Turbine Engine Reliability Analysis Using Reliability Availability Maintainability (RAM)

Oyong Novareza[1,2*], Zefry Darmawan[1], Nasir Widha Setyanto[1,2], Effendi Bin Mohamad[3]

[1]*Industrial Engineering Department, Universitas Brawijaya, Jl. MT. Haryono, 167, Malang, 65145, Indonesia*
[2]*Engineering Profession Department, Universitas Brawijaya, Jl. MT. Haryono 167, Malang, 65145, Indonesia*
[3]*Faculty of Industrial and Manufacturing Technology and Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia*
**Corresponding author: novareza15@ub.ac.id*

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ABSTRACT

Electrical energy is a vital necessity characterized by ever-increasing electricity consumption. The most dominating power plant in Indonesia in supplying electricity is the steam power plant, which is 50%. In its implementation, there is damage that occurs where the highest damage is to the general unit with the highest damage to the turbine unit. Therefore, the author uses the reliability, availability, and maintainability method or RAM. The purpose of this study is to determine the value of RAM on the turbine system at PLN and provide recommendations for improvements to system performance. The results showed that the MTTF and MTTR values of the components are 112,916 minutes and 7,705.91 minutes, respectively. The MTTF value of the equipment indicates in one year the shutdown occurs 4 to 5 times with a relatively short period of time to repair. RAM analysis is carried out and the value is 4.96% (reliability), 93.612% (availability), and 36.44% (maintainability). It can be interpreted that reliability of the system is low due to the frequency of errors, quite difficult to do a repair procedure, but the system is fairly working in good condition in a year period.

Keywords: *Availability, maintainability, mean time to failure, mean time to repair, reliability*

I. Introduction

Electrical energy is one of the vital needs and cannot be separated from all aspects of life at this time ranging from work, transportation, household life, communication, and entertainment. Electricity consumption in Indonesia itself increases every year [1]. The fulfillment of this electrical energy must be balanced with the provision of a reliable power generation system given the very high demand and need for electricity. However, in practice, there are disruptions in electricity production facilities such as outages and deratings due to problems in electricity production facilities. Both can cause losses for the company because the electricity output is reduced so that the company's revenue is also reduced. In Indonesia, the most dominating power plant is the steam plant where the percentage of generating capacity is at 50% [2].

Maintenance of equipment and reliability of the system is one of the most important factors where these two factors affect the ability of the organization or company to provide

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quality and timely services to customers and to maintain the existence of competition in the industry [3]-[7]. Therefore, maintenance of functionality is essential for sustainable performance for any manufacturer [8]. The performance of the equipment significantly affects the performance of the organization [5]. Various methodologies and tools have been proposed to complement maintenance activities to keep the process productive. The complexity of existing systems ranges from simple to complex repairs where the goal is to prevent failure [4]. Maintenance ensures the organization achieves its planned lifetime, ensures environmental safety, and efficient use of resources [6], [9].

One of the performance analyses that can be used to assess the level of system performance is reliability, availability, and maintainability (RAM). RAM is one of the techniques used as tools to estimate the level of reliability, availability, and maintainability of a system and equipment to provide a baseline as a basis for system operation. It is also used to identify critical and sensitive subsystems in a production system, as well as to identify and measure equipment and system failures that can hinder productive goals. In general, a complex system will be divided into subsystems to facilitate a more detailed examination so that a more detailed change is produced. The purpose of it is to identify critical components or subsystems in operational systems by calculating the parameters of RAM, namely reliability, availability, and maintainability [4], [10], [11].

Reliability refers to the ability of a device to function under desired conditions over a period. Reliability of each subsystem is determined by the best probabilistic distribution function. Availability has the definition of the extent to which a system operates or can be used when needed. Maintainability is the ease with which a system or equipment can be repaired or modified to correct damage or errors, improve performance, or adapt to a changing work environment. RAM itself plays an important role in performance estimation in previous research on tunnelling systems [12], [13]. The RAM framework proposed in the previous study helps decision-makers to plan maintenance activities according to the critical rate occurring in the subsystem and allocate resources accordingly [14].

This research was conducted on steam power plants in Indonesia. PLN has a power plant where the plant relies on kinetic energy from steam where the final product is electrical energy. The main components of the plant itself are boilers, turbines, generators, and condensers [15]. The observed plant is a type of coal-fired plant which has a complex system consisting of many systems and more than 20,000 equipment and consists of unit 1, unit 2, and common. There is a disturbance, namely the frequency of damage where the highest is in common, which has a cumulative value of almost 40% damage or 576 times damage with the highest damage time in the turbine system. Damage to the turbine occurred for 6,741.56 hours in the time span from July 2014 to June 2022. Damage to this system will have an impact on the course of the fuel supply process so that performance is disrupted until it is shut down. If this is allowed, it can cause a decrease in the amount of electricity that can be produced each time so that the company's revenue decreases.

The RAM analysis may combine with other methods i.e. Six Sigma to find the root cause to increase reliability [16]. Fault Tree Analysis also can be added to improve analysis of the performance of steam turbine [17], however, the results show a focus on availability [8]. The purpose of this study is to determine the value of RAM in the turbine system in the power plant, which can make the company realize the condition of the existing system and provide recommendations for improvements that must be made. The correlation between all parameters not well elucidated. RAM analysis is carried out with a statistical approach through fitting distribution and Non-Homogeneous Poisson Process (NHPP). The method states that the time between successive failures is not independent or identically distributed, which makes this model the most important. This study also explains the effect of RAM parameters value to predict and explain the condition of the system.

II. Materials and Methods

1. Reliability

Reliability is the probability of a part or system being able to do its job properly within a specified period when used in a specified operating situation [18]. The system reliability rises when the system runs perfectly or does the predetermined job faster [12]. The reliability value is a function of time, or in other words, the reliability of a system will vary according to the time at which the reliability evaluation is carried out. The reliability function can be derived directly from the CDF (cumulative density function) function as in Figure 1.

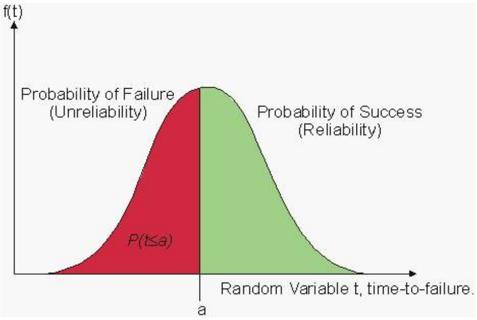

Fig. 1. Reliability vs unreliability [19]

There are two different conditions to find the reliability number. The first one is that the total reliability value *R* in the system is discovered by multiplying each reliability of existing equipment as per shown in Eq. 1 (*Rs*). The calculation must be carried out when the system components are arranged in series. The Eq. 2 (*Rp*) permits to find the total reliability value in different ways. The latter is for the system that arranged in parallel [20]. The next parameter of frequency, which is failures per unit time, when failure occurs to one or more components and giving impacts to the system or subsystem are shown in Eq. 3 [21]. The reliability (as shown in Eq. 4) then can be calculated.

$$R_s = R_1 . R_2 \ldots R_n \quad (1)$$

$$R_p = 1 - \prod_{i=1}^{n} [1 - R_i(t)] \quad (2)$$

$$\lambda(t) = \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} \quad (3)$$

$$R(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}} \quad (4)$$

2. Availability

Availability is a function of a cycle where the production or operation process and downtime take place and symbolizes the success parameter or success of a system in performing certain tasks at an unspecified system call time [10]. A condition between the system is functioned properly until failure occurred can be term as mean time to failure (MTTF) whereas mean time to repair (MTTR) is an average time to conduct a reparation of components in a system until finished. Both can be defined as two reliability terms for Availability [18]. The later meaning of the portion in percentage of the total observation time, which is completed using the equipment in operation. Availability is considered as losses that can result from the termination of programmed operating time for a considerable period that includes damage repair, replacement, adjustment, and setup time [22].

The formulation of availability (*A*) is as follows Eq. 5 [20].

$$A = \frac{MTTF}{MTTF+MTTR} \quad (5)$$

As per reliability equations, as shown in Eq. 5, the availability has similar conditions to do a calculation. The series ones can be seen in Eq. 6 (*As*) and Eq. 7 (*Ap*) shows the parallel.

$$A_s = A_1 . A_2 \dots A_n \quad (6)$$

$$A_p = 1 - \prod_{k=1}^{n} [1 - A_i(t)] \quad (7)$$

Other availability concept is if there is a minimum number of components required in the system to work functionally (denoted with *k*) from the total number of components in the system (denoted with *n*), the availability is formulated with Eq. 8.

$$A_{k\ out\ of\ n} = \sum_{i=k}^{n} \binom{n}{i} A(t)^i \left(1 - A(t)\right)^{n-i} \quad (8)$$

Real-life application in example, 2 out of 6 configurations meaning that a system with 6 components will stay in useful condition if 2 components remain running.

3. *Maintainability*

Relating factors of maintenance occurrence, time to repair, and costs e.g. labour and components shows the value of maintainability. In other words, it can be defined as the rapidity of technician to restore components when failure occurred to reinstate a desired condition according to a predetermined method [18]. During failure occurred, the value of maintainability increased when the mechanics can perform maintenance in short period time and easily to fix the components. Maintainability can be measured by MTTR and indicates an average time that shows the duration it takes an item from damage to being operational again [5].

The use of RAM method can help in determining the maintenance interval and help to determine the plan in organizing the right maintenance strategy [23]. In previous research, it was stated that using RAM carried out in the production subsystem can increase the availability of the company so that it can increase the utility of the company. So, it can be stated that the RAM approach is a useful method for companies because it can assess and evaluate machine performance [24]. Hence, it can be stated that the RAM approach is a useful method for companies because it can assess and evaluate machine performance [25]. If the MTTR is exponentially distributed, the maintainability of a system is formulated by Eq. 9 [20].

$$H(t) = 1 - e^{-\lambda t} \quad (9)$$

The maintainability, as shown Eq. 9, may change due to the probability that a repair can be completed in time t. There are patterns distribution of the MTTR: lognormal, Weibull and Normal distribution with each equation for those conditions as shown in Table 1.

Table 1. Equation for maintainability

Lognormal	Weibull	Normal
$H(t) = \Phi\left(\frac{1}{s} ln \frac{t}{t_{med}}\right)$	$H(t) = 1 - e^{-\left(\frac{t}{\theta}\right)^{\beta}}$	$H(t) = \Phi\left(\frac{t-\mu}{\sigma}\right)$

4. Reliability Block Diagram (RBD)

A diagram that can be used as helping tool namely Reliability Block Diagram (RBD) can be used to decompose systems into multilayer structures (e.g. components, subsystems, coolers, and cooling methods) and solve “dimension damnation” [26]. RBD can be expressed as a diagramming method to show how components of reliability contribute to the success or failure of complex systems [27]. Figure 2 is an example of an RBD of a system.

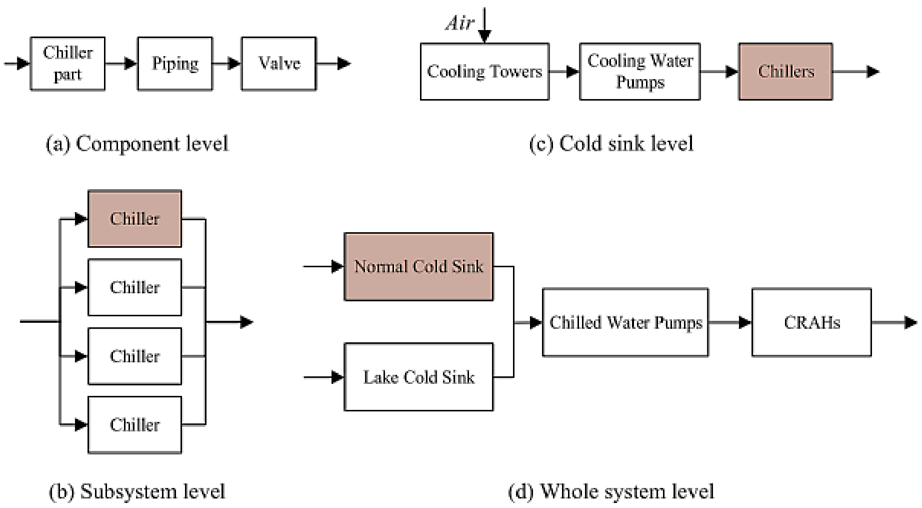

Fig. 2. Reliability block diagram [26]

Observations were made at PT PLN where the first step of the research was to study and observe the problems that exist in the company. This is conducted to provide an overview of the real conditions of the object of observation to obtain the actual conditions of the problem. Furthermore, problem identification is carried out in accordance with the observations that occur and formulate the problems that will be raised in the research. From the formulation of the problem obtained, the research objectives and the limitations and assumptions of the research are determined. The data used for research is primary data and secondary data from PT PLN. The data is used to perform calculations to calculate RAM.

III. Results and Discussions

1. Mean Time to Failure

The initial step is to collect data for damage and repair of the turbine system at PT PLN where observations were carried out from July 2014 to June 2022 for CWHE 2A components. Data on damage and repair of components are presented in Table 2.

Table 2. Turbine system breakdown and repair data for CWHE 2A components

Component	Report date	Repair start	Repair end
CWHE 2A	20/03/2018 14:32	20/03/2018 14:32	11/04/2018 15:37
	30/04/2018 15:47	02/05/2018 09:28	10/05/2018 14:31
	24/05/2018 19:01	26/05/2018 10:00	26/05/2018 12:00
	28/05/2018 07:50	28/05/2018 09:45	02/06/2018 10:47
	20/02/2019 07:58	18/04/2021 10:45	18/04/2021 15:59
	21/02/2019 07:56	21/02/2019 09:53	27/02/2019 13:55
	28/02/2019 07:35	06/03/2019 13:52	06/03/2019 13:52
	06/03/2019 07:41	06/03/2019 09:06	11/03/2019 13:09
	24/03/2019 09:47	24/03/2019 09:47	24/03/2019 11:00
	08/04/2019 07:53	10/04/2019 08:43	13/04/2019 10:48
	15/04/2019 08:18	16/04/2019 09:00	16/04/2019 12:00
	06/04/2021 13:58	12/06/2022 10:25	12/06/2022 10:25
	20/03/2018 14:32	20/03/2018 14:32	11/04/2018 15:37
	30/04/2018 15:47	02/05/2018 09:28	10/05/2018 14:31

From the data in Table 1, data processing will be carried out directly to calculate time to failure and MTTF or mean time to failure. The TTF calculation itself uses the Weibull distribution. TTF calculation data for CWHE 2A components are presented in Table 3.

Table 3. TTF calculation for CWHE 2A components

Number of failures	TTF (minute)	Number of failures	TTF (minute)
1	-	7	1,060
2	27,370	8	8,646
3	20,430	9	18,518
4	2,630	10	21,413
5	378,551	11	2,730
6	1,438	12	1,038,358

After knowing the TTF value, the next step is to find the MTTF value, which is intended to determine the average time of a part until it is damaged again using the Weibull distribution. The calculation is presented in Figure 3.

MTTF = 112,916 *minute*

MTTF di PoF = 75%

*L*10 = 296,760 (Performance decreases dramatically and wear rate increases)

R 90 = 11,896.8 (engine performance drops to 90% or enters the time to replace phase)

Due to beta < 1, the equipment is included in the infant mortality or burn in phase, in this phase failure can be caused by manufacturing defects, welding defects, cracks, poor QC, poor workmanship, and others. This can be avoided by burn in testing, Process screening, QC, and acceptance testing.

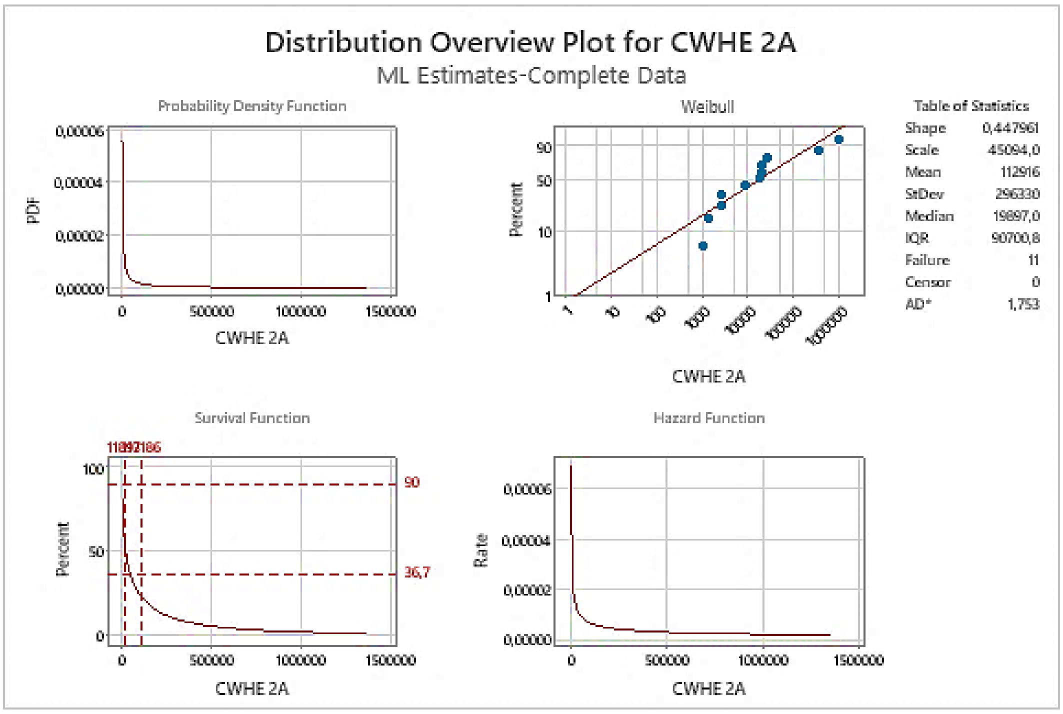

Fig. 3. TTF CWHE 2A graph

2. *Mean Time to Repair*

Time to repair calculations are performed on each existing repair data. TTR (time to repair) is the time used to fix or repair a component and restore it so that it can return to carrying out tasks in accordance with procedures. Table 4 presents the results of the TTR for the CWHE 2A component.

Table 4. TTR calculation for CWHE 2A components

Number of failures	TTR (minute)	Number of failures	TTF (minute)
1	31,745	7	0
2	11,823	8	7,443
3	120	9	73
4	7,262	10	4,445
5	314	11	180
6	8,882	12	0

After intended the TTR value, the next step is to discover the MTTR value to find out how much average time is needed in the activity of repairing and returning components that have been repaired to return to function. The calculation is carried out in accordance with the Weibull statistical distribution, which has parameters β and θ which have also been calculated previously. The calculation is presented in Figure 4.

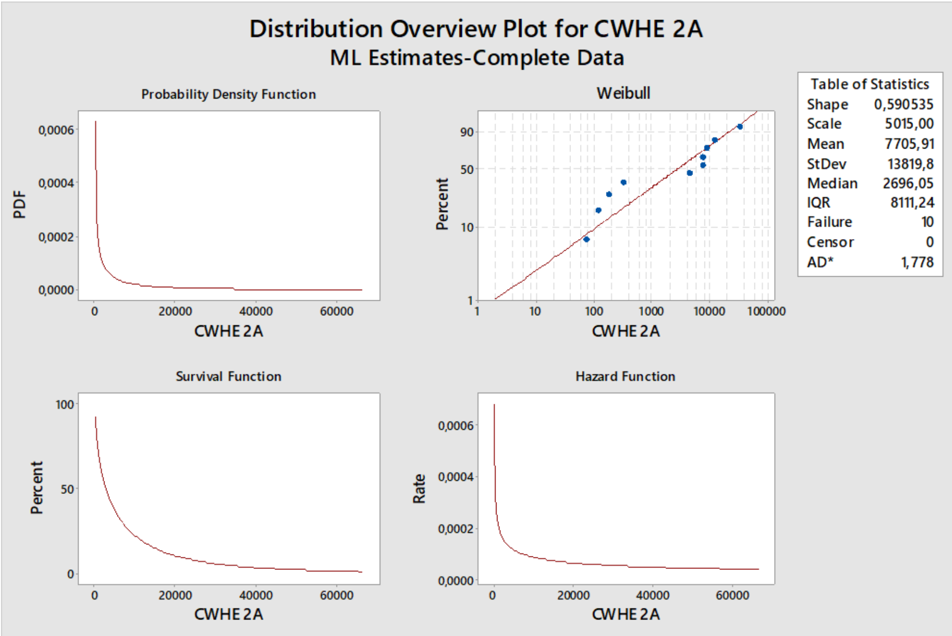

Fig. 4. TTR CWHE 2A graph

$MTTR$ = 7,705.91 *minute*

β = 0.590535

θ = 5,015

Based on the graph (Figure 4), it is known that the MTTR for CWHE 2A components is 7,705.91 minutes. The β shown in Figure 4 is 0.590535, which is for MTTR calculation whereas the β shown in Figure 3 is 0.447961. The latter is for MTTF value calculation.

3. Reliability, Availability, and Maintainability

Reliability is the probability of a part or system to perform its duties in accordance with a predetermined function for a certain period when used in a predetermined operating condition. This reliability calculation is carried out based on the selected model that has been analysed previously. This availability calculation is inherent availability which is calculated based on the value of MTTR and MTTF. While the calculation of maintainability is carried out based on the selected model that has been analysed previously.

- CWHE 2A reliability calculation

  In the distribution test conducted, it was found that Weibull was the chosen distribution. Weibull distribution has parameters β, θ, and t value, which is obtained from the previous MTTF value.

$$R(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}}$$

$$R(t) = e^{-\left(\frac{112{,}916}{45{,}094}\right)^{0.447961}}$$

$$R(t) = 0.2212197741$$

The result above (0.2212197741) is the reliability value based on the time value of the existing MTTF. Furthermore, reliability calculations are carried out with a period of 1 year or 525,600 minutes, that is 4.96% (see the next calculation).

$$R(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}}$$

$$R(t) = e^{-\left(\frac{525,600}{45,094}\right)^{0.447961}}$$

$$R(t) = 0.04956538434$$

$$R = 4.96\%$$

- CWHE 2A Availability Calculation

  The calculation of availability is an inherent availability that is calculated based on the value of MTTR and MTTF.

$$A = \frac{MTTF}{MTTF+MTTR}$$

$$A = \frac{112,916}{112,916 + 7,705.91}$$

$$A = 0.93612$$

$$A = 93.612\%$$

- CWHE 2A Maintainability Calculation

  The test that was conducted to find the type of distribution found that the MTTR value was lognormal distributed with parameters β, θ, and t value.

$$H(t) = 1 - e^{-\left(\frac{t}{\theta}\right)^{\beta}}$$

$$H(t) = 1 - e^{-\left(\frac{7,705.91}{45,094}\right)^{0.447961}}$$

$$H(t) = 0.3644036517$$

$$H = 36.44\%$$

Based on the data that has been processed, the MTTF, MTTR, reliability, availability, and maintainability values for CWHE 2A components in the turbine system are obtained. The MTTF value for CWHE 2A equipment is 112,916 minutes, and the MTTR value is 7,705.91 minutes. This MTTR value is considered low while seen to the failures that occurred in a year time. In relation to MTTF value, the frequency of the failure that occurred in the system in one year is approximately 4 to 5 times every year. From the experience, the system downtime can be caused by electronic devices malfunction i.e. sensors, relays, and electronic panels. The components may be broken due to excessive lifetime, vibration, and excessive load [28].

The calculation shows although the failure frequency is low but is found to reduce the reliability value to 4.96%. Meanwhile, the MTTR value of 7,705.91 minutes means that it may be caused by slow spare parts availability, technician skills, troubleshooting procedures, tool availability, poor diagnosis capabilities, and inadequate facilities. Start-up process after system experience from shutdown may need calibration that increases the TTR. It can be seen from the maintainability value of 36.44%, although the system only needs to change one electric component, the process to ensure the system working properly is found to be time-consuming.

Critical machine parts with low reliability affect the overall safety of the parts [25]. There are three most important factors that can impact the maintainability of a production line, namely resource availability, human resource management, and maintenance planning procedures [23]. Another study stated in the RAM analysis of the company that the company's capacity was unused by 17% due to maintenance problems and 15% due to management problems [29]. The method that can be used is to understand failure patterns and accurately measure reliability and how the characteristics of the existing system. By identifying key points on the production line that need to be further improved through an effective maintenance strategy [30].

From the result of low-reliability value for CWHE 2A (4.96%), it is interesting to observe the availability value of 93.612%, which reflects the system in relatively good condition. The value (93.612%) is close to IVARA standard of 95%, however, the reliability and maintainability were found to be low. Low reliability is derived from the rate of shutdown (4 to 5) but the calculation to MTTR shows the value is not affected to availability. The time-consuming repair may come from start-up process until the system working properly. It is proven by seeing into the maintainability value (36.44%) that is far below the standard where the IVARA standard is 80%, which means that the company must conduct further analysis and improve the components handling. Other considerations are looking into design errors and non-compliance with manufacturer's guidelines

From the problems that occur, there are several recommendations given to the company, including creating regular maintenance schedule for the heat exchanger. It permits to find and replace the damaging of components ea. pipes, tubes, plates, and gaskets. The next is heat exchangers often have the problem of deposit buildup such as scale or corrosion on the heat exchange surfaces. Consider doing regular cleaning, such as descaling or chemical cleaning, to keep the surfaces clean. The quality of water cooling is the next concern with ensuring the cooling water used is clean and free from contaminants that can damage the heat exchange surfaces. Adding proper additive may also increase the quality followed by adjusting the cooling water in the system to rise the efficiency.

Besides the hardware side, the use of software analysis i.e. CFD (Computational Fluid Dynamics) Flow Analysis. It permits to find of persistent performance issues by analysing the flow to understand the fluid flow patterns and identify areas with flow issues. It also can be used as monitoring the system ea. input and output temperature and pressure. It must be monitored frequently and ensure those should be within the appropriate ranges according to the heat exchanger design and cooling application. The data from two above, TTF and TTR, must be analyse to the heat exchanger performance. The heat exchanger may contribute to damage to the system resulting in downtime. This can help identify performance issues and trends that may not be immediately apparent.

IV. Conclusions

The research focuses on CWHE 2A and found the MTTF and MTTR are 112,916 minutes and 7,705.91 minutes, respectively. The system shutdown approximately 4 or 5 times that bring the low value of reliability, 4.96%. Low value of maintainability, 36.44%, indicates that the probability of failure needs quite long time to ensure the system working properly. However, the availability value of 93.612% indicates that the maintainability nor affect much in overall system performance. Judging from the results obtained, the RAM parameters are below the IVARA standard. Based on the analysis of MTTR, MTTF, and RAM values for CWHE 2A, the equipment is experiencing failures that can be attributed to aging, material quality, inadequate preventive maintenance, failure of other components, poor operational conditions, design errors, and non-conformance with manufacturer guidelines. So, there are several improvement suggestions offered for the company because the problems that occur are severe problems that cannot be taken lightly so that the company can improve the MTTR, MTTF, and RAM values.

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Nomenclature

R	: reliability
Rs	: reliability in series
Rp	: reliability in parallel
$R(t)$	: probability of system or components working properly up to desired time
A	: availability
As	: availability in series
Ap	: availability in parallel
H	: maintainability
$H(t)$	: probability density function for repair time data
t	: time
$\lambda(t)$	: failure rate
n	: the total number of components in the system
k	: components required in the system to work functionally
L	: likelihood
s	: standard deviation
t_{med}	: median of repair times
μ	: mean time to failure
σ	: standard deviation from time to failure data value
β	: shape parameter of Weibull distribution
θ	: scale parameter of Weibull distribution

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