JURNAL LOCUS: Penelitian & Pengabdian
Volume 4 No. 9 September 2025
E-ISSN 2829-7334| P-ISSN 2829-5439
Hompage: https://locus.rivierapublishing.id/

Optimization of Maintenance Inspection Scheduling Decision by Integrating Predictive Maintenance and Operational Management Constraints: Case Study of Storage Tank Maintenance in Central Java

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Abstract

This study aims to optimize the cleaning and inspection schedule of storage tanks by integrating predictive maintenance with operational decision-making. The research addresses the challenges faced by the Oil and Gas Company in balancing asset reliability with continuous operational demands, using a mixed methods approach. Predictive modeling, conducted using RapidMiner, classified tank conditions based on technical data such as bottom plate thickness, corrosion rates, and coating conditions from previous reports (2022–2024), achieving a model accuracy of 94%. Simultaneously, the Analytical Hierarchy Process (AHP) was employed to evaluate operational criteria, including product demand, stock availability, redundant tank presence, overdue cleaning, vendor readiness, and alternative supply plans. Seven regional Terminal Managers participated as respondents to determine the prioritization of these factors and the weighting of each criterion. The results of AHP indicate that the technical condition of tanks (24.4%) and overdue cleaning (18.4%) are the most influential criteria in the decision-making process. By integrating AHP with predictive maintenance simulations, the study proposes a structured, proactive, and risk-based model to guide tank maintenance decisions. This model enhances reliability, minimizes operational disruptions, and ensures optimal resource utilization.

Keywords: Predictive Maintenance, AHP, Storage Tank, Maintenance Optimization, Oil and Gas, Operational Decision-Making

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INTRODUCTION

Oil and gas industry around the world is dealing with the issue of aging infrastructure. Many facilities, such as refineries, pipelines, and storage terminals, have been in use longer than their originally intended lifespan (Sari & Öztürk, 2025). This situation meets serious risks, including leaks, spills, equipment failures, and safety hazards, which can lead to environmental disasters and operational shutdowns (Arshad & Ahmad, 2022).

At the same time, these facilities must continue operating for support business continuity and energy distribution. It is the challenges for companies to ensure asset integrity without interrup the business process (Hosseini et al., 2019).

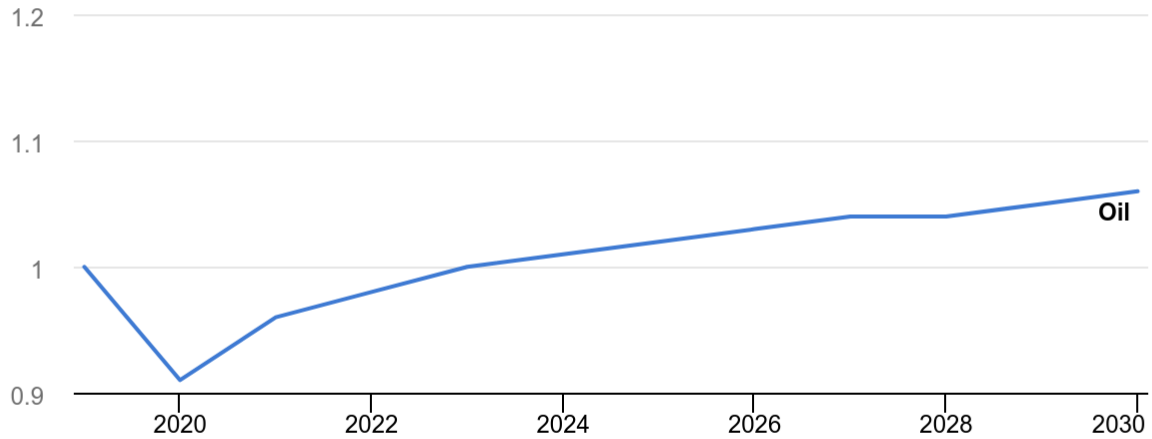

Figure 1. Primary energy demand by fuel, Indexed to 2019 levels
(Source: Report Energy Outlook. Retrieved from https://www.iea.org/, 2025)

The graphic indicates that following a steep decrease in 2020 primarily due to the COVID-19 epidemic and its considerable effects on global transportation and industrial operations oil demand starts to recover incrementally. This corresponds with actual occurrences in which global oil demand decreased by over 8 million barrels per day in 2020 because of lockdowns and economic downturns. By 2022, oil demand approaches prepandemic levels and exhibits a gradual yet consistent increase until 2030.

Storage tanks have the important role in fuel supply chain operation. However, determining the optimal cleaning and inspection time are the complex issue. Each company has their own strategy to maintain their aging facilities. It depends on their organization, manpower, operational condition, etc.

The goal may be to attain an ideal equilibrium between the distribution of maintenance resources and the production of plant outputs, but in practice, the formulation is more intricate than this. It normally begins with discussions between the owners, users, and safety departments and the maintenance department. (Salonen, 2009)

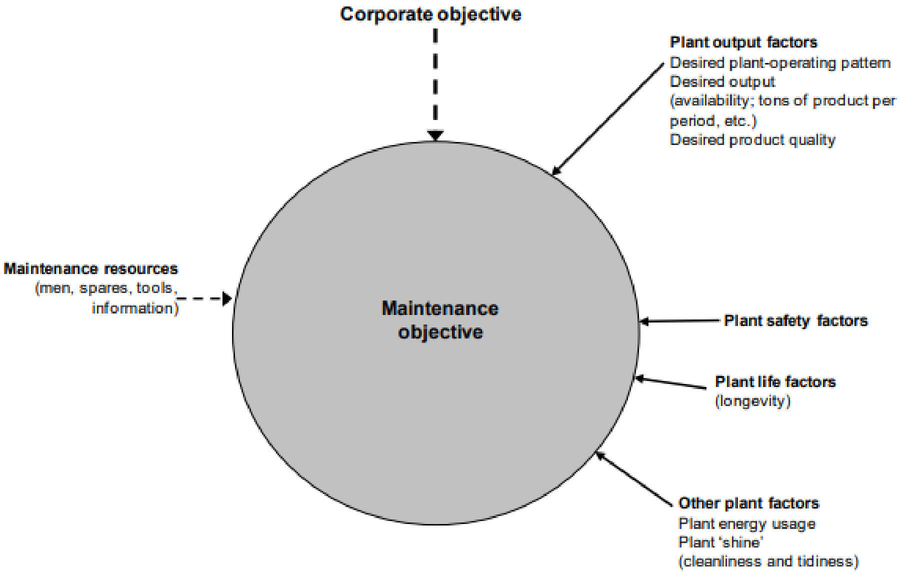

Figure 2. Factors influencing maintenance objective setting
(Source: Salonen, 2009)

Most storage tanks are scheduled based on fix time interval to depend on each sompany condition, which often doesn't reflect the actual condition of assets. Because of that issue, this research aims to address it by integrating technical condition monitoring and operational consideration to decide storage tank maintenance timing optimally.

The maintenance storage tank at Central Java pertains not only to technical integrity but also to a crucial feature of operational decision making. The organization must guarantee that maintenance tasks, such as cleaning and inspection, are performed without interrupting operating continuity (Shin & Jun, 2015; Sotoodeh, 2024; Zhang et al., 2024).

Storage units are critical part for trading of the petrochemical products (Zain 2021). In practice, the company often meet the difficulty of executing tank cleaning and inspection schedule due to high product demand, limited redundant facilities without interrupt the operation activities. This creates the dilemma between maintaining asset reliability with fulfilling operational requirements.

In fact, maintenance procedures frequently encounter delays due to operational restrictions such as elevated product demand, insufficient redundancy facilities, and stringent distribution schedules. These problems underscore the link between maintenance planning and operational execution. Hence, there is a needed to align the maintenance schedule planning with the operational decision making.

The issue of aging infrastructure in the oil and gas industry has been discussed in previous studies, such as in the work of Zain (2021), which focuses on the challenges faced by companies in maintaining storage tanks without interrupting operations. Zain's research highlights the operational dilemma companies face when balancing asset reliability with high product demand. However, Zain's study lacks an integration of technical condition monitoring with operational considerations for maintenance scheduling, which is essential for optimizing tank cleaning and inspection procedures. Salonen addressed maintenance objectives, emphasizing the importance of balancing maintenance resources with production needs but did not explore how this balance can be dynamically adjusted using real-time data on asset conditions. The gap this research aims to fill lies in the integration of condition monitoring with operational constraints to optimize maintenance scheduling, specifically for storage tanks in the oil and gas sector. This study proposes a method for aligning maintenance schedules with operational decision-making, offering a more nuanced approach to handling the complex maintenance challenges that arise due to aging infrastructure.

The objectives of this research are: (1) to integrate technical condition monitoring with operational considerations in order to optimize maintenance scheduling for storage tanks in the oil and gas industry, and (2) to develop a model for determining the optimal timing for cleaning and inspection activities, reducing operational disruptions. The findings of this study can provide practical insights for the oil and gas industry in improving the efficiency of their maintenance procedures, minimizing operational downtime, and extending the lifespan of critical infrastructure. This research also contributes to the broader field of asset management by offering an innovative solution to optimizing maintenance schedules in industries with complex operational constraints.

RESEARCH METHOD

This study employed a mixed-method approach combining both qualitative and quantitative methods to analyze and optimize the maintenance schedule of storage tanks in the oil and gas industry. The qualitative method was used to determine the sub-criteria for operations in the *Analytic Hierarchy Process* (*AHP*). This process involved an in-depth analysis of the factors influencing maintenance decisions, such as technical conditions and operational needs, which had to be considered to maximize maintenance effectiveness. On the other hand, the quantitative method was applied to predict facility conditions based on data mining, allowing the identification and prioritization of key criteria that influenced decision-making in scheduling maintenance, particularly for cleaning and inspection activities. The study involved seven key stakeholders selected using a purposive sampling technique, a non-random sampling method that selects participants based on specific attributes relevant to the research goals. This technique was chosen because it allowed the researcher to select respondents who had direct knowledge and experience in managing storage tank maintenance, based on their power and interest in the decision-making process. Data collection was carried out through in-depth interviews, field observations, and relevant documentation, aiming to gain a comprehensive understanding of the challenges and solutions in managing the maintenance of these facilities.

RESULTS AND DISCUSSION

Predictive Maintenance Simulation

RapidMiner is used for simulation to do predictive maintenance with supervised machine learning Methode to get the best decision tree. Here is the model of RapidMiner Simulation.

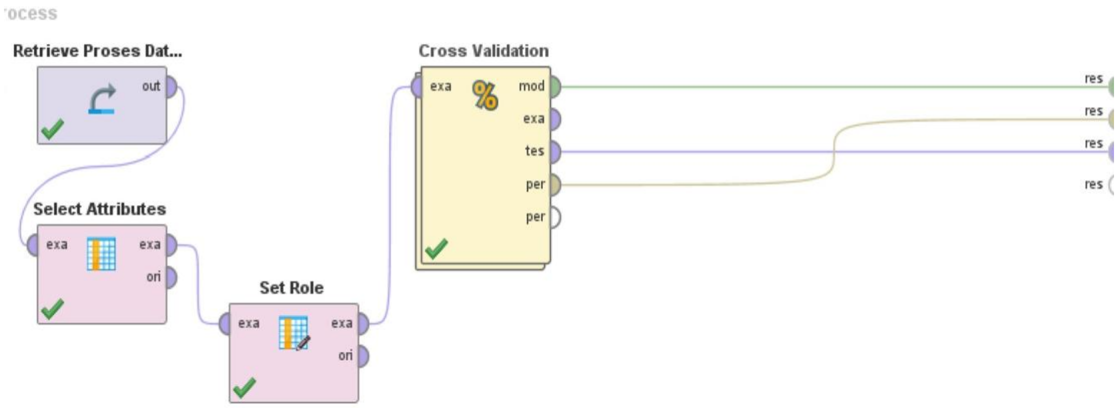

Figure 3 RapidMiner Model Simulation

At this simulation, uses 4 operators to simulate the best result in predicting the maintenance based on historical data / inspector result. The operators are:

1. Retrieve Proses Data: To call the raw data that will be process
2. Select Attributes: Selecting the parameters that will be simulate
3. Set Role: Setting the attribute role, especially for label/output role
4. Cross Validation: Methode to simulate the data

The best resul from the simulation are figured in the decision tree below.

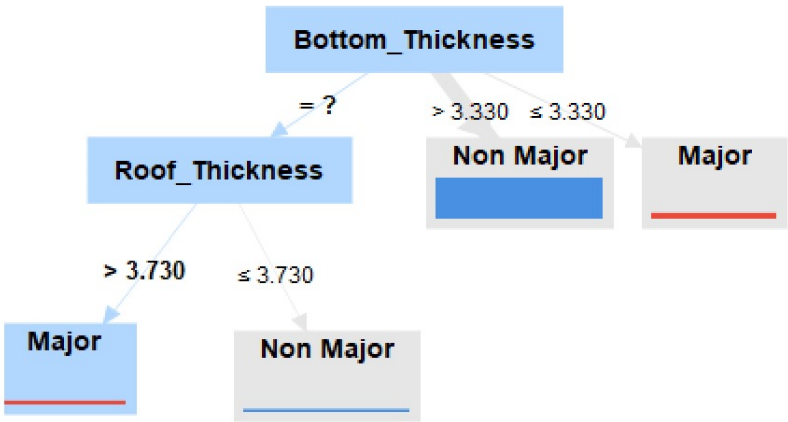

Figure 4 Figure 22 Decision Tree Result

Based on data training from predictive maintenance model, the result accuracy of model is 94%. Data Training is data that used from 10% of original data for simulation after RapidMiner Get the best pattern/decision tree. The result from simulation gets 2 false predictions for Major Condition and 1 for Non-Major Condition from 158 Simulation after getting the model. So based on this result it can show that predictive maintenance is possible to implement in storage tank.

accuracy: 94.00% +/- 9.66% (micro average: 98.10%)

	true Non Major	true Major	class precision
pred. Non Major	133	2	98.52%
pred. Major	1	22	95.65%
class recall	99.25%	91.67%	

Figure 5 Simulation Result

Analytical Hierarchi Process

Analytical Hierarchi Process is used for getting the best decision model for determining cleaning and inspection activity. All primary data collected from questionnaires to the interest and influence stakeholder.

Structuring Criteria & Sub Criteria

As mentioned on previous section, criteria on AHP divided into two conditions, Technical and Operationl. Sub Criteria of Operational is getting from questionnaires that distributed to the interest and influence stakeholder in Central Java Oil Company. Then from that data the author defines the following criteria and sub criteria to be used in AHP model as consideration to decide cleaning and inspection.

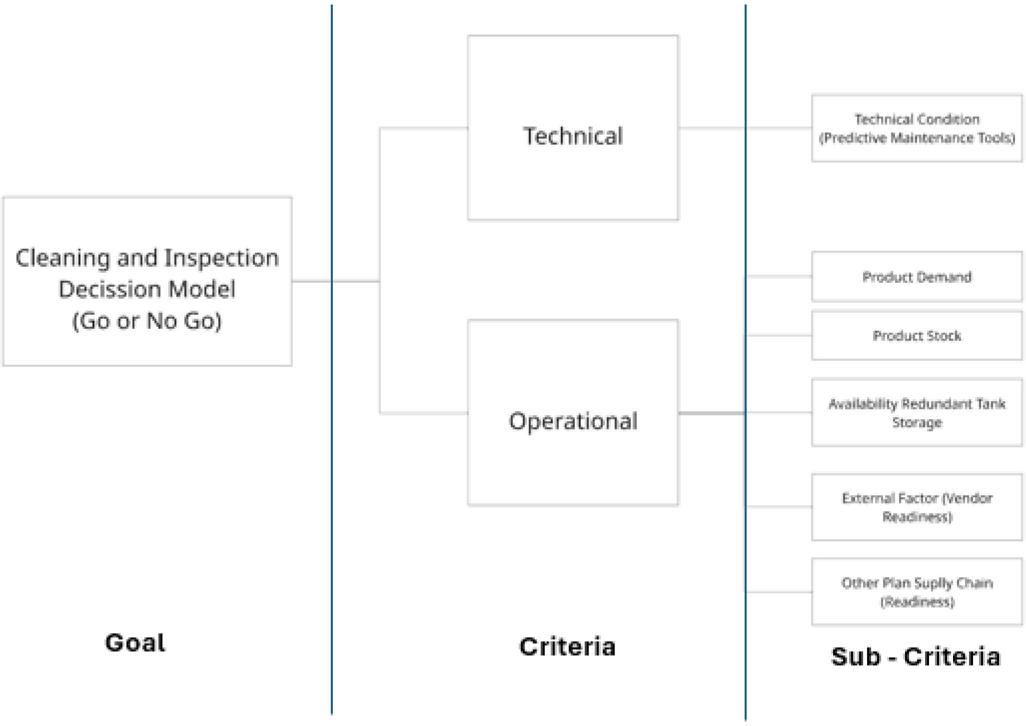

Figure 5. AHP Decision Making Framework

The Following explanation below are definitions of Criteria & SubCriteria

Table 1. Definition of Criteria and SubCriteria AHP

Criteria & Sub Criteria	Description
Technical	**Technical Aspect of Tank Storage**
Technical Condition	Based On Predictive Maintenance Resul (Need Major Repair or No Need Major Repair)
Operational	**Operational Constraint to decide Cleaning and Inspection Activity**
Product Demand	It shows that the demand in Normal or High Demand condition. High Demand Condition mean that the availability cleaning and inspecting is lower than Normal Demand.
Product Stock	It Show the availability of stock to supply the demand. More Stock mean the availability cleaning is higher.
Availability Redundant Tank Storage	It shows the redundant tank. There are more than two storage tanks with the same product is more availability to be cleaned and inspected.
Tank Overdue Cleaning	The tank must be cleaned in 5 years-based company Regulation but if more than 5 years the storage tank not cleaning yet it means overdue condition. So, Tank overdue cleaning is How long the tank over from due date cleaning and inspection (in 5 years). More overdue mean that the storage tank must be cleaned and inspected.
External Factor (Vendor Readiness)	The readiness of vendor include capability. More ready mean the storage is more available to be cleaned and inspected.
Other Plan Suplly Chain (Readiness)	The readiness Plan B for supplying the Terminal stock if a storage tank is off for cleaning and inspection. Ther is Other Plan Supply Chain mean the storage is more available to be cleaned and inspected.

Pairwise Comparison

After developing the criteria and sub-criteria, the author starts to develop the pairwise comparison matrix questionnaire and provide it to respondents. They expected to fill the questionnaire based on their expertise in excel spreadsheet. All their answers then calculate in excel sheet provided by (Goepel, 2018) that has the formula to calculate the consistency of the answer also to is to provide weighting of the respondents in group decision making by using the formula of weighted geometric mean for aggregation of individual priorities (AIP). The details of Pairwise Comparison Question for the questionnaire used in this research are shown in the following below:

Q1. Product Demand vs Product Stock
Q2. Product Demand vs Redundant Tank Availability
Q3. Product Demand vs Tank Overdue Cleaning
Q4. Product Demand vs Vendor Readiness
Q5. Product Demand vs Alternate Supply Chain Plan
Q6. Product Demand vs Tank Technical Condition
Q7. Product Stock vs Redundant Tank Availability
Q8. Product Stock vs Tank Overdue Cleaning
Q9. Product Stock vs Vendor Readiness
Q10. Product Stock vs Alternate Supply Chain Plan
Q11. Product Stock vs Tank Technical Condition

Q12. Redundant Tank Availability vs Tank Overdue Cleaning
Q13. Redundant Tank Availability vs Vendor Readiness
Q14. Redundant Tank Availability vs Alternate Supply Chain Plan
Q15. Redundant Tank Availability vs Tank Technical Condition
Q16. Tank Overdue Cleaning vs Vendor Readiness
Q17. Tank Overdue Cleaning vs Alternate Supply Chain Plan
Q18. Tank Overdue Cleaning vs Tank Technical Condition
Q19. Vendor Readiness vs Alternate Supply Chain Plan
Q20. Vendor Readiness vs Tank Technical Condition
Q21. Alternate Supply Chain Plan vs Tank Technical Condition

The Quantitative Rating is used to each sub-criteria to produce the numeric parameter value from each option that is to be computed and ranked.

Verification of all Respondents

After calculating the weights for each respondent, the consistency must be validated using the Consistency Ratio. The verification result is shown table below by referencing the Consistency Ratio calculation.

	Criterion	Comment	Weights	+/-
1	Product Demand	It shows that the demand in Normal or High Demand condition	9,4%	2,3%
2	Product Stock	The availability of stock to supply the demand	17,4%	2,0%
3	Availability Redundat Tank Storage	There are more than two storage tanks with the same product	15,5%	4,1%
4	Tank Overdue Cleaning	How long the tank is overdue for cleaning and inspection	18,4%	4,3%
5	External Factor (Vendor Readiness)	The readiness of vendor include capability	5,5%	1,3%
6	Other Plan Suplly Chain (Readiness)	the readiness Plan B for supplying the Terminal stock if a storage tank is o	9,4%	2,9%
7	Technical Condition	Technical Condition of Tank	24,4%	2,2%
8			0,0%	0,0%
9		for 9&10 unprotect the input sheets and expand the	0,0%	0,0%
10		question section ("+" in row 66)	0,0%	0,0%

Eigenvalue			Lambda:	7,150				MRE:	22,6%
Consistency Ratio	0,37	GCI:	0,07	Psi:	9,5%	CR:	1,9%		

Figure 6. Verification all Respondents

According to the final AHP results from seven respondents, the predominant reason for determining the postponement of tank cleaning and inspection is Technical Condition, which holds the maximum weight of 24.4%. This signifies that the tank's physical state is paramount in decision-making. The second most critical aspect is Tank Overdue Cleaning (18.4%), indicating that the duration of overdue time is a vital concern.

Additional significant criteria encompass Product Stock (17.4%), which signifies the relevance of accessible inventory in assessing whether a tank may be decommissioned. The presence of redundant tank storage (15.5%) significantly enhances operational flexibility during maintenance by providing backup tanks.

Simultaneously, Product Demand (9.4%), Other Plan Supply Chain (9.4%), and External Factor/Vendor Readiness (5.5%) possess lesser weights however contribute to the overall decision-making process.

Business Solution: Decision Making Model Using AHP Result and Rapid Miner Simulation for deciding Storage Tank Cleaning and Inspection (Go or No Go)

After completing the analysis of Secondary and Primary data using Rapid Miner and AHP. This section presents how the best decision-making model for determining the optimum cleaning and inspection time. Based on AHP results it can see that total weight of all parameters is100%. So, if the parameters weight fulfilled more or equal to the priority weight (24.4%) then the storage must be cleaned and inspected. Terminal Manager must consider Technical Condition of Tank Storage first before deciding for cleaning and inspection in 5 years interval. The condition of operational tank storage can be predicted using Rapid Miner simulation with the accuracy ± 94% like the previous section about Technical Aspect. Then if the Technical Condition say that the storage in Major Condition the storage must be cleaned and inspected at that time. But, if the condition after simulation is still in Non-Major Condition, then Terminal Manager must consider the tank overdue. The table below explain about the condition that can be fulfilled in each parameter.

Table 2. Decision Making Model for Cleaning and Inspection Activity (Composite Scoring Model)

Parameter	Condition Fulfilled to be Cleaned and Inspected	Weights	Technical & Operational Condition	Composite Score
Technical Condition	Major Condition Based on Predictive Simulation	24.4%	Major =1 Non-Major = 0	
Tank Overdue Cleaning	Last Inspection More than 5 years	18.4%	Tank Overdue = 1 Non-Tank Overdue = 0	
Product Stock	Product Stock can cover the demand if tank in off condition	17.4%	Sufficient stock = 1 No Sufficient Stock = 0	
Availability Redundant Tank Storage	Tank Storage with same product has more than 2 units	15.5%	Available Redundant = 1 No Available = 0	
Product Demand	Product Demand in low or normal condition	9.4%	Normal Demand = 1 Peak Season = 0	
Other Plan Supply Chain (Readiness)	There is availability the other supply chain plan	9.4%	Available Other Plan Supply = 1 No Available = 0	
External Factor (Vendor Readiness)	Vendor has capability to do cleaning and repairing the storage tank	5.5%	Vendor Ready = 1 Vendor not Ready = 0	
		Total		

In comparison to conventional methods, the quality of decision making is substantially improved by the incorporation of AHP and predictive maintenance. The system's ability to adapt to dynamic field conditions, reduced outage, cost efficiency, and objectivity are its primary advantages. This results in a decision-making process that is more responsive, accountable, and focused on the integrity and reliability of assets.

Table 3. Comparison Table Before and After Using Model

Aspect	Current Process (Conventional)	Integration of Predictive Maintenance + AHP
Basis of Decision	Based on operational directives, experience, or fixed intervals	Utilizing multi criteria analysis, historical trends, and real time data
Nature of Decision Making	Subjective, derived from intuition or standard policies	Objective, systematic, and quantifiable
Risk Response	Reactive (awaits the occurrence of failures)	Proactive (identifies prospective failures prior to their occurrence)
Prioritization & Scheduling	Manual scheduling and operational availability are the determining factors.	Prioritized according to the business impact, reliability, and risk ranking
Resource Alignment	Less optimal, it may result in bottlenecks or inactive time.	More optimal, taking into account operational constraints and technical capabilities

CONCLUSION

This study presents an integrated decision-making model that optimizes the timing of storage tank cleaning and inspection company in Central Java by combining predictive maintenance with data mining and operational prioritization via the Analytical Hierarchy Process (AHP). The predictive model created using RapidMiner, classified tank conditions with 94% accuracy, while AHP analysis demonstrated that technical condition (24.4%) and overdue cleaning (18.4%) are the most relevant aspects in decision-making. The resultant composite scoring model enables proactive, risk-based maintenance planning that considers both asset integrity and operational restrictions, boosting dependability, reducing interruptions, and increasing resource efficiency. It is recommended that future studies explore the integration of real-time monitoring systems with this model to enhance the accuracy and responsiveness of maintenance decisions.

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