

¹ Rakhmad
Sazuli*
² Mohammad Isa
Irawan

**Power Plant Maintenance Investment
Decision Making Based on Reliability,
Availability, Maintainability and Risk Cost
Case Study: Replacement Tube HRSG 1.2
Combine Cycle Power Plant Belawan**



Abstract: - This study analyzes the feasibility of investing in the HRSG 1.2 replacement tube as a guide in making decisions based on reliability, availability, maintainability as an operational aspect, and risk cost as a risk aspect and analyzes the financial aspect. This feasibility analysis was carried out on 3 alternative options, namely just replacing the leaking HRSG 1.2 tube or corrective maintenance, doing the HRSG 1.2 tube replacement as a whole and doing the HRSG 1.2 tube replacement partially. In the analysis of operational aspects, it was obtained an increase in the reliability value of HRSG 1.2 by 0.137, an increase in the availability of HRSG 1.2 by 0.016 and an increase in the maintainability of HRSG 1.2 by 0.0006, so that it could increase operational performance combine cycle power plant block I. In the financial aspect analysis, capital budgeting was calculated which resulted in a net present value of IDR 360.419.186.184 and an internal rate of return of 7,51%. Meanwhile, in the risk aspect analysis, the risk cost value is below the risk appetite statement and in the moderate category. So that the investment work to maintain the HRSG 1.2 CCPP Belawan replacement tube is feasible to increase company value.

Keywords: Availability, maintainability, reliability, risk cost.

I. INTRODUCTION

The Belawan Combine Cycle Power Plant located in Medan city, Indonesia, is one of the power plants operated by PT. PLN and plays a crucial role in the Northern Sumatra Subsystem. The CCPP Belawan consists of two blocks, each with 2 gas turbines, 2 heat recovery steam generators (HRSGs), and 1 steam turbine.

One of the key components of CCPP is the heat recovery steam generator (HRSG). HRSGs are responsible for converting the energy from the exhaust gases of the gas turbines into steam to drive the steam turbine [1]. Currently, HRSG 1.2 has been in operation for about 28 years, leading to tube thinning due to erosion from exhaust gas flow and increased corrosion rates on tube materials due to its aging. This has resulted in HRSG failures, primarily due to tube leaks, causing significant losses in terms of high-water consumption and necessitating shutdowns for maintenance. This leads to a derating of steam turbine 1.0 by approximately 50% of its capacity, impacting the plant's performance, including a decrease in the equivalent availability factor (EAF) and an increase in the equivalent forced outage rate (EFOR).

To enhance the reliability of HRSG 1.2, it is proposed to replace its tubes, and this is included in the company's investment budget. Before proceeding with the investment, a feasibility analysis is essential. Feasibility analysis allows decision-makers to obtain comprehensive information and results regarding the viability of an investment project, providing a basis for deciding whether the project should be implemented or not [2].

In the industrial world, especially in the power industry, reliability, availability, maintainability, and risk analysis have become significant issues. One of the main causes of customer dissatisfaction is disruptions in the electricity supply due to unexpected failures. Therefore, by integrating reliability, availability, maintainability, and supportability (RAMS) and risk analysis into maintenance management in thermal power plants, the frequency of failures can be reduced, along with their consequences [3]. Integrating RAMS with risk analysis can minimize failures and their consequences, thereby reducing a company's business risks [4].

Reliability, availability, and maintainability modelling can assist in evaluating and improving the performance of a system [5]. For example, reviewing data on the reliability, availability, and maintainability of offshore wind turbines can lead to recommendations for improving performance predictions for future wind turbine projects [6]. Other research has shown that achieving maximum availability of a power plant depends heavily on the reliability and maintainability of the equipment or system used in the plant [7]. Furthermore, the proposed reliability, availability, and maintainability (RAM) framework can help decision-makers plan appropriate maintenance activities for different levels of criticality in equipment, subsystems, and systems to optimize plant availability [8]. The objective of this research is to determine whether the proposed investment in Replacement Tube HRSG 1.2 is

¹ Interdisciplinary School of Management and Technology, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia.
rakhmad.sazuli@gmail.com

² Interdisciplinary School of Management and Technology, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia. mii@its.ac.id

feasible based on:

- Operational aspects, including reliability, availability, and maintainability analysis,
- Financial aspects, including net present value and internal rate of return analysis,
- Risk analysis, including risk cost analysis.

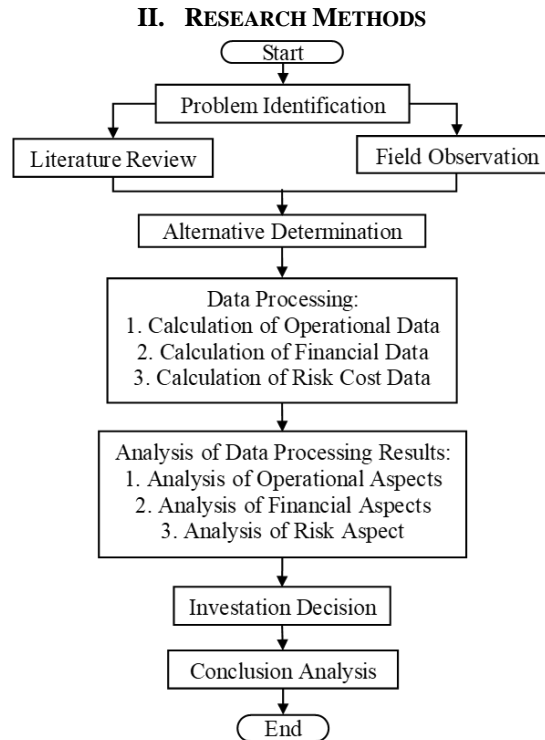


Fig. 1. Research proses flow.

In this study, an analysis is conducted using three alternatives:

1. Corrective Maintenance, this involves replacing the leaking tubes in.
2. Complete Replacement of HRSG 1.2, this alternative entails replacing all the tubes.
3. Partial Replacement of HRSG 1.2, this option involves replacing only some of the tubes.

The data used for this analysis includes maintenance data for HRSG 1.2, operational data for block I, and financial data for block I. Fig. 1 illustrates the research process flow. The methods used for this feasibility analysis are as follows:

A. Reliability Analysis

Reliability is the ability of equipment or a system to operate or perform its functions as designed under the operational conditions it faces during its projected lifetime [9]. Reliability is closely related to the failure of equipment or a system. High reliability reduces the cost of repairing equipment failures. Reliability is measured as the probability of operating without failure [3], as indicated by the following equation:

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

Where θ is the scale parameter, β is the shape parameter, λ is the failure rate, $F(t)$ is the cumulative distribution function and t is the time.

B. Availability Analysis

Availability can be defined as the probability of a system operating properly or not failing or undergoing repair while in operation. Availability is a function of both reliability and maintainability [10]. Availability can be calculated using the following equation:

$$A = \left[\left(\frac{\mu}{\lambda + \mu} \right) + \left(\left(\frac{\mu}{\lambda + \mu} \right) e^{-(\lambda + \mu)t} \right) \right] \quad (2)$$

Where A is the availability, λ is the failure rate and μ is the mean time to repair.

C. Maintainability Analysis

Maintainability is expressed as the probability that failed or damaged equipment can be restored to working condition within a specified time [8]. Maintainability can be calculated using the following equation:

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

Where θ is the scale parameter and β is the shape parameter.

D. Net Present Value (NPV) Analysis

Net present value is the difference between the present value of expected cash inflows generated by an investment and the initial investment outlay, considering the minimum desired rate of return (discount rate) of the investor [11]. NPV is calculated using the following equation:

$$NPV = \sum_{t=1}^N \frac{CF_t}{(1+K)^t} - IO \quad (4)$$

Where NPV is the net present value, CF_t is the annual cash flow generated by the project, K is the required rate of return (discount rate), N is the project's investment life and IO is the initial outlay. A project can be continued if this indicator is greater than zero ($NPV > 0$).

E. Internal Rate of Return (IRR) Analysis

The Internal Rate of Return (IRR) is a discount rate expressed as a percentage that calculates the interest rate at which the present value of a project's net cash flows equals the present value of the initial investment [12]. IRR is calculated using the following equation:

$$IRR = \frac{\sum_{t=0}^N CF_t}{\sum_{t=0}^N CF_t (1+IRR)^t} = 0 \quad (5)$$

Where IRR is the internal rate of return and N is the project's investment life. The internal rate of return is the interest rate that makes the net present value of the project equal to zero.

F. Risk Cost Analysis

Risk cost feasibility analysis is presented based on the prediction of risk cost for the power generation unit. Risk cost for the power generation unit is obtained from the total annual losses due to lost income and failure costs resulting from power generation unit failures [13]. Risk cost is calculated using the following equation:

$$RC = (\lambda \times M_{CR}) + (CR_{ROM} \times (EFDH + FOH)) + ((EFDH + FOH) \times AC) + F_f \quad (5)$$

Where RC is the risk cost for the power generation unit, λ is the failure rate of the power generation unit, M_{CR} is the average material cost per failure rate of the power generation unit, CR_{ROM} is the average service cost per failure rate per hour of the power generation unit, FOH is the force outage hour, $EFDH$ is the equivalent force derating hour, F_f is the fuel cost, and AC is the asset critically

III. RESULTS AND DISCUSSIONS

A. Reliability Analysis

Reliability is calculated using Reliasoft Weibull++ version 6 software, using maintenance record data for HRSG 1.2 from 2020, 2021, and 2022, as shown in Table I. The software calculations yield a Weibull distribution with three parameters: beta, eta, and gamma, as indicated in Table II. Thus, predictions for the reliability of HRSG 1.2 for each alternative can be calculated for the years 2023 through 2031 or until the end of the asset's life, using Equation (1).

By using the data in Table I, the predicted failure rate shown in Fig. 2 indicates that alternative 2 is the best option, as it results in the lowest failure rate. Since the failure rate represents the number of failures that occur per unit of time, replacing the tubes in HRSG 1.2 can reduce the frequency of failures over time. This, in turn, leads to a reduction in corrective maintenance costs and can increase the company's revenue.

From Fig. 3, the reliability predictions can be analyzed, indicating that alternative 2 provides the best reliability impact compared to other alternatives. All alternatives still have reliability above 0.8 at an operating time of 8,760 hours, or in the year 2023, where the system is likely to function properly if $R \geq 0.8$. In alternative 1, $R=0.79$ at an operating time of 9,488 hours, alternative 2 has $R=0.79$ at an operating time of 14,528 hours, and alternative 3 has $R=0.79$ at an operating time of 11,102 hours. This indicates that the replacement of HRSG 1.2 tubes can increase the operating hours of HRSG 1.2 with a higher probability of proper functioning and a lower likelihood of failure.

Table I
Maintenance Records of HRSG 1.2

Work Order	Description	Actual Start	Actual Finish
WO436963	HRSG 1.2; HP Blowdown pipe leak	17/05/2020 11:05	20/05/2020 16:29
WO558895	HRSG 1.2; LP Evaporator tube leak	18/06/2020 12:27	21/06/2020 19:09
WO436964	HRSG 1.2; Venting LP drum pipe leak	17/09/2020 15:12	19/09/2020 17:30
WO444964	HRSG 1.2; Drain inlet HP Circulation pipe leak	01/12/2020 15:47	01/02/2021 11:00
WO474841	HRSG 1.2; HP main steam pipe leak	11/02/2021 09:19	15/02/2021 09:19
WO487989	HRSG 1.2; LP feed pump no.1 drain min flow pipe leak	04/03/2021 09:01	13/03/2021 09:17
WO498842	HRSG 1.2; LP feed pump no.2 discharge pipe leak	17/04/2021 11:35	05/05/2021 08:26
WO524731	HRSG 1.2; HP drum venting pipe leak	10/06/2021 09:53	15/06/2021 09:53
WO541447	HRSG 1.2; LP drum pipe leak	14/06/2021 07:54	22/06/2021 09:54
WO561231	HRSG 1.2; LP drum venting pipe leak	20/07/2021 10:40	29/07/2021 14:41
WO655296	HRSG 1.2 LP Evaporator tube leak	04/11/2021 10:42	08/11/2021 10:40
WO672628	HRSG 1.2; Bypass transmitter pressure pipe leak	01/12/2021 08:59	01/12/2021 11:59
WO691067	HRSG 1.2; LP feed pump No.1 discharge pipe leak	23/12/2021 08:00	23/12/2021 14:00
WO692478	HRSG 1.2; LP feed pump No.1 minimum flow pipe leak	12/01/2022 16:16	17/02/2022 14:05
WO784240	HRSG 1.2; HP drum pipe to level switch leak	28/04/2022 08:18	19/05/2022 09:52
WO791111	HRSG 1.2; HP Circulation pump pipe leak	02/06/2022 09:00	19/06/2022 11:30
WO884256	HRSG 1.2; CBD pipe leak	30/08/2022 15:42	30/08/2022 20:43
WO919890	HRSG 1.2; HP main steam isolating pipe and valve leak	20/09/2022 08:40	29/09/2022 11:41
WO932997	HRSG 1.2; Condensate preheater tube leak	22/10/2022 14:43	26/10/2022 14:40
WO930900	HRSG 1.2; HP drum pipe to safety valve leak	01/11/2022 08:38	05/11/2022 17:39
WO949995	HRSG 1.2; HP circulating pump No.2 drain pipe leak	15/11/2022 08:40	18/11/2022 16:40
WO945149	HRSG 1.2; HP feed water pump pipe to HRSG leak	23/11/2022 08:42	25/11/2022 19:32
WO947039	HRSG 1.2; HP circulation pump No.2 drain pipe leak	26/11/2022 09:47	30/11/2022 21:28

Table II
Weibull Parameter and MTTR

Alternative	Beta	Eta	Gamma	Rho	MTTR
1	2,5368	21562	-2710,06	0,986	468,1
2	2,5384	21571	2321	0,986	234,1
3	2,5382	21570	-1105	0,986	417,5

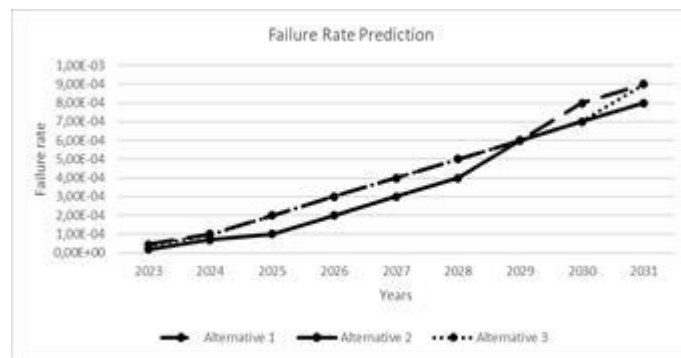


Fig. 2. The prediction of the failure rate of HRSG 1.2 from 2023 to 2031 for each alternative

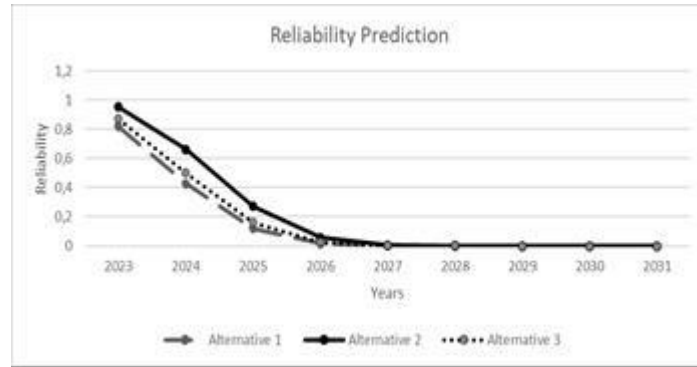


Fig. 3. The prediction of the reliability of HRSG 1.2 from 2023 to 2031 for each alternative

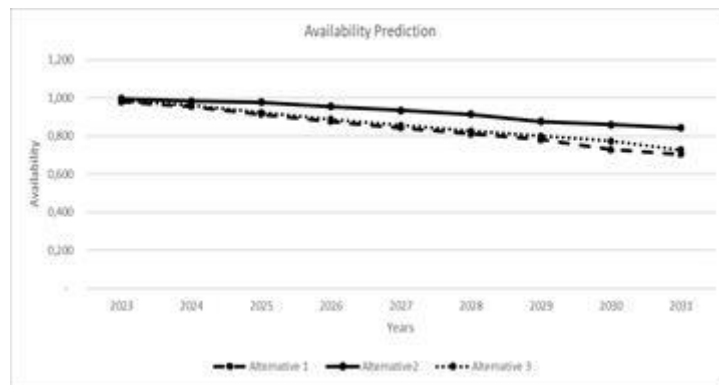


Fig. 4. The prediction of the availability of HRSG 1.2 from 2023 to 2031 for each alternative

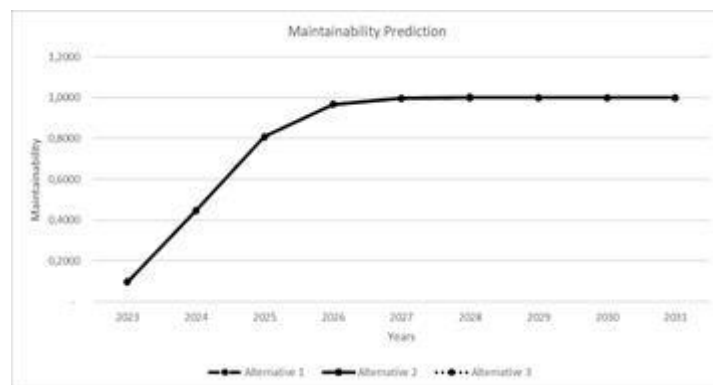


Fig. 5. The prediction of the maintainability of HRSG 1.2 from 2023 to 2031 for each alternative

B. Availability Analysis

By using the MTTR data in Table II and the failure rate from Fig. 2, the availability value of HRSG 1.2 for each alternative can be calculated using Equation (2). From Fig. 4, the availability of HRSG 1.2 can be analyzed, indicating that performing alternative 2 predicts better availability compared to other options. Furthermore, the impact is that the availability of HRSG 1.2 can be maintained above 0.8 until its end of life. In contrast, alternative 1 and alternative 2 have availabilities that drop below 0.8 by the year 2029 or after 70,080 hours of operation.

C. Maintainability Analysis

By using the eta and beta data resulting from the Weibull distribution calculations in Table 1, the maintainability value can be calculated using Equation (3). In maintainability analysis, the focus is on how quickly a piece of equipment, or a system can be restored to operational condition, where a value of one indicates that equipment or subsystem can maintain its condition for operation. From Fig. 5, the time required to restore HRSG 1.2 is quite long, and the time is the same for each option. This happens because maintainability is influenced by maintenance methods, procedures, and strategies. To accelerate the recovery time of HRSG 1.2, improvements in maintenance strategies, methods, and procedures are needed.

From the discussion of operational aspects, including reliability, availability, and maintainability analysis above,

it can be concluded that alternative 2, or the replacement of HRSG 1.2 tubes, is justified based on operational aspects. Performing a thorough retubing of HRSG 1.2 can improve the reliability and availability of HRSG 1.2, which impacts the operational performance of block I, leading to increased revenue for the company.

Table III
The cost of investment for each alternative

No	Alternative	Investment Value (IDR)
1	Alternative 1 (corrective maintenance on HRSG 1.2)	0
2	Alternative 2 (Replacement tube HRSG 1.2)	108.048.660.960
3	Alternative 3 (Partial Retubing HRSG 1.2)	34.579.315.000

Table IV
The financial assumptions that are used

Parameter	Assumption	Description
Exchange (IDR/US\$)	IDR 15,502	Exchange rate as of 11/03/2023
Corporate Tax Rate	22%	Corporate Income Tax rate source: https://taxsummaries.pwc.com/in-donesia/corporate/taxes-on-corporate-income
Inflation	4,40%	inflation rate, average consumer prices
Discount Rate	5,33%	WACC
Interest rate	5,40%	PLN loan interest rate
Loan Tenor	8 years	
Loan Portion	80%	
Equity Portion	20%	
Electricity Rate	IDR 1,740.13/kWh	
Natural Gas Price	USD 7.85/mmbtu	
HSD Fuel Price	IDR 6,851.92/liter	
Useful Life	40 years	Perdir 0040.P/DIR/2016

Table V
Calculated NVP and IRR indicators for each alternative

No	Alternative	Net Present Value (IDR)	Internal Rate of Return (%)
		NPV > 0	IRR > WACC (5,33%)
1	Alternative 1	334.073.741.949	7,41%
2	Alternative 2	360.419.186.184	7,51%
3	Alternative 3	340.490.364.168	7,44%

D. Net Present Value and Internal Rate of Return Analysis

To calculate the net present value (NPV) and internal rate of return (IRR), the researcher used data such as investment value data from Table III, assumptions listed in Table IV, and other financial data. This was done using Equations (4) and (5). Calculations were performed for each alternative, resulting in the outcomes presented in Table V.

From the data in the calculation results for IRR and NPV in Table V, it can be observed that all alternatives meet the requirements set by the company. The NPV for all options is positive or greater than zero, which enhances the company's value. Alternative 2, which involves the Investment in the Replacement Tube for HRSG 1.2, yields an NPV of IDR 360,419,186,184. This is more than IDR 19.92 billion higher than alternative 3 and IDR 26.34 billion higher than alternative 1. This is because alternative 2 provides higher reliability and availability compared to the other alternatives, resulting in higher block I production. Thus, based on the NPV analysis, the proposed maintenance investment project, which is the Replacement Tube for HRSG 1.2, can be accepted or deemed feasible.

In Table V, the results of the IRR calculations show that all three alternatives have values above the calculated WACC or above 5.33%. These three alternatives are economically feasible and can be implemented. As can be seen, the internal rate of return in alternative 2 is higher than the others. Therefore, the proposed maintenance investment project, which is the Replacement Tube for HRSG 1.2, can be accepted or deemed feasible.

E. Risk Cost Analysis

Risk analysis is conducted to determine risk cost that may arise due to its unavailability to serve the system. The prediction of risk costs for block I is calculated using Equation (6), resulting in the risk cost for each option from 2023 until the end of life, as shown in Table VI.

The risk cost indicator is calculated and presented in Table VI and Fig. 6. Table VI displays the predicted risk costs for each alternative, where alternative 1 yields the smallest predicted risk cost compared to the others. Figure 6 illustrates the trend of the risk cost values for each alternative, which tend to increase over time. However, the risk cost value for alternative 2 is the smallest and significantly different from the risk costs of the other alternatives.

Table VI
Calculated risk cost value for each alternative

Years	RISK COST (in million rupiah)		
	ALTERNATIVE 1	ALTERNATIVE 2	ALTERNATIVE 3
2023	118.862,72	109.342,96	114.967,82
2024	121.424,32	108.516,44	116.788,73
2025	123.911,69	110.375,80	119.295,39
2026	126.337,24	113.469,38	122.123,83
2027	128.709,56	117.413,55	125.328,57
2028	131.031,05	121.767,19	128.643,57
2029	133.299,63	125.653,07	131.648,82
2030	135.523,77	128.025,20	134.063,58
2031	137.712,83	130.158,95	136.336,35

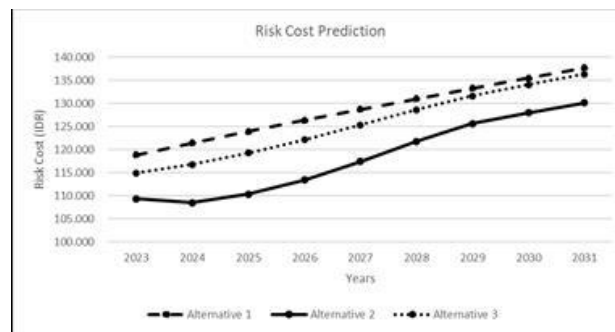


Fig. 6. The prediction of the risk cost from 2023 to 2031 for each alternative

Table VII
The risk impact criteria on financial and market aspects

FINANCE & MARKETS	IMPACT CRITERIA				
	Not significant	Minor	Medium	Significant	Very Significant
Opportunity Profit/Loss (IDR)	<0,1% of the company's one-year earnings	0,1% - 0,5% of the company's one-year earnings	0,5% - 1% of the company's one-year earnings	1% - 2% of the company's one-year earnings	>2% of the company's one-year earnings
			RISK APPETITE		
	13.098.796.625	65.493.983.123	130.987.966.246	261.975.932.492	261.975.932.492

The risk cost indicator is calculated and presented in Table VI and Fig. 6. Table VI displays the predicted risk costs for each alternative, where alternative 1 yields the smallest predicted risk cost compared to the others. Figure 6 illustrates the trend of the risk cost values for each alternative, which tend to increase over time. However, the risk cost value for alternative 2 is the smallest and significantly different from the risk costs of the other alternatives.

Based on the impact criteria on financial and market aspects shown in Table VII and the predicted risk costs in

Table VI, it can be observed that alternative 1 and alternative 3 have predicted risk costs in the significant impact category. Meanwhile, alternative 2 has predicted risk costs in the medium impact category. Therefore, it can be concluded that based on the risk analysis, carrying out the maintenance investment project for the Replacement Tube for HRSG 1.2 is justified because the potential risk costs generated remain below the risk appetite or medium impact criteria.

IV. CONCLUSION

Investment project proposals should be assessed for feasibility before deciding to implement them. Feasibility analysis methods such as reliability, availability, maintainability, and risk cost are highly helpful in decision-making by management, in addition to financial considerations, of course. A case study analyzing the feasibility of an investment project proposal in this research recommends that the investment project proposal for the replacement of HRSG 1.2 combined cycle power plant tubes in Belawan is feasible and worthy of implementation.

Our ongoing research is aimed at analyzing investment project proposals for several types of projects only. For other types of projects, such as regulatory compliance projects, using reliability, availability, and maintainability methods may not be suitable. Therefore, in future studies, feasibility analysis can be developed using other methods that are more appropriate for the proposed project type, such as analyzing safety and environmental aspects, social aspects, and market aspects. Additionally, in analyzing risk aspects, other alternatives such as Monte Carlo simulation, decision trees, or other risk analysis methods can also be used.

REFERENCES

- [1] R. Kehlhofer, R. Bachmann, H. Nielsen, and J. Warner, "Combined-cycle gas and steam turbine power plant," Second Edition, Pennwell Publishing Company, Oklahoma, 1997.
- [2] H. Jo, H. Lee, S. Suh, J. Kim, and Y. Park, "A dynamic feasibility analysis of public investment projects: an integrated approach using system dynamics and agent-based modeling," *International Journal of Project Management*, vol. 33, Issue 8, pp. 1863-1876, 2015.
- [3] M. C. Eti, S. O. T. Ogaji, and S. D. Probert, "Integrating reliability, availability, maintainability, and supportability with risk analysis for improved operation of the Afam thermal power-station," *Applied Energy*, vol. 84, no. 2, pp. 202-221, 2007.
- [4] T. Marqueset, and U. Kumar, "Integration of RAMS and risk analysis in product design and development work processes a case study," *Journal of Quality in Maintenance Engineering*, vol. 9, no. 4, pp. 393-410, 2003.
- [5] A. Mishra, and R. P. Mishra, "RAM modeling for performance analysis of a coal handling system," *Materials Today: Proceedings*, vol. 28, part 4, pp. 2149-2155, 2020.
- [6] D. Cevasco, S. Koukoura, A. J. Kolios, "Reliability, availability, maintainability data review for the identification of trends in offshore wind energy applications," *Renewable and Sustainable Energy Reviews*, vol. 136, 2021.
- [7] F. J. G. Carazas, G. F. M. De Souza, "Availability analysis of gas turbines used in power plants," *Int. J. Thermodyn.*, vol. 12, no. 1, pp. 28-37, 2009.
- [8] H. P. Jagtap, A. K. Bewoor, R. Kumar, M. H. Ahmadi, M. E. H. Assad, and M. Sharifpur, "RAM analysis and availability optimization of thermal power plant water circulation System Using PSO," *Energy Report*, vol. 7, pp. 1133-1153, 2021.
- [9] A. A. Chowdhury, and D. O. Koval, "Power Distribution System Reliability: Practical Methods and Applications," *The IEEE Press Series on Power Engineering*, John Wiley & Sons, Inc., New Jersey, 2009.
- [10] H. Sabouhi, A. Abbaspour, Fotuhi, M. Firuzabad, and P. Dehghanian, "Reliability modeling and availability analysis of combined cycle power plants," *International Journal of Electrical Power and Energy Systems*, no. 79, pp. 108-119, 2016.
- [11] S. A. Ross, W. W. Randolph and J. Jeffrey, "Corporate Finance 9th Edition," Mc Graw-Hill, New York, 2010.
- [12] A. Damodaran, "Corporate finance: theory and practice second international edition," John Wiley & Sons, New York, 2001.
- [13] Anonymous, "Standarisasi kajian kelayakan proyek: penyusunan kajian kelayakan proyek sesuai kategori investasi berdasarkan perdir no. 069/2021," PT. PLN, Jakarta, 2022.