isolation. This study aims to develop an integrated, decision-oriented framework that unifies these value drivers into a structured and measurable decision rule. The research addresses three key questions: how to integrate multi-dimensional value drivers into a single framework, how to improve decision transparency and alignment with asset management objectives, and how to enhance robustness under uncertainty. The proposed framework combines AHP–SAW, engineering economic (EE) analysis, and an AI-based Decision Tree (C4.5) to establish a quantitative decision boundary. Application to real-world case studies demonstrate that the framework produces rational and context-sensitive decisions, with Economic Cost (C1) as the dominant factor, followed by C3, C2, and C4 within a narrow range. Sensitivity analysis confirms model stability under varying conditions. This study contributes by introducing a defensible, data-driven decision tool that links analytical optimization with practical implementation, supporting transparent asset management repair-replacement decisions under uncertainty.

Keywords: *AHP, Asset, Decision Tree, Engineering Economy, Repair Decision, Replacement Decision*

INTRODUCTION

A. Indonesia Oil & Gas Demand and Infrastructure Challenges

Indonesia, as one of the largest emerging economies in Asia, is experiencing rapid economic growth that depends on reliable energy systems. Indonesia's National Energy Master Plan projects that "energy demand will increase significantly, from 1.76 million barrels of oil per day (bopd) in 2025 to 3.72 million bopd in 2050."[3] The increase in

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[3] Republic of Indonesia. (2017). Presidential Regulation of the Republic of Indonesia No. 22 of 2017: National Energy Master Plan. *Jakarta: Cabinet Secretariat of the Republic of Indonesia*

demand has not been matched by an increase in investment in the downstream sector, resulting in a structural imbalance between demand and infrastructure conditions, as illustrated in Figures 1 and 2.

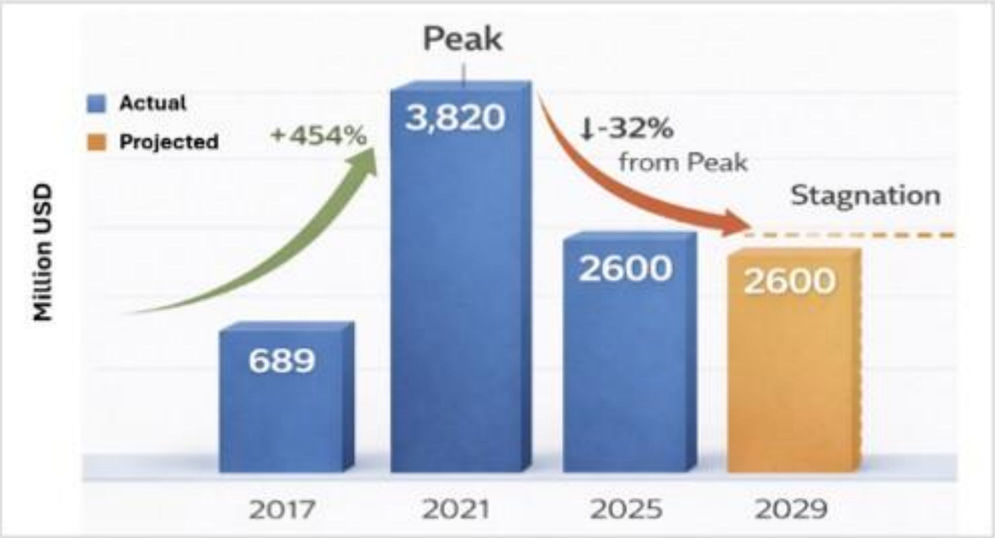

Figure 1. Indonesia's Oil and Gas Downstream Investment Outlook[4]

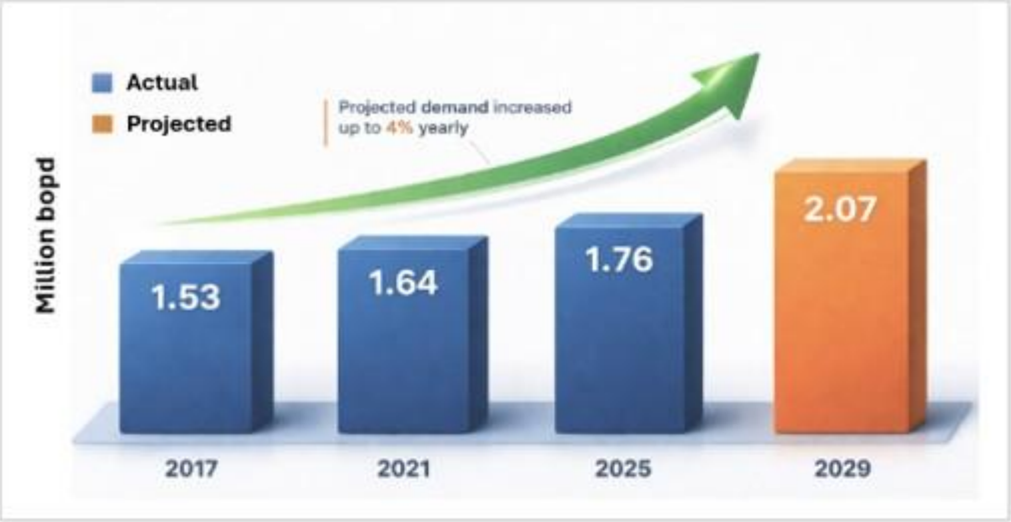

Figure 2. Indonesia's Energy Masterplan[5]

This mismatch is compounded by aging infrastructure, as Knight et al. (2024) state, "Many of the world's 12,000 offshore oil and gas platforms are nearing the end of their

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[4] Republic of Indonesia. Loc. Cit.

[5] Indonesian Directorate General of Oil and Gas. (2025). 2025 Performance Report: Directorate General of Oil and Gas of Indonesia. *Indonesian Ministry of Energy and Mineral Resources*. https://www.esdm.go.id

lives."[6] In Indonesia, the company report that "86.7% of the oil and gas storage tanks in Indonesia are still in use beyond design life,"[7] confirming that this condition is a global structural phenomenon supported by similar reports in Africa, the U.S., and Europe[8,9,10,11].

Figure 3. The Value of Asset Management Model[12]

From an asset management perspective, "value must be derived from the balanced interaction of value drivers."[13,14] In aging infrastructure, previous reports found that "more value drivers are essential for determining whether an asset should be repaired or

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[6] Knights, A., Lemasson, A., Frost, M., & Somerfield, P. (2024). The world must rethink plans for ageing oil and gas platforms. Nature, 627, 34 - 37. https://doi.org/10.1038/d41586-024-00645-0.

[7] Saputra, Andika J. (2026, March 22). W4.0_AJS_Repair or replacement decision: Strategic decision approach using decision tree C4.5 algorithm (Part 1). 14 Clovers. https://14cloversaace.wordpress.com/2026/03/22/w4-0_ajs_repair-or-replacement-decision-strategic-decision-approach-using-decision-tree-c4-5-algorithm-part-1/

[8] Akashraj, D., P., & Maleith, K. (2020). The Impact of Ageing Facilities on Oil Production in South Sudan. *International Journal of Research, 7,* 489-498.

[9] Khan, R., Mad, A., Osman, K., & Aziz, M. (2019). Maintenance Management of Aging Oil and Gas Facilities. *Maintenance Management.* https://doi.org/10.5772/intechopen.82841.

[10] U.S. Department of Energy. (2016). Long-term strategic review of the U.S. Strategic Petroleum Reserve: Report to Congress. https://www.energy.gov/

[11] European Commission. (2020). Commission staff working document: Offshore oil and gas infrastructure in the European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020SC0269

[12] By Author

[13] GFMAM. (2016). The value of asset management to an organization. Global Forum on Maintenance and Asset Management.

[14] International Organization for Standardization. (2024). ISO 55000: Asset management – Vocabulary, overview and principles.

replaced"[15,16]. Figure 3 illustrates that asset management decisions are driven by a balance of cost, technical performance, risk, and opportunity. Given the presence of risk, organizations need to balance it against opportunities. According to Giammalvo, as quoted in the Stretton's Report, "It is the project SPONSORS who are responsible for the business case and who make the STRATEGIC decisions."[17,18] However, Hamasha et al. report that "in practice, many organizations still make these decisions reactively, rather than using a structured, value-focused evaluation. [19] Consequently, there is no integrated mechanism to balance the value drivers into a unified decision rule, reflecting a systemic failure in Front-End Loading.

B. Limitations of Existing Decision Approaches

Existing approaches to repair–replacement decisions are fragmented across value drivers and lack a unified framework. This condition is inconsistent with the principle that "value must be derived from the balanced interaction of value drivers"[20], as illustrated in Figure 4.

As illustrated in Figure 5, repair-replacement decision influence is strongest during early lifecycle stages of FEL, while the ability to influence outcomes declines significantly as expenditures become committed. Consequently, many repair–replacement decisions are made too late, when flexibility is limited, and opportunities for value optimization have diminished.

The Engineering Economics (EE) is currently the primary methodology for analyzing repair and replacement needs using the "defender–challenger" framework[21]. According to multiple studies, "economic approaches tend to prioritize cost efficiency as the primary decision driver, which can lead to implementation failures due to system dependencies,

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[15] Elsahhar, A., Ezzat, A., Elsabbagh, A., & Elbanhawy, A. (2025). Analysis of Failure and Maintenance Records in Aging Wind Farms to Inform End-of-Life Asset Management. *Wind Energy*. https://doi.org/10.1002/we.70024.

[16] Marsili, F., & Bödefeld, J. (2021). Integrating Cluster Analysis into Multi-Criteria Decision Making for Maintenance Management of Aging Culverts. *Mathematics*. https://doi.org/10.3390/math9202549.

[17] Stretton, A. (2019). Contexts of projects undertaken by supplier organisations and owner organisations. *PM World Journal*, 8(7). https://pmworldlibrary.net/wp-content/uploads/2019/08/pmwj84-Aug2019-Stretton-projects-by-supplier-and-owner-organisations-PM-context-series-3.pdf

[18] Giammalvo, P. D. (2019). Agile is not a subset of project management. *PM World Journal*, 8(4).

[19] Hamasha, M., Bani-Irshid, A., Mashaqbeh, S., Shwaheen, G., Qadri, L., Shbool, M., Muathen, D., Ababneh, M., Harfoush, S., Albedoor, Q., & Al-Bashir, A. (2023). Strategical selection of maintenance type under different conditions. *Scientific Reports*, 13. https://doi.org/10.1038/s41598-023-42751-5.

[20] GFMAM. Loc. Cit

[21] Sullivan, W. G., Wicks, E. M., & Koelling, C. P. (2018). *Engineering economy* (17th ed.). *Pearson.*

production constraints, and capital limitations."[22,23,24] According to Green et al. (2022), "unsupported judgement under operational constraints remains a key limitation in maintenance decision-making."[25] Similarly, technical and risk-based approaches improve understanding of asset condition and failure consequences but remain isolated from economic evaluation. [26]

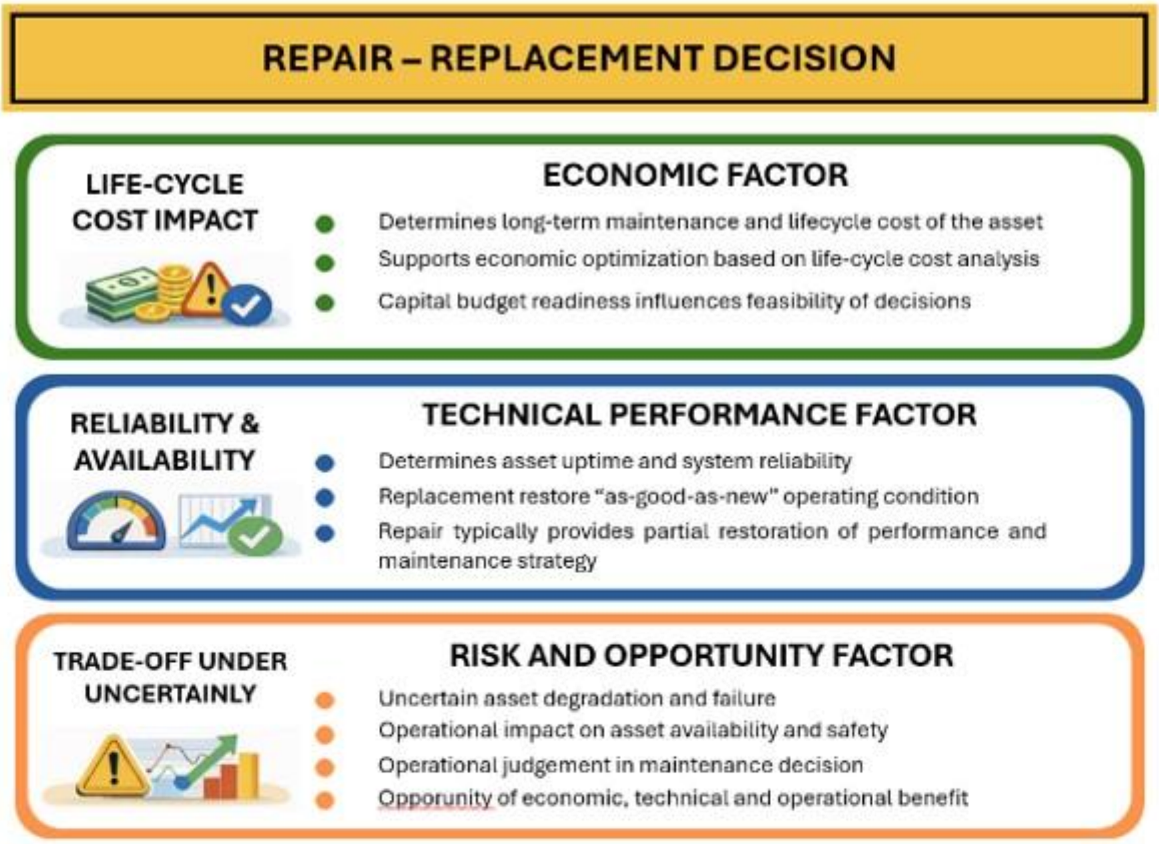

Figure 4. Key Reason for Repair-Replacement Decision[27]

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[22] Abubakar, A. S., Wahab, M. M. B. A., Shafiq, N., Danyaro, K. U., & Adebanjo, A. U (2024). Integrating Life Cycle Cost Analysis into Pipeline Asset Integrity Management: A Comprehensive Approach in Decision Support Systems. *Journal of Hunan University Natural Sciences*. https://doi.org/10.55463/issn.1674-2974.51.1.10.

[23] Kere, K., & Huang, Q. (2024). An analytical approach to evaluate life-cycle cost of deteriorating pipelines. Reliab. Eng. Syst. Saf., 250, 110287. https://doi.org/10.1016/j.ress.2024.110287.

[24] Nogueira, A., Silva, R., Aguiar, V., & Pontes, R. (2025). Economical Assessment of Industrial Motor Replacement from the Perspective of Life Cycle Cost Analysis. *IEEE Latin America Transactions*, 23, 144-152. https://doi.org/10.1109/tla.2025.10851461.

[25] Green, R., McNaught, K., & Saddington, A. (2022). Engineering maintenance decision-making with unsupported judgement under operational constraints. *Safety Science*. https://doi.org/10.1016/j.ssci.2022.105756.

[26] Rios, M., Kaiser, B., Caiado, R., Ivson, P., & Roehl, D. (2025). Decision Framework for Asset Criticality and Maintenance Planning in Complex Systems: An Offshore Corrosion Management Case. *Applied Sciences*. https://doi.org/10.3390/app151910407.

[27] By Author

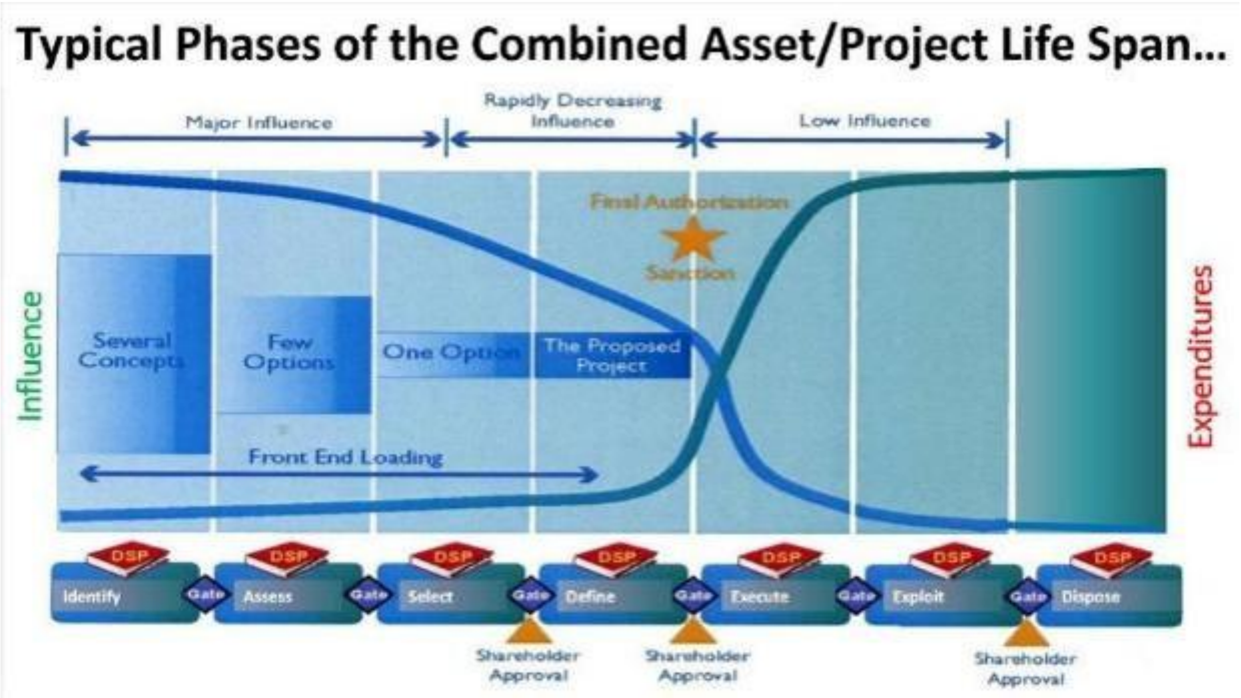

Figure 5. The Asset Lifecycle Decision Influence (MacLeamy Curve)[28]

This situation leaves decision-makers without a consistent, defensible basis for timing repairs or replacements, which is a major problem. This condition creates a gap between analytical output and governance-level decisions and forms the basis for the limitations discussed in the following section.

C. The Need for an Integrated Decision Framework

To address this gap, this study aims to develop a comprehensive, decision-oriented framework that systematically integrates all value drivers, bridging the gap between analytical results and strategic decision-making. The proposed framework uses the Analytic Hierarchy Process (AHP) to organize multi-criteria analysis[29]. EE analysis is included to assess the economic side[30]. Deciding between repair and replacement is often difficult due to asset status, operational constraints, and project costs. This study introduces a threshold-based quantitative approach with balancing value drivers in the repair and replacement decision. To address this, an AI-based Decision Tree is added to

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[28] PTMC, & Giammalvo, P. D. (2021). 1.4.1.1 unit 1 – Governance and Integration

[29] Saputra, A. J., & Suharjito, S. (2025). Optimization Strategy for Electric Vehicle Charging Station Development at Gas Stations Using GIS-AHP-SAW Framework. *Jurnal Teknik Informatika (Jutif),* 6(6), 5401-5418. https://doi.org/10.52436/1.jutif.2025.6.6.4744

[30] Sullivan, W. G., Wicks, E. M., & Koelling, C. P. Op. Cit.

guide decisions when results are urgent or conditions are uncertain[31,32]. This framework was developed by combining the Analytic Hierarchy Process (AHP), engineering economics, and decision tree analysis to support decision-making.

The research addresses the following questions:

1. How can a repair–replacement decision framework be developed that explicitly integrates the four value drivers of the value drivers into a strategic decision rule?
2. How does the integration of AHP and EE improve decision transparency and alignment with organizational asset management objectives?
3. How can AI-based Decision Tree analysis enhance the robustness of repair–replacement decisions by addressing uncertainty?

METHODOLOGY

This study adopts the seven-step engineering economic analysis procedure for evaluating repair–replacement alternatives under uncertainty, as illustrated in **Figure 6**.

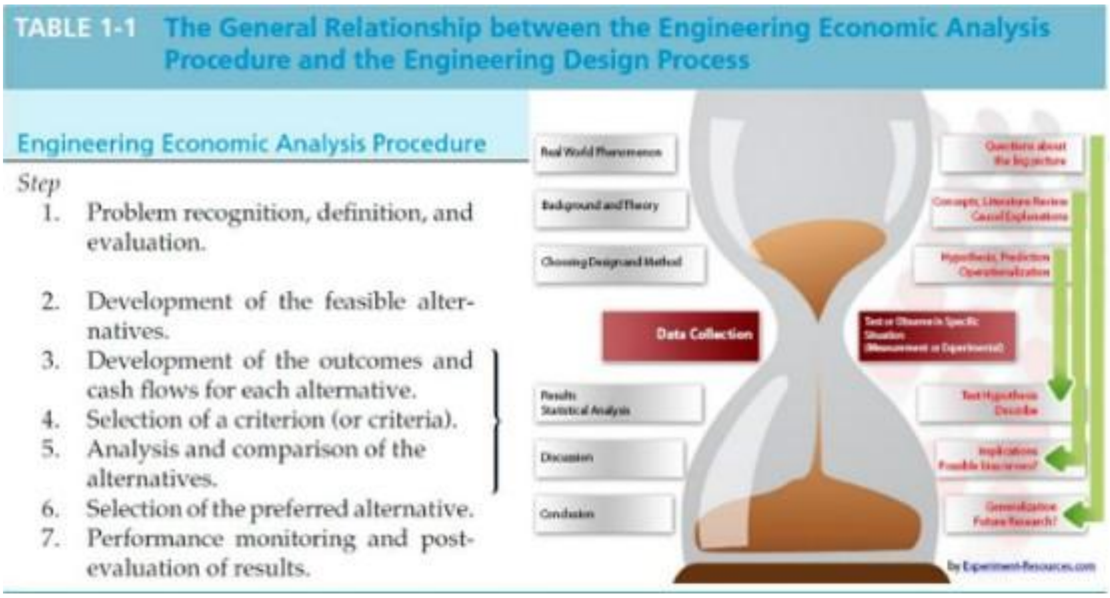

TABLE 1-1 The General Relationship between the Engineering Economic Analysis Procedure and the Engineering Design Process

Engineering Economic Analysis Procedure

Step
1. Problem recognition, definition, and evaluation.
2. Development of the feasible alternatives.
3. Development of the outcomes and cash flows for each alternative.
4. Selection of a criterion (or criteria).
5. Analysis and comparison of the alternatives.
6. Selection of the preferred alternative.
7. Performance monitoring and post-evaluation of results.

Figure 6. Engineering Economic Analysis Procedure[33,34]

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[31] Charbuty, B., & Abdulazeez, A. (2021). Classification Based on Decision Tree Algorithm for Machine Learning. *Journal of Applied Science and Technology Trends*. https://doi.org/10.38094/jastt20165.

[32] Nengsi, E., Komalla, D., Wulandari, A., Lorensya, C., & Aziz, M. (2025). Socio-Economic Status Classification of Neighborhood Residents Using the Decision Tree Algorithm. *Journal of Artificial Intelligence and Engineering Applications (JAIEA)*. https://doi.org/10.59934/jaiea.v4i3.1216.

[33] Sullivan, W. G., Wicks, E. M., & Koelling, C. P. Op. Cit.

[34] Shuttleworth, M. (2008, February 2). What is research? https://explorable.com/what-is-research

The research flowchart is illustrated in Figures 7 and 8 below:

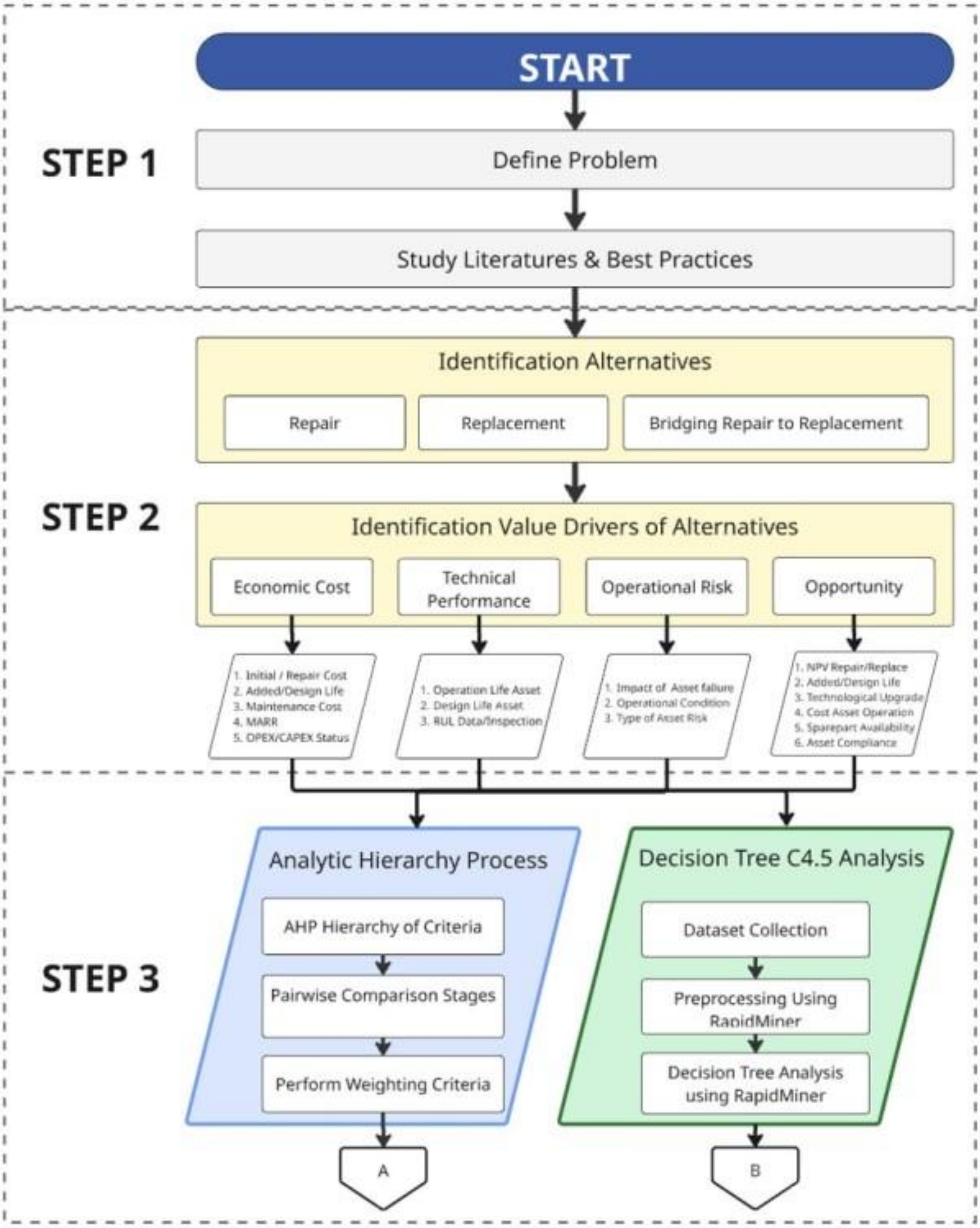

Figure 7. Research Flowchart (part 1)[35]

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[35] By Author

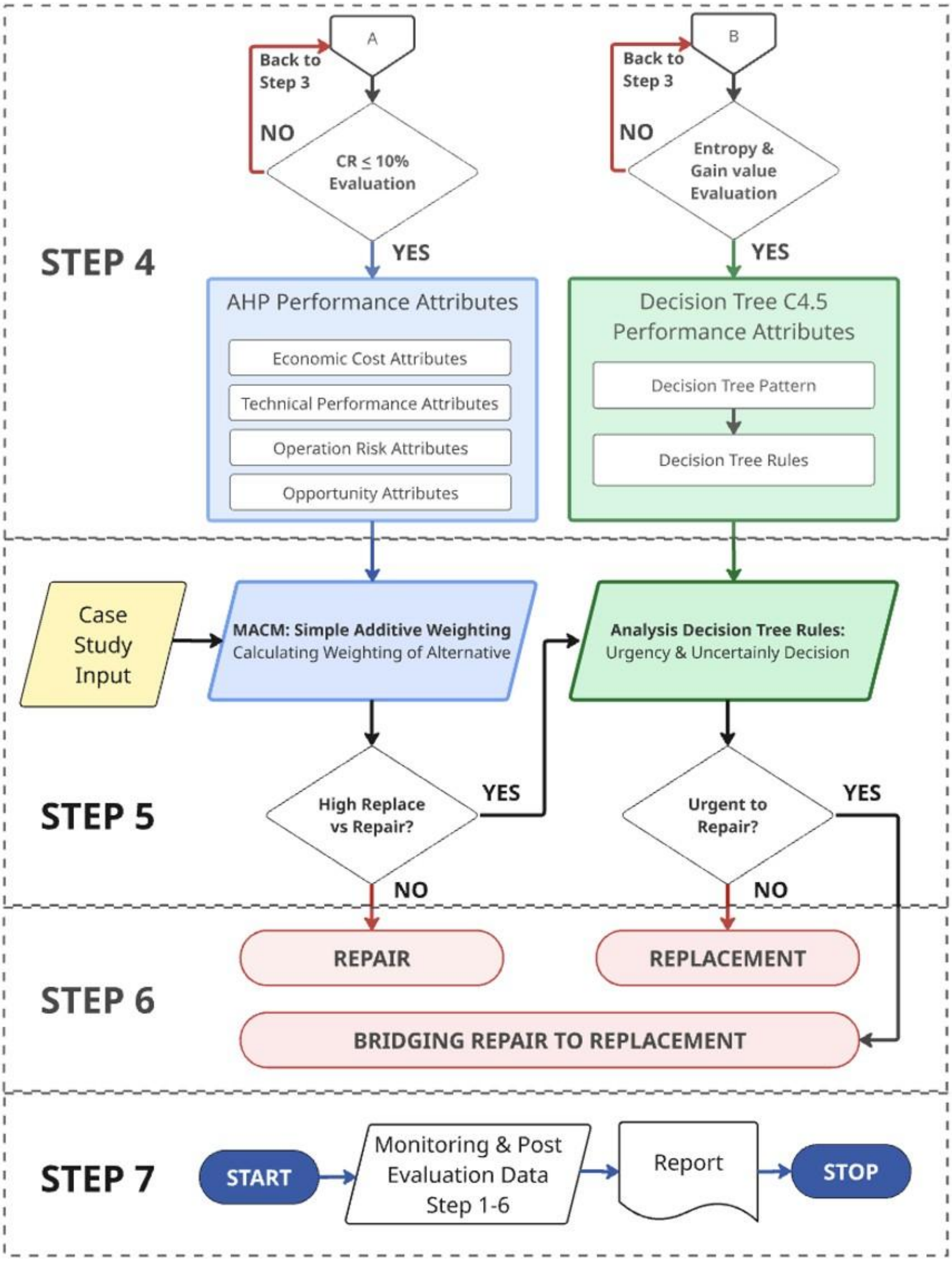

Figure 8. Research Flowchart (part 2)[36]

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[36] By Author

Step 1 - Problem Recognition

The main issue in this study is the inability of project sponsors to make defensible repair–replacement decisions for aging oil and gas assets. In Indonesia, “86.7% of fuel storage tanks are already operating beyond their design life,”[37] as illustrated in Figure 9, while energy demand continues to increase.

Figure 9. Fuel Storage Tank Condition in Indonesia[38]

This condition reflects the absence of an integrated decision mechanism capable of balancing the Value Model, as shown in Figure 3[39]. As identified in section B, existing approaches evaluate value drivers in isolation, creating a gap between the analysis result and governance-level decision.

This statement is supported by previous research by the author, where “decision-making based solely on technical and operational factors only results in a 32% probability of incorrect repair-replacement decision.”[40]. Accordingly, the decision problem addressed in this study is the lack of an integrated and value-based mechanism for determining

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[37] Saputra, Andika J. (2026, March 22). Loc. Cit.
[38] By Author
[39] GFMAM. Loc. Cit
[40] Saputra, Andika J. Loc. Cit

whether an aging asset should be repaired, replaced, or temporarily bridged under uncertainty.

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

1. To develop an integrated repair–replacement decision framework based on the value of asset management.
2. To improve decision consistency and transparency, through a structured evaluation method and alignment with asset management objectives.
3. To establish a decision threshold mechanism under uncertainty to support robust decisions, including bridging repair to replacement

Step 2 – Identification of Alternative and Value Drivers Structures

2.1 Alternatives Definition

This study defines three alternatives to represent the range of possible lifecycle interventions for aging assets:

- **Repair Asset (Defender)**: Restore asset functionality to maintain short-term operational continuity.

- **Replace Asset (Challenger):** Involves full asset renewal to achieve long-term performance and reliability.

- **Replace Asset with Bridging Repair**: A transitional strategy where repair is implemented as an interim solution before planned replacement under constraints and uncertain conditions.

The inclusion of the bridge alternative is intended to better reflect real-world decision-making conditions. As noted by NASA, “Uncertainty in key inputs creates substantial uncertainty in the ranking of alternatives and points to risks that may need to be managed, and extra attention is warranted to clarify objectives and formulate decisions when the set of stakeholders reflects a diversity of values, preferences, and perspectives.”[41,42] This situation has created a need for an alternative solution to address uncertainties—particularly regarding operational urgency—and the diversity of stakeholders involved in decision-making.

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[41] NASA. (2019). SEH 6.0 crosscutting technical management. https://www.nasa.gov/reference/6-0-crosscutting-technical-management/

[42] NASA. (2016). NASA systems engineering handbook (SP-2016-6105 Rev. 2).

2.2 Value Drivers Structures & Attributes

This framework incorporates four value drivers: Economic Cost (C1), Technical Performance (C2), Operational Risk (C3), and Opportunity (C4), as shown in Tables 1 and 2. A balance among these value drivers is expected to lead to decisions that align with the organization's values, rather than relying solely on a single primary criterion.

Table 1. The Definition and Decision Relevance of Value Drivers Criteria[43]

Value Driver (Criteria)	Definition (What)	Decision Relevance (Why)
(C1) Economic Cost	Financial resources required across lifecycle	Determines affordability and capital allocation efficiency
(C2) Technical Performance	Asset Condition and Functional Capability	Determines reliability and ability to sustain operation
(C3) Operational Risk	Urgency and Consequence of Asset Failure	Determines intervention priority and operational impact
(C4) Opportunity	The potential value obtained when the alternative is implemented	determines long-term value creation and improvement

Table 2. The Definition and Decision Relevance of Value Drivers Sub-Criteria[44]

Criteria	Sub-Criteria	Definition (What)	Decision Relevance (Why)
C1	**(C1.1) Cost Efficiency**	Cost Required per added service life	Enables comparison of cost effectiveness across alt.
	(C1.2) Lifecycle Cost	Total cost over asset lifecycle	Ensures cost comparison across different lifespans
	(C1.3) Budget Feasibility	Availability and priority of funding	refrects practical constraint in capital allocation
C2	**(C2.1) Aging Severity**	Asset age relative to design life	Indicates degradation level and asset aging level
	(C2.2) Remaining Usefull life	Expected remaining service life	Refrects actual asset capability beyond nominal age
C3	**(C3.1) Operational Consequences**	Impact on Production Continuity	Measure operational disruption severity
	(C3.2) HSSE Consequences	Safety, environmental, reputational impacts	Capture non-operational risk exposure
C4	**(C4.1) Economic Benefit**	Financial value generated	Capture investment value creation
	(C4.2) Technical Benefit	Additional service life gained	represents lifecycle estension potential
	(C4.3) Operational Benefit	non-financial operational improvements	Capture compliance, safety, and efficiency gains

2.3 The Framework Methods Overview

In this study, the main methods will be integrated into a unified decision-making architecture, the Integrated Framework.

- **Analytic Hierarchy Process with MADM Aggregation**

  Saaty stated that "the AHP decomposes complex decision problems into a hierarchy and derives priority scales through pairwise comparison."[45,46]. This

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[43] By Author
[44] By Author
[45] Saaty, R. W. (1987). The Analytic Hierarchy Process-What it is and how it is Used. *Pergamon Journals Ltd, 9*(5), 161–176.
[46] Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences, 1*(1), 83–98.

method is used as the primary mechanism for converting qualitative expert judgment into quantitative weights and for integrating multiple value drivers into a comparable decision structure.[47].

- **Engineering Economic Analysis**

  This method is applied to quantify the economic dimension, primarily using EUAC[48], NPV Analysis, present worth (PW), or simplified LCC, consistent with GAO[49].

- **AI-Based Decision Tree (C4.5 Algorithm)**

  Quinlan stated that "decision trees provide a structured approach to modeling decision logic under uncertainty through recursive partitioning."[50]. This method acts as a conditional decision layer that complements AHP when the preferred alternative is sensitive to urgency and uncertain operating conditions.

- **Scale and Normalization Approach**

  To ensure comparability across heterogeneous criteria, this study applies normalization techniques, non-dimensional scaling, Guttman scaling[51], and compositional data analysis[52].

Step 3 - Development of The Outcome for Each Alternative

3.1 Analytic Hierarchy Process (AHP)

The AHP procedure is used to derive the relative importance of criteria and sub-criteria and to evaluate the alternatives in a structured multi-criteria environment. The implementation consists of the following stages:

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[47] Lee, H. C., & Chang, C. Ter. (2018). Comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan. *Renewable and Sustainable Energy Reviews, 92*, 883–896. https://doi.org/10.1016/j.rser.2018.05.007

[48] Ardinata, R. (2026, March 16). W3.0_RFA_ repair or replace? An owner's decision analysis for heat exchanger E-xa at refrigerated TLPG. 14 Clovers. https://14cloversaace.wordpress.com/2026/03/16/w3-0_ra_-repair-or-replace-an-owners-decision-analysis-for-heat-exchanger-e-xa-at-refrigerated-tlpg/

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

[50] Supriyatin, W., & Rianto, Y. (2024). Comparative Analysis Accuracy ID3 Algorithm and C4. 5 Algorithm in Selection of Candidates Basic Physics Laboratory Assistant. *Komputasi: Jurnal Ilmiah Ilmu Komputer dan Matematika*, *21*(1), 1-14.

[51] Guttman, L. (1944). A basis for scaling qualitative data. *American Sociological Review, 9*(2), 139–150. https://doi.org/10.2307/2086306

[52] Aitchison, J. (1982). The statistical analysis of compositional data. *Journal of the Royal Statistical Society: Series B (Methodological), 44*(2), 139-160.

AHP Hierarchy of Criteria Development

Based on the value drivers' structure in Tables 1 and 2, the hierarchy of criteria is illustrated in Figure 10.

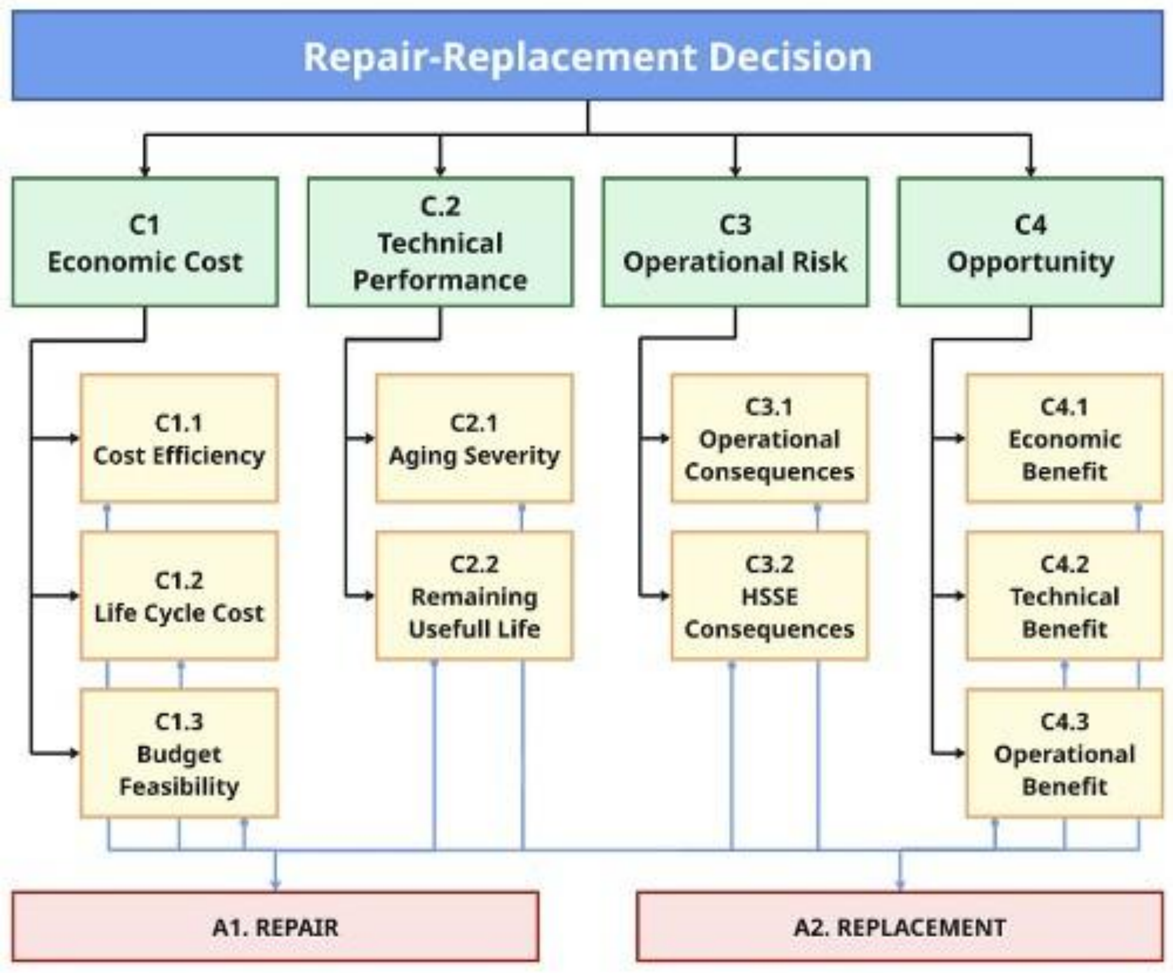

Figure 10. Hierarchy of Criteria[53]

AHP Pairwise Comparison Matrix

Pairwise comparison measures the relative importance among criteria using Saaty's scale, as presented in Table 3. Random Index numbers are shown in Table 4.

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[53] By Author

Table 3. Saaty's Scale[54]

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two criteria contribute equally to the objective
3	Moderate Importance	Slightly favor one criteria over another
5	Strong Importance	strongly favor one criteria over another
7	Very Strong Importance	a criteria dominance demonstrated in practive over another
9	Extreme Importance	Criteria is highest possible order of affirmation over another
2,4,6,8	Definition between two scales	status of one criteria over another is between two scales
Recriprocals of above	if activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption

Table 4. Random Index Number[55]

Matrix Order	1	2	3	4	5	6	7	8	9	10
Random Index (RI)	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Expert Selection

Three experts were selected based on the criteria in Table 5[56]. The use of domain experts is intended to ensure contextual relevance and decision validity.

Table 5. Expert Group[57]

No	Type of Expert	Experience/Degree/Certified
1	Project Sponsor (CAPEX) - Asset Manager	- Experience as Asset manager in oil & gas company >5 years - Minimum Bachelor Degree
2	Project Sponsor (OPEX) - Operational Manager	- Experience as Operation manager in oil & gas company >5 years - Minimum Bachelor Degree
3	Professional Expert	- Experience in oil & gas company >5 years - Minimum Master Degree - Certified in AACE/INCOSE/CMAA/PMI/IAM

The geometric mean method is used to combine the judgments of multiple experts into a single group preference matrix based on pairwise comparison results.[58,59] The

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[54] Saaty, R. W. (1987). Loc. Cit.

[55] Saaty, R. W. (1987). Loc. Cit.

[56] C. J. A. Ter Berg, G. Leontaris, M. van den Boomen, M. T. J. Spaan & A. R. M. Wolfert (2019) Expert judgement based maintenance decision support method for structures with a long service-life, *Structure and Infrastructure Engineering, 15*:4, 492-503, DOI: 10.1080/15732479.2018.1558270

[57] By Author

[58] Xu, Z. (2000). On consistency of the weighted geometric mean complex judgement matrix in AHP. *Eur. J. Oper. Res., 126*, 683-687. https://doi.org/10.1016/s0377-2217(99)00082-x

[59] Grošelj, P., & Dolinar, G. (2023). Group AHP framework based on geometric standard deviation and interval group pairwise comparisons. *Inf. Sci.*, 626, 370-389. https://doi.org/10.1016/j.ins.2023.01.034

aggregated results are presented in Tables 6 and 7, while detailed pairwise comparison results for each expert are provided in Appendix A.

Table 6. Geo-mean Multi-expert of Pairwise Comparison for Criteria[60]

MULTI-EXPERT	(C1) Economic Cost	(C2) Technical Perf	(C3) Operational Risk	(C4) Opportunity
(C1) Economic Cost	1.000	2.289	1.145	1.216
(C2) Technical Perf	0.437	1.000	0.794	1.289
(C3) Operational Risk	0.874	1.260	1.000	1.442
(C4) Opportunity	0.822	0.776	0.693	1.000
Total	3.132	5.325	3.632	4.948

Table 7. Geo-mean Multi-expert of Pairwise Comparison for Sub-Criteria[61]

ULTI-EXPERT	(C1.1) Cost Efficiency	(C1.2) Lifecycle Cost	(C1.3) Budget Feasibility
(C1.1) Cost Efficiency	1.000	0.265	0.454
(C1.2) Lifecycle Cost	3.780	1.000	0.941
(C1.3) Budget Feasibility	2.201	1.063	1.000
Total	6.981	2.327	2.395

MULTI-EXPERT	(C2.1) Aging Severity	(C2.2) Remaining Usefull life
(C2.1) Aging Severity	1.000	0.405
(C2.2) Rem. Usefull Life	2.466	1.000
Total	3.466	1.405

MULTI-EXPERT	(C3.1) Operational Cons.	(C3.2) HSSE Cons.
(C3.1) Operational Cons.	1.000	0.322
(C3.2) HSSE Cons.	3.107	1.000
Total	4.107	1.322

	(C4.1) Economic Benefit	(C4.2) Technical Benefit	(C4.3) Op. Benefit
(C4.1) Economic Benefit	1.000	1.913	1.442
(C4.2) Technical Benefit	0.523	1.000	0.794
(C4.3) Op. Benefit	0.693	1.260	1.000
Total	2.216	4.173	3.236

AHP Weighting of Criteria Normalization

Based on the previous step, the criteria for normalization weights are calculated, as shown in Tables 8 and 9.

These outputs constitute the weighting basis used in the subsequent evaluation of alternatives[62,63]:

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[60] By Author

[61] By Author

[62] Saaty, T. (2013). THE ANALYTIC HIERARCHY PROCESS WITHOUT THE THEORY OF OSKAR PERRON. *International Journal of the Analytic Hierarchy Process*, 5. https://doi.org/10.13033/ijahp.v5i2.191.

[63] Kazibudzki, P. (2021). On the Statistical Discrepancy and Affinity of Priority Vector Heuristics in Pairwise-Comparison-Based Methods. *Entropy*, 23. https://doi.org/10.3390/e23091150.

Table 8. Normalization Matrix of Pairwise Comparison Result for Criteria[64]

MULTI-EXPERT	C1	C2	C3	C4	P-Vector	Weight	Eigen V
(C1) Economic Cost	0.319	0.430	0.315	0.246	1.310	0.328	1.026
(C2) Technical Perf	0.139	0.188	0.219	0.261	0.806	0.202	1.073
(C3) Operational Risk	0.279	0.237	0.275	0.291	1.082	0.271	0.983
(C4) Opportunity	0.262	0.146	0.191	0.202	0.801	0.200	0.990
Total	1.000	1.000	1.000	1.000	4.000	1.000	4.072

Table 9. Normalization Matrix of Pairwise Comparison Result for Sub-Criteria[65]

LTI-EXPERT	C1.1	C.1.2	C1.3	P-Value	Weight	Eigen V
(C1.1) Cost Efficiency	0.143	0.114	0.190	0.447	0.149	1.039
(C1.2) Lifecycle Cost	0.541	0.430	0.393	1.364	0.455	1.058
(C1.3) Budget Feasibility	0.315	0.457	0.417	1.189	0.396	0.950
Total	1.000	1.000	1.000	3.000	1.000	3.047

·EXPERT	C2.1	C.2.2	P-Value	Weight	Eigen V
(C2.1) Aging Severity	0.288	0.288	0.577	0.288	1.000
(C2.2) Rem. Usefull Life	0.712	0.712	1.423	0.712	1.000
Total	1.000	1.000	2.000	1.000	2.000

MULTI-EXPERT	C3.1	C3.2	P-Value	Weight	Eigen V
(C3.1) Operational Cons.	0.243	0.243	0.487	0.243	1.000
(C3.2) HSSE Cons.	0.757	0.757	1.513	0.757	1.000
Total	1.000	1.000	2.000	1.000	2.000

-EXPERT	C4.1	C4.2	C4.3	P-Value	Weight	Eigen V
(C4.1) Economic Benefit	0.451	0.458	0.446	1.355	0.452	1.001
(C4.2) Technical Benefit	0.236	0.240	0.245	0.721	0.240	1.003
(C4.3) Op. Benefit	0.313	0.302	0.309	0.924	0.308	0.996
Total	1.000	1.000	1.000	3.000	1.000	3.000

3.1 AI-Based Decision Tree (C4.5 Algorithm)

Data Collection

The scenario cards were distributed as a questionnaire (see Appendix B) to Project Sponsors at the oil & gas company to validate equivalent decisions based on the Dataset and Attributes Label in Table 10[66].

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[64] By Author

[65] By Author

[66] Kumratova, A., Popova, E., Aleshchenko, V., Bykov, A., & Bashieva, A. (2021). Decision tree as a tool for implementing a scenario approach for multi-level predictive models. *IOP Conference Series: Earth and Environmental Science*, 839. https://doi.org/10.1088/1755-1315/839/3/032050.

Table 10. Dataset and Attributes Label[67]

Attributes	Description	Label Value
Tech_RUL	Technical Performance Factor, Remaining Usefull Life of Asset	RUL < 4 years; RUL 4-20 years; RUL > 20 years.
Tech_Lifespan	Technical Performance Factor, Comparison of service life to design life	Service Life > Design Life; Service Life < Design Life.
Operationak_Risk	Operational Risk Factor, the impact if asset breakdown	Operational Shutdown (Full/Separatelly); Cover by RAE Plan; Backup by Redundant.
Judgement	Sponsor judgement	Urgent to Repair; Waiting Replacement.

Preprocessing Data

This stage cleans and normalizes the data to ensure all features are on the same scale using RapidMiner[68]. The results of preprocessing data are shown in Appendix C.

Decision Tree Algorithm Analysis

The preprocessed data consists of 990 samples and 4 attributes and is split into an 80:20 train: test split, as shown in Figure 11[69].

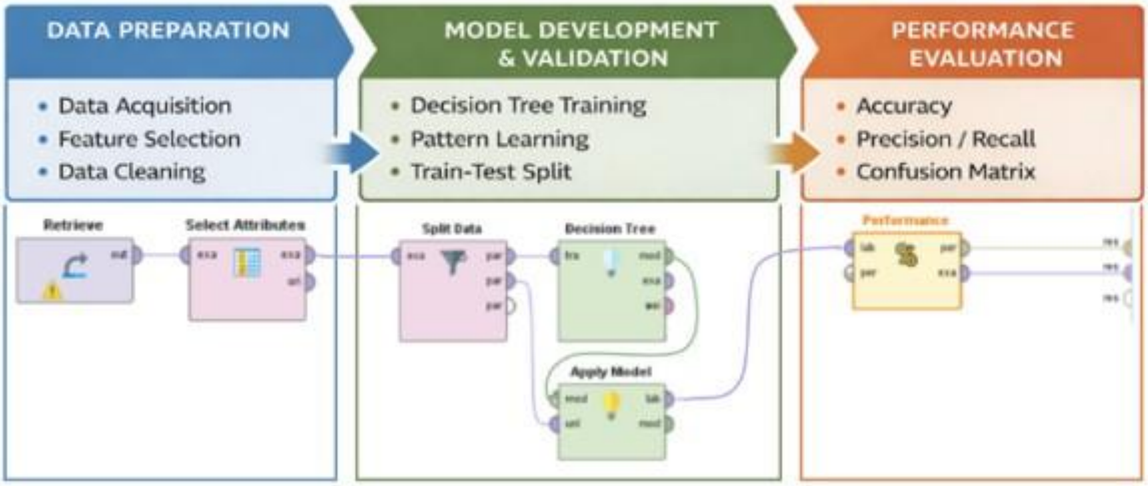

Figure 11. RapidMiner Flow Process[70]

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[67] By Author

[68] Marzukhi, S., Awang, N., Alsagoff, S. N., & Mohamed, H. (2021, August). RapidMiner and machine learning techniques for classifying aircraft data. In *Journal of Physics: Conference Series* (Vol. 1997, No. 1, p. 012012). IOP Publishing.

[69] Mustapha, M., Zulkifli, A., Kairan, O., Zizi, N., Yahya, N., & Mohamad, N. (2023). The prediction of student's academic performance using RapidMiner. *Indonesian Journal of Electrical Engineering and Computer Science*. https://doi.org/10.11591/ijeecs.v32.i1.pp363-371.

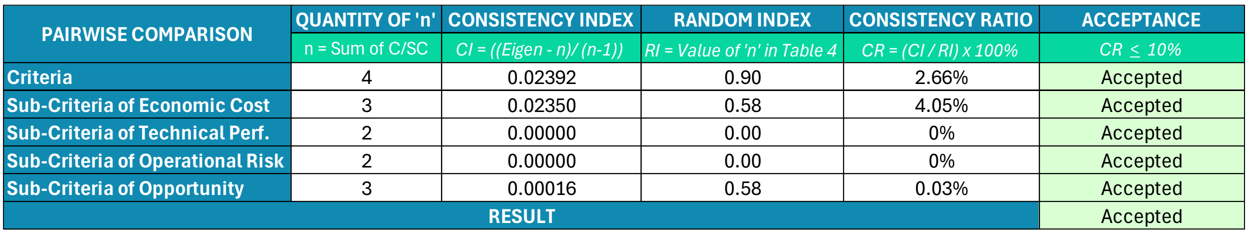
[70] By Author

Step 4 - Model Validation and Decision Acceptance Criteria

4.1 AHP Consistency Evaluation

Based on the results presented in Tables 8 and 9, consistency is evaluated using the Consistency Ratio (CR), with an acceptance threshold of 10%[71]. The CR calculation and evaluation results are presented in Table 11.

Table 11. Consistency Ratio Evaluation of AHP[72]



PAIRWISE COMPARISON	QUANTITY OF 'n'	CONSISTENCY INDEX	RANDOM INDEX	CONSISTENCY RATIO	ACCEPTANCE
	n = Sum of C/SC	*CI = ((Eigen - n)/ (n-1))*	*RI = Value of 'n' in Table 4*	*CR = (CI / RI) x 100%*	*CR ≤ 10%*
Criteria	4	0.02392	0.90	2.66%	Accepted
Sub-Criteria of Economic Cost	3	0.02350	0.58	4.05%	Accepted
Sub-Criteria of Technical Perf.	2	0.00000	0.00	0%	Accepted
Sub-Criteria of Operational Risk	2	0.00000	0.00	0%	Accepted
Sub-Criteria of Opportunity	3	0.00016	0.58	0.03%	Accepted
RESULT					Accepted

4.2 Decision Tree Validation

This model is validated using entropy reduction, information gain, and the logical consistency of the generated decision rules in RapidMiner. RapidMiner evaluates these results consistently, as shown in Figure 12:

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[71] Chotikunnan, P., & Chotikunnan, R. (2023). Dual Design PID Controller for Robotic Manipulator Application.
[72] By Author

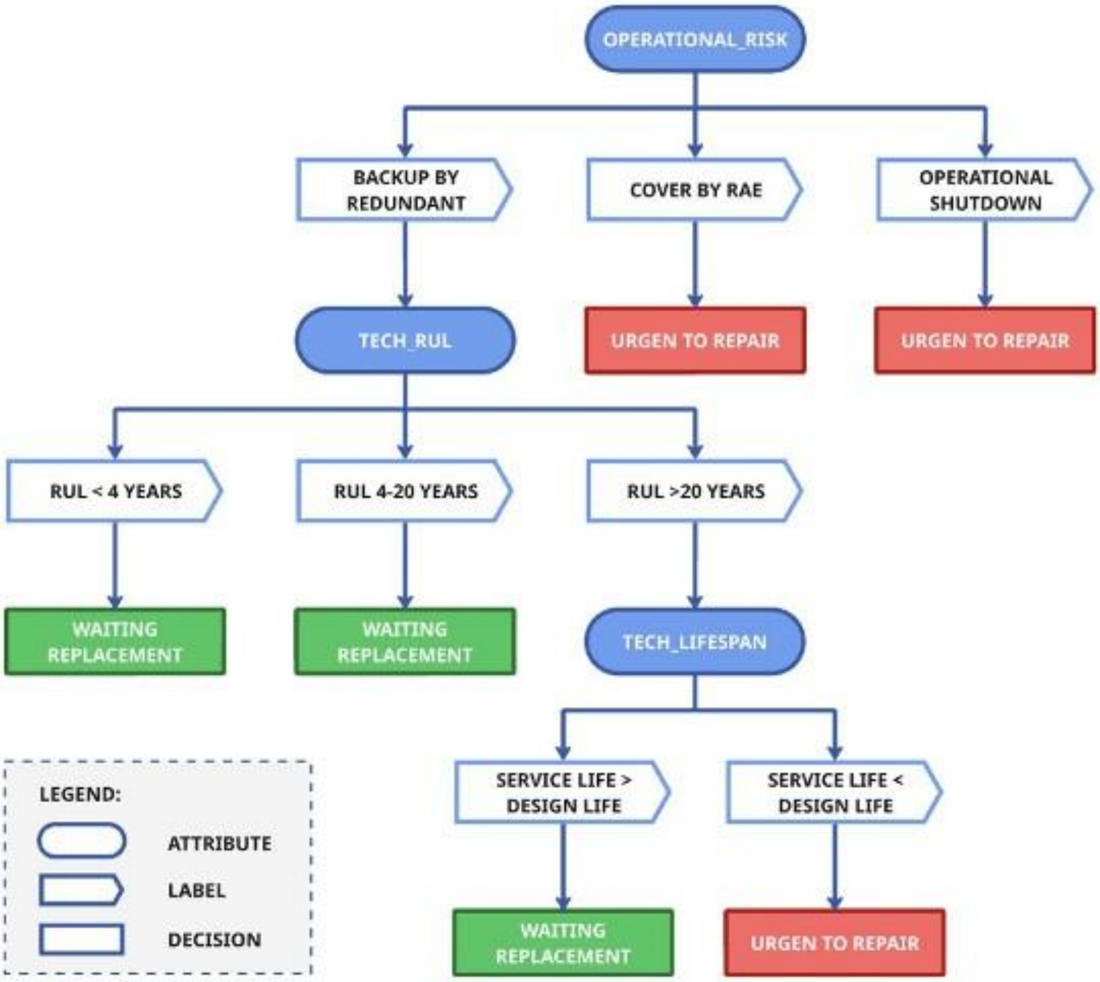

Figure 12. RapidMiner Decision Tree Pattern[73]

4.3 Alternative Decision Acceptance

After confirming that both AHP and Decision Tree models are valid, the framework applies the following decision acceptance criteria:

- **Repair Decision:** The AHP comparison of alternative weights indicates that “Repair” has a higher weight than “Replacement”.
- **Replacement Decision:** The AHP alternative weights comparison indicates that “Replacement” has a higher weight than “Repair”, and the decision tree indicates that the asset’s condition is “not urgent to repair”.

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[73] By Author

- **Replace Asset with Bridging Repair**: The AHP alternative weights indicate that “Replacement” has a higher weight than “Repair”, and the decision tree indicates that the asset’s condition is “urgent to repair.”

Accordingly, AHP serves as the primary value-based ranking mechanism, while the Decision Tree acts as a bridging strategy under urgent uncertainty. To support AHP weighting, the performance of each alternative must be evaluated for each criterion using formulas in APPENDIX D.

FINDING

Step 5 - Analysis of Alternative

This step integrates the quantitative results from AHP–SAW with the rule-based qualitative outputs of the Decision Tree (C4.5), producing an evaluation that is not only economically optimal and aligned with sponsor judgment but also balances all value drivers within the asset management value model.[74]

5.1 AHP Weighting of Criteria

Based on the preceding analysis, the AHP-derived weights reflect optimal preferences across economic, technical, risk, and opportunity attributes. The four value drivers exhibit relatively balanced weights, with Economic Cost (C1) as the dominant criterion at 32.8%, followed by Operational Risk (C3), Technical Performance (C2), and Opportunity (C4). At the sub-criteria level, HSSE Consequences (C3.2) has the strongest influence at 20.5%, while the combined opportunity sub-factors contribute approximately 20%. Detailed results are presented in Figure 13.

---

[74] Saputra, A.J. (2026, March 30). *W5.0_AJS_Repair or replacement decision: Economic approach (Part 2)*. 14 Clovers. https://14cloversaace.wordpress.com/2026/03/30/w5-0_ajs_repair-or-replacement-decision-economic-approach-part-2/

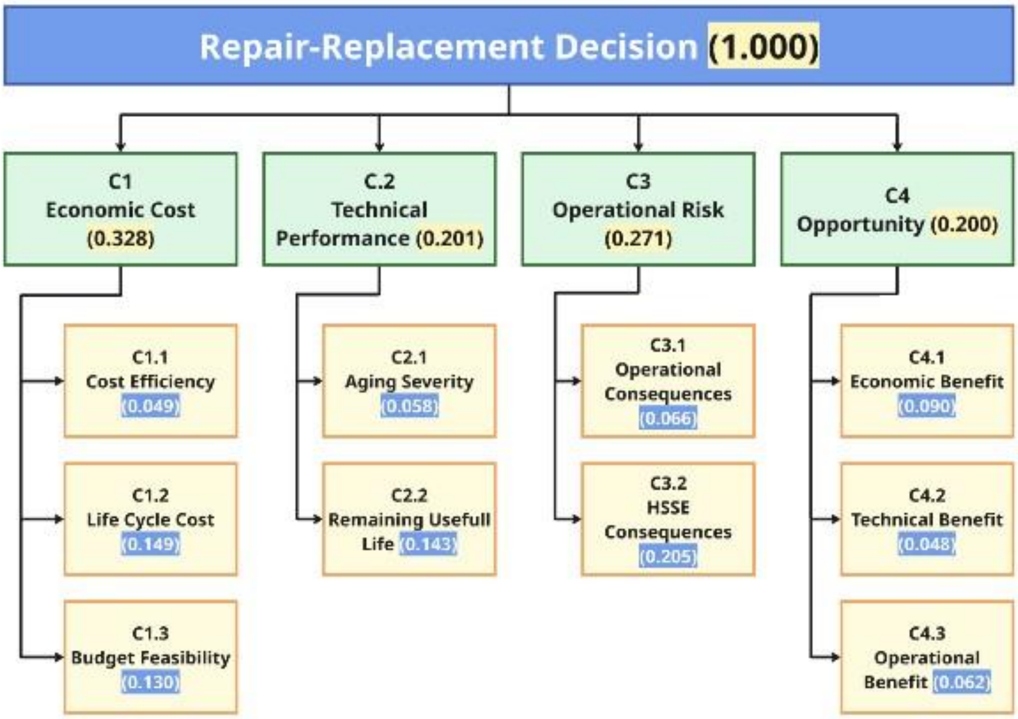
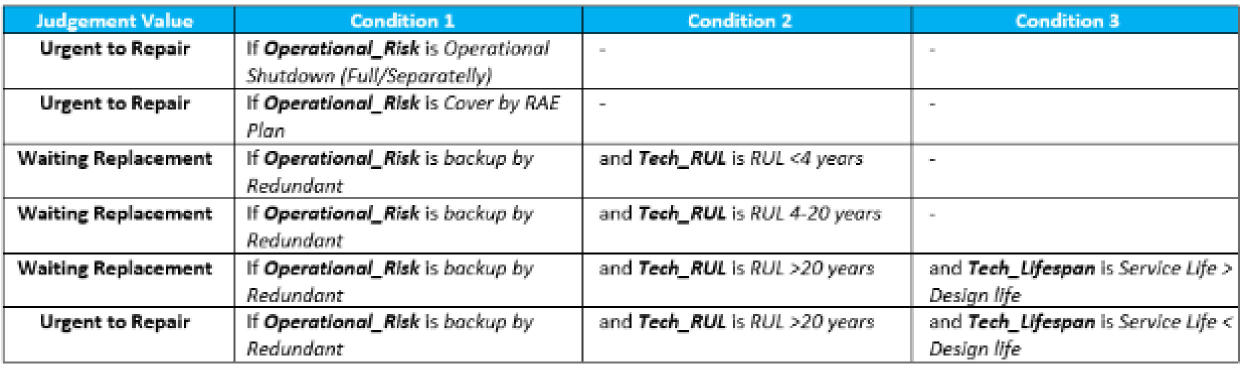


Figure 13. Weight of Criteria AHP[75]

5.2 Decision Tree Rules Analysis

The results from the previous stage, using RapidMiner, show that the C4.5 Decision Tree model effectively generates rule-based decision patterns for evaluating operational conditions, including urgency, degradation uncertainty, and intervention needs. The output reflects real-world field conditions, as summarized in Table 12.

Table 12. Decision Rules[76]



Judgement Value	Condition 1	Condition 2	Condition 3
Urgent to Repair	If ***Operational_Risk*** is *Operational Shutdown (Full/Separatelly)*	-	-
Urgent to Repair	If ***Operational_Risk*** is *Cover by RAE Plan*	-	-
Waiting Replacement	If ***Operational_Risk*** is *backup by Redundant*	and ***Tech_RUL*** is *RUL <4 years*	-
Waiting Replacement	If ***Operational_Risk*** is *backup by Redundant*	and ***Tech_RUL*** is *RUL 4-20 years*	-
Waiting Replacement	If ***Operational_Risk*** is *backup by Redundant*	and ***Tech_RUL*** is *RUL >20 years*	and ***Tech_Lifespan*** is *Service Life > Design life*
Urgent to Repair	If ***Operational_Risk*** is *backup by Redundant*	and ***Tech_RUL*** is *RUL >20 years*	and ***Tech_Lifespan*** is *Service Life < Design life*

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[75] By Author
[76] By Author

Each judgment has specific conditions that must be met. In this study, as shown in the flowchart in Figure 8, the “Urgent to Repair” judgment indicates that the asset requires a bridging strategy before replacement, whereas the “Waiting for Replacement” judgment indicates that it does not.

5.3 Framework Implementation in Applied Case Study

To demonstrate the proposed framework, a practical application was applied to two representative asset case studies: CS1: Storage Tank and CS2: Transfer Pump to represent different asset characteristics, operational roles, degradation patterns, and maintenance decision-making contexts. For this analysis, a 12.57% MARR was used.[77] To facilitate implementation and replication, the author has created a Decision Form, which is available in the SUPPLEMENTARY and the implementation of this form in APPENDIX E.

CS1 – Storage Tank Applied Case Study

In CS1, a storage tank is simulated that is aging, has a low remaining useful life, and requires major repairs. Operational conditions indicate that the assets are redundant, and a decision on repair or replacement needs to be analyzed[78].

a) The first step is to collect the criteria parameters from the defender and challenger, as shown in Tables 13, 14, and 15.

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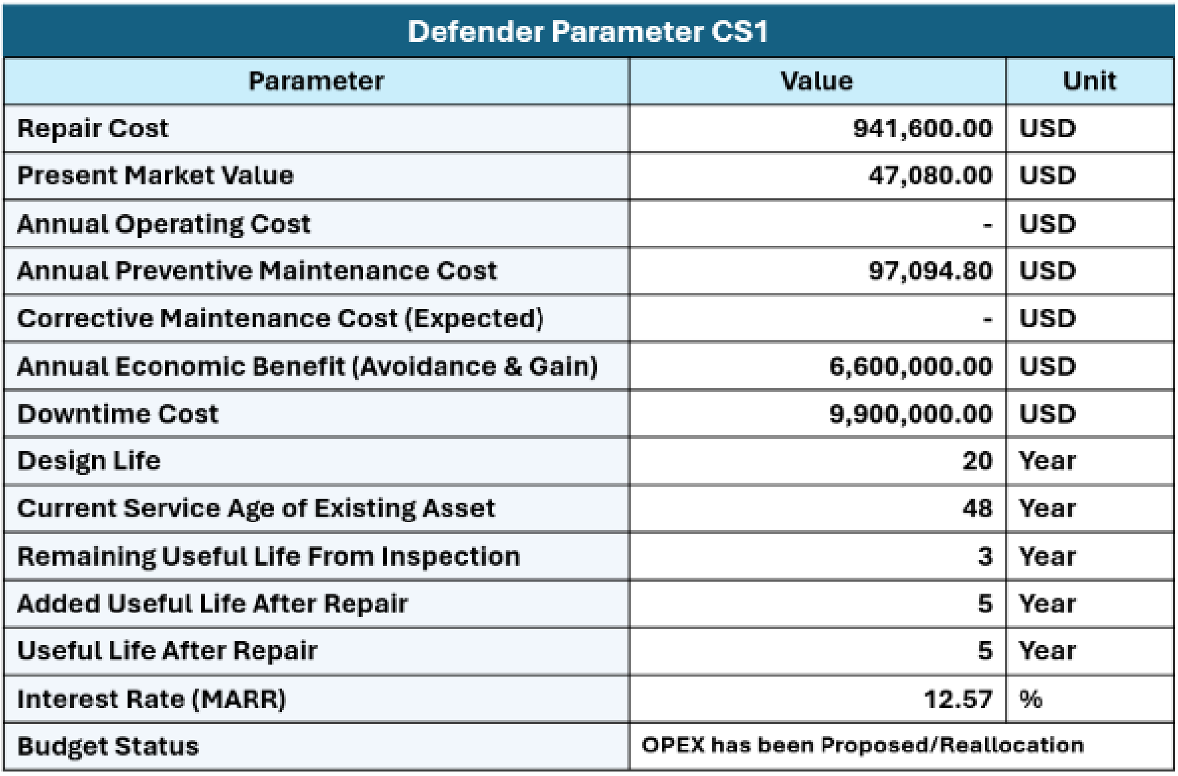
[77] Mukti, Tengku. R. F (2026). W3.0_TRF_Calculating WACC & MARR for NOC Subholding Commercial and Trading. https://14cloversaace.wordpress.com/2026/03/13/w3-0_trf_calculating-wcc-marr-for-noc-subholding-commercial-and-trading/

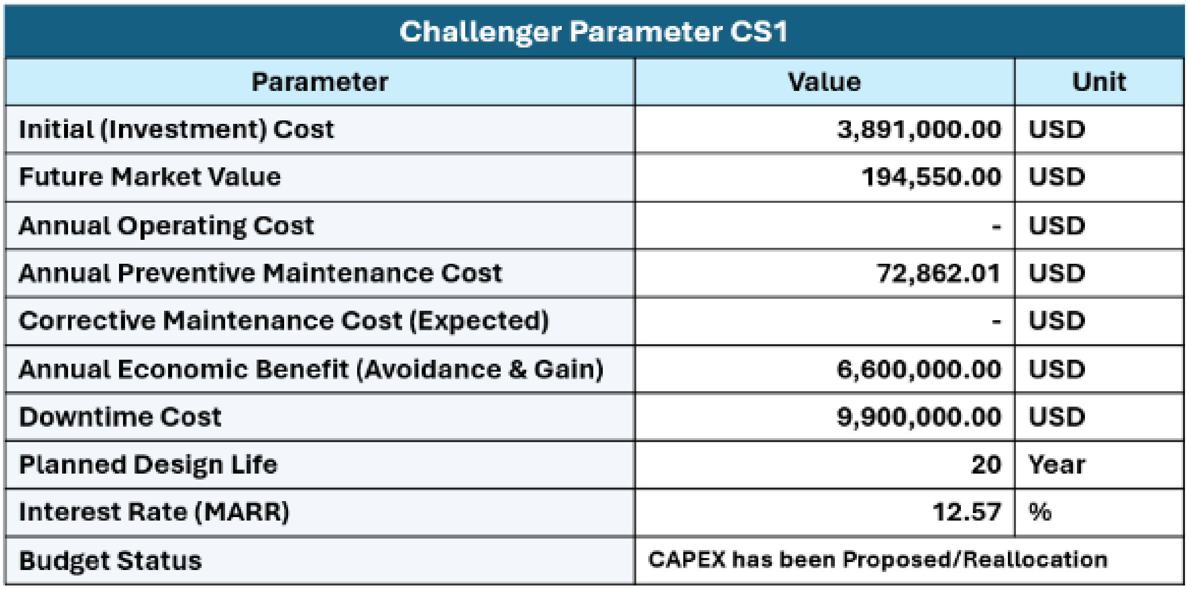
[78] Saputra, A.J. (2026, April 13). W7.0_AJS_Repair or replacement decision: Proposed framework using multi-criteria decision making (Part 3). 14 Clovers. https://14cloversaace.wordpress.com/2026/04/13/w7-0_ajs_repair-or-replacement-decision-proposed-framework-using-multi-criteria-decision-making-part-3/

***Table 13. Defender Parameter of CS1*[79]**



Defender Parameter CS1		
Parameter	**Value**	**Unit**
Repair Cost	941,600.00	USD
Present Market Value	47,080.00	USD
Annual Operating Cost	-	USD
Annual Preventive Maintenance Cost	97,094.80	USD
Corrective Maintenance Cost (Expected)	-	USD
Annual Economic Benefit (Avoidance & Gain)	6,600,000.00	USD
Downtime Cost	9,900,000.00	USD
Design Life	20	Year
Current Service Age of Existing Asset	48	Year
Remaining Useful Life From Inspection	3	Year
Added Useful Life After Repair	5	Year
Useful Life After Repair	5	Year
Interest Rate (MARR)	12.57	%
Budget Status	OPEX has been Proposed/Reallocation	

***Table 14. Challenger Parameter of CS1*[80]**



Challenger Parameter CS1		
Parameter	**Value**	**Unit**
Initial (Investment) Cost	3,891,000.00	USD
Future Market Value	194,550.00	USD
Annual Operating Cost	-	USD
Annual Preventive Maintenance Cost	72,862.01	USD
Corrective Maintenance Cost (Expected)	-	USD
Annual Economic Benefit (Avoidance & Gain)	6,600,000.00	USD
Downtime Cost	9,900,000.00	USD
Planned Design Life	20	Year
Interest Rate (MARR)	12.57	%
Budget Status	CAPEX has been Proposed/Reallocation	

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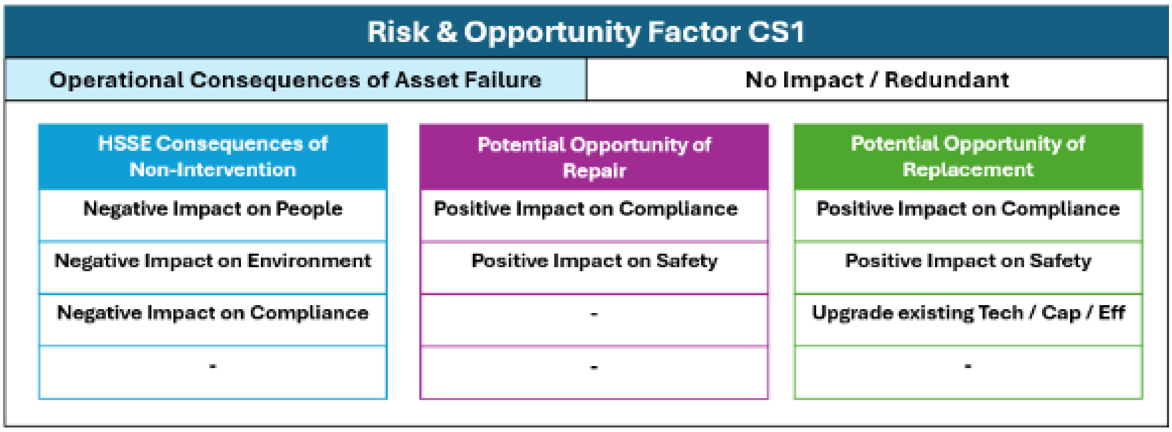
[79] By Author
[80] By Author

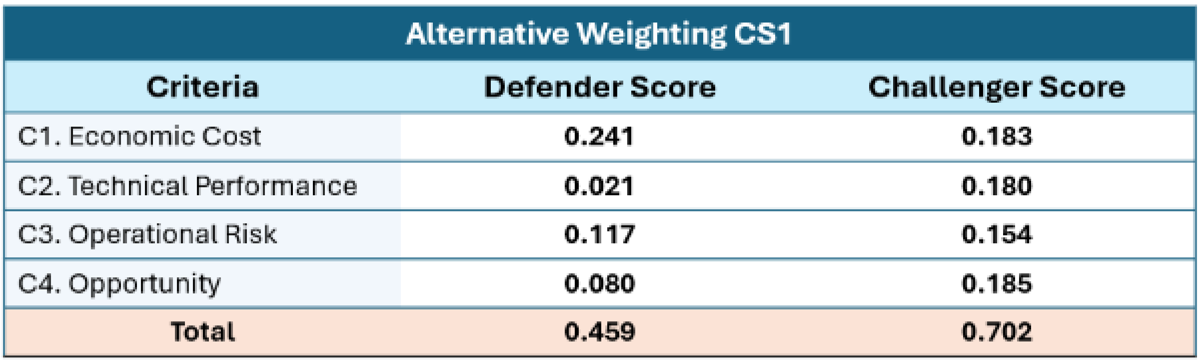
Table 15. Risk & Opportunity Factors of CS1[81]



Risk & Opportunity Factor CS1		
Operational Consequences of Asset Failure	**No Impact / Redundant**	
HSSE Consequences of Non-Intervention	**Potential Opportunity of Repair**	**Potential Opportunity of Replacement**
Negative Impact on People	Positive Impact on Compliance	Positive Impact on Compliance
Negative Impact on Environment	Positive Impact on Safety	Positive Impact on Safety
Negative Impact on Compliance	-	Upgrade existing Tech / Cap / Eff
-	-	-

b) Next, perform an AHP weighting analysis to calculate the alternative weights using Appendix D and the criteria weights in Figure 13. The results are shown in Table 16.

Table 16. Alternative Weighting Analysis of CS1[82]



Criteria	Defender Score	Challenger Score
C1. Economic Cost	**0.241**	**0.183**
C2. Technical Performance	**0.021**	**0.180**
C3. Operational Risk	**0.117**	**0.154**
C4. Opportunity	**0.080**	**0.185**
Total	**0.459**	**0.702**

From the analysis using this method, the analysis concluded that "Replace Asset is more favorable with a confidence level of 70%, compared with "Repair Asset" at 46%.

c) Finally, a decision-rule analysis was conducted based on Table 12. The results are shown in Figure 14.

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[81] By Author
[82] By Author

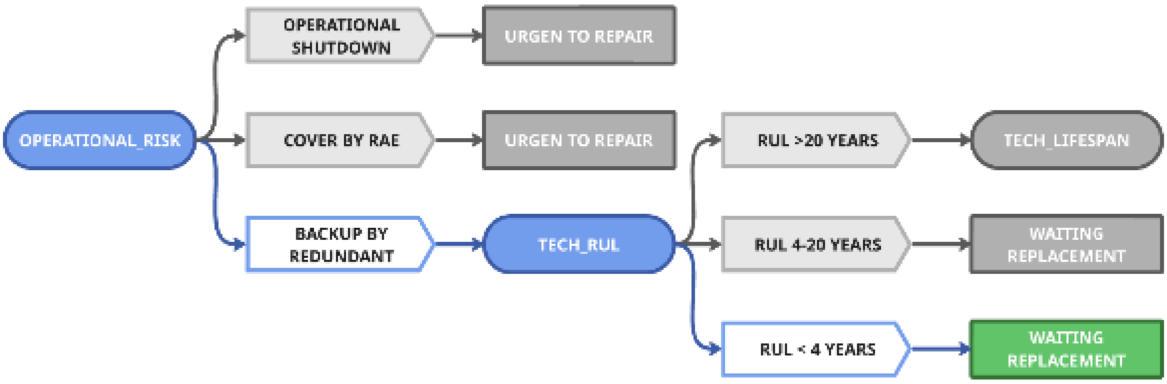

Figure 14. Decision Rules & Pattern CS1[83]

The Decision Rules used for this case are “waiting replacement”, Based on the asset condition, no bridging strategy is needed. In conclusion, the chosen alternative for CS1 is “Replace Asset”.

CS2 – Transfer Pump Applied Case Study

In CS2, a transfer pump for a pipeline in an aging condition and with high operating costs due to diesel fuel use is simulated. Operational conditions indicate that if it fails, the operational plant needs an Emergency Plan. It is necessary to analyze whether continuous repairs are more effective than replacing the pump with an electric motor-driven one.

a) The first step is to collect the criteria parameters from the defender and challenger, as shown in Figures 17, 18, and 19.

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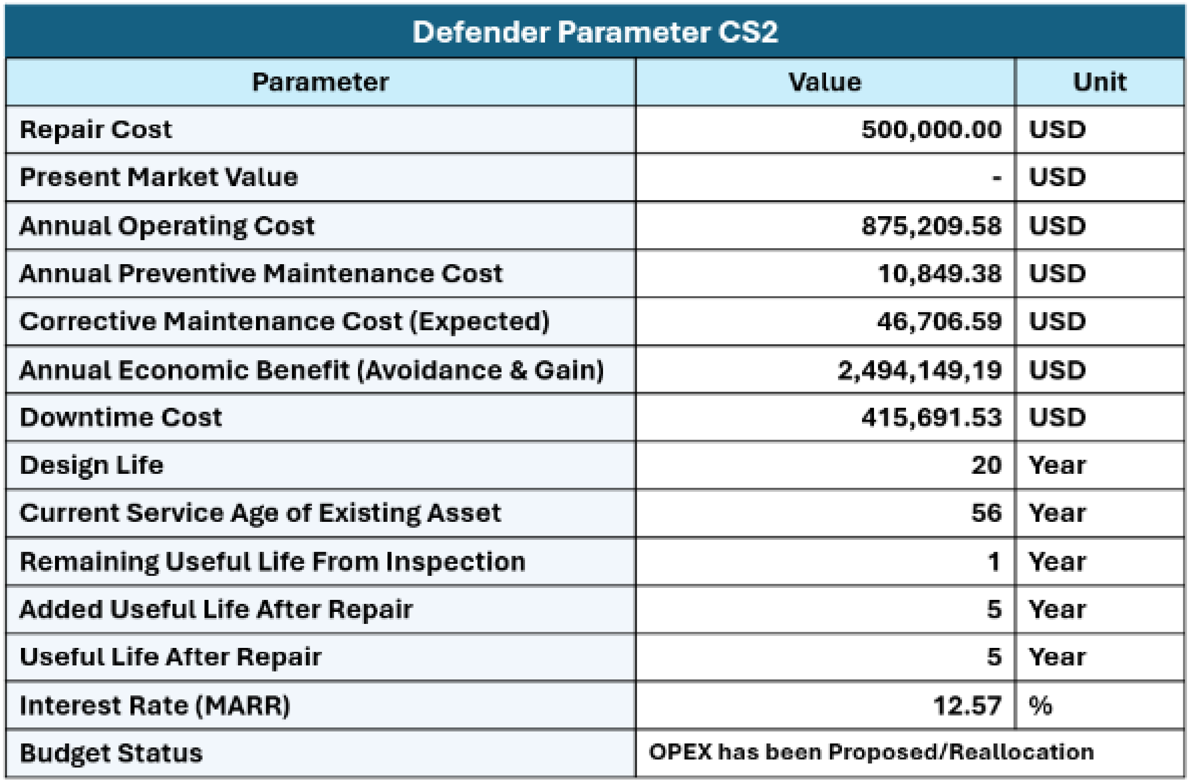
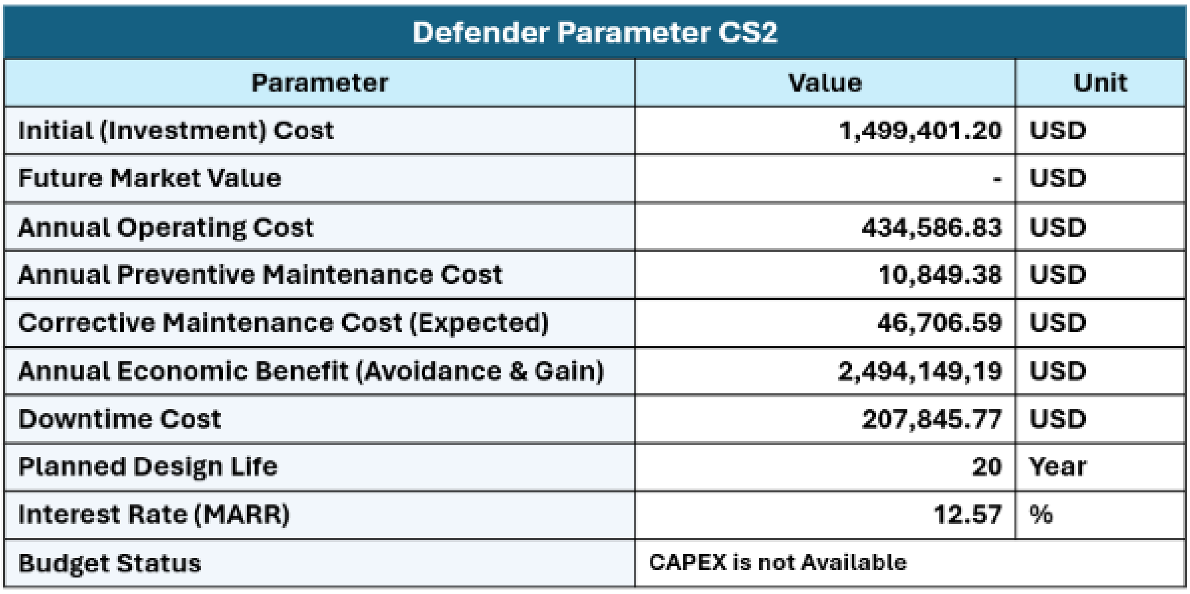
[83] By Author

Table 17. Defender Parameter of CS2[84]



Defender Parameter CS2		
Parameter	**Value**	**Unit**
Repair Cost	500,000.00	USD
Present Market Value	-	USD
Annual Operating Cost	875,209.58	USD
Annual Preventive Maintenance Cost	10,849.38	USD
Corrective Maintenance Cost (Expected)	46,706.59	USD
Annual Economic Benefit (Avoidance & Gain)	2,494,149,19	USD
Downtime Cost	415,691.53	USD
Design Life	20	Year
Current Service Age of Existing Asset	56	Year
Remaining Useful Life From Inspection	1	Year
Added Useful Life After Repair	5	Year
Useful Life After Repair	5	Year
Interest Rate (MARR)	12.57	%
Budget Status	OPEX has been Proposed/Reallocation	

Table 18. Challenger Parameter of CS2[85]



Defender Parameter CS2		
Parameter	**Value**	**Unit**
Initial (Investment) Cost	1,499,401.20	USD
Future Market Value	-	USD
Annual Operating Cost	434,586.83	USD
Annual Preventive Maintenance Cost	10,849.38	USD
Corrective Maintenance Cost (Expected)	46,706.59	USD
Annual Economic Benefit (Avoidance & Gain)	2,494,149,19	USD
Downtime Cost	207,845.77	USD
Planned Design Life	20	Year
Interest Rate (MARR)	12.57	%
Budget Status	CAPEX is not Available	

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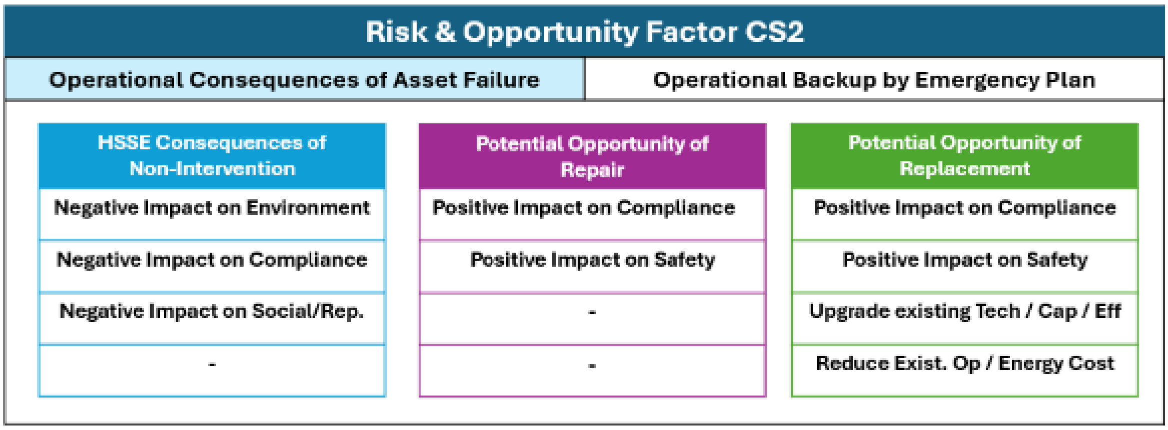
[84] By Author
[85] By Author

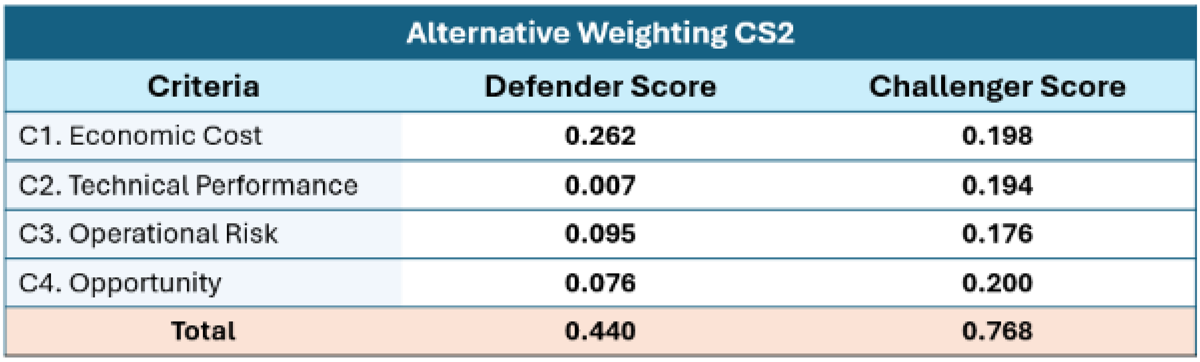
Table 19. Risk & Opportunity Factors of CS2[86]



Risk & Opportunity Factor CS2		
Operational Consequences of Asset Failure	Operational Backup by Emergency Plan	
HSSE Consequences of Non-Intervention	**Potential Opportunity of Repair**	**Potential Opportunity of Replacement**
Negative Impact on Environment	Positive Impact on Compliance	Positive Impact on Compliance
Negative Impact on Compliance	Positive Impact on Safety	Positive Impact on Safety
Negative Impact on Social/Rep.	-	Upgrade existing Tech / Cap / Eff
-	-	Reduce Exist. Op / Energy Cost

b) Next, perform an AHP weighting analysis to calculate the alternative weights using Appendix D and the criteria weights in Figure 13. The results are shown in Table 20.

Table 20. Alternative Weighting Analysis of CS2[87]



Alternative Weighting CS2		
Criteria	**Defender Score**	**Challenger Score**
C1. Economic Cost	0.262	0.198
C2. Technical Performance	0.007	0.194
C3. Operational Risk	0.095	0.176
C4. Opportunity	0.076	0.200
Total	0.440	0.768

From the analysis using this method, the analysis concluded that “Replace Asset is more favorable with a confidence level of 77%, compared with “Repair Asset” at 44%.

c) Finally, a decision-rule analysis was conducted based on Table 12. The results are shown in Figure 15.

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[86] By Author
[87] By Author

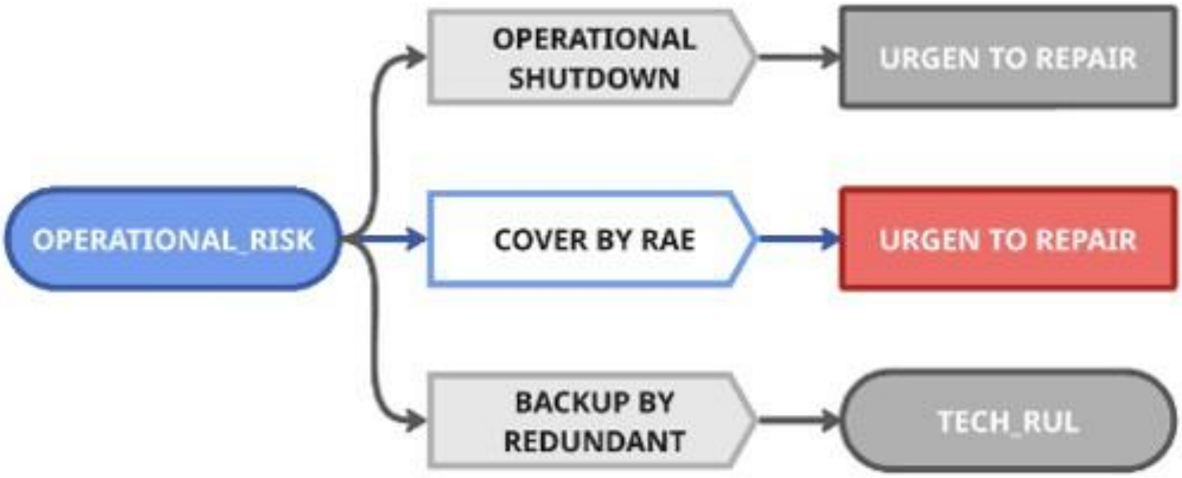

Figure 15. Decision Rules & Pattern CS2[88]

In accordance with the decision rules, this asset requires a transitional strategy in which repair is implemented as an interim solution before planned replacement. The chosen alternative for CS2 is “Replace Asset with Bridging Repair”.

5.4 Sensitivity Analysis

To test the sensitivity of the four value drivers, the Opportunity criterion (C4) is treated as a driver variable. This analysis is to determine whether fluctuations in managerial perceptions of Opportunity affect the results or whether the framework remains stable. The changes will be based on several research references[89,90,91,92]. The results of the sensitivity analysis are shown in Tables 21, 22, and 23:

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[88] By Author

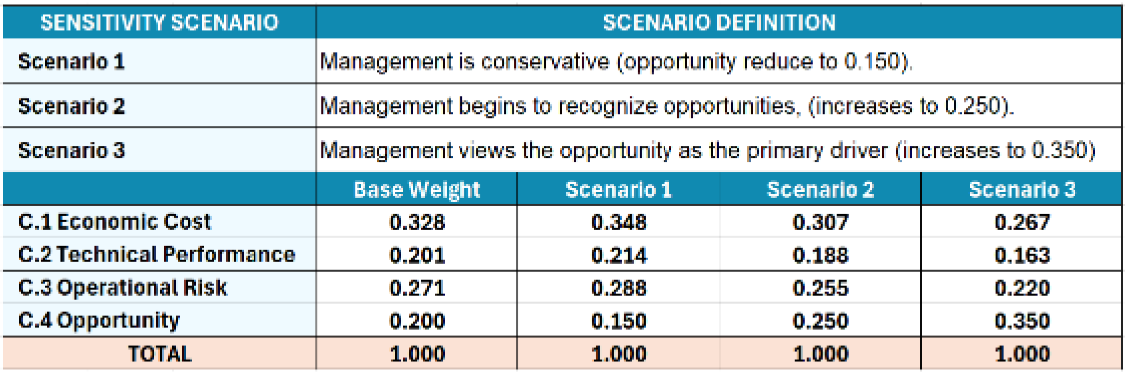
[89] Więckowski, J., & Sałabun, W. (2023). Sensitivity analysis approaches in multi-criteria decision analysis: A systematic review. *Applied Soft Computing*, *148*, 110915.

[90] Özkurt, P. (2026). A Scenario-Robust Intuitionistic Fuzzy AHP–TOPSIS Model for Sustainable Healthcare Waste Treatment Selection: Evidence from Türkiye. *Sustainability*, *18*(3), 1167.

[91] Briscilla S, Jenifer and Rajan, R. Sundar, The Impact of Sensitivity Analysis on Multi-Criteria Decision Making – Implications for Location Selection Performance. Available at SSRN: http://dx.doi.org/10.2139/ssrn.5145859

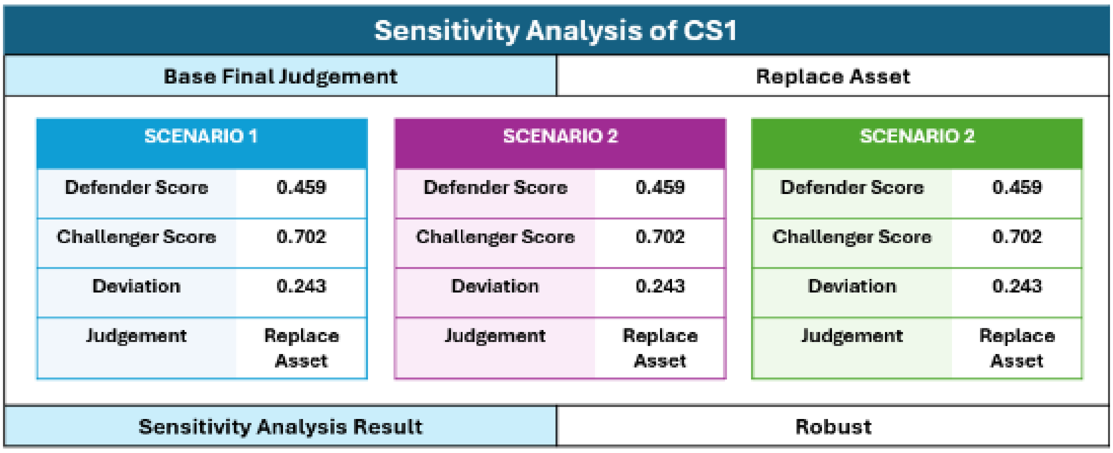
[92] Zhang, H., Shao, Z., Hua, B., Huang, X., Zhao, J., Wu, W., & Fan, Y. (2021). Evaluating the weight sensitivity in AHP-based flood risk estimation models. *arXiv preprint arXiv:2107.133 68*

Table 21. Sensitivity Analysis Scenarios[93]



SENSITIVITY SCENARIO	SCENARIO DEFINITION			
Scenario 1	Management is conservative (opportunity reduce to 0.150).			
Scenario 2	Management begins to recognize opportunities, (increases to 0.250).			
Scenario 3	Management views the opportunity as the primary driver (increases to 0.350)			
	Base Weight	**Scenario 1**	**Scenario 2**	**Scenario 3**
C.1 Economic Cost	**0.328**	**0.348**	**0.307**	**0.267**
C.2 Technical Performance	**0.201**	**0.214**	**0.188**	**0.163**
C.3 Operational Risk	**0.271**	**0.288**	**0.255**	**0.220**
C.4 Opportunity	**0.200**	**0.150**	**0.250**	**0.350**
TOTAL	**1.000**	**1.000**	**1.000**	**1.000**

Table 12. Sensitivity Analysis of CS1[94]



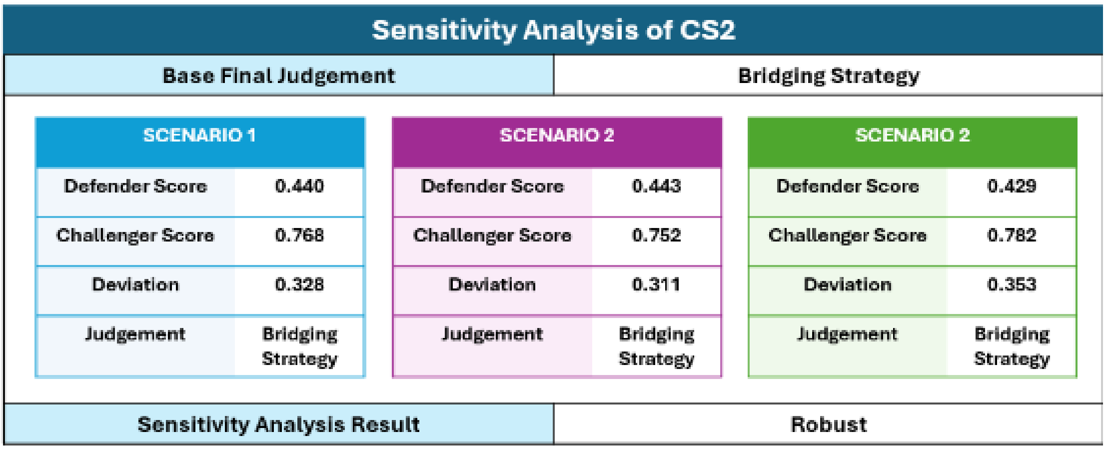
Sensitivity Analysis of CS1

Base Final Judgement	**Replace Asset**

SCENARIO 1		**SCENARIO 2**		**SCENARIO 2**	
Defender Score	**0.459**	**Defender Score**	**0.459**	**Defender Score**	**0.459**
Challenger Score	**0.702**	**Challenger Score**	**0.702**	**Challenger Score**	**0.702**
Deviation	**0.243**	**Deviation**	**0.243**	**Deviation**	**0.243**
Judgement	**Replace Asset**	**Judgement**	**Replace Asset**	**Judgement**	**Replace Asset**

Sensitivity Analysis Result	**Robust**

Table 17. Sensitivity Analysis of CS2[95]



Sensitivity Analysis of CS2

Base Final Judgement	**Bridging Strategy**

SCENARIO 1		**SCENARIO 2**		**SCENARIO 2**	
Defender Score	**0.440**	**Defender Score**	**0.443**	**Defender Score**	**0.429**
Challenger Score	**0.768**	**Challenger Score**	**0.752**	**Challenger Score**	**0.782**
Deviation	**0.328**	**Deviation**	**0.311**	**Deviation**	**0.353**
Judgement	**Bridging Strategy**	**Judgement**	**Bridging Strategy**	**Judgement**	**Bridging Strategy**

Sensitivity Analysis Result	**Robust**

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[93] By Author
[94] By Author
[95] By Author

Across all scenarios, both case studies maintain consistent final judgments; these results confirm that Opportunity remains a critical and actively integrated value driver that enhances decision-making by shaping perspective on future benefits. At the same time, the model ensures that its influence is balanced, preserving rational, data-driven decision outcomes.

Step 6 - Selection of the Preferred Alternative

Using the proposed framework, the applied case studies effectively capture the actual condition of the assets. For CS1 (Storage Tank), the analysis indicates that “Replace Asset” is the preferred option, with a confidence level of 70% compared to 46% for “Repair Asset.” Based on the decision rules, no bridging strategy is required, confirming “Replace Asset” as the selected alternative.

For CS2 (Transfer Pump), the analysis similarly identifies “Replace Asset” as the more favorable option, with a confidence level of 77% versus 44% for “Repair Asset.” However, according to the decision rules, a transitional strategy is necessary, with repair serving as an interim solution before replacement. Accordingly, the selected alternative is “Replace Asset with Bridging Repair.”

Overall, the framework consistently produces rational and context-sensitive decisions, as confirmed by sensitivity analysis, demonstrating alignment between analytical outcomes and operational realities.

Step 7 - Performance Monitoring and Evaluation

The analysis confirms that the proposed framework successfully integrates multi-dimensional value drivers into a single decision structure, demonstrating that defensible, auditable, and logically consistent with organizational priorities for repair–replacement analysis in complex industrial systems. To ensure continued relevance and alignment with evolving management priorities, ongoing monitoring and periodic evaluation are required. These evaluations primarily include:

1. **Periodic reassessment of AHP weights**
   AHP weights are updated based on input from project sponsors and experts to reflect changing strategic priorities.

2. **Updating Decision Tree rules based on actual outcomes**
   Decision Tree logic is refined using actual operational data to capture better real conditions, uncertainty, and execution constraints in the field

3. **Alignment with organizational objectives**
   All updates are carried out in line with current management directions to ensure the framework continues to support practical and relevant decision-making[96].

These evaluation strategies ensure that the model remains robust and relevant over time, as ongoing feedback helps improve its long-term reliability and effectiveness. The model must evolve with organization; otherwise, it becomes accurate, but no longer relevant.

CONCLUSION

This study addresses the lack of a defensible and integrated approach to repair–replacement decision-making in aging oil and gas assets by examining how economic, technical, risk, and opportunity considerations can be unified into a structured decision rule. The findings confirm that such a framework can be developed by integrating AHP–SAW, EE analysis, and a Decision Tree into a framework that establishes a measurable decision boundary. Empirical results from the case studies show that the economic driver (C1) emerges as the dominant factor, followed by C3, C2, and C4 within a relatively narrow weighting range, indicating a balanced multi-criteria structure. The application to CS1 (Storage Tank) and CS2 (Transfer Pump) consistently produces rational and context-sensitive decisions, demonstrating alignment between analytical outcomes and operational realities.

The results further demonstrate that integrating AHP and EE significantly enhances decision transparency and alignment with asset management objectives. The use of structured pairwise weighting combined with quantitative economic evaluation ensures that decisions are defensible, auditable, and logically consistent with organizational priorities. In addition, incorporation of a Decision Tree enhances decision robustness by explicitly capturing uncertainty, system interdependence, and operational constraints. Sensitivity analysis shows that the model remains stable under parameter variations, confirming that the framework is not biased toward a single value driver while still preserving the role of future-oriented considerations.

This study contributes to the literature by introducing a quantitative decision threshold that integrates all value drivers into a single defensible decision tool, thereby bridging the gap between analytical optimization and practical asset management implementation. From a managerial perspective, this enables decision-makers to justify asset strategies with defensible, data-driven evidence, align organizational objectives with capital allocation, and support strategic repair–replacement decisions in capital-intensive industries, where misalignment can have significant consequences. Future research

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[96] Maceika, A., Bugajev, A., Šostak, O. R., & Vilutienė, T. (2021). Decision tree and AHP methods application for projects assessment: a case study. Sustainability, 13(10), 5502.

should incorporate real-time data and predictive analytics to enhance adaptability. Accordingly, integrating multi-dimensional value drivers into a single framework is essential for achieving rational, transparent, and executable asset management decisions in complex industrial systems.

SUPPLEMENTARY

Repair Replacement Decision Form Download Link

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APPENDICIES

APPENDIX A – Pairwise Comparison of Each Expert (1 of 3)

Pairwise Comparison for Criteria of Expert 1

EXPERT 1	(C1) Economic Cost	(C2) Technical Perf	(C3) Operational Risk	(C4) Opportunity
(C1) Economic Cost	1,000	2,000	0,500	3,000
(C2) Technical Perf	0,500	1,000	1,000	5,000
(C3) Operational Risk	2,000	1,000	1,000	5,000
(C4) Opportunity	0,333	0,200	0,200	1,000
Total	3,833	4,200	2,700	14,000

Pairwise Comparison for Sub-Criteria of Expert 1

EXPERT 1	(C1.1) Cost Efficiency	(C1.2) Lifecycle Cost	(C1.3) Budget Feasibility
(C1.1) Cost Efficiency	1,000	0,333	3,000
(C1.2) Lifecycle Cost	3,000	1,000	5,000
(C1.3) Budget Feasibility	0,333	0,200	1,000
Total	4,333	1,533	9,000

EXPERT 1	(C2.1) Aging Severity	(C2.2) Remaining Usefull life
(C2.1) Aging Severity	1,000	0,333
(C2.2) Remaining Usefull	3,000	1,000
Total	4,000	1,333

EXPERT 1	(C3.1) Operational Cons.	(C3.2) HSSE Cons.
(C3.1) Operational Cons.	1,000	0,200
(C3.2) HSSE Cons.	5,000	1,000
Total	6,000	1,200

EXPERT 1	(C4.1) Economic Benefit	(C4.2) Technical Benefit	(C4.3) Op. Benefit
(C4.1) Economic Benefit	1,000	4,000	3,000
(C4.2) Technical Benefit	0,250	1,000	0,500
(C4.3) Op. Benefit	0,333	2,000	1,000
Total	1,583	7,000	4,500

Verification:

Consistency Ratio Expert 1 <10% = Accepted

APPENDIX A – Pairwise Comparison of Each Expert (2 of 3)

Pairwise Comparison for Criteria of Expert 2

EXPERT 2	(C1) Economic Cost	(C2) Technical Perf	(C3) Operational Risk	(C4) Opportunity
(C1) Economic Cost	1,000	3,000	3,000	3,000
(C2) Technical Perf	0,333	1,000	1,000	3,000
(C3) Operational Risk	0,333	1,000	1,000	3,000
(C4) Opportunity	0,333	0,333	0,333	1,000
Total	2,000	5,333	5,333	10,000

Pairwise Comparison for Sub-Criteria of Expert 2

EXPERT 2	(C1.1) Cost Efficiency	(C1.2) Lifecycle Cost	(C1.3) Budget Feasibility
(C1.1) Cost Efficiency	1,000	0,111	0,125
(C1.2) Lifecycle Cost	9,000	1,000	0,500
(C1.3) Budget Feasibility	8,000	2,000	1,000
Total	18,000	3,111	1,625

EXPERT 2	(C2.1) Aging Severity	(C2.2) Remaining Usefull life
(C2.1) Aging Severity	1,000	1,000
(C2.2) Rem. Usefull Life	1,000	1,000
Total	2,000	2,000

EXPERT 2	(C3.1) Operational Cons.	(C3.2) HSSE Cons.
(C3.1) Operational Cons.	1,000	0,333
(C3.2) HSSE Cons.	3,000	1,000
Total	4,000	1,333

EXPERT 2	(C4.1) Economic Benefit	(C4.2) Technical Benefit	(C4.3) Op. Benefit
(C4.1) Economic Benefit	1,000	7,000	3,000
(C4.2) Technical Benefit	0,143	1,000	0,500
(C4.3) Op. Benefit	0,333	2,000	1,000
Total	1,476	10,000	4,500

Verification:

Consistency Ratio Expert 2 <10% = Accepted

APPENDIX A – Pairwise Comparison of Each Expert (3 of 3)

Pairwise Comparison for Criteria of Expert 3

EXPERT 3	(C1) Economic Cost	(C2) Technical Perf	(C3) Operational Risk	(C4) Opportunity
(C1) Economic Cost	1.000	2.000	1.000	0.200
(C2) Technical Perf	0.500	1.000	0.500	0.143
(C3) Operational Risk	1.000	2.000	1.000	0.200
(C4) Opportunity	5.000	7.000	5.000	1.000
Total	7.500	12.000	7.500	1.543

Pairwise Comparison for Sub-Criteria of Expert 3

EXPERT 3	(C1.1) Cost Efficiency	(C1.2) Lifecycle Cost	(C1.3) Budget Feasibility
(C1.1) Cost Efficiency	1.000	0.500	0.250
(C1.2) Lifecycle Cost	2.000	1.000	0.333
(C1.3) Budget Feasibility	4.000	3.000	1.000
Total	7.000	4.500	1.583

EXPERT 3	(C2.1) Aging Severity	(C2.2) Remaining Usefull life
(C2.1) Aging Severity	1.000	0.200
(C2.2) Rem. Usefull Life	5.000	1.000
Total	6.000	1.200

EXPERT 3	(C3.1) Operational Cons.	(C3.2) HSSE Cons.
(C3.1) Operational Cons.	1.000	0.500
(C3.2) HSSE Cons.	2.000	1.000
Total	3.000	1.500

EXPERT 3	(C4.1) Economic Benefit	(C4.2) Technical Benefit	(C4.3) Op. Benefit
(C4.1) Economic Benefit	1.000	0.250	0.333
(C4.2) Technical Benefit	4.000	1.000	2.000
(C4.3) Op. Benefit	3.000	0.500	1.000
Total	8.000	1.750	3.333

Verification:

Consistency Ratio Expert 3 <10% = Accepted

APPENDIX B – Scenario Card

No of Scenario	Condition 1 (Asset Status)	Condition 2 (Aging Status)	Condition 3 (impact of Asset Failure)	Answer*
1	RUL < 4 years	Service Life > Design Life	Operational Shutdown (Full/Separatelly)	
2	RUL < 4 years	Service Life > Design Life	Cover by RAE Plan	
3	RUL < 4 years	Service Life > Design Life	Backup by Redundant	
4	RUL < 4 years	Service Life < Design Life	Operational Shutdown (Full/Separatelly)	
5	RUL < 4 years	Service Life < Design Life	Cover by RAE Plan	
6	RUL < 4 years	Service Life < Design Life	Backup by Redundant	
7	RUL 4-20 years	Service Life > Design Life	Operational Shutdown (Full/Separatelly)	
8	RUL 4-20 years	Service Life > Design Life	Cover by RAE Plan	
9	RUL 4-20 years	Service Life > Design Life	Backup by Redundant	
10	RUL 4-20 years	Service Life < Design Life	Operational Shutdown (Full/Separatelly)	
11	RUL 4-20 years	Service Life < Design Life	Cover by RAE Plan	
12	RUL 4-20 years	Service Life < Design Life	Backup by Redundant	
13	RUL > 20 years	Service Life > Design Life	Operational Shutdown (Full/Separatelly)	
14	RUL > 20 years	Service Life > Design Life	Cover by RAE Plan	
15	RUL > 20 years	Service Life > Design Life	Backup by Redundant	
16	RUL > 20 years	Service Life < Design Life	Operational Shutdown (Full/Separatelly)	
17	RUL > 20 years	Service Life < Design Life	Cover by RAE Plan	
18	RUL > 20 years	Service Life < Design Life	Backup by Redundant	
Code *	Answer with "Urgent to Repair" or "Waiting Replacement"			

Respondent:

1. Asset Manager at Oil & Gas Company
2. Operation Manager at Oil & Gas Company

Total Respondent:

55 respondents

Total Data Sample:

990 Samples

APPENDIX C – Result of Preprocessing Data (Sample)

No	Tech_RUL	Tech_Lifespan	Operational_Risk	Judgement
1	RUL < 4 years	Service Life > Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair
2	RUL < 4 years	Service Life > Design Life	Cover by RAE Plan	Urgent to Repair
3	RUL < 4 years	Service Life > Design Life	Backup by Redundant	Urgent to Repair
4	RUL < 4 years	Service Life < Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair
5	RUL < 4 years	Service Life < Design Life	Cover by RAE Plan	Urgent to Repair
6	RUL < 4 years	Service Life < Design Life	Backup by Redundant	Urgent to Repair
7	RUL 4-20 years	Service Life > Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair
8	RUL 4-20 years	Service Life > Design Life	Cover by RAE Plan	Urgent to Repair
9	RUL 4-20 years	Service Life > Design Life	Backup by Redundant	Urgent to Repair
10	RUL 4-20 years	Service Life < Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair
11	RUL 4-20 years	Service Life < Design Life	Cover by RAE Plan	Urgent to Repair
12	RUL 4-20 years	Service Life < Design Life	Backup by Redundant	Urgent to Repair
13	RUL > 20 years	Service Life > Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair
14	RUL > 20 years	Service Life > Design Life	Cover by RAE Plan	Urgent to Repair
15	RUL > 20 years	Service Life > Design Life	Backup by Redundant	Urgent to Repair
16	RUL > 20 years	Service Life < Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair
17	RUL > 20 years	Service Life < Design Life	Cover by RAE Plan	Urgent to Repair
18	RUL > 20 years	Service Life < Design Life	Backup by Redundant	Urgent to Repair
19	RUL < 4 years	Service Life > Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair
20	RUL < 4 years	Service Life > Design Life	Cover by RAE Plan	Urgent to Repair
21	RUL < 4 years	Service Life > Design Life	Backup by Redundant	Waiting Replacement
22	RUL < 4 years	Service Life < Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair
23	RUL < 4 years	Service Life < Design Life	Cover by RAE Plan	Urgent to Repair
24	RUL < 4 years	Service Life < Design Life	Backup by Redundant	Waiting Replacement
25	RUL 4-20 years	Service Life > Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair
26	RUL 4-20 years	Service Life > Design Life	Cover by RAE Plan	Urgent to Repair
27	RUL 4-20 years	Service Life > Design Life	Backup by Redundant	Waiting Replacement
28	RUL 4-20 years	Service Life < Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair
29	RUL 4-20 years	Service Life < Design Life	Cover by RAE Plan	Urgent to Repair
30	RUL 4-20 years	Service Life < Design Life	Backup by Redundant	Waiting Replacement
31	RUL > 20 years	Service Life > Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair
32	RUL > 20 years	Service Life > Design Life	Cover by RAE Plan	Urgent to Repair
33	RUL > 20 years	Service Life > Design Life	Backup by Redundant	Waiting Replacement
34	RUL > 20 years	Service Life < Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair
35	RUL > 20 years	Service Life < Design Life	Cover by RAE Plan	Urgent to Repair
36	RUL > 20 years	Service Life < Design Life	Backup by Redundant	Waiting Replacement
37	RUL < 4 years	Service Life > Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair
38	RUL < 4 years	Service Life > Design Life	Cover by RAE Plan	Urgent to Repair
39	RUL < 4 years	Service Life > Design Life	Backup by Redundant	Urgent to Repair
40	RUL < 4 years	Service Life < Design Life	Operational Shutdown (Full/Separatelly)	Urgent to Repair

Notes:

Due to space limitations, the detailed Appendix C has been summarized in this paper. Anyone requiring access to the complete dataset may contact the author directly.

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APPENDIX D – Performance of Alternative for Each Sub-criterion (1 of 3)

DECISION	C1.1 COST EFFICIENCY		
	QUOTATION OF VALUE	PERFORMANCE LABEL	PERFORMANCE (0-1)
REPAIR (as Defender)	$Eff_D = \frac{Cost_D}{n}$ Details: Eff_D = $Efficiency\ Cost\ Value\ of\ Defender$ $Cost_D$ = $Repair\ cost\ of\ Defender$ n = $Usefull\ Life\ of\ Defender\ (After\ Repair)$	$D = \frac{Min(Eff_D, Eff_C)}{Eff_D}$ Details: D = $Defender\ Performance\ Score$ $Min\ (x, y)$ = $Minimum\ Value\ of\ "x"\ or\ "y"$ Eff_D = $Efficiency\ Cost\ Value\ of\ Defender$ Eff_C = $Efficiency\ Cost\ Value\ of\ Challenger$	**0 ≤ Score ≤1**
REPLACEMENT (as Challenger)	$Eff_C = \frac{Cost_C}{n}$ Details: Eff_C = $Efficiency\ Cost\ Value\ of\ Challenger$ $Cost_C$ = $Initial\ cost\ (challenger)$ n = $Usefull\ life\ of\ Challenger$	$C = \frac{Min(Eff_D, Eff_C)}{Eff_C}$ Details: C = $Challenger\ Performance\ Score$ $Min\ (x, y)$ = $Minimum\ Value\ of\ "x"\ or\ "y"$ Eff_D = $Efficiency\ Cost\ Value\ of\ Defender$ Eff_C = $Efficiency\ Cost\ Value\ of\ Challenger$	**0 ≤ Score ≤1**

DECISION	C1.2 LIFE CYCLE COST		
	QUOTATION OF VALUE	PERFORMANCE LABEL	PERFORMANCE (0-1)
REPAIR (as Defender)	$EUAC_D = (Cost_D + MV_D).\left(\frac{A}{P}, i, n\right) + Cost_{Op} + Cost_{PM}$ Details: $Cost_D$ = $Repair\ Cost\ of\ Defender$ MV_D = $Present\ Market\ Value\ of\ Asset$ A/P = $Annual\ Value\ per\ Present\ Value$ i = $Interest\ rate\ (MARR)$ n = $Usefull\ life\ of\ defender\ (After\ Repair)$ $Cost_{Op}$ = $Operational\ Cost\ (yearly)$ $Cost_{PM}$ = $Preventive\ Maint\ Cost\ (yearly)$	$D = \frac{Min(EUAC_D, EUAC_C)}{EUAC_D}$ Details: D = $Defender\ Performance\ Score$ $Min\ (x, y)$ = $Minimum\ Value\ of\ "x"\ or\ "y"$ $EUAC_D$ = $EUAC\ value\ of\ Defender$ $EUAC_C$ = $EUAC\ value\ of\ Challenger$	**0 ≤ Score ≤1**
REPLACEMENT (as Challenger)	$EUAC_C = Cost_C.\left(\frac{A}{P}, i, n\right) - MV_C.\left(\frac{A}{F}, i, n\right) + Cost_{Op} + Cost_{PM}$ Details: $Cost_C$ = $Initial\ Cost\ (Challenger)$ MV_C = $Future\ Market\ Value\ of\ Asset$ A/P = $Annual\ Value\ per\ Present\ Value$ A/F = $Annual\ Value\ per\ Future\ Value$ i = $Interest\ rate\ (MARR)$ n = $Usefull\ life\ of\ Challenger$ $Cost_{Op}$ = $Operational\ Cost\ (yearly)$ $Cost_{PM}$ = $Preventive\ Maint\ Cost\ (yearly)$	$C = \frac{Min(EUAC_D, EUAC_C)}{EUAC_C}$ Details: C = $Challenger\ Performance\ Score$ $Min\ (x, y)$ = $Minimum\ Value\ of\ "x"\ or\ "y"$ $EUAC_D$ = $EUAC\ value\ of\ Defender$ $EUAC_C$ = $EUAC\ value\ of\ Challenger$	**0 ≤ Score ≤1**

DECISION	C1.3 BUDGET FEASIBILITY		
	QUOTATION OF VALUE	PERFORMANCE LABEL	PERFORMANCE (0-1)
REPAIR (as Defender)	Budget Availability and Project Planned Status	OPEX is available, and the project has been planned	**1**
		OPEX is available, and the project has not been planned	**0.667**
		OPEX has been proposed or required reallocation	**0.334**
		OPEX is not available	**0**
REPLACEMENT (as Challenger)	Budget Availability and Project Planned Status	CAPEX is available, and the project has been planned	**1**
		CAPEX is available, and the project has not been planned	**0.667**
		CAPEX has been proposed or required reallocation	**0.334**
		CAPEX is not available	**0**

APPENDIX D – Performance of Alternative for Each Sub-criterion (2 of 3)

DECISION	C2.1 AGING SEVERITY		
	QUOTATION OF VALUE	PERFORMANCE LABEL	PERFORMANCE (0-1)
REPAIR **(as Defender)**	$Severity = \frac{Service\ Age}{n}$ Details: $Service\ Age = Current\ service\ age\ of\ Asset\ since\ Comm.$ $n = Planned\ Design\ Life\ of\ Asset$	$D = 1 - Severity \quad , minimum\ 0$	**0 ≤ Score ≤1**
REPLACEMENT **(as Challenger)**		***Challenger Severity is Zero***	**1**

DECISION	C2.2 REMAINING USEFULL LIFE		
	QUOTATION OF VALUE	PERFORMANCE LABEL	PERFORMANCE (0-1)
REPAIR **(as Defender)**	Remaining Usefull Life of Asset from Inspection/Last Inspection	$D = \frac{RUL}{n} \quad , maximum\ 1$ Details: $D = Defender\ Score$ $RUL = Remaining\ usefull\ Life$ $n = Planned\ Design\ Life\ of\ Asset$	**0 ≤ Score ≤1**
REPLACEMENT **(as Challenger)**		$C = 1 - D \quad , mininum\ 0$ Details: $C = Challenger\ Score$ $D = Defender\ Score$ $n = Planned\ Design\ Life\ of\ Asset$	**0 ≤ Score ≤1**

DECISION	C3.1 OPERATIONAL CONSEQUENCES		
	QUOTATION OF VALUE	PERFORMANCE LABEL	PERFORMANCE (0-1)
REPAIR **(as Defender)**	Impact of asset failure to operational	No Impact / Redundant	**1**
		Operational Backup by Emergency Plan	**0.667**
		Operational Partially Shutdown	**0.334**
		Operational Fully Shutdown	**0**
REPLACEMENT **(as Challenger)**	Impact of asset failure to operational	Operational Fully Shutdown	**1**
		Operational Partially Shutdown	**0.667**
		Operational Backup by Emergency Plan	**0.334**
		No Impact / Redundant	**0**

DECISION	C3.2 HSSE CONSEQUENCES		
	QUOTATION OF VALUE	PERFORMANCE LABEL	PERFORMANCE (0-1)
REPAIR **(as Defender)**	HSSE Consequences of Non-Intervention: a. Negative impact on People b. Negative impact on the Environment c. Negative impact on Compliance d. Negative impact on Social/Reputation	Meets 0 out of 4 impact criteria	**1**
		Meets 1 out of 4 impact criteria	**0.750**
		Meets 2 out of 4 impact criteria	**0.500**
		Meets 3 out of 4 impact criteria	**0.250**
		Meets 4 out of 4 impact criteria	**0**
REPLACEMENT **(as Challenger)**	HSSE Consequences of Non-Intervention: a. Negative impact on People b. Negative impact on the Environment c. Negative impact on Compliance d. Negative impact on Social/Reputation	Meets 4 out of 4 impact criteria	**1**
		Meets 3 out of 4 impact criteria	**0.750**
		Meets 2 out of 4 impact criteria	**0.500**
		Meets 1 out of 4 impact criteria	**0.250**
		Meets 0 out of 4 impact criteria	**0**

APPENDIX D – Performance of Alternative for Each Sub-criterion (3 of 3)

DECISION	C4.1 ECONOMIC BENEFIT		
	QUOTATION OF VALUE	PERFORMANCE LABEL	PERFORMANCE (0-1)
REPAIR (as Defender)	$D_{NPV} = C_{in} - C_{out}$ $C_{in} = B_D.\left(\frac{P}{A}, i, n\right)$ $C_{out} = MV_D + Cost_D + Cost_{DT} + Cost_{OPMD}.\left(\frac{P}{A}, i, n\right)$ Details: D_{NPV} = Net Present Value of Defender $Cost_D$ = Repair Cost of Defender $Cost_{DT}$ = Downtime Cost B_D = Net Economic yearly benefit of Defender (avoidance + gain) $Cost_{OPM}$ = Operational and Preventive Maintenance Cost (yearly) MV_D = Present Market Value of Asset i = Interest rate (MARR) n = Usefull life of Defender (After repair)	$D = \frac{D_{NPV}}{max(C_{NPV}, D_{NPV})}$, if negative = 0 Details: D = Defender Score D_{NPV} = Net Present Value of Defender C_{NPV} = Net Present Value of Challenger	**0 ≤ Score ≤1**
REPLACEMENT (as Challenger)	$C_{NPV} = C_{in} - C_{out}$ $C_{in} = B_C.\left(\frac{P}{A}, i, n\right) + MV_C.\left(\frac{P}{F}, i, n\right)$ $C_{out} = Cost_C + Cost_{DT} + Cost_{OPM}.\left(\frac{P}{F}, i, n\right)$ Details: C_{NPV} = Net Present Value of Challenger $Cost_C$ = Initial Cost of challenger $Cost_{DT}$ = Downtime Cost B_C = Net Economic yearly benefit of Challenger (avoidance + gain) $Cost_{OPM}$ = Operational and Preventive Maintenance Cost (yearly) MV_C = Future Market Value of Asset i = Interest rate (MARR) n = Usefull life of Challenger	$C = \frac{C_{NPV}}{max(C_{NPV}, D_{NPV})}$, if negative = 0 Details: C = Challenger Score D_{NPV} = Net Present Value of Defender C_{NPV} = Net Present Value of Challenger	**0 ≤ Score ≤1**

DECISION	C4.2 TECHNICAL BENEFIT		
	QUOTATION OF VALUE	PERFORMANCE LABEL	PERFORMANCE (0-1)
REPAIR (as Defender)	D_n = Usefull life of Defender (After Repair)	$D = \frac{D_n}{max(D_n, C_n)}$ Details: D = Defender Score D_n = Usefull life of Defender (After Repair) C_n = Usefull life of Challenger	**0 ≤ Score ≤1**
REPLACEMENT (as Challenger)	C_n = Usefull life of Challenger	$C = \frac{C_n}{max(D_n, C_n)}$ Details: C = Challenger Score D_n = Usefull life of Defender (After Repair) C_n = Usefull life of Challenger	**0 ≤ Score ≤1**

DECISION	C4.3 OPERATIONAL BENEFIT		
	QUOTATION OF VALUE	PERFORMANCE LABEL	PERFORMANCE (0-1)
REPAIR (as Defender)	The Repair Decision benefit: a. Positive impact on compliance b. Positive impact on Safety c. Upgrade Tech//Capacity/Efficiency d. reduce operating/energy costs	Meets 4 out of 4 benefit criteria	**1**
		Meets 3 out of 4 benefit criteria	**0.750**
		Meets 2 out of 4 benefit criteria	**0.500**
		Meets 1 out of 4 benefit criteria	**0.250**
		Meets 0 out of 4 benefit criteria	**0**
REPLACEMENT (as Challenger)	The Replacement Decision benefit: a. Positive impact on compliance b. Positive impact on Safety c. Upgrade Tech//Capacity/Efficiency d. reduce operating/energy costs	Meets 4 out of 4 benefit criteria	**1**
		Meets 3 out of 4 benefit criteria	**0.750**
		Meets 2 out of 4 benefit criteria	**0.500**
		Meets 1 out of 4 benefit criteria	**0.250**
		Meets 0 out of 4 benefit criteria	**0**

APPENDIX E – Decision Form (1 of 4)

CS1	**REPAIR-REPLACEMEMENT DECISION FORM**	Revision	0
		Date	
		Evaluator	

ASSET PROFILE

Type of Asset	:	Storage Tank	
Serial / Tag Number	:	F215/XXX/XXX	
Location	:	IT/FT/IT Terminal	

DEFENDER PARAMETERS

Repair Cost	:	941,600.00	USD
Present Market Value	:	47,080.00	USD
Annual Operating Cost	:	-	USD
Annual Preventive Maintenance Cost	:	97,094.80	USD
Annual Expected Corrective Maintenance Cost	:	-	USD
Annual Economic Benefit (Avoidance and Gain)	:	6,600,000.00	USD
Downtime Cost	:	9,900,000.00	USD
Planned Design Life of Existing Asset	:	20.00	Year
Current Service Age of Existing Asset	:	48.00	Year
Remaining Service Age of Existing Asset	:	-	Year
Remaining Useful Life From Inspection	:	3.00	Year
Added Usefull Life After Repair	:	5.00	year
Usefull Life After Repair	:	5.00	Year
Interest Rate (MARR)	:	12.57%	
Budget Status	:	OPEX has been proposed or required reallocation	

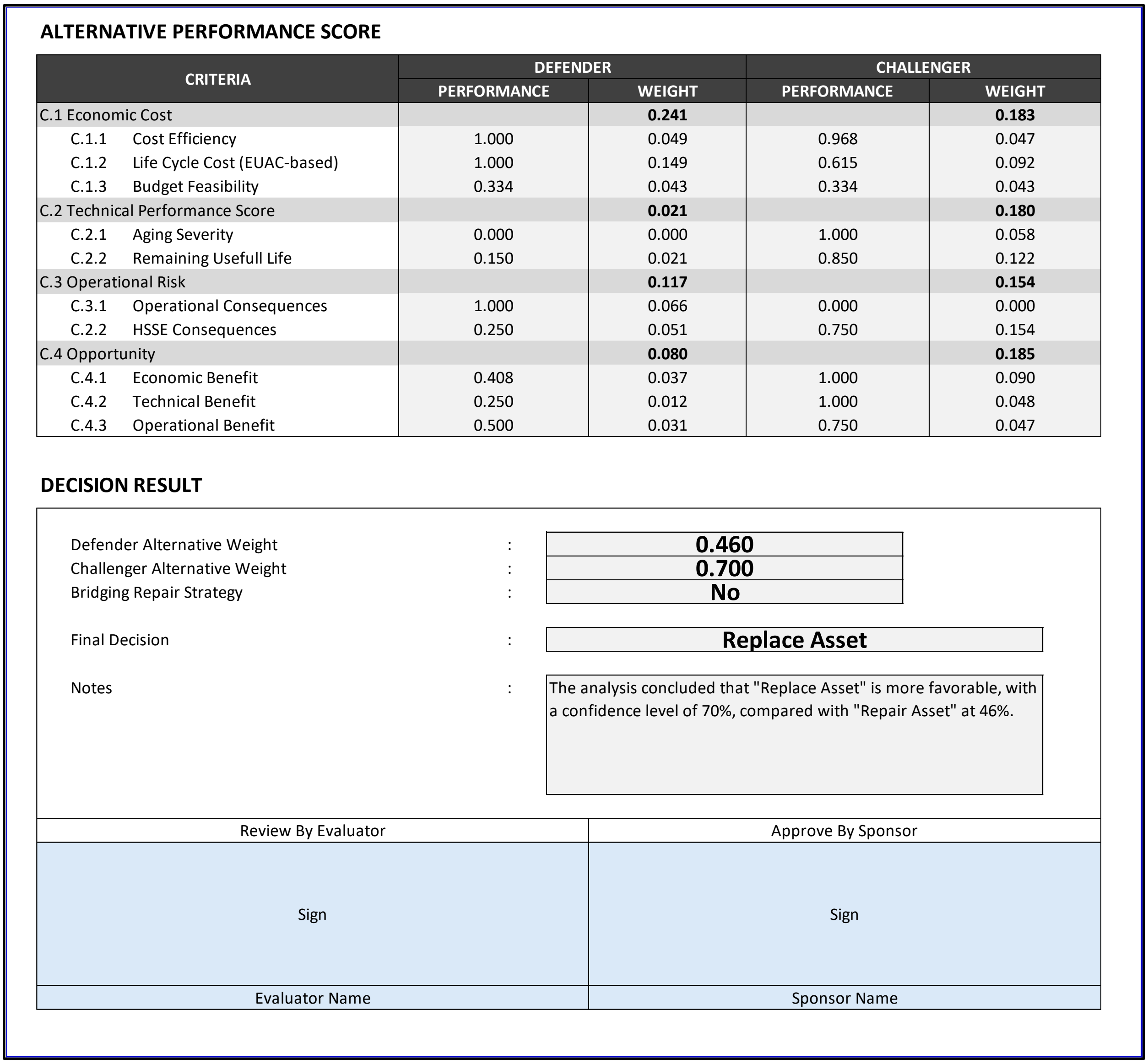
CHALLENGER PARAMETERS

Initial (Investment) Cost	:	3,891,000.00	USD
Future Market Value (Salvage)	:	194,550.00	USD
Annual Operating Cost	:	-	USD
Annual Preventive Maintenance Cost	:	72,862.01	USD
Annual Expected Corrective Maintenance Cost	:	-	USD
Annual Economic Benefit (Avoidance and Gain)	:	6,600,000.00	USD
Downtime Cost	:	13,200,000.00	USD
Planned Design Life of Challenger	:	20.00	Year
Interest Rate (MARR)	:	12.57%	
Budget Status	:	CAPEX has been proposed or required reallocation	

RISK AND OPPORTUNITY FACTORS

Operational Consequences of Asset Failure	:	No Impact / Redundant
HSSE Consequences of Non-Intervention		
a. Negative Impact on People	:	Yes
b. Negative Impact on the Environment	:	Yes
c. Negative Impact on Compliance	:	Yes
d. Negative Impact on Social/Reputation	:	No
Potential Opportunity of Repair		
a. Positive Impact on Compliance	:	Yes
b. Positive Impact on Safety	:	Yes
c. Upgrade Existing Tech / Capacity / Eff	:	No
d. Reduce Existing Operating / Energy Cost	:	No
Potential Opportunity of Replacement		
a. Positive Impact on Compliance	:	Yes
b. Positive Impact on Safety	:	Yes
c. Upgrade Existing Tech / Capacity / Eff	:	Yes
d. Reduce Existing Operating / Energy Cost	:	No

APPENDIX E – Decision Form (2 of 4)



ALTERNATIVE PERFORMANCE SCORE

CRITERIA	DEFENDER		CHALLENGER	
	PERFORMANCE	WEIGHT	PERFORMANCE	WEIGHT
C.1 Economic Cost		**0.241**		**0.183**
C.1.1 Cost Efficiency	1.000	0.049	0.968	0.047
C.1.2 Life Cycle Cost (EUAC-based)	1.000	0.149	0.615	0.092
C.1.3 Budget Feasibility	0.334	0.043	0.334	0.043
C.2 Technical Performance Score		**0.021**		**0.180**
C.2.1 Aging Severity	0.000	0.000	1.000	0.058
C.2.2 Remaining Usefull Life	0.150	0.021	0.850	0.122
C.3 Operational Risk		**0.117**		**0.154**
C.3.1 Operational Consequences	1.000	0.066	0.000	0.000
C.2.2 HSSE Consequences	0.250	0.051	0.750	0.154
C.4 Opportunity		**0.080**		**0.185**
C.4.1 Economic Benefit	0.408	0.037	1.000	0.090
C.4.2 Technical Benefit	0.250	0.012	1.000	0.048
C.4.3 Operational Benefit	0.500	0.031	0.750	0.047

DECISION RESULT

Defender Alternative Weight	:	**0.460**
Challenger Alternative Weight	:	**0.700**
Bridging Repair Strategy	:	**No**
Final Decision	:	**Replace Asset**
Notes	:	The analysis concluded that "Replace Asset" is more favorable, with a confidence level of 70%, compared with "Repair Asset" at 46%.

Review By Evaluator	Approve By Sponsor
Sign	Sign
Evaluator Name	Sponsor Name

APPENDIX E – Decision Form (3 of 4)

CS2	**REPAIR-REPLACEMEMENT** **DECISION FORM**	Revision	0
		Date	
		Evaluator	

ASSET PROFILE

Type of Asset	:	Transfer Pump	
Serial / Tag Number	:	F215/XXX/XXX	
Location	:	IT/FT/IT Terminal	

DEFENDER PARAMETERS

Repair Cost	:	500,000.00	USD
Present Market Value	:	-	USD
Annual Operating Cost	:	875,209.58	USD
Annual Preventive Maintenance Cost	:	10,849.38	USD
Annual Expected Corrective Maintenance Cost	:	46,706.59	USD
Annual Economic Benefit (Avoidance and Gain)	:	2,494,149.19	USD
Downtime Cost	:	415,691.53	USD
Planned Design Life of Existing Asset	:	20.00	Year
Current Service Age of Existing Asset	:	56.00	Year
Remaining Service Age of Existing Asset	:	-	Year
Remaining Useful Life From Inspection	:	1.00	Year
Added Usefull Life After Repair	:	5.00	year
Usefull Life After Repair	:	5.00	Year
Interest Rate (MARR)	:	12.57%	
Budget Status	:	OPEX is available, and the project has been planned	

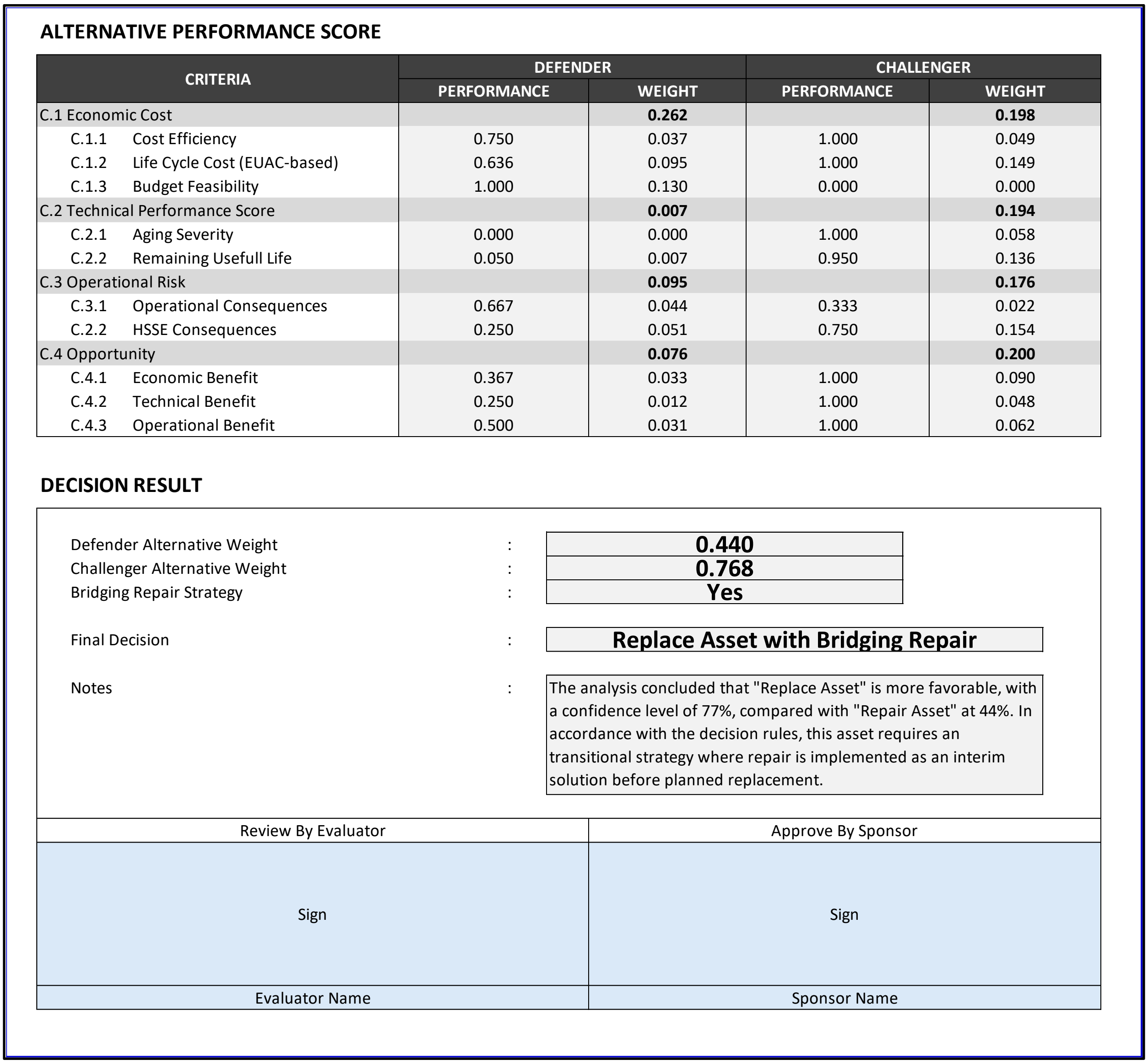
CHALLENGER PARAMETERS

Initial (Investment) Cost	:	1,499,401.20	USD
Future Market Value (Salvage)	:	-	USD
Annual Operating Cost	:	434,586.83	USD
Annual Preventive Maintenance Cost	:	10,849.38	USD
Annual Expected Corrective Maintenance Cost	:	46,706.59	USD
Annual Economic Benefit (Avoidance and Gain)	:	2,494,149.19	USD
Downtime Cost	:	207,845.77	USD
Planned Design Life of Challenger	:	20.00	Year
Interest Rate (MARR)	:	12.57%	
Budget Status	:	CAPEX is not available	

RISK AND OPPORTUNITY FACTORS

Operational Consequences of Asset Failure	:	Operational Backup by Emergency Plan
HSSE Consequences of Non-Intervention		
a. Negative Impact on People	:	No
b. Negative Impact on the Environment	:	Yes
c. Negative Impact on Compliance	:	Yes
d. Negative Impact on Social/Reputation	:	Yes
Potential Opportunity of Repair		
a. Positive Impact on Compliance	:	Yes
b. Positive Impact on Safety	:	Yes
c. Upgrade Existing Tech / Capacity / Eff	:	No
d. Reduce Existing Operating / Energy Cost	:	No
Potential Opportunity of Replacement		
a. Positive Impact on Compliance	:	Yes
b. Positive Impact on Safety	:	Yes
c. Upgrade Existing Tech / Capacity / Eff	:	Yes
d. Reduce Existing Operating / Energy Cost	:	Yes

APPENDIX E – Decision Form (4 of 4)



ALTERNATIVE PERFORMANCE SCORE

CRITERIA	DEFENDER		CHALLENGER	
	PERFORMANCE	WEIGHT	PERFORMANCE	WEIGHT
C.1 Economic Cost		**0.262**		**0.198**
C.1.1 Cost Efficiency	0.750	0.037	1.000	0.049
C.1.2 Life Cycle Cost (EUAC-based)	0.636	0.095	1.000	0.149
C.1.3 Budget Feasibility	1.000	0.130	0.000	0.000
C.2 Technical Performance Score		**0.007**		**0.194**
C.2.1 Aging Severity	0.000	0.000	1.000	0.058
C.2.2 Remaining Usefull Life	0.050	0.007	0.950	0.136
C.3 Operational Risk		**0.095**		**0.176**
C.3.1 Operational Consequences	0.667	0.044	0.333	0.022
C.2.2 HSSE Consequences	0.250	0.051	0.750	0.154
C.4 Opportunity		**0.076**		**0.200**
C.4.1 Economic Benefit	0.367	0.033	1.000	0.090
C.4.2 Technical Benefit	0.250	0.012	1.000	0.048
C.4.3 Operational Benefit	0.500	0.031	1.000	0.062

DECISION RESULT

Defender Alternative Weight : **0.440**
Challenger Alternative Weight : **0.768**
Bridging Repair Strategy : **Yes**

Final Decision : **Replace Asset with Bridging Repair**

Notes : The analysis concluded that "Replace Asset" is more favorable, with a confidence level of 77%, compared with "Repair Asset" at 44%. In accordance with the decision rules, this asset requires an transitional strategy where repair is implemented as an interim solution before planned replacement.

Review By Evaluator	Approve By Sponsor
Sign	Sign
Evaluator Name	Sponsor Name

About the Author

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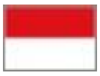

Andika Jaka Saputra is an engineer with over six years of professional experience in the oil and gas sector. Currently, he works as a maintenance engineer at the national oil company of Indonesia. Several projects have been completed in various downstream oil and gas projects, including fuel terminal, LPG terminal, and related infrastructure, with a focus on maintenance and asset reliability. He holds a diploma in Electrical Engineering from Semarang State Polytechnic, as well as both a bachelor's and a master's degree in industrial engineering from Bina Nusantara University. 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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