



Optimization Strategy for Power Plant Asset Management Using Reliability Analysis and Life Cycle Cost: Case Study of Steam-Dominated Geothermal Power Plant Unit 1 at PT RST

Adam Kusuma Wardana*, Raden Dadan Ramdan & M. Ali Ashat

Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung
Jl. Ganesha No.10, Bandung, West Java, Indonesia. 40132

*Email: 22623025@mahasiswa.itb.ac.id

Abstract. PT RST is one of the largest power generation companies in Southeast Asia, with a total capacity of 21.08 GW. One of its units, the Steam-Dominated Geothermal Power Plant Unit 1, has been operating for over 40 years, presenting increasing challenges in maintaining reliability and cost efficiency. The aging condition of critical equipment in this facility necessitates a strategic asset management approach to support informed decision-making in maintenance and replacement planning.

This study integrates reliability analysis with economic life assessment to develop an optimized strategy for equipment replacement. The Equivalent Uniform Annual Cost (EUAC) is used to determine the most economical service life of each equipment unit, while the reliability index is calculated using a Weibull-based Non-Homogeneous Poisson Process (NHPP) model via AeROS software. Key input variables include equipment failure history, repair time, downtime, acquisition cost, and operation and maintenance (O&M) costs.

By combining cost and reliability indicators, a structured equipment replacement strategy is formulated, classifying assets into four categories: retain, prepare for replacement, immediate analysis required, and further evaluation. This integrated approach supports data-driven asset management decisions and contributes to improved performance and reduced electricity production costs at Steam-Dominated Geothermal Power Plant Unit 1.

Keywords: *Reliability Index, Equivalent Uniform Annual Cost, Weibull-NHPP, Economic Life, Asset Replacement Strategy*

1 Introduction

PT RST is one of the largest power generation companies in Southeast Asia, with a total installed capacity of 21.08 GW. Its operations span across conventional and renewable energy sectors, including several geothermal power plants. One of its facilities, the Steam-Dominated Power Plant Unit 1, has been operating for more than 40 years. This long operational period presents significant challenges

in terms of equipment degradation, increased maintenance frequency, and rising operational costs. As assets age, balancing depreciation and rising maintenance costs becomes crucial in asset replacement decisions.

To support these decisions, a combination of reliability analysis and life cycle cost assessment provides a quantitative framework. Reliability analysis evaluates the frequency and distribution of failures, as well as the effectiveness of maintenance activities, using historical data such as downtime, repair time, and failure modes. In parallel, economic life is assessed using the Equivalent Uniform Annual Cost (EUAC) method, which calculates the annualized cost over the asset's operational life by incorporating acquisition, operation, and maintenance costs.

Previous research, such as that conducted by Anugrah & Suef [1], has successfully applied this integrated approach in a Combined Cycle Power Plant. However, such an approach has not yet been applied to Geothermal Power Plant which present distinct operational characteristics and maintenance profiles.

This study aims to address this gap by developing a structured equipment replacement strategy for Steam-Dominated Geothermal Power Plant Unit 1 at PT RST. The strategy integrates Weibull-based NHPP reliability modeling and EUAC analysis to classify critical equipment into strategic categories for replacement planning. The resulting framework supports asset management decisions that improve plant performance and contribute to reducing the basic cost of electricity supply.

2 Literature Review

Effective asset management in the power generation sector requires a strategic balance between reliability and cost efficiency, especially for aging infrastructure such as geothermal units operating beyond their original design life. Various methodologies have been proposed in the literature to support maintenance and replacement decisions, particularly by integrating reliability modeling with life cycle cost analysis. Effective asset management in power generation demands a strategic balance between reliability and cost, especially for aging geothermal units that exceed their original design life. Numerous methods have been developed to support maintenance and replacement decisions, notably by combining reliability analysis with life cycle cost evaluation.

Reliability modeling offers a quantitative basis to assess equipment degradation over time. Core concepts such as failure rate trends and MTTF are elaborated in the works of Ebeling [3] and Elsayed [6], where Weibull distribution models are widely used to describe time-dependent failures. These models are extended

through NHPP formulations, suitable for systems under progressive degradation and imperfect maintenance—typical conditions in mature geothermal facilities.

In parallel, life cycle cost (LCC) analysis supports decisions on whether to retain or replace aging assets. Barringer [4] highlights that initial procurement cost is only a fraction of total ownership cost, with O&M and disposal expenses dominating. He advocates LCC as an engineering tool to reveal hidden long-term costs and support better asset planning.

Cesca and Novaes [2] introduced a non-smooth optimization approach using Equivalent Property Cost (EPC) to determine replacement timing for physical assets, addressing irregular cost behaviors without relying on the EUAC model. Their method enables greater modeling flexibility for real-world industrial applications.

Chowdhury and Raghavan [5] developed a comprehensive Life Cycle Management (LCM) framework for thermal and nuclear plants, integrating reliability modeling, failure mode analysis, and NPV-based evaluations. While focused on non-geothermal systems, their framework is adaptable to geothermal environments that face similarly high performance and cost constraints.

Anugrah and Suef [1] combined reliability and EUAC analysis to guide replacement strategy in a Combined Cycle Power Plant. Their classification scheme, based on technical and economic thresholds, supports prioritization in asset replacement planning. However, this method has not yet been applied to Geothermal Power Plant, which exhibit unique operational and maintenance profiles.

This study extends prior work by adapting an integrated reliability–economic life framework specifically for Steam-Dominated Power Plant Unit 1 at PT RST. The proposed method addresses both technical degradation and cost efficiency, offering a tailored solution for geothermal systems in emerging energy markets.

3 Method

The optimization strategy in this study aims to determine the most appropriate timing for equipment replacement by jointly evaluating economic viability and reliability performance. The key decision variables are the reliability index, derived from a Weibull-based Non-Homogeneous Poisson Process (NHPP), and the Equivalent Uniform Annual Cost (EUAC), which is calculated from acquisition cost, increasing operation and maintenance (O&M) expenses, and a specified discount rate.

Rather than applying algorithmic optimization, this study employs a criteria-based evaluation framework that facilitates practical and intuitive decision-making. Each equipment unit is assessed based on the intersection of its technical reliability and economic service life, allowing for structured classification into replacement priority categories. This dual-criteria approach supports effective asset management, particularly in aging geothermal power systems.

The methodology is outlined in Figure 1, which summarizes the major stages: (1) identifying critical equipment, (2) collecting failure and cost data, (3) computing reliability indices and EUAC values, and (4) analyzing results to formulate a replacement strategy consistent with the study objectives.

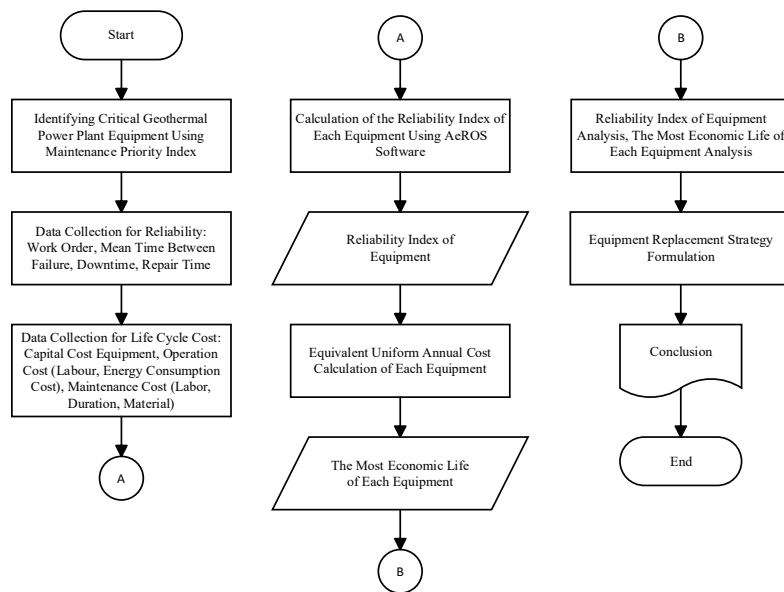


Figure 1 Research Methodology.

3.1 Data Collection

The data collection process was conducted through expert interviews and document analysis. The identification of critical equipment at the Steam-Dominated Geothermal Power Plant was carried out by reviewing the Maintenance Priority Index document and engaging in discussions with field engineers. Once the critical equipment was identified, supporting data were collected to calculate the Reliability Index and the Equivalent Uniform Annual Cost (EUAC) for each piece of equipment.

For the calculation of the equipment reliability index, the following data were collected:

1. Equipment failure history (Work Orders)
2. Mean Time Between Failures (MTBF)
3. Downtime durations
4. Repair times

For Life Cycle Cost, to compute the Equivalent Uniform Annual Cost (EUAC) of equipment, the following data were obtained:

1. Equipment capital cost
2. Operating costs, including labor cost and energy consumption costs:
3. Maintenance costs, categorized as:
 - a. Corrective maintenance costs (labor costs, work duration, material costs)
 - b. Overhaul maintenance costs (labor costs, work duration, material costs)
 - c. Preventive maintenance costs (labor costs, work duration, material costs)
 - d. Predictive maintenance costs (labor costs, work duration)

3.2 Data Processing

At this stage, the reliability and EUAC values of each equipment are calculated. The reliability analysis is conducted to obtain the Reliability Index, while the EUAC calculation aims to determine the most economical year in the equipment's life cycle.

3.2.1 Reliability Index Calculation

The equipment reliability index in this study is calculated using AeROS software. After obtaining equipment failure history data (Work Orders), which includes failure types, failure durations, and repair durations, a data validation process is carried out. The reliability index calculation is then performed only for the failure types that result in downtime (when the equipment is unable to operate). Following validation, the time between failures for each piece of equipment is entered into the AeROS software. The distribution used in AeROS is the Weibull-based NHPP (Non-Homogeneous Poisson Process), as it is well-suited for time-varying failure types and because repairs do not restore the system to a “like-new” condition. The mathematical formulation is presented as follows:

Cumulative Intensity Function of NHPP:

$$\Lambda(t) = \left(\frac{t}{\eta}\right)^\beta \quad (1)$$

Where:

- $\Lambda(t)$ = expected cumulative number of failures up to time t
- t = system operating time
- η = scale parameter of the Weibull distribution ($\eta > 0$)
- β = shape parameter of the Weibull distribution ($\beta > 0$)

Conditional Reliability Function of NHPP:

$$R(t | T_n) = \exp \left[- \left(\left(\frac{T_n+t}{\eta} \right)^\beta - \left(\frac{T_n}{\eta} \right)^\beta \right) \right] \quad (2)$$

Where:

- $R(t | T_n)$ = probability that the system survives the next mission time t
- T_n = current system age (cumulative operating time)
- t = mission time for reliability prediction
- η = scale parameter
- β = shape parameter

Failure Intensity Function:

$$\lambda(t) = \frac{d\Lambda(t)}{dt} = \beta \cdot \frac{t^{\beta-1}}{\eta^\beta} \quad (3)$$

Where:

- $\lambda(t)$ = instantaneous failure rate at time t
- $\Lambda(t)$ = expected cumulative number of failures up to time t

Mean Time Between Failures (MTBF):

$$MTBF = \eta \cdot \Gamma \left(1 + \frac{1}{\beta} \right) \quad (4)$$

Where:

- MTBF = mean time between two consecutive failures
- $\Gamma(.)$ = Euler Gamma function

3.2.2 EUAC (Equivalent Uniform Annual Cost) Calculation

This stage aims to identify the minimum EUAC value, which represents the most economical service life of the equipment. The EUAC calculations are performed by projecting costs over the expected operational life of the plant, which extends to the year 2047.

The EUAC is calculated using the following formula:

$$EUAC = \text{Annual O\&M Cost} + \text{Annual Acquisition Cost} \quad (5)$$

Annual O&M Cost is calculated using the formula:

$$\text{Annual O\&M Cost} = (\Sigma \text{Operation Cost} + \Sigma \text{Maintenance Cost}) \times (A/P, i, n) \quad (6)$$

Where:

(A/P, i, n) = Capital Recovery Factor

Annual Acquisition Cost is calculated using the formula:

$$\text{Annual Acquisition Cost} = \text{Capital Cost} \times (A/P, i, n) \quad (7)$$

3.2.3 Operation Cost Formula

The operational cost of equipment consists of labor costs and electricity consumption costs. The formula for calculating the operational cost is as follows:

$$\Sigma \text{Operation Cost} = \Sigma \text{Salary} \left(\frac{\text{Capital}_{\text{equipment}}}{\text{Capital}_{\text{plant}}} \right) \times \Sigma \text{Electricity Consumption Cost} \quad (8)$$

3.2.4 Maintenance Cost Formula

At PT RST, several types of maintenance activities are implemented, including Preventive Maintenance (PM), Predictive Maintenance (PdM), Corrective Maintenance (CM), and Overhaul (OH). The total annual maintenance cost incurred by each piece of equipment is calculated using the following formula:

$$\Sigma \text{Maintenance Cost} = \Sigma \text{Material} + \Sigma \text{Labor} \quad (9)$$

$$\begin{aligned} \Sigma \text{Maintenance Cost} = & \left(F(t) \times t_{\text{repair}}^{n_{\text{operator}}} \right) + \\ & (PM_{\text{interval}} \times PM_{\text{duration}} \times PM_{\text{operation}}) + \\ & (PdM_{\text{interval}} \times PdM_{\text{duration}} \times PdM_{\text{operation}}) + \\ & (OH_{\text{interval}} \times OH_{\text{duration}} \times OH_{\text{operation}}) \times \left(\frac{Rp}{\text{hour}} \right) \end{aligned} \quad (10)$$

3.3 Data Analysis

At this stage, the results of the reliability index and EUAC calculations are jointly analyzed to determine maintenance priorities and classify equipment into

strategic categories—such as replacement, continued operation, or further evaluation. This classification is based on the replacement strategy developed by Anugrah and Suef [1], which integrates reliability and economic thresholds to guide asset management decisions.

Equipment with reliability indices below a defined threshold and approaching or exceeding their optimal economic life are designated as replacement candidates. Conversely, units that remain within acceptable technical and economic limits are either retained or subjected to further maintenance evaluation, depending on their position relative to the threshold boundaries. These assessments culminate in a mapped classification of all equipment units, providing a comprehensive overview of their technical and economic conditions.

The optimization strategy employed here is not a mathematical minimization of a single objective function, but rather a structured decision-support mechanism that identifies equipment requiring action based on dual criteria. This approach ensures that replacement decisions are both technically justified and economically efficient.

4 Results and Discussion

A steam-dominated geothermal system comprises a structured configuration of equipment that enables the conversion of geothermal energy into electricity. This system includes both critical and supporting equipment. In this study, the research focuses on the critical equipment at Unit 1 of the Steam-Dominated Geothermal Power Plant, as presented in Table 1.

Table 1 Critical Equipments of Unit 1.

No.	Asset Code	Equipment
1	RST11PAD01AC001-001	(A) COOLING TOWER CELL 01 UNIT 1
2	RST11PAD02AC001-001	(A) COOLING TOWER CELL 02 UNIT 1
3	RST11PAD03AC001-001	(A) COOLING TOWER CELL 03 UNIT 1
4	RST11PAC01AP001-001	CIRCULATING (MAIN COOLING) WATER PUMP 01 UNIT 1
5	RST11PAC02AP001-001	CIRCULATING (MAIN COOLING) WATER PUMP 02 UNIT 1
6	RST11MAA11AA011-001	MAIN STEAM CONTROL VALVE 01 UNIT 1
7	RST11MAA12AA011-001	MAIN STEAM CONTROL VALVE 02 UNIT 1
8	RST11MAC10HA101-001	(A) TURBINE UNIT 1
9	RST11MKC20GH002-001	CABINET FOR AUTOMATIC VOLTAGE REGULATOR 1 (AVR1) UNIT 1
10	RST11MKB43GH001-001	ROTATING DIODES MONITORING SYSTEM UNIT 1
11	RST11MKA10HA001-001	(A) GENERATOR UNIT 1
12	RST11MKA10HA002-001	STATOR GENERATOR UNIT 1
13	RST11MKA10HA003-001	ROTOR GENERATOR UNIT 1
14	RST11BAT10GT001-001	(A) MAIN TRANSFORMER T1 (11BAT10) UNIT 1
.....
204	RST11QFA31AT004-001	AIR DRYER UNIT 02 VESSEL UNIT 1

The selection of critical equipment is based on the Main Priority Index provided by PT RST. Subsequently, the failure history of the identified critical equipment was examined over the period from 2017 to 2024. Using Pareto analysis, the ten

most failure-prone units were selected from a total of 204 critical equipment items, as detailed in Table 2.

Table 2 The Most Failure-Prone Critical Equipments of Unit 1.

Asset Code	Equipment	Number of Downtimes
RST11PAD02AC001-001	(A) COOLING TOWER CELL 02 UNIT 1	10
RST11SCA01AN001-001	AIR COMPRESSOR 01 UNIT 1	9
RST11MAV91AT001-001	LUBE OIL PURIFIER UNIT 1	7
RST11QFA31AT004-001	AIR DRYER UNIT 02 VESSEL UNIT 1	6
RST11SCA02AN001-001	AIR COMPRESSOR 02 UNIT 1	5
RST11MAA12AA001-001	MAIN STEAM STOP VALVE 02 UNIT 1	4
RST11MKC20GH002-001	CABINET FOR AUTOMATIC VOLTAGE REGULATOR 1 (AVR1) UNIT 1	4
RST11PAC01AP001-001	CIRCULATING (MAIN COOLING) WATER PUMP 01 UNIT 1	4
RST11PAD03AC001-001	(A) COOLING TOWER CELL 03 UNIT 1	4
RST11PAD01AC001-001	(A) COOLING TOWER CELL 01 UNIT 1	3

It is observed that equipment Cooling Tower Cell 02 Unit 1, experienced the highest number of failures during the observation period, with a total of 10 occurrences. In the subsequent analysis, this critical equipment will be further examined with respect to reliability parameters, operating and maintenance costs, as well as capital costs, in order to estimate its Equivalent Uniform Annual Cost (EUAC).

4.1 Reliability Index Analysis

Calculating the equipment reliability index requires historical failure data, including the number of failures, their durations, and time intervals between them. These inputs are essential for determining the appropriate failure distribution in the reliability analysis. As an example, Figure 2 presents the failure history of Cooling Tower Cell 02 Unit 1 during the 2017–2024 observation period. The time-between-failure data from this record is used as input in AeROS software to compute the equipment’s reliability index.

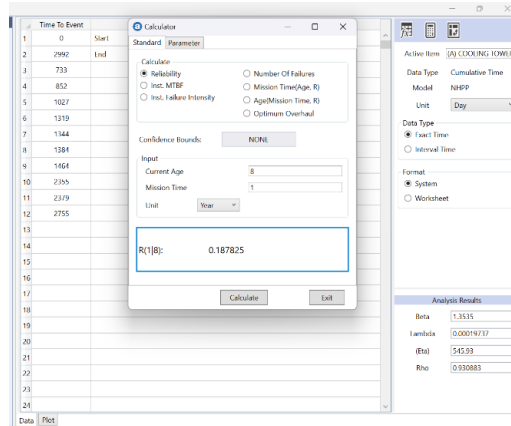


Figure 2 Reliability Index Calculation on AeROS.

In the AeROS software, the input data include the initial operational time of the equipment, designated as day 0 (January 1, 2017), the final observation time at day 2922 (December 31, 2024), and the “time-to-event” data representing the specific days on which failures occurred. Once the data are entered, the software performs calculations to estimate the distribution parameter values. AeROS automatically selects the most appropriate probability distribution that best fits the failure data. Given that the failure modes vary over time and that repairs do not restore the equipment to a “like-new” condition, the Weibull-based Non-Homogeneous Poisson Process (NHPP) distribution is applied. The resulting distribution parameters derived from the analysis are presented in Table 3.

The parameters obtained from the AeROS calculation and iteration process are then automatically utilized to compute the reliability index of the critical equipment at Steam-Dominated Geothermal Power Plant Unit 1. This reliability index reflects the projected reliability performance for the year 2025. The calculated reliability index values for each critical equipment unit are presented in Table 4.

Table 3 Distribution Types and Distribution Parameters Used in AeROS.

Asset Code	Equipment	Distribution Type	Distribution Parameter
RST11PAD02AC001-001	(A) COOLING TOWER CELL 02 UNIT 1	NHPP	Beta: 1.3535 Lambda: 0.00019737 Eta: 545.93 Rho: 0.930883
RST11SCA01AN001-001	AIR COMPRESSOR 01 UNIT 1	NHPP	Beta: 2.72906 Lambda: 3.13462E-09 Eta: 1306.23 Rho: 0.988309
RST11MAV91AT001-001	LUBE OIL PURIFIER UNIT 1	NHPP	Beta: 1.1844 Lambda: 0.000458388 Eta: 659.112 Rho: 0.859263
RST11QFA31AT004-001	AIR DRYER UNIT 02 VESSEL UNIT 1	NHPP	Beta: 1.22042 Lambda: 0.000353634 Eta: 673.089 Rho: 0.910878
RST11SCA02AN001-001	AIR COMPRESSOR 02 UNIT 1	NHPP	Beta: 0.850407 Lambda: 0.00564586 Eta: 440.308 Rho: 0.938183
RST11MAA12AA001-001	MAIN STEAM STOP VALVE 02 UNIT 1	NHPP	Beta: 0.994676 Lambda: 0.00142834 Eta: 725.1 Rho: 0.751765
RST11MKC20GH002-001	CABINET FOR AUTOMATIC VOLTAGE REGULATOR 1 (AVR1) UNIT 1	NHPP	Beta: 0.933998 Lambda: 0.00226735 Eta: 678.198 Rho: 0.884147
RST11PAC01AP001-001	CIRCULATING (MAIN COOLING) WATER PUMP 01 UNIT 1	NHPP	Beta: 0.660024 Lambda: 0.0203162 Eta: 366.254 Rho: 0.876108
RST11PAD03AC001-001	(A) COOLING TOWER CELL 03 UNIT 1	NHPP	Beta: 2.10739 Lambda: 1.98843E-07 Eta: 1513.53 Rho: 0.883173
RST11PAD01AC001-001	(A) COOLING TOWER CELL 01 UNIT 1	NHPP	Beta: 2.56987 Lambda: 3.50227E-09 Eta: 1951.2 Rho: 0.874255

Table 4 Reliability Index for Critical Equipments.

Asset Code	Equipment	Reliability Index
RST11PAD02AC001-001	(A) COOLING TOWER CELL 02 UNIT 1	0.18
RST11SCA01AN001-001	AIR COMPRESSOR 01 UNIT 1	0.03
RST11MAV91AT001-001	LUBE OIL PURIFIER UNIT 1	0.42
RST11QFA31AT004-001	AIR DRYER UNIT 02 VESSEL UNIT 1	0.39
RST11SCA02AN001-001	AIR COMPRESSOR 02 UNIT 1	0.6
RST11MAA12AA001-001	MAIN STEAM STOP VALVE 02 UNIT 1	0.61
RST11MKC20GH002-001	CABINET FOR AUTOMATIC VOLTAGE REGULATOR 1 (AVR1) UNIT 1	0.63
RST11PAC01AP001-001	CIRCULATING (MAIN COOLING) WATER PUMP 01 UNIT 1	0.72
RST11PAD03AC001-001	(A) COOLING TOWER CELL 03 UNIT 1	0.32
RST11PAD01AC001-001	(A) COOLING TOWER CELL 01 UNIT 1	0.37

4.2 EUAC Analysis

To calculate the Equivalent Uniform Annual Cost (EUAC) of critical equipment at the Steam-Dominated Geothermal Power Plant Unit 1, several historical data inputs are required. These include the asset acquisition cost and detailed operation and maintenance (O&M) costs, which consist of both operational expenditures and maintenance-related expenses. The acquisition cost refers to the total expenditure incurred by the company at the time of asset procurement and is recorded as the initial book value. This value is then used to compute the Annualized Acquisition Cost for each equipment unit, forming the basis of the EUAC curve. In this study, acquisition cost data are taken from historical records in 2017, as the EUAC analysis spans a 30-year period from 2017 to 2047.

The O&M cost captures the total operational burden borne by the equipment over its lifecycle. Operational costs in this context include labor allocation per equipment unit and electricity consumption, while maintenance costs cover corrective, preventive, predictive, and overhaul activities. By consolidating these cost components and applying the EUAC formula, a representative computation for Cooling Tower Cell 02 Unit 1 is illustrated in Table 5 to demonstrate the annualized cost trend over time.

The minimum EUAC value for equipment Cooling Tower Cell 02 Unit 1 occurs in the year 2023. This indicates that 2023 represents the most economical service life of the equipment, with a minimum EUAC of Rp1,239,743,058. Using the same calculation method, the EUAC results for the remaining critical equipment are summarized in Table 6.

Table 5 EUAC Calculation for Cooling Tower Cell 02 Unit 1

Year	O&M Cost	Present Value (P/F, i, n)	Capital Recovery Factor (A/P,i,n)	Annualized O&M cost	Acquisition Cost	Annualized Acquisition Cost	EUAC
2017	Rp864,829,457	Rp800,768,016	1.08	Rp864,829,457	Rp950,026,448	Rp1,064,029,622	Rp1,928,859,079
2018	Rp925,813,903	Rp1,594,504,215	0.56	Rp894,148,902		Rp562,128,857	Rp1,456,277,759
2019	Rp1,049,253,321	Rp2,427,435,330	0.39	Rp941,926,261		Rp395,542,543	Rp1,337,468,804
2020	Rp1,407,553,293	Rp3,462,029,020	0.30	Rp1,045,258,587		Rp312,781,422	Rp1,358,040,009
2021	Rp984,351,377	Rp4,131,962,027	0.25	Rp1,034,876,560		Rp263,546,582	Rp1,298,423,142
2022	Rp995,032,117	Rp4,759,001,046	0.22	Rp1,029,445,149		Rp231,070,865	Rp1,260,516,015
2023	Rp1,048,453,083	Rp5,370,763,349	0.19	Rp1,031,575,414		Rp208,167,644	Rp1,239,743,058
2024	Rp1,519,280,962	Rp6,191,583,580	0.17	Rp1,077,426,934		Rp191,243,023	Rp1,268,669,958
2025	Rp1,108,713,958	Rp6,746,216,592	0.16	Rp1,079,932,390		Rp178,299,908	Rp1,258,232,298
2026	Rp1,141,252,188	Rp7,274,837,174	0.15	Rp1,084,165,264		Rp168,139,637	Rp1,252,304,901
2027	Rp1,174,766,565	Rp7,778,674,417	0.14	Rp1,089,608,259		Rp159,999,088	Rp1,249,607,347
2028	Rp1,687,734,321	Rp8,448,896,937	0.13	Rp1,121,126,522		Rp153,369,237	Rp1,274,495,759
2029	Rp1,244,665,166	Rp8,906,557,735	0.13	Rp1,126,873,763		Rp147,897,453	Rp1,274,771,215
2030	Rp1,281,281,932	Rp9,342,784,316	0.12	Rp1,133,250,334		Rp143,331,674	Rp1,276,582,008
.....
2047	Rp2,100,908,470	Rp14,773,624,538	0.09	Rp1,301,663,935		Rp117,505,025	Rp1,419,168,960

Table 6 Minimum EUAC and The Most Economical Service Life of Critical Equipments.

Asset Code	Equipment	The Most Economical Service Life	EUAC Minimum
RST11PAD01AC001-001	(A) COOLING TOWER CELL 01 UNIT 1	2023	Rp1,219,519,388
RST11PAD02AC001-001	(A) COOLING TOWER CELL 02 UNIT 1	2023	Rp1,239,743,058
RST11PAD03AC001-001	(A) COOLING TOWER CELL 03 UNIT 1	2023	Rp1,251,094,518
RST11SCA01AN001-001	AIR COMPRESSOR 01 UNIT 1	2031	Rp575,459,354
RST11SCA02AN001-001	AIR COMPRESSOR 02 UNIT 1	2031	Rp566,394,030
RST11QFA31AT004-001	AIR DRYER UNIT 02 VESSEL UNIT 1	2039	Rp68,052,059
RST11MAV91AT001-001	LUBE OIL PURIFIER UNIT 1	2035	Rp730,842,001
RST11MAA12AA001-001	MAIN STEAM STOP VALVE 02 UNIT 1	2031	Rp254,461,377
RST11MKC20GH002-001	CABINET FOR AUTOMATIC VOLTAGE REGULATOR 1 (AVR1) UNIT 1	2043	Rp780,532,900
RST11PAC01AP001-001	CIRCULATING (MAIN COOLING) WATER PUMP 01 UNIT 1	2027	Rp3,599,814,977
RST11MAA11AA504-001	CONTROL VALVE 01 SLOW CLOSE SOLENOID VALVE UNIT 1	2047	Rp127,253,845

4.3 Formulating Equipment Replacement Strategy

In 2020, Anugrah and Suef [1] developed an equipment replacement strategy for a Combined Cycle Power Plant by defining parameter thresholds for evaluating replacement decisions, specifically the reliability index limit and the economic life threshold. The reliability index limit represents the minimum reliability value at which equipment is considered acceptable for continued operation without requiring maintenance reassessment. The economic life threshold defines the range of years used to determine whether equipment should remain in operation, be prepared for replacement, or replaced immediately.

The reliability index limit was established through simulations of optimal overhaul timing for critical components. This process compared corrective maintenance costs with overhaul costs, and the reliability index at each optimum overhaul point was averaged across components, resulting in a recommended threshold of 0.6. Equipment with a reliability index below this value requires evaluation of its maintenance strategy.

The economic life threshold refers to internal planning cycles at the company, particularly the Unit Long-Term Planning Document (valid for 5 years) and the Unit Budget Work Plan (prepared annually). Based on this, the acceptable gap between calculated economic life and the observation year is set between 1 and 5 years.

Although originally developed for a Combined Cycle Plant, the strategy is applicable to other plant types. In this study, the framework is adapted for implementation at the Geothermal Power Plant, as illustrated in Figure 3.

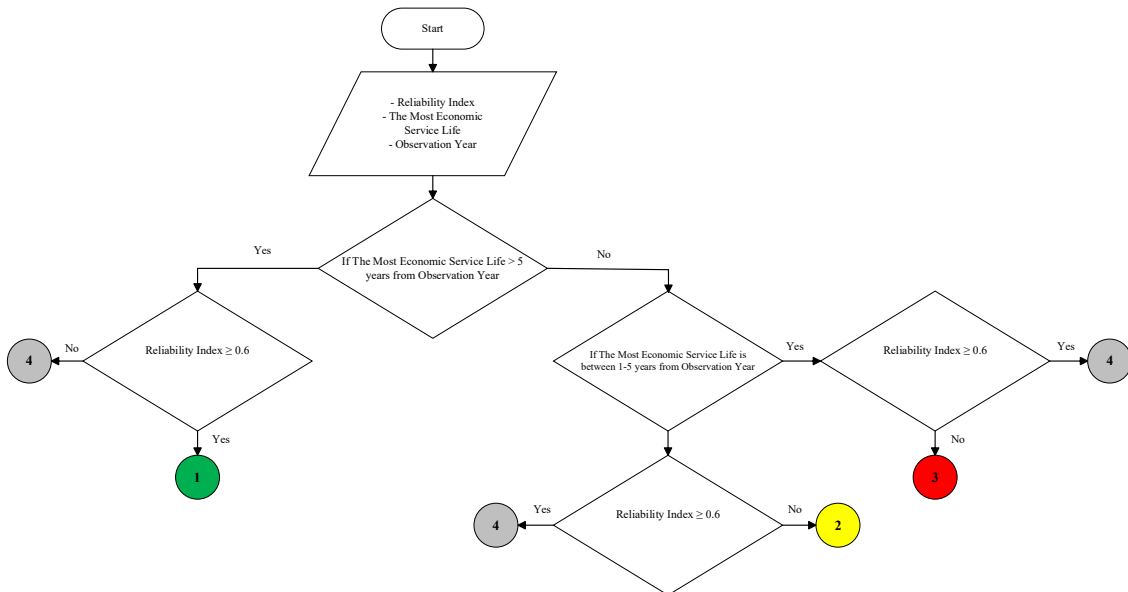


Figure 3 Flowchart Diagram of Equipment Replacement Strategy.

Based on the flowchart, equipment is classified into four strategic categories. Each classification is associated with a specific maintenance or replacement approach:

- a. Category 1 – Keep and Improve / Keep as It Is
Equipment in this category can continue operating with existing maintenance practices or minor improvements, without requiring further replacement analysis.
- b. Category 2 – Prepare for Replacement Analysis
Equipment under this category should be scheduled for replacement planning and further evaluation.
- c. Category 3 – Do Replacement Analysis Immediately
Equipment in this category requires immediate analysis to proceed with the replacement process.

d. Category 4 – Need Future Analysis

This category represents uncertain cases where the equipment condition requires further assessment. Several evaluations can be conducted, including:

- Review of corrective and scheduled maintenance, focusing on cost structure and reliability impact.
- Assessment of project history and operational costs, including internal consumption and efficiency losses.
- Optimization of maintenance strategy if current efforts fail to improve reliability.

Based on the results of the strategy formulation, the condition of each critical equipment unit at the Steam-Dominated Geothermal Power Plant Unit 1 can be mapped according to the defined parameters, as presented in Table 7.

Table 7 Classification of Unit 1 Critical Equipments.

Asset Code	Equipment	Reliability Index	The Most Economical Service Life	Classification
RST11PAD01AC001-001	(A) COOLING TOWER CELL 01 UNIT 1	0.37	2023	3
RST11PAD02AC001-001	(A) COOLING TOWER CELL 02 UNIT 1	0.17	2023	3
RST11PAD03AC001-001	(A) COOLING TOWER CELL 03 UNIT 1	0.32	2023	3
RST11SCA01AN001-001	AIR COMPRESSOR 01 UNIT 1	0.04	2031	4
RST11SCA02AN001-001	AIR COMPRESSOR 02 UNIT 1	0.6	2031	1
RST11QFA31AT004-001	AIR DRYER UNIT 02 VESSEL UNIT 1	0.39	2039	4
RST11MAV91AT001-001	LUBE OIL PURIFIER UNIT 1	0.42	2035	4
RST11MAA12AA001-001	MAIN STEAM STOP VALVE 02 UNIT 1	0.61	2031	1
RST11MKC20GH002-001	CABINET FOR AUTOMATIC VOLTAGE REGULATOR 1 (AVR1) UNIT 1	0.63	2043	1
RST11PAC01AP001-001	CIRCULATING (MAIN COOLING) WATER PUMP 01 UNIT 1	0.72	2027	4
RST11MAA11AA504-001	CONTROL VALVE 01 SLOW CLOSE SOLENOID VALVE UNIT 1	0.58	2047	4

The analysis reveals a clear divergence in equipment reliability and economic performance. Cooling Tower Cell 01, 02, and 03 (Category 3) show both low reliability indices (<0.6) and EUAC values indicating they’ve exceeded their economic life—making them strong candidates for immediate replacement. Their inefficiencies likely contribute to higher auxiliary consumption and unplanned downtimes, impacting plant availability.

In contrast, Air Compressor 02 and AVR Cabinet 1 (Category 1) maintain high reliability and remain within economic service life. While continued operation is justified, minor performance improvements—such as enhanced predictive maintenance—may sustain reliability.

Category 4 includes assets like Circulating Water Pump 01 and Lube Oil Purifier, with marginal reliability and EUAC nearing current year projections. Though not immediate replacement candidates, these units require monitoring, as rising O&M costs may signal underlying inefficiencies that could escalate future costs.

Overall, this classification model acts as a strategic tool linking technical condition with economic metrics, guiding replacement and maintenance

planning. It also supports regulatory goals for cost efficiency, especially for aging assets beyond warranty coverage.

5 Conclusion

Historical failure data causing equipment downtime were analyzed to obtain failure distribution parameters, which were then used to evaluate degradation trends and compute the annual reliability index of each critical asset. This index reflects both equipment performance and maintenance effectiveness, serving as a key input for replacement decisions.

In parallel, the Equivalent Uniform Annual Cost (EUAC) was calculated based on acquisition cost and annual O&M expenses, allowing identification of each equipment's economic life. By integrating reliability and economic indicators, threshold criteria were established to classify asset condition and replacement urgency.

The resulting strategy categorizes equipment into four groups: (1) Keep and Improve / Keep as It Is, (2) Prepare for Replacement Analysis, (3) Do Replacement Analysis Immediately, and (4) Need Future Analysis—thus supporting structured, data-driven decision-making in maintenance and replacement planning.

References

- [1] Anugrah, G.B. & Suef, M., *Reliability Analysis and Economic Life Calculation for Asset Management Optimization (Case Study in Steam Power Generation Unit at XYZ Company)*, 2020. (Journal)
- [2] Cesca, I.G. & Novaes, D.D., *Physical Assets Replacement: an Analytical Approach*, Universidade Estadual de Campinas, 2012. (Journal)
- [3] Ebeling, C.E., *An Introduction to Reliability and Maintainability Engineering*, Singapore: The McGraw-Hill Companies, Inc., 1997. (Book)
- [4] Barringer, P., *Life Cycle Cost and Good Practices*, San Antonio, NPRA Maintenance Conference, 1998. (Journal)
- [5] Chowdhury, B. & Raghavan, S., *Developing Life Cycle Management Plans for Power Plant Components*, U.S: North American Power Symposium, 2008. (Journal)
- [6] Elsayed, E.A., *Reliability Engineering*. Second ed. USA: John Wiley & Sons, Inc., Hoboken, New Jersey, (2012). (Book)