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Implementation of the Fuzzy AHP, PROMETHEE II, and VIKOR Methods in Selecting Priority Projects in the Utilities Area of the PT ABC Refinery

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Abstract

The Utilities Plant at PT ABC's LNG Plant has experienced declining reliability due to aging infrastructure. Data from the 2019–2024 period showed that 8 out of 13 Process Train operational failure cases were attributed to utility area failures, resulting in losses amounting to hundreds of billions of rupiahs. Capital investment evaluation (CAPEX) has traditionally focused primarily on financial indicators without incorporating non-financial parameters. This study applied a three-stage hybrid multicriteria decision-making (MCDM) model consisting of Fuzzy Analytical Hierarchy Process (FAHP) based on Buckley's approach, PROMETHEE II, and VIKOR to optimize the selection of eight strategic project alternatives. The FAHP results identified Safety (35.06%) and Reliability (22.48%) as the highest-priority criteria. The PROMETHEE II method ranked HV Transformer Replacement (A3) as the first priority (net flow = +0.5308) and DCS Upgrade (A2) as the second priority (net flow = +0.5223). However, the Acceptable Advantage test in the VIKOR method indicated a very small difference in the compromise index ($\Delta Q = 0.0469 < 0.1429$), suggesting that the ranking difference between the top alternatives was not sufficiently significant. Sensitivity analysis within the ±5% range resulted in shifts in the priority rankings, confirming the interdependence between power supply reliability and control automation systems. This study recommends HV Transformer Replacement (A3) and DCS Upgrade (A2) as co-priority project alternatives for implementation.

INTRODUCTION

The utility unit is the operational backbone of the Liquefied Natural Gas (LNG) refinery, providing energy supplies and processing media to the main processing units. As the LNG industry is classified as a high-risk, capital-intensive, and technology-intensive sector within the upstream oil and gas industry, disruptions to supporting systems may trigger significant cascading impacts, including unplanned shutdowns, environmental damage, and threats to personnel safety (Memiş et al., 2022; Widodo, 2018)). Currently, PT ABC is experiencing an aging plant phase, with an operational age exceeding 30 years, which has significantly reduced system reliability. Historical data from the 2019–2024 period show that 62% of process train trip incidents were caused by utility system failures, resulting in financial losses reaching hundreds of billions of rupiahs.

On the other hand, management faces limitations in capital expenditure (CAPEX) allocation and turnaround windows. The project selection process has been biased because it has relied primarily on conventional financial indicators, such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period. This traditional approach may fail to capture critical qualitative factors, including process safety, system reliability, maintainability, and spare parts logistics readiness (Karthikeyan et al., 2021). Consequently, critical non-revenue-generating projects with substantial risk mitigation impacts are often deprioritized or excluded (Sudipa et al., 2023).

To address differences in preferences among multidisciplinary stakeholders (Doan & De Smet, 2018), the asset selection paradigm needs to shift toward a Multi-Criteria Decision-Making (MCDM) approach. The application of fuzzy logic has proven effective in addressing ambiguity in expert linguistic assessments (Gül, 2020; Kaya et al., 2020), while technical parameters such as availability and Mean Time Between Failures (MTBF) should serve as key indicators (Al-Araidah et al., 2021; Prabowo & Saptadi, 2019). In addition, environmental compliance and carbon emission considerations represent regulatory requirements that cannot be overlooked (Wu et al., 2019; Zhao et al., 2022). For ranking conflicting alternatives, the PROMETHEE II method provides a stable priority order based on outranking relations (Alinezhad et al., 2021; Ismail et al., 2023), whereas the VIKOR method is effective in identifying compromise solutions for critical equipment selection problems (Boroushaki et al., 2022; Rezaei, 2023).

The novelty of this research lies in the development of a comprehensive three-stage hybrid decision model that integrates Buckley's Fuzzy Analytic Hierarchy Process (FAHP) for criterion weighting, PROMETHEE II for ranking alternatives based on net outranking flow, and VIKOR as a validation mechanism for identifying multicriteria compromise solutions with minimal individual regret. This integrated approach provides advantages over single-method applications by combining the complementary strengths of each technique. According to Govindan et al. (2015) and Kshanh and Tanaka (2024), integrating FAHP for weight determination with multiple MCDM methods can improve decision robustness and reliability. The FAHP approach developed by Buckley (1985) provides a systematic framework for addressing uncertainty and subjectivity in expert judgments through fuzzy geometric means, making it suitable for capital-intensive infrastructure projects where expert assessments may vary. The PROMETHEE II method established by Brans and Vincke (1985) and further developed by Brans and Mareschal (2005) offers a transparent outranking approach for evaluating alternatives with conflicting criteria and diverse stakeholder preferences. The VIKOR method introduced by Opricovic (1998) and further applied by Opricovic and Tzeng (2004) provides compromise ranking by balancing group utility and individual regret, ensuring that selected alternatives represent acceptable solutions for decision-makers. Furthermore, the inclusion of sensitivity analysis using weight variation scenarios (±5%, ±10%, and ±20%) and decision strategy parameter testing ($v = 0.1$ to $v = 0.9$) strengthens the robustness evaluation by ensuring that recommendations remain stable under different decision-making conditions (Kabassi & Martinis, 2021).

Based on this synthesis, this study proposed a comprehensive three-stage hybrid decision model. The framework integrated Buckley's Fuzzy Analytic Hierarchy Process (FAHP) method to calculate criterion weights objectively, followed by PROMETHEE II to generate alternative rankings based on net outranking flow (Liu & Wang, 2021). Finally, the VIKOR method was applied as a validation step to identify multicriteria compromise solutions with minimal individual regret. The integration of these three methodologies was expected to produce a dynamic, robust, and accountable decision-support system (Pranata & Hidayat, 2022) to support the achievement of zero downtime and zero accident targets at the LNG Plant Utilities.

METHOD

This study employed a descriptive-analytical quantitative method using a Multi-Criteria Decision-Making (MCDM) approach. This design was selected due to the complexity of prioritizing infrastructure projects and facility upgrades in the Utilities unit of the LNG Plant, where multiple and often conflicting criteria must be considered in the decision-making process (Zavadskas et al., 2014).

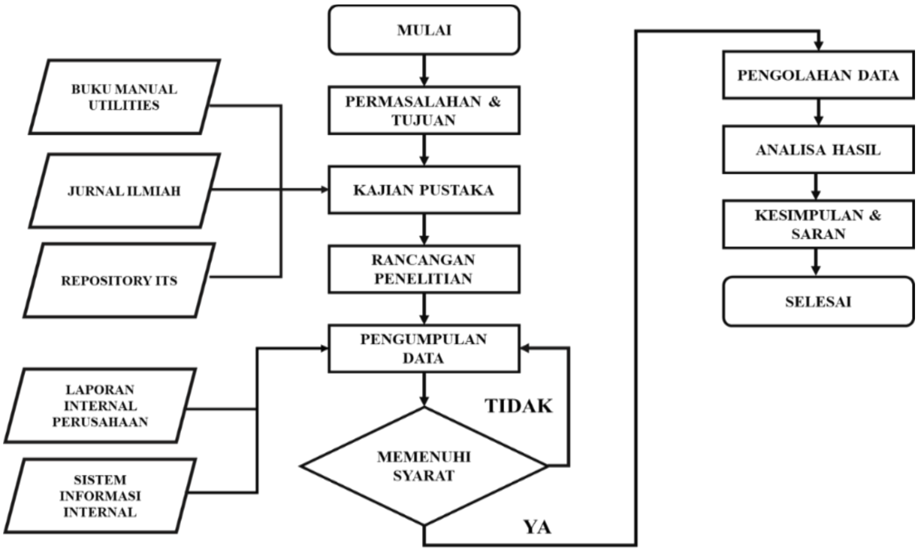

Figure 1. Research Flow Diagram

Objects, Subjects, and Data Collection

a) Object: 8 alternative strategic projects in PT ABC's utility unit. The project data is shown in Table 1 as follows

Table 1. List of Project Alternatives in the LNG Plant Utilities Area

Code	Project Name	Purpose
A1	Eductor Asam Sulfat	Eliminates *moving parts*, reducing the risk of chemical leaks.
A2	Upgrade DCS	Mitigate the risk of *hardware obsolescence* and improve process control.
A3	Ganti Trafo HV 34.5 kV	Prevent *total blackout* due to old transformer insulation failure (>30 yrs).
A4	Air Pipeline Interconnection	Flexibility of the instrument air supply between *trains* during *maintenance*.

Code	Project Name	Purpose
A5	O2 Analyzer Boiler	Combustion optimization (Fuel Saving ~3%) & NOx emission reduction.
A6	Upgrade AVR Turbine	Stabilizes the excitation of the generator when load *swings* occur in the network.
A7	Control Comp. Air	Integration of compressor loading sequence for electrical efficiency.
A8	Ganti Chiller Nitrogen	Using environmentally friendly refrigerants & improving *the purity of N2.*

b) Subject (Expert): A tripartite expert panel consisting of 3 technical/managerial authority holders with >10 years of experience in the LNG industry (*Operation Senior Supervisor, Project Engineer,* and *HSE Specialist*).
c) Data Collection Technique: Triangulation of primary data through a structured questionnaire of a paired comparison scale (AHP) and a firm performance scale of 1-9. As well as secondary data from the company's internal reports (*Project Cost Estimate, Mean Time Between Failure*, and *Risk Assessment Matrix*).

Structure of Criteria and Sub-Criteria

Based on consensus through *the Focus Group Discussion* (FGD), a hierarchical structure consisting of 6 criteria and 12 sub-criteria was determined:

1. Keandalan (C1): C.1.1 *Availability* (Max), C.1.2 MTBF (Max).
2. Financial (C2): C.2.1 CAPEX (Min), C.2.2 OPEX (Min).
3. Technical (C3): C.3.1 Compatibility (Max), C.3.2 Energy Efficiency (Max).
4. Safety (C4): C.4.1 Process Safety (Max), C.4.2 Regulation (Max).
5. Maintenance (C5): C.5.1 Ease of Maintenance (Max), C.5.2 Spare Parts Logistics (Min).
6. Environment (C6): C.6.1 Waste Management B3 (Min), C.6.2 Carbon Emissions (Min).

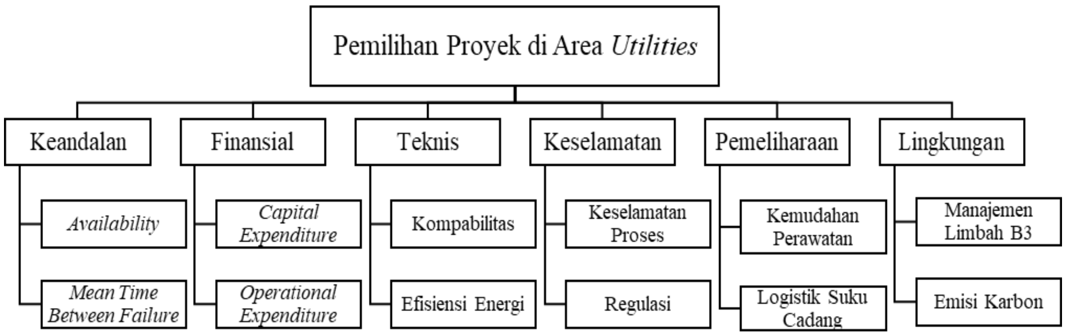

Figure 2. Hierarchy of Criteria and Sub-Criteria to be used in *the AHP* Fuzzy Method

Data Processing

Data analysis was carried out in stages using a three-stage hybrid decision model that integrated the *Fuzzy Analytical Hierarchy Process* (FAHP) methods of Buckley, PROMETHEE II, and VIKOR (Figure 3). The data processing framework is divided into three main phases along with the following validation procedures:

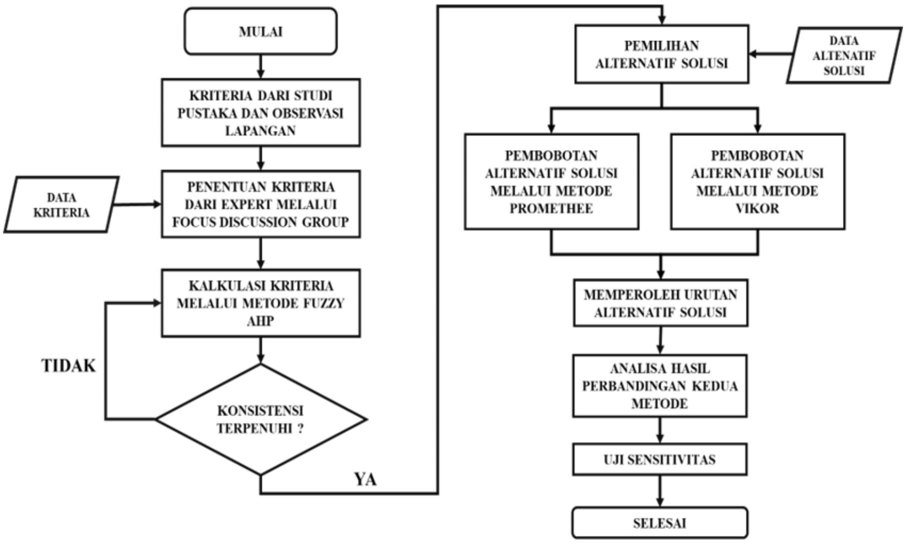

Figure 3. Data Processing Flow Diagram

RESULTS AND DISCUSSION

Weighting Analysis (FAHP Buckley)

In the initial stage, *the initial crisp questionnaire* from the three experts was tested for consistency. The results of the initial calculation showed that *the Consistency Ratio* (CR) value was inconsistent because it was above 10% (*Operation*: 18.04%, *Project*: 14.71%, *HSE:* 15.35%) due to individual sectoral bias. After a perception reconciliation forum was conducted through the FGD, the comparative logic was harmonized so that the advanced CR value was significantly lowered below the safe limit (*Operation*: 5.63%, *Project*: 6.31%, *HSE:* 4.61%).

The Fuzzy Geometric Mean *aggregation process* and Center of Area *(CoA) fuzzification* resulted in the following final criterion weights: Safety (35.06%), Reliability (22.48%), Technical (12.82%), Financial (12.74%), Maintenance (10.34%), and Environment (6.18%).

The multiplication between the criterion weights and the local weights results in the order of global weights of the sub-criteria shown in Table 2 as follows

Table 2. Global Weights of Sub-Criteria

Criteria	Weight	Presentation	Peringkat
C.1.1 Availiability	0,1502	15,02%	2
C.1.2 MTBF	0,0782	7,82%	5
C.2.1 CAPEX	0,0620	6,20%	8
C.2.2 OPEX	0,0654	6,54%	6
C.3.1 Compatibility	0,0813	8,13%	4
C.3.2 Energy Efficiency	0,0470	4,70%	9
C.4.1 Process Safety	0,2353	23,53%	1
C.4.2 Regulation	0,1153	11,53%	3
C.5.1 Ease of Care	0,0641	6,41%	7
C.5.2 Spare Parts Logistics	0,0393	3,93%	11
C.6.1 B3 Waste Management	0,0407	4,07%	10
C.6.2 Absorption Carbon	0,0212	2,12%	12
Total	1	100 %	

Preference Flow Analysis (PROMETHEE II)

The above global weights are integrated into the performance appraisal matrix of 8 alternative projects that are filtered using *the Usual* (Type I), *Linear* (Type III), and *Level* (Type V) preference functions. The calculation of *the accumulated Net Outranking Flow* through equation (10) results in the order of linear absolute priority shown in Table 3 as follow:

Table 3. Final Calculation Results of PROMETHEE II

Code	Project Alternate Name	*Leaving Flow* $(+)\theta$	*Entering Flow* $(\theta -)$	*Net Flow* (θ)	Rank
A3	Ganti Trafo HV	+0,6078	-0,077	+0,5308	1
A2	Upgrade DCS	+0,5953	-0,0729	+0,5223	2
A4	Air Pipe	+0,4905	-0,132	+0,3585	3
A7	Compressor Control	+0,2410	-0,2813	-0,0403	4
A6	Upgrade AVR	+0,2025	-0,3415	-0,139	5
A5	Oxygen Analyzer Boiler	+0,1436	-0,4740	-0,3304	6
A1	Eductor Asam	+0,1262	-0,4620	-0,3358	7
A8	Ganti Chiller	+0,0182	-0,5844	-0,5661	8

Determination of Compromise Solutions (VIKOR)

The results of the processing of the VIKOR compromise integration index value (Qi) with the balanced consensus strategy parameter (v=0.5) resulted in the alternative ranking order of the project shown in table 4 as follows.

Table 4. Calculation Results of the VIKOR Method

Code	Project Alternate Name	*Utility* (S)	*Regret* (R)	VIKOR Index (Q)	Rank
A3	Ganti Trafo HV	0.1647	0.0641	0.0063	1
A2	Upgrade DCS	0.2427	0.0619	0.0532	2
A4	Air Pipe	0.3657	0.0641	0.1434	3
A7	Compressor Control	0.5448	0.1153	0.4131	4
A6	Upgrade AVR	0.6299	0.1153	0.4712	5
A5	Oxygn Analyzer Boiler	0.7705	0.1497	0.6663	6
A1	Eductor Asam Sulfat	0.6948	0.1711	0.6764	7

Code	Project Alternate Name	*Utility* (S)	*Regret* (R)	VIKOR Index (Q)	Rank
A8	Ganti Chiller	0.8977	0.2359	1	8

The VIKOR method requires two stringent conditions before deciding on the first rank as a mathematically valid compromise solution:

a) Condition 1 (Acceptable Advantage): The difference between the second and first rank is Q(A2) - Q(A3) = 0.0532 - 0.0063 = 0.0469. The minimum eligibility threshold value is DQ = 1/(8-1) = 0.1429. Because 0.0469 < 0.1429, Condition 1 Fails to Be Met. The margin of advantage is not statistically significant enough to designate a single winner.

b) Condition 2 (Acceptable Stability): Project A3 secures the smallest absolute Utility (S) value (0.1647), so that Condition 2 is Perfectly Met.

As a result of the failure of Condition 1, VIKOR formulated a *compromise solution set* based on the upper limit of Q(An) - Q(A1) < DQ (Q < 0.1492). The results officially established Alternative A3 (Replace HV Transformer) and Alternative A2 (Upgrade DCS) as Co-Winners with an equal level of priority.

Comparative Analysis of PROMETHEE II and VIKOR

The analysis continued by conducting *cross-method validation* through the comparison of ranking results between the PROMETHEE II and VIKOR methods. This cross-method testing is crucial to test the *robustness*, consistency, and reliability of the decision model (Doan & De Smet, 2018). Although both methods use the same FAHP Buckley global input and weights database, the mathematical differences in processing performance score deviations have the potential to trigger the phenomenon of *ranking shift*. The following are the results of the comparison of the two methods shown in Table 5 as follows.

Table 5. Comparison of PROMETHEE II and VIKOR Method Ratings

Code	Project Alternate Name	*Net Flow* (θ) PROMETHEE II	PROMETHEE II Ratings	VIKOR Index (Q)	VIKOR Ratings	Consistency Status
A3	Ganti Trafo HV	+0,5308	1	0,0063	1	Consistent
A2	Upgrade DCS	+0,5223	2	0,0532	2	Consistent
A4	Air Pipe	+0,3585	3	0,1434	3	Consistent
A7	Compressor Control	-0,04	4	0,4131	4	Consistent
A6	Upgrade AVR	-0,139	5	0,4712	5	Consistent
A5	Oxygen Analyzer Boiler	-0,3304	6	0,4712	6	Consistent

Code	Project Alternate Name	*Net Flow* (θ) PROMETHEE II	PROMETHEE II Ratings	VIKOR Index (Q)	VIKOR Ratings	Consistency Status
A1	Eductor Asam Sulfat	-0,3358	7	0,6764	7	Consistent
A8	Ganti Chiller	-0,5661	8	1,0000	8	Consistent

Cross-Method Sensitivity Analysis

Stress-testing through simulated weight fluctuations of ±5%, ±10%, and ±20% on the two main criteria showed that the model was very resilient in the mid-bottom cluster, but sensitive in the apex position. A decrease in the weight of the Reliability criterion (<5%) or an increase in the Safety criterion (>+5%) immediately triggers a shift in ranking, where Alternative A2 (Upgrade DCS) shifts the position of A3 (Replace HV Transformer) as the first rank. Back-and-forth crosses at a slim threshold (±5%) confirm the status *of the co-winners of both.*

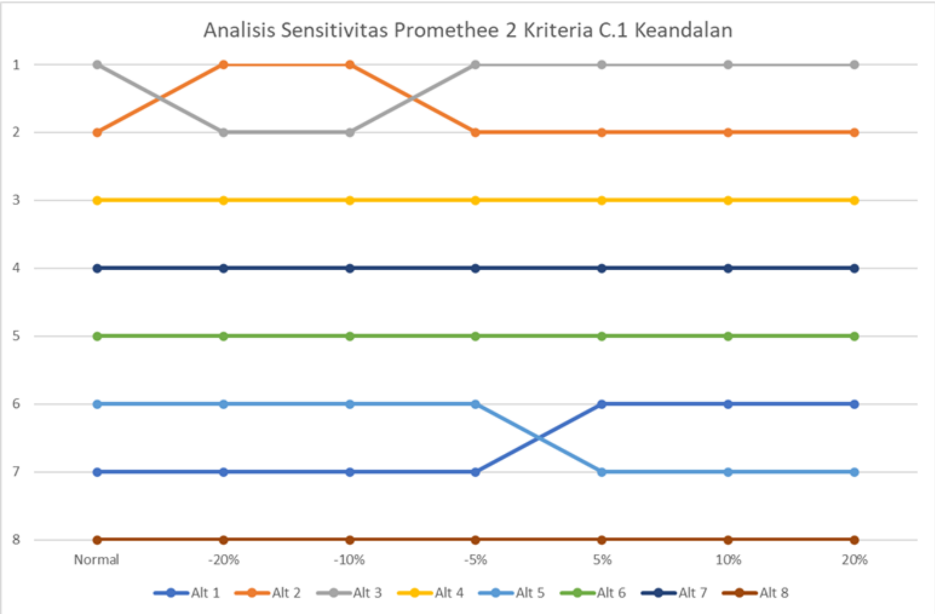

Figure 4. Alternative Rating Change Graph of PROMETHEE II Method Project with Weight Change Scenario Criterion C.1 Reliability

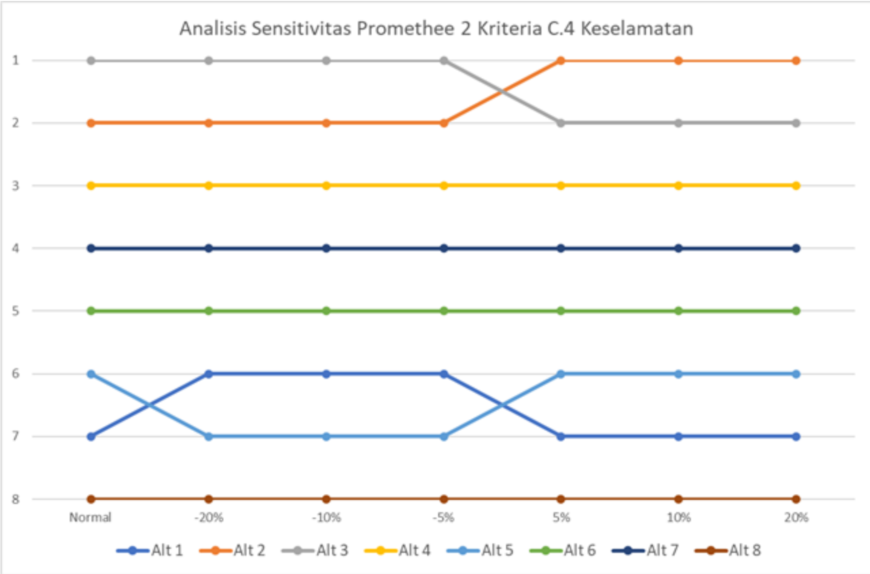

Figure 5. PROMETHEE II Method Project Alternative Rating Change Graph with Weight Change Scenario Criterion C.4 Safety

VIKOR Strategy Sensitivity**.** Testing of variation in the parameters of the decision strategy (v=0.1 to v=0.9) showed strong *robustness*. The top priority clusters (A3, A2, A4) did not experience a *zero ranking shift* at all, proving that these projects excelled multidimensionally without any fatal *flaws*. Minor shifts occur only in the lower cluster (A1 shifts A5 at v>0.7).

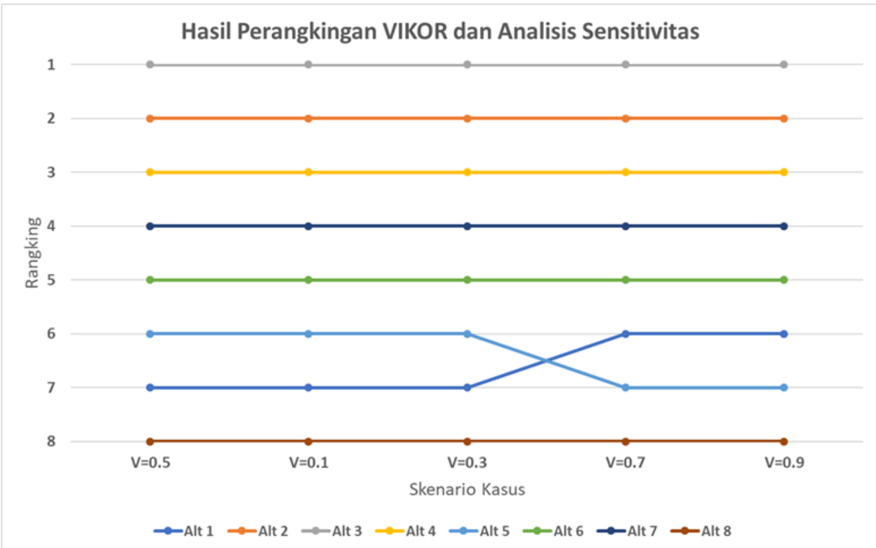

Figure 6. VIKOR Method Project Alternative Rating Change Chart with Parameter Value Change Scenario v

Clustering of Project Alternatives and Managerial Recommendations

In order to convert the results of the calculations of PROMETHEE II and VIKOR into management policies, 8 project alternatives were grouped into three decision clusters. This grouping considers the level of urgency of risk mitigation, group utility, and minimization of the worst risk (*individual regret*). Details of cluster distribution and policy recommendations are presented as follows:

1. Klaster I: Proyek Mandatori & Kritis (*Critical/Mandatory Projects*)
   a. Cluster Members: HV Transformer Replacement (A3) and *DCS Upgrade* (A2)
   b. Policy Recommendations: Delays in execution have the potential to trigger total systemic plant failure (*blackout* or loss of safety interlocks). Management is required to execute the budget directly without delay.
2. Cluster II: Supplementary Projects
   1. Cluster Members: Airway Re-piping (A4) and Compressor Control Modernization (A7)
   2. Policy Recommendations: Projects are recommended for approval as soon as Cluster I budget needs are met, to support long-term efficiencies through decarbonization and energy saving programs.
3. Cluster III: Eliminated Projects
   1. Cluster Members: *AVR Upgrade* (A6), Sulfuric Acid Eductor Modification (A1), Boiler Analyzer System (A5), and Chiller Replacement (A8)
   2. Policy Recommendations: Management is recommended to conduct a total *budget freeze* in the current year, as the allocation of funds in this cluster is inefficient and does not have a significant impact on risk mitigation in the utility area.

CONCLUSION

The integration of pairwise comparison questionnaires within the hybrid model successfully reduced decision-making ambiguity, with Safety (35.06%) and Reliability (22.48%) identified as the highest-priority criteria in LNG refinery operations. The Process Safety sub-criterion ranked highest (23.53%), indicating that practitioners prioritize operational risk mitigation over conventional financial considerations.

Cross-validation results showed 100% consistency in ranking convergence between PROMETHEE II and VIKOR. However, from a managerial perspective, the feasibility assessment identified the HV Transformer Replacement (A3) and DCS Upgrade (A2) projects as equivalent co-winners. Technically, the findings indicate that these two infrastructure projects are systemically interdependent, as power supply reliability and automation control systems cannot be considered separately in maintaining utility refinery stability.

Managerial Recommendations and Future Research

Managerial Recommendations: PT ABC management is advised to prioritize the simultaneous execution of Cluster I projects (A3 and A2) to mitigate the risk of major systemic plant failures, such as power outages. Cluster II projects (A4 and A7) may be implemented as tactical initiatives to support medium-term operational expenditure (OPEX) efficiency. Meanwhile, Cluster III projects (A6, A1, A5, and A8) should be reassessed and potentially deferred due to their relatively lower efficiency and limited operational impact.

Suggestions for Further Research: Future research may extend this study by applying the Analytic Network Process (ANP) method with a larger number of experts, expanding the model application to main process units (Processing Trains), and developing a digital implementation of the hybrid decision model through web-based software to support automated annual budgeting cycles.

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