International Conference on Management of Technology, Innovation, and Project (MOTIP) 2020

July 25th 2020, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Reliability Analysis and Economic Life Calculation for Asset Management Optimization (Case Study in Steam Power Generation Unit at XYZCompany)

Gede Bayu Anugrah[1] and Mokhamad Suef[2]

[1]Department of Technology Management, Institut Teknologi Sepuluh Nopember, Surabaya

[2]Department of Industrial and Systems Engineering, Institut Teknologi Sepuluh Nopember, Surabaya

e-mail: wahyu_w@statistika.its.ac.id

***Abstract*—In a competitive market driven industry at a power generation business, requires The electricity producers to provide electricity with a low cost of supply. On the other hand, the large number of equipment assets managed by the power plant companies requires an appropriate asset management process, in order to reduce the increased maintenance and investment costs of equipment which which can cause an increase in the cost of supply. XYZ Company as a company that manages assets of more than Rp 174 trillion has challenges in the process of optimizing its company's asset management. The decreasing amount of maintenance and investment budget in the company each year and the equipment conditions that have been operated for more than 20 years, requires an asset management method that can provide a comprehensive understanding of the technical and economic conditions of each equipment, so it can be provide appropriate information to support the decision making process that is expected to reduce cost of supply.In this study, the authors conducted an analysis of asset conditions at XYZ Company by combining the method of reliability analysis and calculation of the economic life of the equipment. Case study was conducted at one of the units at XYZ Company precisely in Steam Turbine Unit 2.0. The purpose of this study is to obtain comprehensive information including the value of reliability and economic life of each equipment in the unit to facilitate management in the decision making process for the selection of maintenance strategies and asset replacement.Reliability analyzes were performed using RBD, RGA, and Weibull software. Reliability calculation will be done by looking at the amount and time between damages. Economic life calculation is done by calculating the annual equivalent cost. The analysis was performed on each equipment in the Steam Turbine Unit 2.0. From this analysis, it's resulted the procedure for the classification of power plant equipment for the replacement process in accordance with the limits of the parameters of the reliability index and economic lifereliability and economic life conditon. Moreover, It's resulted the mapping of Steam Turbine critical quipment. This mapping illustrates the amount of equipment that must be replaced immediately, still maintained, and the maintenance strategy needs to be evaluated immediately. This information is used by management in deciding the evaluation of equipment maintenance strategies and replacement strategies to reduce the power plant cost of supply.**

***Keywords*—Reliability Analysis, Economic Life, Asset Management, Replacement Strategy.**

I. INTRODUCTION

XYZ Company as a leading Power Plant Company in Indonesia that manages assets of more than Rp 174 trillion and manage more than 30 Power Plant Units has challenges in the process of optimizing its company's asset management. This challenge is in accordance with the strategic goals of XYZ Company to increase Return on Assets (ROA) by 3.2% in 2021. In line with this condition, Gresik Power Plant Unit as one of the largest business units owned by XYZ Company with a total installed capacity of 2,218 MW has the same challenges as optimizing its assets. Gresik Power Plant Units consists of 18 power plant including steam power plants (PLTU), gas power plants (PLTG), and gassteam power plants (PLTGU).

In asset management every equipment has a limited lifetime [1]. Asset management is carried out on the power plant equipment management with the aim of optimizing the function of equipment and supporting costs over the life of the asset. A tool or method is needed that can provide a clear picture related to the reliability of equipment and the use of

Table 1.
Total number of failure of Critical Equipments

Equip No.	Equipment Name	Total Number of Failure
GC0642	Condenser	159
GC0499	Lp Boiler Feed Pump (D)	52
GC0022	Main Transformer	37
GC0497	LP Boiler Feed Pump (B)	36
GC0498	LP Boiler Feed Pump (C)	36
GC0500	HP Boiler Feed Pump (A)	34
GC0864	Sea Water Boster Pump (B)	34
GC0501	HP Boiler Feed Pump (B)	33
GC0863	Sea Water Boster Pump (A)	33

Table 2.
Total number of failure of Critical Equipments

Equip No.	Equipment Name	Failure time	TBF (day)
GC0861	Sea Water Boster Pump (A)	5-Mar-02	794
GC0861	Sea Water Boster Pump (A)	14-Mar-02	9
GC0861	Sea Water Boster Pump (A)	10-Mar-03	361
GC0861	Sea Water Boster Pump (A)	18-Mar-03	8
GC0861	Sea Water Boster Pump (A)	19-Mar-03	1
GC0861	Sea Water Boster Pump (A)	11-Aug-06	1241
GC0861	Sea Water Boster Pump (A)	23-Aug-06	12
…	…	…	…
GC0861	Sea Water Boster Pump (A)	4-Feb-16	528

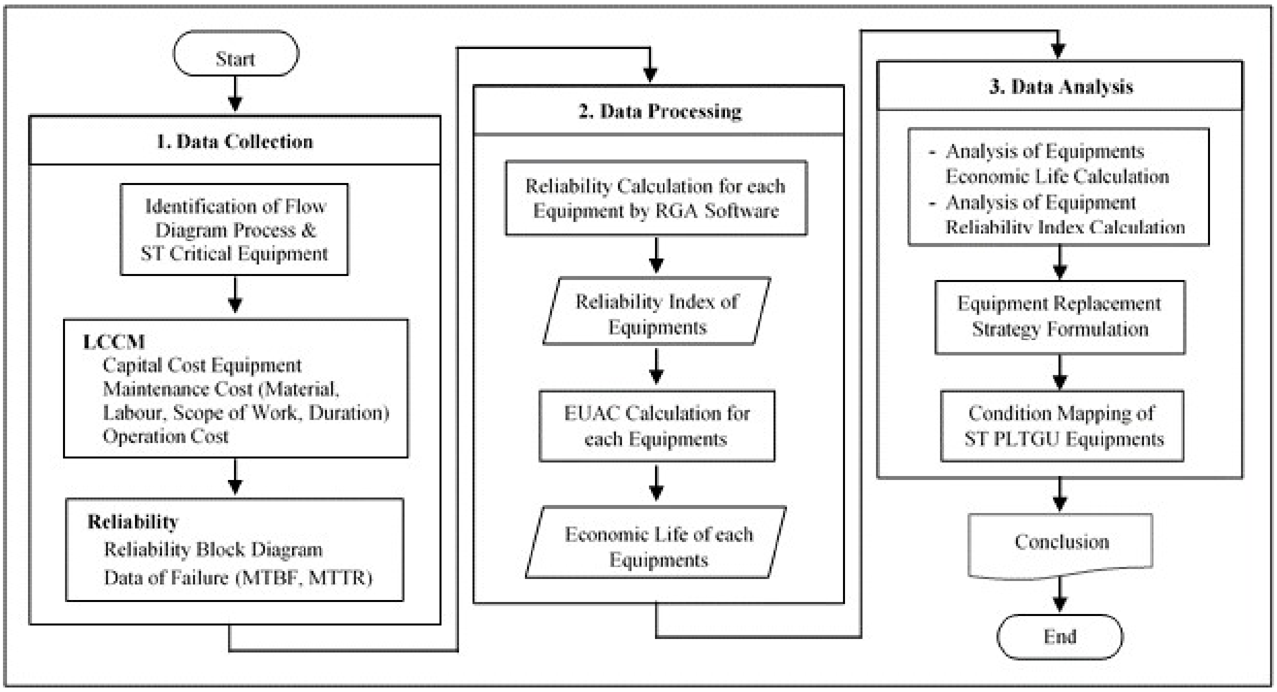

Figure 1. Thesis Methodology.

Figure 2. Economic Life of an Asset.

costs of each equipment owned by the company. So that the asset manager can map the condition of each equipment and be able to make strategic decisions about the equipment condition.

This is very important to implement the strategy for XYZ Company in the intensive competition in Indonesia Power Generation Businesses. Current competition requires each Power Plant unit to be able to do efficiency and reduce the cost of production. In the power generation business, especially in the Gresik Power Plant Unit, two types of costs that greatly affect the composition of the cost of production are investment costs (depreciation) and maintenance costs. Depreciation costs are influenced by the level of investment in new equipment made by the company in previous years, while maintenance costs are the amount of costs incurred for the process of maintaining equipment in the unit. Asset management through monitoring the equipment reliability and the use of costs of each equipment is very important to do at Gresik Power Plant Unit to be able to create more effective maintenance strategies and assist the decision making process in managing assets (repair or replace) which can ultimately reduce the cost of production from power plants.

The trend over the past 5 years show that the Gresik Power Plant Unit's budget allocation for investment costs has declined in order to reduce the cost of production. This becomes a challenge for Gresik Power Plant Unit to be able to optimize the maintenance process of the equipment and allocate investments appropriately. In asset management is know The Economic Life method which can be used to estimate when an asset should be replaced. The calculation of the economic life of an asset can be used to find the point in time where the total annual costs incurred on the asset are minimum [2]. This total annual fee is also known as the Equivalent Annual Cost (EAC). Equivalent annual cost (EAC) is the annual cost of owning and maintaining an asset determined by dividing the net present value of the asset purchase, operations and maintenance cost by the present value of annuity factor [3]. The application of the economic life method calculation for all generating equipment can give a general picture related to the conditions of cost consumption and the optimum replacement time points of each power plant equipment[4]. On the other hand to ensure the performance conditions of each equipment, the reliability calculation can be applied by calculating the duration of time between failure and repair time[5]. Chowdhury and Raghavan research offers

Table 3.
Value & Types of distribution parameter

Equip No.	Equipment Name	*Beta (β)*	*Eta (η)*	Distribution Model
GC0641	Condenser	1,515	5,060,644	2P-Wibull
GC0485	LP Boiler Feed Pump (D)	15,122	481,881	2P-Wibull
GC0019	Main Transformer	12,906	3,726,446	2P-Wibull
GC0483	LP Boiler Feed Pump (B)	13,839	4,502,713	2P-Wibull
GC0484	LP Boiler Feed Pump (C)	14,342	5,904,522	2P-Wibull
GC0862	Sea Water Boster Pump (B)	13,481	10,652,451	2P-Wibull
GC0486	HP Boiler Feed Pump (A)	10,727	1,887,114	2P-Wibull
GC0861	Sea Water Boster Pump (A)	11,429	4,927,144	2P-Wibull
GC0487	HP Boiler Feed Pump	11,078	2,145,814	2P-Wibull

a framework that links the reliability and economic analysis of an asset during the life cycle. The assets examined by Chowdhury & Raghavan (2012) are reliability based assets, which are assets prepared for a specific target of reliability performance [6].

In this study, the writer wants to get a mapping of the reliability condition and equivalent annual cost of the equipment in the Steam Turbine unit of Gresik power Plant Unit. The expected results in this study can later provide an overview of the reliability and equivalent annual cost conditions of each equipment in the Steam Turbine Unit that can be used as a basis for formulating an evaluation of equipment maintenance strategies and decision making towards asse t replacement.

II. METHOD

In this study the methodology used is as in Figure 1, covering the process of collecting and processing data to calculate the reliability Index and the EUAC of equipment that will be used as the basis for strategy formulation, analysis of data processing results and strategy formulation until drawing conclusions to answer the research objectives.

A. Data Collection

Data collection process are carried out using several methods, including conducting documentation studies, observations, interviews and brainstorming. Data collection step is start from identified flow diagram process of Steam Turbine system to determine the critical components and supporting components that will be used to develope block diagram of steam turbine system. From that selection of equipment components, it will be collected supporting data for the calculation process of EUAC variables and equipment

Table 5.
Reliability Index of Critical Equipment in ST 2.0

Equip No.	Equipment Name	Reliability Index
GC0641	Condenser	0,74
GC0485	LP Boiler Feed Pump (D)	0,74
GC0019	Main Transformer	0,72
GC0483	LP Boiler Feed Pump (B)	0,54
GC0484	LP Boiler Feed Pump (C)	0,72
GC0862	Sea Water Booster Pump (B)	0,77
GC0486	HP Boiler Feed Pump (A)	0,07
GC0861	Sea Water Booster Pump (A)	0,4
GC0487	HP Boiler Feed Pump (B)	0,34

reliability. As for the data needed in calculating the EUAC value of the equipment include:

1. Equipment Capital Cost
2. Maintenance Cost (Material,Labour, Scope of Work, Duration)
   a. Corrective Maintenance Cost
   b. Preventive Maintenance Cost
   c. Predictive Maintenance Cost
   d. Overhaul Cost
   e. Project Cost
3. Operation Cost
   a. Energy Consumption
   b. Loss of Output

For Reliability Calculation of each equipment, we do data collection, including:

1. Equipment faiure data (Work Order)
2. Failure clasifiation data
3. Downtime
4. Mean Time Between failure data
5. Repair duration data

Quantitative data that use in this study was taken from an integrated information system owned by XYZ Company.

B. Data Proccesing

At the data processing stage, the EUAC value and equipment reliability are calculated. The EUAC value is calculated to find the economic life of each equipment and the calculation of the reliability value is performed to find the Reliability Index.

1) Reliability Index Calculation

In this study, the reliability index of equipment is calculate using Reliasoft software. In the first step, we collected the failure data of each critical equipment in steam turbine system, The failure data includes failure type data, failure duration, repair time and repair duration. From this failure data we do a validation process, where the reliability calculation is done only on the type of failure that results in downtime (equipment can't operate). After the validation process, then we input that failure data and the time between failure of all the failure data in RGA Software. In the RGA we will select the best type of distribution (The fittest distribution type) for the failure data to calculate the reliability. From this calculation we will get the distribution parameter of Time between failure (TBF) that next will be use to calculate the reliability index. After that, we will calculate the distribution parameter of time to repair (TTR)

Table 4.
Result of TTR Distribution fitting in Weibull++ Software

Equip No.	Equipment Name	Value	Distribution Type
GC0641	Condenser	*Beta: 3,969444* *Eta (hr): 6,469904*	*Weibull 2P*
GC0485	LP Boiler Feed Pump (D)	*Beta: 1,803331* *Eta (hr): 5,614975* *Gamma (hr): 0,71*	*Weibull 3P*
GC0019	Main Transformer	*Beta: 4,37878* *Eta (hr): 8,104923* *Gamma (hr): -0,44*	*Weibull 3P*
GC0483	LP Boiler Feed Pump (B)	*Beta: 3,48041* *Eta (hr): 6,523619* *Gamma (hr): 0,92*	*Weibull 3P*
GC0484	LP Boiler Feed Pump (C)	*Beta: 2,320369* *Eta (hr): 5,632566* *Gamma (hr): 1,435*	*Weibull 3P*
GC0862	Sea Water Boster Pump (B)	*Beta: 1,064119* *Eta (hr): 3,968824* *Gamma (hr): 1,38*	*Weibull 3P*
GC0486	HP Boiler Feed Pump (A)	*Beta: 2,974694* *Eta (hr): 8,307399* *Gamma (hr): -0,315*	*Weibull 3P*
GC0861	Sea Water Boster Pump (A)	*Beta: 2,020625* *Eta (hr): 4,393418* *Gamma (hr): 0,485*	*Weibull 3P*
GC0487	HP Boiler Feed Pump (B)	*Beta: 2,673274* *Eta (hr): 7,011274*	*Weibull 2P*

from the critical equipment in Weibull++ Software. After the value of TBF distribution paramater & TTR distribution parameter was obtained, we draw the equipment block diagram in Blocksim Software to calculate the future estimation of its reliability index. In this study, all of the critical equipment failure data is fit with the weibull distribution. The formula of Weibull distribution is follows as:

$$F(t) = \frac{\beta}{\eta}\left[\frac{t-\gamma}{\eta}\right]^{\beta-1} \exp\left[-\frac{t-\gamma^{\beta}}{\eta}\right] \quad (1)$$

Where:
β = Shape Parameter, β >0
η = Scale Parameter, η >0
γ = Location Parameter

Reliability function of Weibull Distribution :

$$F(t) = \exp\left[-\frac{t-\gamma^{\beta}}{\eta}\right] \quad (2)$$

Laju kegagalan distribusi Weibull:

$$\lambda(t) = \frac{\beta}{\eta}\left[\frac{t-\gamma}{\eta}\right]^{\beta-1} \quad (3)$$

MTBF untuk distribusi Weibull adalah:

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

2) *EUAC Calculation*

The aim of this step is to finding the EUAC value and the economic life of each equipment that is the object of research. EUAC equipment calculations carried out several stages, including:

1. Collecting the parameters that will be used in the EUAC calculation process
2. Inventory the historical data of each parameter that will be used in the calculation (Cost parameters that will be used in this calculation are equipment historical data taken from 2001 - 2018).
3. Perform EUAC calculations by inputting predetermined cost parameters for each equipment. EUAC fee calculation is done using the LCCM HOME App.
4. Plotting an EUAC chart for each equipment.
5. Determine the economic life value of each equipment that is the object of research.

In this study, the EUAC calculation process is carried out by planning horizon up to the projected life span of the power plant in 2056. EUAC is obtained by adding up the value of Annual Operation & Maintenance Costs and Annual Acquisition Cost [8] as shown as figure 2.

The formula of EUAC is,

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

$$Annual\ O\&M\ Cost = \sum Maintenance\ Cost + \sum Operational\ Cost + \sum Consequentiaal\ Cost \quad (6)$$

$$Annual\ Acq\ Cost = Capital\ Cost\ x\ (A/P, i\%, N) \quad (7)$$

3) *Maintenance Cost Formula*

At XYZ Company there are several types of maintenance that are applied to every critical plant equipment. cost components included in the calculation of maintenance costs in this study include Corrective maintenance costs, Prefentive

Table 6.
EUAC Calculation of Critical Equipment SWBP (A)

Tahun	Biaya O & M	(P/F, *i* , n)	*Annual O & M Cost*	*Annual Acquisition Cost*	EUAC
2001	Rp 4,545,612	Rp 4,213,512	Rp 4,472,404	Rp 1,289,489,702	Rp 1,293,962,106
2002	Rp 116,906,657	Rp 104,661,919	Rp 57,201,944	Rp 681,239,843	Rp 738,441,786
2003	Rp 6,687,871	Rp 109,988,439	Rp 41,257,665	Rp 479,355,110	Rp 520,612,775
2004	Rp 179,346,035	Rp 242,391,918	Rp 70,183,547	Rp 379,057,514	Rp 449,241,060
2005	Rp 12,261,705	Rp 250,782,853	Rp 59,768,862	Rp 319,390,172	Rp 379,159,034
2006	Rp 274,926,140	Rp 425,175,215	Rp 86,857,179	Rp 280,033,089	Rp 366,890,268
2007	Rp 13,099,816	Rp 432,877,658	Rp 77,941,755	Rp 252,276,843	Rp 330,218,597
2008	Rp 581,952,076	Rp 750,055,219	Rp 121,476,633	Rp 231,766,019	Rp 353,242,652
2009	Rp 14,122,604	Rp 757,190,021	Rp 112,024,003	Rp 216,080,352	Rp 328,104,355
2010	Rp 670,749,235	Rp 1,071,298,187	Rp 146,551,901	Rp 203,767,194	Rp 350,319,095
2011	Rp 18,342,781	Rp 1,079,260,443	Rp 137,854,393	Rp 193,901,723	Rp 331,756,115
2012	Rp 222,752,405	Rp 1,168,888,762	Rp 140,526,736	Rp 185,867,054	Rp 326,393,791
2013	Rp 13,845,301	Rp 1,174,052,654	Rp 133,741,374	Rp 179,235,839	Rp 312,977,214
2014	Rp 878,215,654	Rp 1,477,670,876	Rp 160,398,709	Rp 173,702,606	Rp 334,101,315
2015	Rp 82,825,734	Rp 1,504,213,500	Rp 156,341,664	Rp 169,043,165	Rp 325,384,829
2016	Rp 294,216,106	Rp 1,591,610,577	Rp 159,057,797	Rp 165,089,243	Rp 324,147,039
2017	Rp 35,995,370	Rp 1,601,745,598	Rp 154,469,001	Rp 161,712,057	Rp 316,181,058
2018	Rp 38,964,190	Rp 1,612,144,589	Rp 150,509,693	Rp 158,811,377	Rp 309,321,070
2019	Rp1,240,866,175	Rp 1,926,049,444	Rp 174,566,734	Rp 156,308,033	Rp 330,874,766
…	…	…	…	…	…
2056	Rp 180,619,259	Rp 4,449,651,365	Rp 283,452,705	Rp 138,402,235	Rp 421,854,940

Information:
= Economic Life

Table 7.
The EUAC Value and Optimum Life of Critical Equipment

Equip No.	Equipment Name	Optimum Life	Minimum EUAC
GC0641	Condenser	2030	Rp 2,857,951,343
GC0485	Lp Boiler Feed Pump (D)	2027	Rp 208,657,207
GC0019	Main Transformer	2056	Rp 2,379,223,467
GC0483	Lp Boiler Feed Pump (B)	2027	Rp 187,248,954
GC0484	Lp Boiler Feed Pump (C)	2030	Rp 165,308,411
GC0862	Sea Water Booster Pump (B)	2027	Rp 195,715,314
GC0486	Hp Boiler Feed Pump (A)	2024	Rp 305,249,686
GC0861	Sea Water Booster Pump (A)	2018	Rp 309,321,070
GC0487	Hp Boiler Feed Pump (B)	2024	Rp 328,130,507

maintenance costs, costs, Predictive maintenance, Overhaul costs, Project costs for the equipment and other maintenance costs. The formula for calculate the total maintenance cost per year that consume by the critical equipment is as follows:

$$\sum Maintenance\ Cost = \sum Material\ \ x\ \sum Labour \quad (8)$$

$$\sum Maintenance\ Cost = F(t)x\left(\frac{Cost}{Failure}\right)_{Material} + PM.Cost_{Material} + PdM.Cost_{Material} + OH.Cost_{Material} \quad (9)$$

$$\sum Maintenance\ Cost = \left(F\ (t)x\ t_{repair} n_{operator}\right) + \left(PM_{interval}\ x\ PM_{duration}\ x\ PM_{operation}\right) + \left(PdM_{interval}\ x\ PdM_{duration}\ x\ PdM_{operation}\right) + \left(OH_{interval}\ x\ OH_{duration}\ x\ OH_{operation}\right) x \left(\frac{Rp}{hour}\right) \quad (10)$$

4) Operational Cost

Equipment Operational Costs consist of labor costs per equipment and Energy (electricity or fuel) consumption costs. The formula of Operational cost is as follows :

$$\sum Operation\ \ Cost = \sum Salary\ \left(\frac{Capital_{Equip}}{Capital_{Plant}}\right) x\ \sum Electricity\ + \sum Fuel\ Cost \quad (11)$$

5) Consequential Cost

Consequential costs are one component of operational and maintenance costs that arise due to the failure conditions on equipment that result in a decrease in unit production (derating) or can not operate or shut down (outage)

$$\sum\ Consequential\ Cost = \sum Loss\ Output\ \ x\ \sum Energy\ price \quad (12)$$

C. Data Analysis

In this stage a result analysis of the economic life and reliability calculation of each equipment from the previous stage was carried out. The economic life and reliability value of each equipment is compared to determine maintenance priorities and decide the asset criteria that must be replace, keep, or the maintenance strategy needs to be immediately evaluated. The criteria formulation will be formulated using expert judgment and top management discussion.

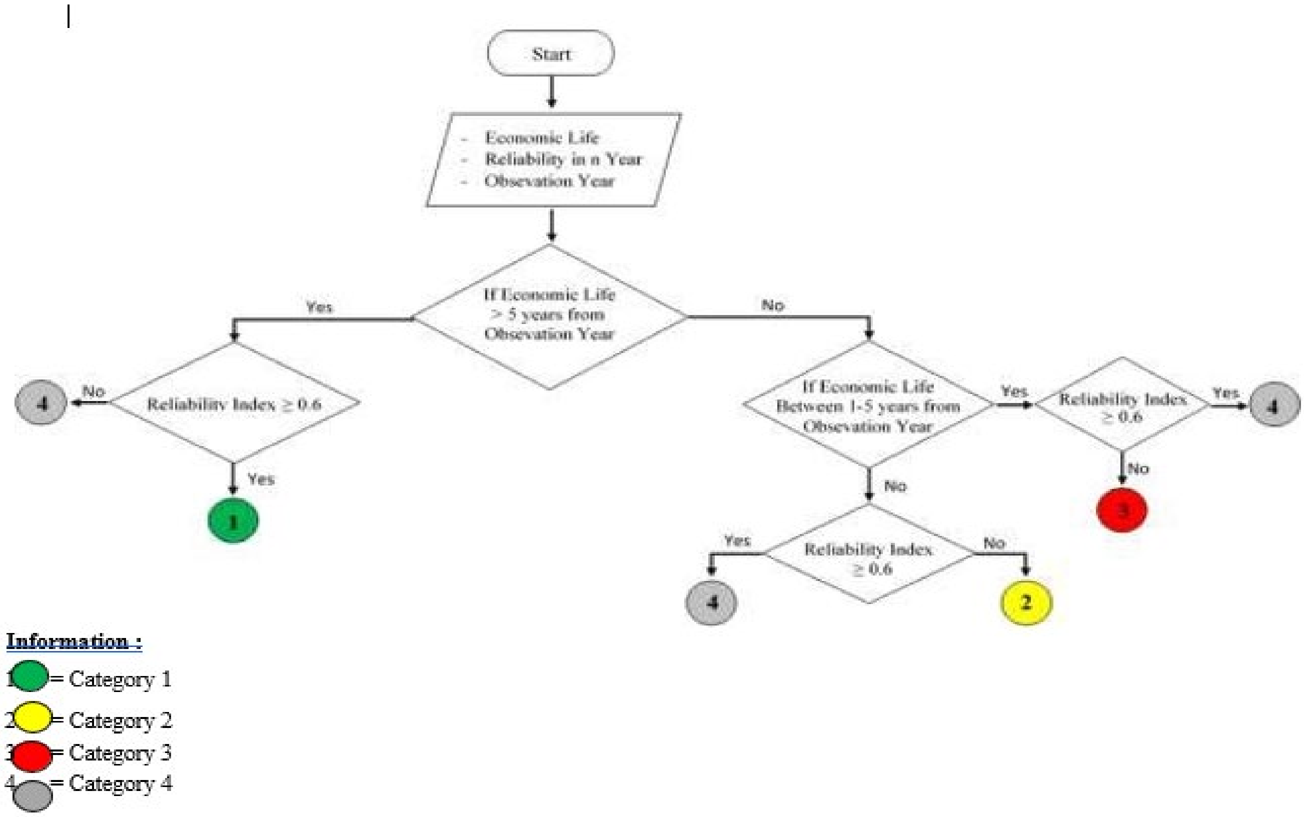

Figure 3. The Formulating Strategy Flowchart.

Table 8.
Mapping of Steam Turbine Unit critical equipment

Equip No.	Equipment Name	Economic Life	Reliability Index	Klasifikasi
GC0641	Condenser	2030	0,74	Category1
GC0485	LP Boiler Feed Pump (D)	2027	0,74	Category 1
GC0019	Main Transformer	2035	0,72	Category 1
GC0483	LP Boiler Feed Pump (B)	2027	0,54	Category 4
GC0484	LP Boiler Feed Pump (C)	2024	0,72	Category 4
GC0862	Sea Water Booster Pump (B)	2027	0,77	Category 1
GC0486	HP Boiler Feed Pump (A)	2024	0,07	Category 4
GC0861	Sea Water Booster Pump (A)	2018	0,4	Category 3
GC0487	HP Boiler Feed Pump (B)	2024	0,34	Category 4

Equipment that has a reliability value below the specified criteria and economic life is approaching (with certain criteria) or past the observation time can be included in the group of equipment that can be identified to be replaced. For equipment that is outside the value of the criterion or is between the value of the specified criteria can continue to be used or included in the group that needs to be evaluated for its maintenance strategy. The results of the calculation and analysis of each equipment will be mapped to provide a clear picture related to the condition of each equipment that is the object of research.

III. RESULT AND DISCUSSION

The Steam Turbine System in Steam Gas Power Plant Units consists of a systematic array of equipment that makes up the process of generating electricity. The equipments in the steam turbine system was arranged in series or parallel. The steam turbine system consists of several main equipment and supporting equipment. In this study, the focus of object is in critical equipment (critical) of the main equipment in PLTGU Steam Turbine System Block 2. The Critical equipment was chosen base on the total number of it's failure in range of 2001 - 2018. in this study, we choose 20% of equipment with the highest number of failure (Top 20%) from all of the main equipment in Steam Turbine Unit Block 2. This was chosen because considering the number of failure that will be affect the value of reliability and the amount of consumption costs that required from the equipment. From a number of main equipment that displayed in table 1, 9 critical equipment were selected to be the object of observation in this study. Table 1 below shows the number of failure and a list of critical equipment that will be the object of further observation.

From the table 1, we can see that condensor equipment has the highest number of failure in the block 2 steam turbine system with total failure during the observation year were 159 damage. The parameters on This Critical equipment will be identified in the next process that related to the reliability and consumption of operational and maintenance and capital costs for estimation the Equivalent Uniform Annual Cost (EUAC) equipment.

A. Reliability Calculation

To calculate the equipment reliability index required data related to equipment failure. failure data will indicate the amount of equipment faiure, duration of failure and the time between failure occurred. This is used to see the distribution of failure that will be used to calculate the reliability index of the equipment. As an example below is the failure data of critical equipment Sea Water Boster Pump (A) that occurred during the time of observation, where from it's time beetween failure data will be used as a basis for calculation in Reliasoft software to calculate its reliability index Critical equipment failure data that has been validated in the previous process is entered in the RGA software. In the RGA software, we input the "time to event" data when failure occurs, minus the initial operation time of the equipment. After the data input process, the calculation process is carried out so that the distribution parameter values are obtained. Total number of failure critical equipments can see Table 2.

In the RGA Software the failure data distribution is automatically directed to use the most appropriate distribution (fitted) with the data distribution inputted. From that calculation we get the distribution parameter values are as Table 3.

After calculating the parameters of beta (β) and eta (η) for each critical equipment on the RGA software, the main time to repair (MTTR) calculation is done for any failure to the critical equipment using Weibull ++ software. From the calculation results of Weibull ++ software for each MTTR value of critical equipment the distribution parameter values are obtained as shown in table 4. Table 4 shows the most suitable distribution types for each MTTR of critical equipment and the distribution parameter values.

Result parameters that have been obtained from the calculation of the time between damage (TBF) in the RGA software and the calculation of the time between repairs (TTR) from the Weibull ++ software are then entered into the blocksim software to be simulated. From the results of calculations using the Blocksim software for each critical equipment in the Steam Turbine Block 2 Steam Power Plant obtained the reliability value of each of the equipment. This reliability value is the calculated reliability value for the 2020 projection. Reliability index of critical equipment in ST 2.0 can see Table 5.

B. EUAC Calculation

To calculate the Equivalent Uniform Annual Cost (EUAC) value of the critical equipment of the Steam Turbine Unit. There are some historical data related to the equipment needed. The data includes the asset acquisition cost data, the details of the operation & maintenance costs include equipment operating costs, maintenance costs and consequential costs.

In the EUAC Calculation, acquisition cost is all costs incurred by the company when buying an asset (the initial book value recorded when buying assets). In the calculation of EUAC the acquisition cost value will be used to calculate the Annualized Acquisition Cost of each equipment, which will later compile the equivalent annual cost graph. In this study, the data acquisition cost was taken from historical data on the value of assets in 2002, this was done considering the EUAC calculation was carried out in the span of 2000 - 2056. Operation & Maintenance Cost is the total cost consumed by the equipment during its lifetime. In this study operational costs include labor costs per equipment, electricity and fuel consumption costs. Whereas maintenance costs include corrective, preventive, predictive and overhaul maintenance costs. And other components of O&M costs are consequential costs.

All data is taken from historical data from 2000 - 2016 and is projected to the life span of the plant in 2056. By processing all the data and calculating it according to the EUAC formula above, an example of EUAC calculation for critical equipment Sea Water booster Pump (A) can be found as the table 6.

Table 6 above shows the minimum EUAC value of sea water booster pump (A) equipment occurring in 2018, this shows the economic life of the equipment with a minimum EUAC value of equipment of Rp 309,321,070, -. Using the same equation above can be seen the results of the EUAC calculation of other critical equipment as in table 7.

C. Formulating Strategy & Mapping

The strategy formulation in this research was carried out through Focus Group Discussion (FGD) and expertise discussion. The strategy formulation is carried out to formulate the equipment replacement procedure, through determining the limits of the parameters used. The formulation of the strategy focused on determining the limits of the parameters used in evaluating the replacement of this equipment, including: limits on the reliability index and expected economic age limits. The reliability index limit is the equipment reliability index limit that is allowed by the plant to continue to operate as it should (it does not need a maintenance evaluation process). The economic age limit is the range of years that is used to determine the equipment to be used, prepared for replacement or must be replaced immediately.

The formulation of the reliability index limit is obtained by using Reliasoft software. The reliability index limits allowed by the power plant are taken from the calculation of the average reliability index of critical components to carry out their optimum overhaul time. Simulation of optimum overhaul time calculation for each critical component, considering the amount of corrective maintenance costs compared to the cost of overhauling the equipment. The reliability index at the optimum time is averaged for each critical equipment to become the limit of reliability index. So we get the average reliability value agreed to be the limit value is 0.6. This value will be used to determine whether the equipment retains the existing maintenance process or requires a maintenance evaluation process.

The agreed limit of economic life in this study is referring to the time frame of the planning process for preparing the Unit Long Term Planning Document and Unit Budget Work Planning Document at the company. The Unit Long Term Planning Document is compiled and valid for a period of 5 years and Unit Budget Work Planning Document is a program description and budgeting of annual planning. So, from this reference, it was decided that the time limit between the economic lifes calculated and the annual observation period would be in the range of 1 - 5 years. This time interval will then be used to decide when the equipment must be immediately replaced by a replacement analysis process, prepared to be replaced or maintained. From the results of the FGDs and the formulation of limit values for each parameters above, we get the equipment replacement procedure flowchart are as follows Figure 3.

From the flowchart above, obtained 4 equipment classification categories. The descriptions and strategies for each classification category are as follows:

1) Category 1 - Keep and Improve / Keep as It Is

Equipment in this category can be maintained or improved in the maintenance process and does not require further replacement review processes.

2) Category 2 - Prepare for Replacement Analysis

Equipment in this category can be immediately prepared or planned for equipment replacement analysis.

3) Category 3 - Do Replacement Analysis Immediately

Equipment in this category can be immediately carried out further replacement analysis to be replaced.

4) Category 4 - Need Future Analysis

Category 4 is the gray category. Equipment that falls into this category is equipment whose condition requires further maintenance analysis. For equipment in this category there are several evaluation analyzes that can be carried out to determine the follow-up to handling these conditions, including:

1. Evaluation of unplaned maintenance (Corrective Maintenance) activities covering the portion of material & labor costs
2. Evaluate scheduled maintenance activities (Preventive, Predictive, and Overhaul)) covering the portion of material & Labor costs
3. If scheduled maintenance activities are still not optimal, optimization is needed to improve the reliability of the equipment so that future equipment failures can be avoided
4. Evaluation of Project activities that have been carried out
5. Evaluation of Operation costs related to costs incurred due to self use (PS) and Losses due to efficiency
6. Evaluation of Outage / Derating events that have occurred

From the results of the strategy formulation, it can be mapped the condition of each critical equipment of the Steam Turbine based on the parameters that have been determined are as follows Table 8.

Table 8 shows that there are 4 equipment included in category 1 including; Condenser, LP Boiler Feed Pump (D), Main Transformer and Sea Water Booster Pump (B). equipment that is in category 1 can be maintained and operated as usual or just improve for eficiency. There are 4 equipment included in category 4, namely: LP Boiler Feed Pump (B), LP Boiler Feed Pump (C), HP Boiler Feed Pump (A) and HP Boiler Feed Pump (B). Equipment in category 4 is equipment that requires further study related to the evaluation of the maintenance process of each equipment. There is 1 equipment that is included in category 3, which is Sea Water Booster Pump (A) equipment. in this Category 3, Sea Water Booster Pump (A) equipment is expected to be able to immediately conduct an equipment replacement analysis given the economic life conditions and the reliability index is below the limit value.

IV. CONCLUSION

From this study it can be concluded several things as follows:(1)Through the calculation of the value of annual operational and maintenance costs as well as the cost of equipment acquisition can be calculated the EUAC value of each critical equipment in the Steam Turbine Power Plant. This calculation serves to see the value of the equivalent annual cost consumed by each critical equipment and determine the economic life of the equipment. The calculation of EUAC value and economic life is used as one of the parameters to determine equipment replacement decisions and evaluate the annual cost consumption of critical equipment; (2)Processing of historical failure data that causes equipment downtime is used to calculate distribution parameters to see the trend of the failure rate and the the reliability index of critical equipment in the Steam Turbine Power Plant. This reliability index calculation, which will be calculated annually to evaluate the condition of the performance of the equipment and the results of maintenance carried out as well as being a determining parameter for the process of replacing critical equipment in the Steam Turbine PLTGU; (3)Through the formulation of strategies using the reliability index parameters and the economic life of the equipment, it can be formulated the limits of the values of each parameter to classify each equipment in the Steam Turbine PLTGU system, in order to obtain categories of equipment conditions that help the decision making process in the procedure of replacing equipment and evaluating maintenance equipment. From the formulation of the strategy obtained 4 equipment classification categories including: Category 1-Keep and Improve, Category 2-Prepare for Replacement Analysis, Category 3-Do Replacement Analysis Immediately, Category 4-Need Future Analysis.

ACKNOWLEDGMENT

This research is supported by all lecturers in master program of Technology Management Department Sepuluh Nopember Institute of Technology. We very thankful to The Power Plant Company for support us all the data for the research. Last, I am especially grateful for Dr. Ir. Mokh. Suef, M.sc (Eng) as my advisor for warm support, advice and thoughtful guidance to finish this research.

REFERENCES

[1] Pujawan, I. N., 2009. *Ekonomi Teknik.* Surabaya: Guna Widya.
[2] Frenning, L., 2001. Pump Life Cycle Cost. a guide to LCC analysis for pumping systemns, p. 194.
[3] Elsayed, E. A., 2012. *Reliability Engineering.* Second ed. USA: John Wilcy & Sons, Inc., Hoboken, New Jersey.
[4] Park, C. S., 2007. Engineering Economics. United Stated : Pearson Prentice Hall.
[5] Igor G. Cesca, Douglas D. Novaes., Physical Assets Replacement: an Analytical Approach. Universidade Estadual de Campinas, 2012 [6] Barringer , P., 1998. Life Cycle Cost and Good Practies. San Antonio, NPRA Maintenance Conference.
[7] Barringer, P. & Weber, D., 1996. Life Cycle Cost Tutorial. Fifth International Conference on Process Plant Reliability. Texas, Gulf Publishing Company.
[8] Chowdhury, B. & Raghavan, S., 2012. Developing Life Cycle Management Plans For Power Plant Components, U.S: North American Power Symposium.
[9] Daryus, Asyari, 2007, Diktat Manajemen Pemeliharaan Mesin, Universitas Darma Persada – Jakarta.
[10] Davidson, J., 1988. The Reliability of Mechanical Systems. London: Mechanical Engineering Publications Limited for The Institution of Mechanical Engineers.
[11] Davis, R., 2014. An Introduction to Asset Management. s.l.:Blah d Blah design.
[12] de Jong, G. et al., n.d. Journal of Choice Modelling. The impact of fixed and variable cost on household car ownership, 2(2), pp. 173-199.
[13] Dhillon, 2010. Life Cycle Costing for Engineers. United Stated: Taylor and Francis Group.
[14] Ebeling, Charles E. 1997. An Introduction to Reliability and Maintainability Engineering.Singapore : The McGraw-Hill Companies, Inc.
[15] Farr, John V., 2011. Systems lifecycle costing: Economic Analysis, Estimation, and Management. CRC Press.
[16] Freselam Mulubrhan, Ainul Akmar Binti Mokhtar and Masdi Muhammad. Replacement Analysis Using Probabilistic Life Cycle Costing. ARPN Journal of Engineering and Applied Sciences, Vol. 11, 2016.
[17] Ireson, W. G., Clyde, F. C., Jr. & Richard, Y. M., 1996. Handbook of Reliability Engineering and Management. 2nd ed. s.l.:McGraw-Hill.
[18] Joseph C. Hartman and Alison Murphy. Finite-horizon equipment replacement analysis. v *IIE Transactions* 38, 409–419, 2016.
[19] Konstantinos J.Liapis, Dimitrios D.kantianis., Depreciation Methods and Life Cycle Costing Analysis Methodology. Procedia Economis and Finance 19 312-324, 2015.
[20] Laxman Yadu Waghmod, Rajkumar Bhimgonda Patil. Reliability Analysis and Life Cycle Cost Optimization: a Case Study from Indian Industry. International Journal of Quality & Reliability Management Vol. 33, 2016.
[21] Lewis, E. E., (1998), Introduction to Reliability Engineering, John Wiley & Sons, First Edition, New York.
[22] L. Saad, A. Aissani, A. Chateauneuf. Reliability-Based Optimization of Direct and Indirect LCC of RC Bridge Elements Under Coupled Fatigue-Corrosion Deterioration Processes. Engineering Failure Analysis, 2015.
[23] Madhu Jain, Alok Kumar And G. C. Sharma., Maintenance Cost Analysis for Replacement Model With Perfect/Minimal Repair. International Journal of Engineering, 2002.
[24] Massoud Bazargan, Joseph Hartman., Aircraft replacement strategy : Model and analysis. Journal of Air Transport Management 25, 2012.
[25] Moubray, John. 1992. "Reliability Centered Maintenance". Industrial Press Inc, New York [26] Pembangkit Listrik Jawa Bali, 2017. *Annual Report,* s.l.: s.n.
[27] Sullivan, W. G., Wicks, E. M. & Koelling, P. C., 2003. Engineering Economy. United Stated: Pearson Prentice Hall.
[28] Woodward, D., 1997. Information Acquisition and Application International Journal of Project Management. Life Cycle Costing-Theory, 6(15), pp. 335-344.
[29] Yue Shang, Martine van den Boomen, Amy de Man. Reliability-Based Life Cycle Costing Analysis for Embedded Rails in Level Crossings. Proc IMechE, Part F: J Rail and Rapid Transit, 2019.